Water and Environmental Research Institute of the Western Pacific
Annual Technical Report
FY 2011

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 37th 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, 2011 to February 29, 2012 (FY'11).

Currently WERI has a fulltime director who is also a UOG faculty member, five (5) regular and one (1) emeritus research faculty, a water analysis laboratory manager and technician, a GIS and network administrator, two office staff, as well as six (6) graduate research assistants who are completing their MS degree in the UOG Environmental Sciences program.

During FY'11, WERI faculty were involved as principal investigators on thirteen (13) research and training projects. Funding sources for these projects, in addition to the US Geological Survey, included the National Oceanic and Atmospheric Administration, the National Weather Service, the National Science Foundation and the US Military, and local agencies such as the Guam Bureau of Statistics and Plans, the Guam Environmental Protection Agency, the Guam Waterworks Authority, and direct appropriations from the Guam Legislature.

Over the same time frame, WERI faculty and staff taught twelve (12) graduate courses and three (3) undergraduate courses in the Environmental Science MS program and the undergraduate Pre-Engineering curricula respectively. At the same time WERI faculty were first or second authors on sixteen (16) refereed journal articles, seven (7) conference proceedings papers, six (6) technical reports, twenty one (21) professional presentations, and four (4) workshops. WERI faculty members served on eighteen (18) thesis committees of students in the Environmental Science and Biology MS programs and chaired nine (9) of them.

Following is a list of non USGS funding sources and associated projects carried out by the Institute during the 2011-2012 reporting period:

DIRECT LOCAL FUNDING FROM THE GUAM LEGISLATURE SUPPORTS: A. The Guam Comprehensive Water Monitoring Program, a 50:50 cost sharing program with Hawaii District, USGS, and B. The Guam Hydrologic Survey, which in turn has provided funding over this fiscal year for the following projects: 1. Guam Geologic Map Update and Revision; 2. Reconstructing the Climate History of Guam; 3.

Temporal and Spatial Variations in Guam's Groundwater Quality.

GUAM BUREAU OF STATISTICS AND PLANS HAS PROVIDED FUNDS TO: 1. Develop the Erosion Potential GIS Based Tool for the Piti/Asan Watershed; 2. Provide GIS Technical Support for GIS Applications for Watershed Management Projects for Guam's Priority Watersheds; 3. Develop Digital Atlas of Northern Guam; 4. Provide GIS Assessment Tool for Determining Cumulative and Secondary Impacts from Increase Development on Guam.

GUAM WATERWORKS AUTHORITY HAS PROVIDED FUNDS TO: 1. Determine if Guam's Northern Aquifer Should be Classified as Groundwater Under the Direct Influence of Surface Water (GWUDI) in Accordance with the Safe Drinking Water Act, Surface Water Treatment Rule.

NATIONAL SCIENCE FOUNDATION HAS PROVIDED FUNDS TO: 1. Examine the Holocene Hydrologic Variability Across the Western Pacific Warm Pool

NATIONAL WEATHER SERVICE HAS PROVIDED FUNDS FOR: 1. Pacific ENSO Applications Center with University of Hawaii: JIMAR Project, Climate Forecast & Information; 2. Pacific ENSO Applications Center with University of Hawaii: JIMAR Project, Development of an Extended and Long-Range Precipitation System over the Pacific Islands.

OTHER FUNDING SOURCES AND ASSOCIATED PROJECTS: 1. AECOM Environmental Consultants: Review of Water Utility Study to Support EIS MC Relocation from Okinawa, Japan to Guam; 2. Brown and Caldwell LLC: Provide Consulting Services and Related Assistance to Company on Connection with the Closure and Post-Closure Plan Preparation for Ordot Dump Project; 3. Black Construction Corporation: 72-Hour Constant Rate Pump Testing & Adjacent Well Monitoring Plan.

Research Program Introduction

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 Commonwealth of the Northern Mariana Islands (CNMI) and the Federated States of Micronesia (FSM) consist of representatives from various government departments that deal with water resources, representatives from the local colleges, private sector engineers, environmentalists, and planners, and University of Guam research faculty.

WERI held RAC meetings in September through October 2011. Twenty two (22) people attended the Guam meeting, sixteen (16) attended the FSM meeting and twenty (20) attended the CNMI meeting. The meetings provided a scientific forum for information exchange on new and recently completed projects. Each RAC group examined the research education and training priorities identified in past years and added or amended where appropriate.

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.

Six (6) research proposals, two (2) for Guam, two (2) for the CNMI and two (2) for the FSM; three (3) environmental educational programs, two (2) for Guam and one (1) for the CNMI, and two (2) information transfer and training programs for the FSM, were submitted for consideration in response to the RFP. Three regional review panels, each composed of well qualified water resources professionals and RAC members, plus two previous WERI Directors (now retired), were tasked with evaluating each proposal’s regional relevance in accordance with the long-standing criteria listed in the RFP. The appropriate proposals were e-mailed separately to each reviewer along with the critical needs list for the region and a scoring form. The reviewers were advised to work independently and given two weeks to submit their scores and comments to the WERI Director. The proposal scores were then tabulated and the projects ranked in descending order of average score. Projects approved for funding were selected based on their regional ranking and availability of funds.

Comprehensive Analysis of Salinity Trends in Northern Guam Lens Aquifer

Basic Information

Title:	Comprehensive Analysis of Salinity Trends in Northern Guam Lens Aquifer
Project Number:	2011GU194B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Hydrogeochemistry
Descriptors:	Saltwater contamination, salinity trends, Guam
Principal Investigators:	John Jenson, Mark Lander

Publication

1. Simard, Christine A., 2012, Salinity Trends in the Northern Guam Lens Aquifer, M.S. Thesis, Graduate Environmental Science Program, College of Natural and Applied Sciences, University of Guam, Mangilao, Guam, 281 pp.

PROJECT SYNOPSIS REPORT

Project Title: Comprehensive Analysis of Salinity Trends in the Northern Guam Lens Aquifer

Problem and Research Objectives

The Northern Guam Lens Aquifer (NGLA) provides 80% of Guam's drinking water. Current withdrawal by all producers is about 45 million gallons per day (mgd), against a currently estimated sustainable yield of about 80 mgd. The anticipated addition of new US Marine Corps facilities during the next decade is expected to require an additional 5-6 mgd to support the new military activities alone, and additional economic growth on the island will certainly further increase demand for municipal and private production as well. There is thus a compelling need for a new survey, building on historical knowledge, to: (1) Precisely identify and analyze the current trends in salinity in Guam's aquifer and drinking water production wells during the past decade, (2) Investigate the possible causes of the trends, and (3) Recommend appropriate responses to documented trends to promote sustainable development of additional capacity.

Methodology

The proposed project compiled and evaluated historical and current WERI/USGS data collected through the CWMP, along with GWA data on production rates and chloride concentrations. Spatial relationships and trends were identified and evaluated to determine not only the current distribution of relatively low- and high-chloride zones in the aquifer, but also the historical spatial and temporal trends in the relationships between chloride concentrations in Guam's freshwater lens and production wells on the one hand, and spatial and historical trends in production rates and recharge on the other hand.

Principal Findings and Significance

This two-year study of the 39-year records of salinity and groundwater management data from production and observation wells on northern Guam has shown (1) significant increasing groundwater chloride trends at about three-fourths of the production wells, (2) correlations with local precipitation and mean sea-level trends, (3) thinning of the freshwater lens by 2 to 16 meters between 2005 and 2009, (4) seasonal fresh water lens fluctuations of up to 70 meters in the Hagatña Sub-basin between 2005 and 2009, and (5) increasing chloride trends in the supra-basal groundwater zone—which indicates meteoric and/or man-made chloride sources other than over-pumped or over-deep wells. Key recommendations include: (1) installation of additional observation wells across the aquifer, (2) use of dedicated conductivity, temperature, depth (CTD) probes to continuously monitor salinity fluctuations and freshwater lens thickness, (3) studies of candidate natural and man-made sources of chloride in recharging waters, and (4) well-design guidelines for production wells in supra-basal zones and near the saltwater toe of the lens.

Reconstructing the Sea Surface Temperature and Wet-Dry Climate History of Guam

Basic Information

Title:	Reconstructing the Sea Surface Temperature and Wet-Dry Climate History of Guam
Project Number:	2011GU196B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Drought, Geochemical Processes
Descriptors:	Hydrologic cycles, climate history, Guam
Principal Investigators:	John Jenson, Mark Lander

Publications

1. Bell, Tomoko., 2011 Coral and Speleothem in situ Monitoring and Geochemical Analysis: Guam, Mariana Islands, USA, M.S. Thesis, Graduate Environmental Science Program, College of Natural and Applied Sciences, University of Guam, Mangilao, Guam, 72 pp.
2. Bell, Tomoko, John W. Jenson, Mark A. Lander, Richard H. Randall, Judson W. Partin, Benjamin F. Hardt, and Jay L. Banner, 2011, Coral and Speleothem in situ Monitoring and Geochemical Analysis: Guam, Mariana Islands, USA, WERI Technical Report No. 136: Mangilao, Water & Environmental Research Institute of the Western Pacific, University of Guam, Mangilao, Guam, 70 pp.
3. Bell, Tomoko, Tetsuya Endo, John W. Jenson, Ryan Bell, and Mark A. Lander, 2011, Pneumatic Underwater Drill for Extracting Coral Cores, WERI Technical Report No. 135: Mangilao, Water and Environmental Research Institute of the Western Pacific, University of Guam, 17 pp

PROJECT SYNOPSIS REPORT

Project Title: Reconstructing the Sea Surface Temperature and Wet-Dry Climate History of Guam

Problem and Research Objectives

During the 1997-1998 El Niño, which brought to Guam one of the severest droughts in living memory, the governor of Guam and the Guam Legislature committed the island to research, development, and maintenance of long-term drought planning and management (Guam 24th Legislature, 1998). With concern growing over the economic and population growth that will accompany the anticipated relocation of US Marine forces from Okinawa during the next decade-and-a-half, long-term planning has received additional emphasis. The *Critical Water Resources Research Needs* identified by the 2010 Guam Advisory Council, for example, now include (1) developing water budgets for Guam's surface and groundwater watersheds, (2) re-evaluation of sustainable development estimates for the island's principal aquifer, and 3) expanding and updating the rainfall database of Guam to include long-term rainfall variability. Moreover, the USGS-NIWR program has encouraged research that will gain insight into the effects of climate change on the water cycle. The climate history of the West Pacific Warm Pool is of particular importance for understanding the global hydrologic cycle. Unfortunately, the historical record of El Niño-related rainfall and drought for Guam is very limited; it dates back only to the end of World War II.

Methodology

Climate research has shown during the past couple of decades that pre-historic climate trends (e.g., rainfall, drought) in tropical areas correlate with chemical signatures that can be read in the annual growth of corals. In summer 2010, two cores about one meter in length and 80 mm in diameter was extracted at Gabgab beach in Apra Harbor and outside of Haputo Bay on Guam's northwest coast, and sent to the geochemical laboratory at University of Texas-Austin for analysis. Cores were drilled with a novel instrument designed especially for the project; details of the design and application are reported herein. Also included in the study was dripwater from Jinapsan Cave, on the north coast, which is being collected as part of a complementary study of the speleothem record on Guam. Monthly measurements of sea surface temperature (SST), seawater $\delta^{18}O$, and seawater Sr/Ca were taken at one or both of the Gabgab and Haputo sites. We also monitored $\delta^{18}O$ rainwater collected on the University of Guam (UOG) campus on the east-central coast, and $\delta^{18}O$ cave dripwater from Jinapsan Cave. In addition, we monitored nitrate at the Gabgab site and drip water from two sites in Jinapsan Cave to investigate the biological influence on the calcification of coral and speleothems. The concentrations of nitrate at the Gabgab site do not appear to have had any significant affect on the coral calcification system.

Principal Findings and Significance

Monthly seawater samples at the Gabgab site showed seasonal variations in SST, $\delta^{18}O$ and nitrate. SST at the Gabgab and Haputo sites were strongly correlated. Both sites also showed strong correlation with the regional SST record. $\delta^{18}O$ measured at the Gabgab

site was also correlated with the SST record and local station rainwater $\delta^{18}O$. An *amount effect* for $\delta^{18}O$ was observed in local precipitation. Monthly seawater samples at the Gabgab site showed seasonal variations in SST, $\delta^{18}O$ and nitrate. SST at the Gabgab and Haputo sites were strongly correlated. Both sites also showed strong correlation with the regional SST record. $\delta^{18}O$ measured at the Gabgab site was also correlated with the SST record and local station rainwater $\delta^{18}O$. The concentrations of nitrate at the Gabgab site do not appear to have had any significant affect on the coral calcification system. The Gabgab coral core revealed interesting correlations between the Sr/Ca signal and wet-dry climatic conditions on Guam. (The Haputo core proved unsuitable for analysis). The Gabgab core contained some 60 annual bands. Sr/Ca and Hadley SST signals from 1960 to 2010 show the same long-term trends. Sr/Ca shows a relatively strong relationship with maximum air temperature, but not with sea level, ENSO index, or precipitation. Sr/Ca from June to September, dry season segment, showed much higher correlation with Hadley SST than the wet season segment (December to March). It is thus inferred that some factors related to wet season influence the relationship between SST and coral Sr/Ca.

Reconfiguration of Saipan’s Water Distribution System Model

Basic Information

Title:	Reconfiguration of Saipan’s Water Distribution System Model
Project Number:	2011GU199B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Category:	Models, Water Supply, Management and Planning
Descriptors:	Distribution system, Water system operation, Water demands, Model studies
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz, Mariano Iglecias

Publication

1. Khosrowpanah, Shahram, Leroy F. Heitz, Mariano Iglecias, 2011, Abstract, Development of Junction Water Demands for the Saipan Water Distribution System Numerical Model, Asia Pacific Academy of Science, Education, and Environmental Management (APASEEM) General Meeting, November 29-30, 2011, American Memorial Park, Auditorium, Saipan.

PROJECT SYNOPSIS REPORT

Project Title: Reconfiguration of the Saipan's Water Distribution System Model

Problem and Research Objectives

Water hours and low delivery pressure have long been a part of the daily lives of the people in the islands of the Western Pacific. In Saipan, Commonwealth of the Northern Mariana Islands (CNMI), large investments have been made in system improvements, but delivery problems still exist. A stated goal of the Commonwealth of the Northern Mariana Islands (CNMI) government is to provide 24-hour water to all residents served by the Commonwealth Utilities Corporation (CUC) water system. This goal will be unattainable until the CUC has complete knowledge of their water delivery capabilities and system operation.

Saipan's water distribution system is divided into 15 sub-regions as shown in Figure 1. Each sub-region (I.D. numbers shown in red on Figure 1) can be operated as a separate entity or connected with adjacent regions. Each sub-system consists of well or spring sources, transmission piping, tanks for storage of water, and distribution system piping to deliver water to the CUC customers. The Saipan water system serves a population of 53,000 people.

Researchers at the University of Guam Water and Environmental Research Institute of the Western Pacific (WERI) developed computerized models of each of the fifteen sub-regions of the CUC water system using the Haestad WaterCAD water system modeling program. They developed a source, transmission and storage model of the Saipan water system. This includes a skeleton of the existing 15-region water system models with the regions joined together at the boundary points as shown in Figure 2. Using Geographic Information System (GIS) capability and Saipan's 2003 census data the WERI researchers determined the number of users at each system junction node for residential and commercial customers (Heitz, Khosrowpanah 2008). To improve the system operation and maintenance, the WERI researchers developed a GIS data base of the CUC water distribution system (Heitz, Khosrowpanah 2011). Figure 3 shows sample attribute files for CUC Tanks, Pumps, and Pipes that are available in the GIS database. Since the hydraulic model was developed, several improvements have been made on the water system. The overall goal of this project was to 1) update the skeleton model of the CUC water distribution that reflects all the new subdivisions improvements, 2) join the sub-region together according to CUC operation, and 3) update the GIS data base that reflects the new addition to the system.

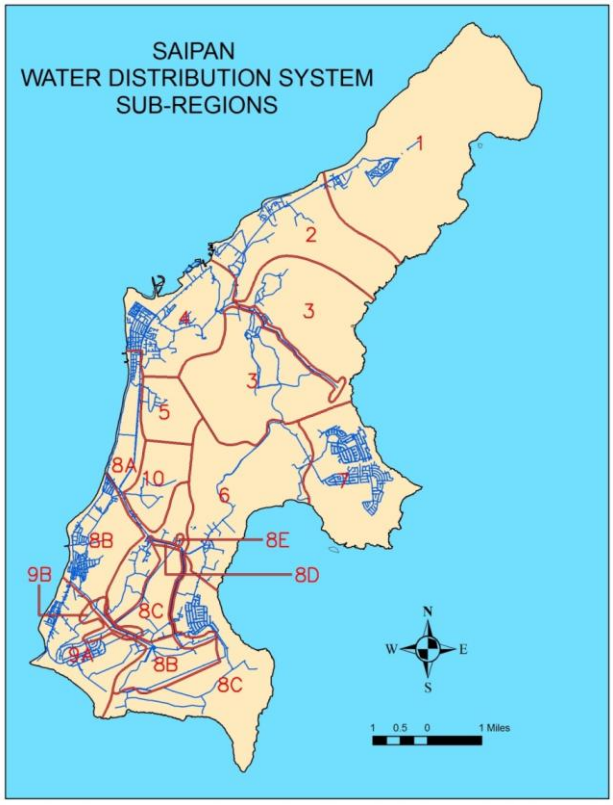


Figure 1: Saipan's Water Distribution System

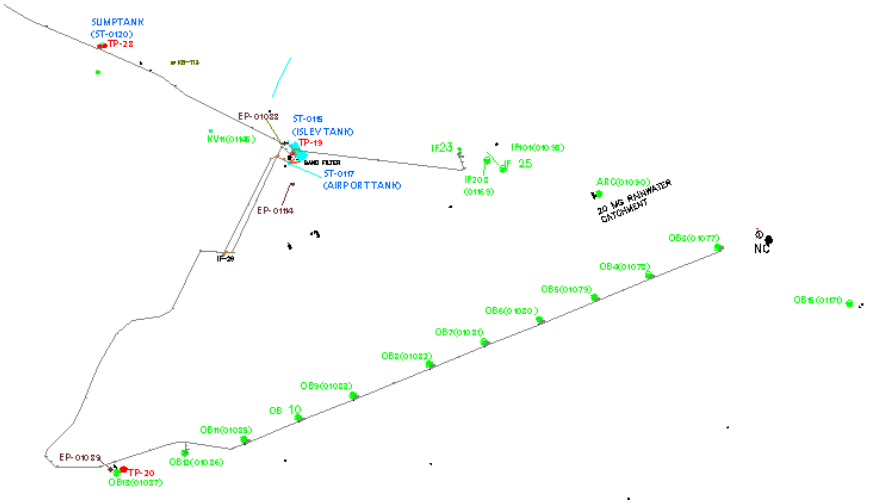


Figure 2: Skeleton of the CUC' region 8C water distribution system

TANK ATTRIBUTE FILE

OBJECTID *	Shape *	LABEL	LABEL_1	DESC_	TOT_ACT	BASE_ELEV	H_MIN	INIT_HGL	MAX_ELEV	H_MAX	MIN_ELEV	H_MIN_1	VI	TANK_D	X	Y	
1	Point	T-ACHUGAO SUMP		ACHUGAO SUMP TANK	23937.66	233	0	237	241	8	233	0	0	0	183722.72	190116.68	
2	Point	T-MAUI		MAUI TANK	999369.17	255	0	256	276	21	255	0	0	90	174982	181420	<Null>
3	Point	T-TASA SUMP		TASA SUMP TANK	14362.6	34	1	42.9	43	9	35	0	0	0	177626.12	186800.31	<Null>
4	Point	T-AGAG TANK		AGAG TANK	103403.28	609	6	620	626	17	615	0	0	40	178847	173820.64	<Null>
5	Point	T-CAPITOL HILL			1000558.89	870	10	885	890	20	880	0	0	130.5	177905	178543	PICTEST1.JPG
6	Point	T-ISLEY TANKa			1000558.89	184	2	190	196	12	186	0	0	130.5	168867.36	148898.48	<Null>
7	Point	T-HOSPITAL			1007594.43	142	5	152	182	40	147	0	0	70	168319.35	159412.02	<Null>
8	Point	T-GUALO RAI		GUALO-RAI TANK	200012.27	303	7	315	327	24	310	0	0	44.75	169951.58	172601.73	<Null>
9	Point	T-ACHUGAO		ACHUGAO TANK	200111.78	221	4	229	233	12	225	0	0	65.25	183301.63	190235.53	<Null>
10	Point	KOBBLER NSUMP 0120			14961.04	125	0	127.5	130	5	125	0	0	0	166236.79	150315.55	<Null>
11	Point	T-SAN VICENTE		SAN VICENTE TANK	500132.32	320	5	330	352	32	325	0	0	56.15	173382.25	159029.02	<Null>
12	Point	T-2			1081322.14	370	0	390	411	41	370	0	0	67	183134.51	166418.85	<Null>

Record: 1 Show: All Selected Records (1 out of 27 Selected) Options

PUMP ATTRIBUTE FILE

LABEL	LABEL_1	PUMP_DEFIN	DESC_	ELEV	X	Y	PUMP_CURVE	PUMP_DATA	PUMP_MAIN_DATA	DIRECT_FEED
PMP-AS-5		AEROMOTOR 50-500 (PMP-24) (PMP-AS-5) (PMP-AS-2)		0	170231.39	157434.51	<Null>	<Null>	<Null>	<Null>
PMP-KUMOY 3		AERMOTOR 6A80-10 (PMP-KUMOY 3)		-14	164613.33	153139.81	<Null>	<Null>	Pump Data-Region 8A.xls	<Null>
PMP-AS-2		AEROMOTOR 50-500 (PMP-24) (PMP-AS-5) (PMP-AS-2)		-5	169112.56	155904.09	<Null>	<Null>	<Null>	<Null>
PMP-KAGMAN B		PEERLESS 3PV11 50 HP (PMP-KAGMAN BOOSTER 1 PMP 1) (PMP-KAGMAN BOOSTER 1 PM		364	182684.57	169310.08	<Null>	<Null>	<Null>	<Null>
PMP-KV 25		AERMOTOR 75-500 (PMP-KV 22) (PMP-KV 25) (PMP-KV 11) (PMP-KV 12) (PMP-KV 17) (PMP-M		-5	161297.16	148113.62	<Null>	<Null>	Pump Data-Region 9A.xls	<Null>
PMP-SQ 11		Aermotor 75-750 (PMP-SQ 6) (PMP-CL 5) (PMP-SQ 12) (PMP-SQ 149) (PMP-PR 164) (PMP-SQ 7)		-2	177228.98	180290.41	TEST PUMP CURVE.pdf	<Null>	Pump Data-Region 4.xls	<Null>
PMP-KG 13		AERMOTOR 35-300 (PMP- KG 7) (PMP-KG 9) (PMP-KG 13) (PMP-KG 14) (PMP-KG 11) (PMP-KG		-4.25	187044.46	165593.94	<Null>	<Null>	Pump Data-Region 7.xls	<Null>
PMP-SQ 150		AERMOTOR 230S250-9BB (PMP-SQ 150)		-2.5	177007.1	183672.21	<Null>	<Null>	Pump Data-Region 4.xls	<Null>
PMP-KAGMAN B		PEERLESS 4PV8A (PMP-KAGMAN BOOSTER II PMP 2) (PMP-KAGMAN BOOSTER II PMP 3) (P		0	184114.4	166842.4	<Null>	<Null>	<Null>	<Null>
PMP-MQ 9		GRUNDFOS 40S75-21		-8	190882.01	195806.22	<Null>	<Null>	Pump Data-Region 1.xls	<Null>
PMP-KV BOOSTE		GRUNDFOS 200-800 9PM (PMP-KV BOOSTER PMP 1) (PMP-KV BOOSTER 1 PMP 2)		131	166229.57	150254.48	<Null>	<Null>	<Null>	<Null>
PMP-IF 206		AERMOTOR 75-500 (PMP-IF 23) (PMP-IF 208) (PMP-IF 206) (PMP-IF 108) (PMP-IF 202) (PMP-IF		-2	171590.87	150069.74	<Null>	<Null>	Pump Data-Region 8A.xls	<Null>

Record: 1 Show: All Selected Records (0 out of 151 Selected) Options

PIPE ATTRIBUTE FILE

OBJECTID *	Shape *	LABEL	LABEL_1	DESC_	L	MATERIAL	MAT_DESC	C	KM	START_NODE	STOP_NODE	D	Shape_Length	INSTALLED_DATE
1	Polyline	P-47a			15	PVC	PVC	150	0	PBV-3	J-31a	16	15.000001	<Null>
2	Polyline	P-172b			261	Asbestos Cement	Asbestos Cement	140	0	J-70b	J-71b	6	260.553234	<Null>
3	Polyline	P-137b			785	PVC	PVC	150	0	J-54c	J-57c	6	785.084823	<Null>
4	Polyline	P-406			349	Asbestos Cement	Asbestos Cement	140	0	J-194a	J-205a	8	349.155325	<Null>
5	Polyline	P-43f			1209	PVC	PVC	150	0	TCV-12e	J-19g	10	1209.376496	<Null>
6	Polyline	P-441			389	Asbestos Cement	Asbestos Cement	140	0	J-225b	J-227c	8	388.70772	<Null>
7	Polyline	P-290d			1324	PVC	PVC	150	0	J-152b	J-136c	8	1323.700223	<Null>
8	Polyline	P-499a			14	PVC	PVC	150	0	FCV-185a	J-58e	8	13.967846	<Null>
9	Polyline	P-13a			173	PVC	PVC	150	0	J-9b	FCV-4a	12	172.999798	<Null>
10	Polyline	P-715			374	PVC	PVC	150	0	J-344	J-345	4	373.855044	<Null>
11	Polyline	P-252a			11	PVC	PVC	150	0	J-115b	FCV-122	10	10.56104	<Null>
12	Polyline	P-217a			26	PVC	PVC	150	0	T-TASA SUMP	PMP-TASA SUMP	12	26.100281	<Null>
13	Polyline	P-446b			2797	PVC	PVC	150	0	J-233c	J-94d	6	2796.872055	<Null>
14	Polyline	P-561a			22	PVC	PVC	150	0	J-281	FCV-216	6	21.837231	<Null>
15	Polyline	P-579			54	PVC	PVC	150	0	J-287	FCV-226	6	53.560594	<Null>

Record: 1 Show: All Selected Records (0 out of *2000 Selected) Options

Figure 3: Sample Attribute files for CUC Tanks Pumps and Pipes that are available in the GIS data Base

Methodology

The steps that were taken to complete the goals of this project were to: update the Saipan water distribution model by adding the new development that was constructed from 2009 to 2011, connecting the sub-regions together according to CUC operation, and finally adding the new information to the CUC's GIS data base.

As mentioned earlier, a stated goal of the CNMI government is to provide 24-hour water service to all CUC customers. This requires new wells, transmission lines, a means of transferring water from the different water system regions, and changes in system operation. The first model of the CUC water distribution system was completed in 2006. In 2009, two major developments were completed by CUC which are shown in Figure 4, and 5. The physical components of the water distribution system for these developments were input to the skeleton of the water distribution for regions 3 and 6. In 2011, as part of a well isolation program the following changes were made to the CUC water distribution system:

Region 6: Wells AS1, 2, 3, 5, and 7 were diverted into San Vicente Tank.
Region 7: Wells KG20, 21, 22 were diverted into new 1 million gallons tank at Kagman.
Region 4: New transmission line was put in place that carries all cobbler wells into Isle tank.
Region 1: New well MQ3 was added to the system as shown in Figure 6.

These changes were added to the CUC skeleton model. The only problem that we encountered was the ground elevation of some of the wells. This is due to the discrepancy between the Saipan base map projection and the CUC AutoCAD drawing map. Hopefully this will be resolved by the CNMI Department of Land Management.

Figure 4: New development, San Vicente, Saipan

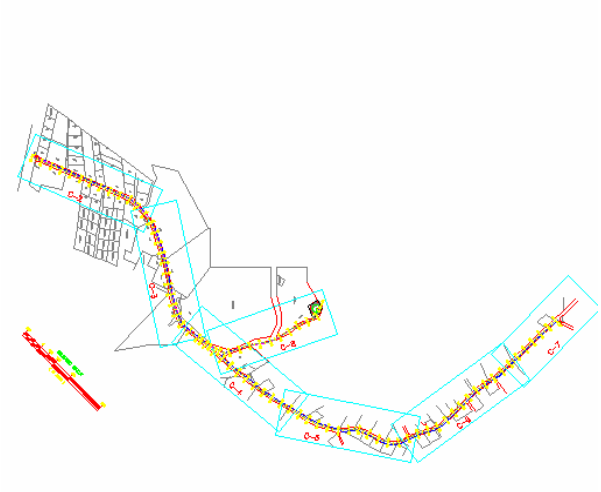


Figure 5: New development, Kannat Tabla, Saipan

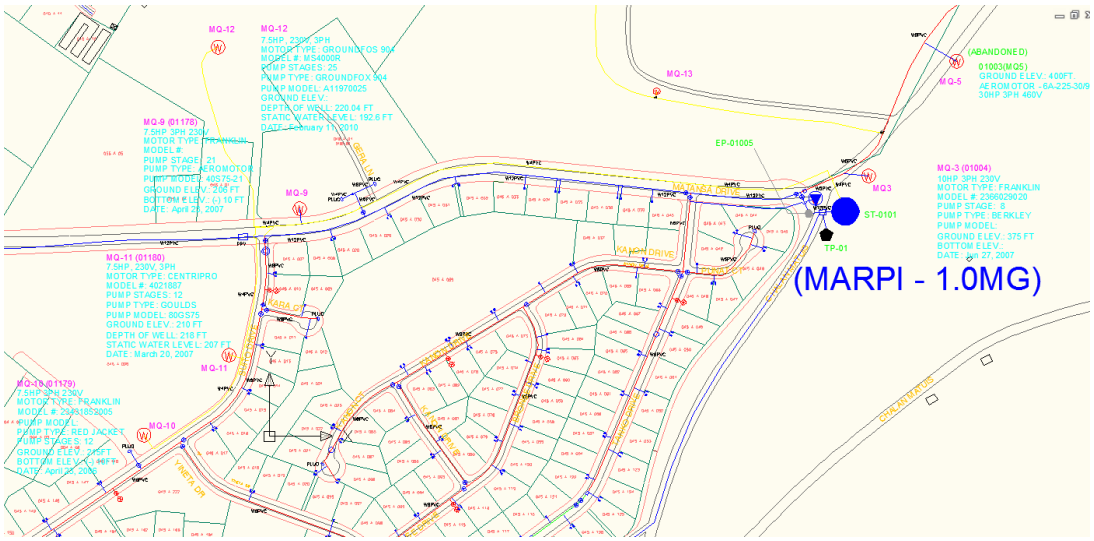


Figure 6: New development, Region 1, Marpi

The next step was connecting the regions together according to how CUC operates the system. As shown in Figure 7, regions 9A, 8A, 8B, and 8C have been connected together for transferring water from Isle tank to CUC's customers providing 24-hour water service. The other regions will be joining together as the new wells are put into the system. Since the CUC system operation changes daily, we developed a procedure for joining the regions together based on the customers demand and adding new elements to the existing models. We provided training to the CUC operation crew on using the procedure in 2007 and 2011. We are in process of adding the pipes, wells, and tank information from the new developments to the CUC's GIS data base that was developed by WERI researchers (Heitz, Khosrowpanah 2011).

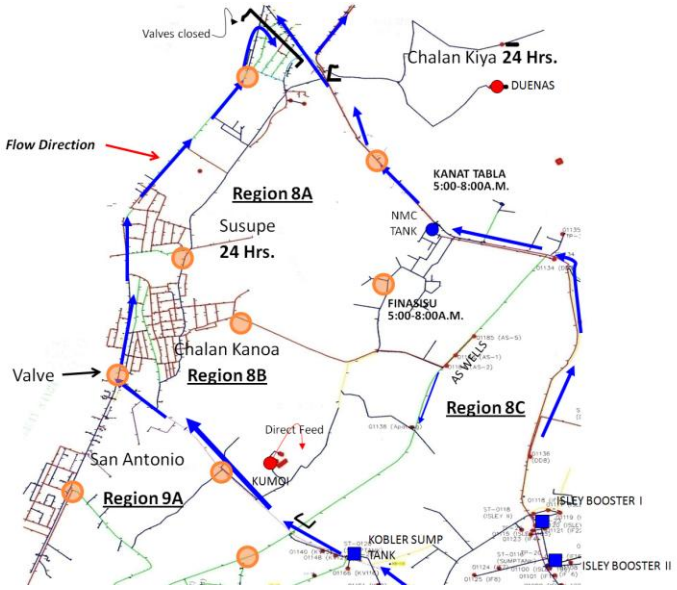


Figure 7: CUC's present operation, joining region 9A, 8A, 8B, and 8C

Principal Findings and Significance

The skeleton of the Saipan water distribution system has been updated. It reflects all the new developments that have been in place since 2009. The water production from wells that has been renovated since 2009 has been input to the model. We conducted two trainings in 2007 and 2011 on how to join the sub-region together based on CUC operation. This will help CUC to transfer water among the regions that are in water shortage. At the present time, 70 percent of the customers are on 24-hours water. Currently CUC is in the process of installing new smart meters throughout the system. The data generated from the smart meters will help to calibrate the system and then CUC can explore various scenarios of system operation. Presently we are in the process of developing water usage patterns (diurnal demand patterns) for the Saipan Water Distribution System. The resulting improvements to the demand estimates, and its changes with time, will provide the CUC water division the capability to: a) determine the amount of the water that is being lost through the system, b) implement various operational systems for transferring water among the 15-sub regions for providing 24-hour water service to the customers, and c) improve water system maintenance.

We conducted training for the CUC engineers on the use of GIS data base that was developed by WERI researchers on June 2011.

Literature Cited

Heitz L. F., Sh. Khosrowpanah, 2008, "Development of Junction Demands for the Saipan Water System Numerical Model", University of Guam, Water and Environmental Resources Research Institute, Mangilao, Guam, Technical Report No. 122, 37pp.

Heitz L. F., Sh. Khosrowpanah, 2011, "Development of a Geographic Information System for the Commonwealth Utility Corporation, Saipan Water Distribution System", University of Guam, Water and Environmental Resources Research Institute, Mangilao, Guam, Technical Report No. 132, 17pp.

Environmental Impact of FUDS and Brownfields Sites in Watersheds on the Eastern Side of Saipan. Phase 1: Contaminant Analysis of Soil and Sediments

Basic Information

Title:	Environmental Impact of FUDS and Brownfields Sites in Watersheds on the Eastern Side of Saipan. Phase 1: Contaminant Analysis of Soil and Sediments
Project Number:	2011GU200B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	n/a
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Sediments
Descriptors:	pollution monitoring and assessment, dumpsites, heavy metals, pesticides, PCBs, drainage pathways, sediment, soil and biota analysis, Saipan, Micronesia
Principal Investigators:	John Starmer, Gary Denton

Publications

There are no publications.

Project Title: Environmental Impact of FUDS and Brownfields Sites in Watersheds on the Eastern Side of Saipan. Phase 1: Chemical Integrity of Soils and Sediments

Problems and Research Objectives

The massive clean-up and redevelopment of Saipan at the end of WWII presented waste disposal problems that were largely solved by either bulldozing unwanted materials into the ocean, burying them in caves, or dumping them at relatively remote locations on land. Virtually every kind of material used in warfare were among the items disposed of in this way, in addition to demolition and construction debris and other residual materials associated with the rebuilding effort. At that particular point in Saipan's history, little thought if any, was given to the long-term impact on the environment or human health, as the island struggled to rebuild. As a consequence, the majority of dumpsites that arose at that time were soon forgotten, having been overgrown by natural vegetation or claimed by the sea.

Renewed interest in their existence did not come about until almost half a century later following the implementation of the Department of Defense (DOD) *Formerly Used Defense Site* (FUDS) *Environmental Restoration Program* in 1986 (Shimmin 2007). This program was established to clean up environmental contamination of lands caused by military services prior to 1986 and fell under the auspices of the US Army Core of Engineers (ACOE). To date, 23 of the 32 FUDS identified in the CNMI occur on Saipan (ACOE 2007). An additional 41 contaminated sites have also been identified and await further assessment under the *Brownfields Program* administered through the USEPA (Masga 2009).

Inventories of materials disposed of at these unrestricted dumpsites are largely based on visual assessments with unexploded ordnances, munitions and demolition materials ranking among the more obvious wastes present (AMPRO 2005, ACOE 2007). What little chemical information exists indicate heavy metals, PCBs and PAHs to be the more commonly encountered contaminants.

Our previous studies have determined the impact of these contaminant groups on aquatic resources along the western seaboard of Saipan (Denton and Starmer 2010, Denton *et al.* 2001, 2006, 2008, 2009, 2010a & b). Extending the study to watersheds on the eastern side of the island (Fig. 1) where several WWII dumpsites have recently been rediscovered is therefore seen as a logical extension of this work.

Figure 1: Map of Saipan Watersheds

The investigation is being conducted in two discrete phases. Phase 1 is now complete and is the subject of this report. It focused on soils and sediment samples retrieved for heavy metal analysis from drainage pathways leading to the coast. Phase 2 is currently underway and is examining metal levels on aquatic resources within impacted watersheds. It will also determine any potential human health risks (if any) associated with their long-term consumption.

Methodology:
Surficial soil and sediment samples were collected in the vicinity of dumpsites and their corresponding drainage pathways and coastal discharge points, along the eastern side of Saipan, and at one dumpsite in a stream that discharged on the western side of the island. In all 34 sites were visited (Fig. 1). Samples were collected using all plastic instruments and containers.

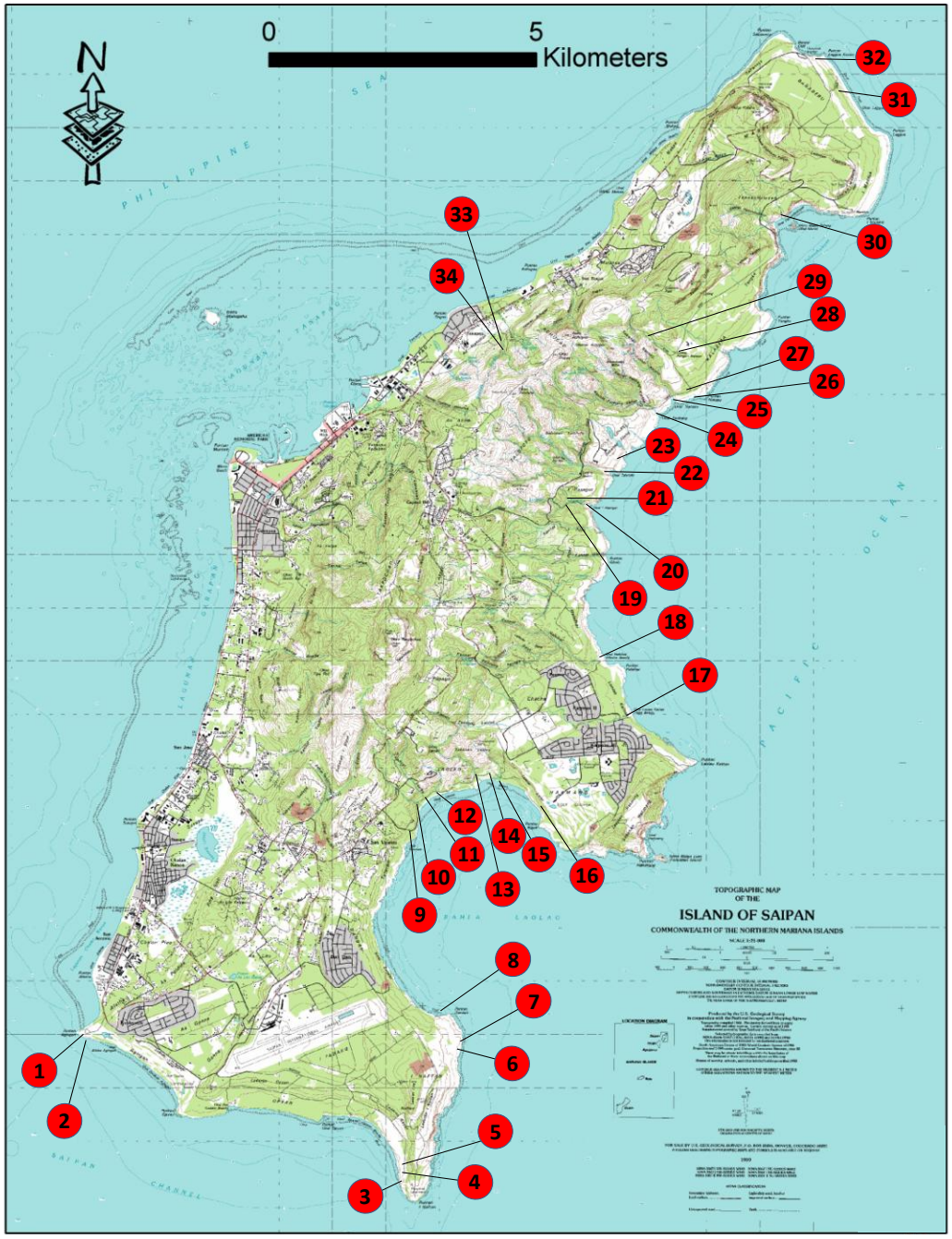


Figure 1: USGS 1-25000 topographic map of Saipan (15°12'N, 145°43'E) showing study sites at or close to: Agingan Dump (sites 1-2), Obyan Dump (sites 3-5), Naftan Dump (sites 6-8), Kagman Dump (sites 17-18); Hospital Dump (sites 22-23), DPS Firing Range (sites 25-29), Banzai Dump (sites 31-32); Dogas Dump (sites 33-34) and various unspecified inland dumpsites (sites 9-16 , 19-21, 24 and 30). See column 2 in Table 1 for additional site information.

In the laboratory, all samples were dried to constant weight in open polyethylene bags at 30°C. The disaggregated deposits were then sieved through a 1-mm nylon screen and tumbled repeatedly with clean, Teflon coated bar magnets to remove fragments of metallic iron. Each sample was digested in duplicate with concentrated nitric acid (1g/10 ml) at100°C, for 3 h, then made up to volume (30 ml) with deionized water and allowed to stand overnight. Finally, clear aliquots of each digest were decanted into polyethylene screw-cap vials (50 ml) for later analysis by atomic absorption spectrophotometry. This method is based upon USEPA SW-846, Method 3050B (USEPA 1995, 1996), with minor modifications described earlier by Denton *et al.* (1999).

Principal Findings and Significance

Dumpsites were generally located well away from residential areas, in sinkholes, streams and ravines, on cliff edges and in the ocean. Some, like 'Kagman Dump' and 'Agingan Dump', had been partially remediated, while others, like 'Dogas Dump' (Fig. 2) and 'Obyan Dump', were essentially in their original state, weathering effects and vegetation overgrowth notwithstanding.

Fig. 2: Dogas stream in the Achugao watershed in northern Saipan served as a general dumping ground for military wastes at the end of WWII. Old rusted out drums that once contained tar for road construction during the rebuilding effort, and an assortment of other military discards, including an old aircraft engine and a partially buried unexploded aerial bomb, are visible in the above photographs. Heavy metal enrichment was noted in sediments downstream of the dump.

The analytical findings are summarized in Table 1. Baseline levels of heavy metals found in uncontaminated US soils (USEPA 2005) and carbonaceous sediments of biogenic origin (Denton *et al.* 2001) are also listed, together with the environmental and ecological screening levels for metals in soils currently employed by Saipan's Division of Environmental Quality (DEQ 2005) and USEPA (USEPA 2005), respectively.

DEQ's environmental screening levels (ESLs) are based on human health and ecological concerns and are considered conservative, i.e., they are well below levels thought to cause immediate, acute health effects. The USEPA's ecological soil screening levels (Eco-SSLs) are conservatively protective of ecological receptors that commonly come into contact with soil or ingest biota that live in or on the soil. Like DEQ's ESLs, they represent a preliminary screening tool for evaluating site contaminant levels and determining if further investigations are necessary. Both were used to assess contaminant levels found in the present study.

Table 1: Heavy Metals in Soil and Sediments from FUDS and Other Post-War Dumpsites in Saipan, CNMI

Map id	Site Description	Sampling Points	Ag	Cd	Cr	Cu	Fe	Hg[a]	Mn	Ni	Pb	Zn
1	Agingan cliffline dump	1	<0.2-0.58	<0.38	9,00-12.7	948-1617	13052-14600	24.4-25.0	102-136	3.91-5.34	1846-2000	919-960
2	Agingan submerged sediments	3	<0.19-0.39	<0.20	4.10-13.1	97.5-157	3506-6245	56.3-136	15.2-77.9	1.99-5.39	1460-1822	49.0-87.1
3	Obyan ravine dump	1	1.36-1.53	21.4-22.7	111-115	11580-11864	42994-45000	142-143	1459-1542	77.6-96.4	1555-1582	8924-9019
4	Obyan ravine dump	1	36.0-42.0	16.2-17.8	94.2-100	2220-2360	50400-50800	604-624	2400-2492	72.6-73.7	1960-2000	5660-5760
5	Obyan ravine dump	1	23.4-23.5	14.6-15.9	59.7-60.2	1403-1647	24706-26688	421-425	960-969	18.6-21.5	1696-1787	2805-2882
6	Naftan cliffline dump	1	<0.20	0.59-0.60	6.30-6.74	16.5-17.0	3974-4184	87.9-88.0	320-336	2.47-2.69	6.97-8.18	21.3-22.5
7	Naftan cliffline dump	1	0.59-0.60	1.58-1.76	32.8-36.6	161-180	49608-50329	58.4-63.9	875-882	13.2-13.3	72.3-73.0	371-407
8	Dan Dan Point: submerged sediments	3	all <0.19	all <0.19	2.90-3.34	0.38-5.10	172-740	3.70-6.87	3.44-5.49	0.97-1.43	all <0.96	0.57-2.94
9	Lau Lau Bay Road: drainage pathway of unspecied inland dump(s)	1	<0.19	0.58-0.60	8.17-10.5	8.85-9.60	7288-9460	12.0-12.5	173-186	2.88-3.50	<1.15	11.7-13.0
10	Lau Lau Bay Road: drainage pathway of unspecied inland dump(s)	1	<0.20	<0.39	4.93-5.81	6.39-6.71	4935-5112	15.7-18.5	103-109	2.42-2.47	<0.99	9.48-10.1
11	Lau Lau Bay Road: drainage pathway of unspecied inland dump(s)	1	<0.20	0.59-0.60	10.4-12.0	32.2-36.6	29600-30397	30.6-31.0	1313-1438	5.46-5.50	<0.99	42.4-45.3
12	Lau Lau Bay Road: drainage pathway of unspecied inland dump(s)	1	<0.20	<0.39	11.6-12.2	44.0-44.6	51513-51800	48.0-55.2	2298-2372	7.40-7.50	<1.00	47.4-52.0
13	Lau Lau Bay Road: drainage pathway of unspecied inland dump(s)	1	<0.19	<0.39	7.92-8.55	39.2-41.1	39935-40701	35.5-36.1	1052-1122	4.38-4.78	<1.15	40.9-42.8
14	Lau Lau Bay Road: drainage pathway of unspecied inland dump(s)	1	<0.19	<0.39	8.24-8.50	49.7-55.7	44503-46065	15.5-17.8	2921-3534	4.47-4.84	<1.10	48.9-51.1
15	Lau Lau Bay beach: drainage discharge point of unspecified inland dump(s)	1	<0.19	<0.19	4.17-4.19	14.3-14.6	15860-16519	9.31-9.37	678-680	1.43-1.90	<1.10	16.2-18.4
16	Lau Lau Bay: unspecified cliffline sinkhole dump	1	<0.19	3.00-3.23	87.4-93.0	56.4-57.3	51800-52595	91.7-106	2718-2947	16.6-17.5	7.82-8.24	90.6-92.3
17	Tank Beach: Kagman dump drainage discharge point	1	<0.20	0.59-0.60	23.1-27.1	33.5-34.8	44118-46200	48.1-52.9	2622-2966	6.00-6.27	<1.15	40.8-41.0
18	Marine Beach: drainage discharge point of unspecified inland dump(s)	1	<0.19	0.77-0.79	25.9-26.7	39.5-43.0	46839-47171	11.8-12.0	3345-4318	7.26-13.8	<1.14	37.7-39.3
19	OMBTS[b]: unimpacted drainage pathway	1	<0.19	<0.19	8.91-11.1	20.5-22.3	25063-27115	10.2-11.0	518-621	1.92-2.37	<1.12	28.3-31.7
20	OMBTS[b] Beach: drainage discharge point of unspecified dump	1	<0.20	<0.19	17.1-18.3	515-614	24909-24423	6.61-7.31	363-442	1.95-2.40	<0.74-9.87	52.2-57.3
21	OMBTS[b]: impacted drainage pathway of unspecified dump	1	<0.20	0.99-1.18	25.3-25.9	46.9-48.0	38481-38487	49.9-51.5	808-855	8.33-8.39	118-149	110-146
22	Talafofo Bay: beach drainage discharge point	1	<0.20	<0.20	5.91-6.16	10.3-11.0	16000-17032	3.10-3.85	205-224	0.97-1.50	<1.18	13.2-13.5
23	Hospital Dump: located on 'Kingfisher Golf Course'	6	<0.20-4.34	0.60-2.55	5.30-63.7	22.8-126	6616-52931	172-741	358-3078	3.71-27.6	0.80-187	49.4-1559
24	Fenhang Beach: unimpacted drainage discharge point	1	<0.20	<0.39	20.0-20.1	26.3-27.4	36711-38289	20.7-22.6	1731-1916	8.30-8.39	<1.16	36.5-36.9
25	Nanasu Beach: drainage discharge point of unspecified inland dump(s)	1	<0.20	1.19-1.37	14.2-15.4	21.4-23.0	22745-25232	22.6-27.9	1533-1546	6.37-6.46	<0.98	35.4-35.5
26	Flemming: drainage pathway from DPS Firing Range	1	<0.19	0.96-0.99	32.4-32.8	29.8-31.0	30000-32293	21.0-28.1	1189-1208	11.3-11.5	1.97-3.82	53.9-54.5
27	Flemming: drainage pathway from DPS Firing Range	1	<0.19	1.56-1.73	59.8-69.7	40.1-42.1	53377-58462	66.9-75.6	1256-1312	14.6-14.9	<0.96	54.2-58.8
28	Liyang: drainage pathway from DPS Firing Range	1	<0.20	2.77-2.78	7.32-8.37	58.0-58.2	14503-15497	98.7-109	1683-1941	6.95-7.45	<0.99	77.5-82.6
29	DPS Firing Range	1	<0.19	3.38-3.48	11.1-11.4	12.4-12.9	19935-20265	35.7-36.7	1144-1283	6.96-7.26	<0.97	29.2-30.0
30	Bird Island Beach: drainage discharge point of unspecified inland dumpsite(s)	1	<0.20	1.57-1.72	12.1-13.9	36.6-37.1	30764-31176	37.9-38.8	1027-1168	6.86-6.93	<1.01	35.3-38.4
31	Banzai Cliff: cliffline dump	1	<0.19	3.87-3.92	45.7-46.4	45.7.47.1	43529-43548	901-1040	1425-1519	10.3-10.6	18.0-26.2	195-194
32	Banzai Cliff: sinkhole dump	1	0.38-0.59	4.14-4.23	93.3-94.4	146-148	43026-43846	49.3-55.4	1954-2129	14.9-17.8	329-331	748-758
33	Dogas Dump: downstream of impacted area	4	all <0.20	<0.20-1.18	4.52-12.9	4.71-31.7	6020-25098	14.5-26.8	131-810	1.34-6.73	<0.9-36.3	20.1-117
34	Dogas Dump: upstream of impacted area	5	all <0.20	<0.20-0.40	6.50-16.4	10.5-17.9	13283-26682	4.73-79.6	440-1039	3.04-5.42	<0.94	19.7-37.9
USGS nationwide soil studies: backgound metal levels (USEPA 2005)		Median	0.6	0.3	48.2	21.0	22045	-	471	18.0	18.0	54.5
		Range	0.5-1.2	0.1-0.9	13.8-122	5.0-96.0	3705-50147	20-60[c]	85-1112	3.8-48.0	5.0-39.0	12.0-233
Background metal levels in clean carbonate sands of biogenic origin (Denton et al 2001)			<0.1	<0.1	1-5	<0.1-3	50-500	2-10	10-50	<0.2-3	<1	<1-5
Saipan 'Environmental Screening Levels (ESLs)' for shallow residential soils (DEQ 2005)			20	7.8	210	230	-	2500	-	150	200	600
USEPA Interim 'Ecological Soil Screening Levels (Eco-SSLs)' for most sensitive receptor[d] (USEPA 2005)			4.2 (B)	0.36 (M)	26 (B)	28 (B)	200 (SM)[e]	100 (670)[e,f]	220 (P)	38 (P)	11 (B)	46 (B)

[a]Values for total mercury are given as ng/g dry weight; dashes indicate no data; [b]OMBTS = 'Old Man by the Sea'; [c]range values for total mercury in soil taken from Kabata-Pendias and Mukherjee(2007); [d](B)=birds, (M)=mammals, (P)=plants, (SM)=soil microorganisms. [e]after Friday (1999) and adopted by USEPA Region 4 Hazardous Waste Management (Superfund) Division; [f]inorganic mercury (methylmercury)

Samples collected for analysis were typically from shallow, well drained soils on limestone escarpments and plateaus. The elemental composition of these deposits varied substantially between sites. Samples taken in the vicinity of 'Obyan Dump' (sites 3-4) were notably enriched with all metals, especially silver, cadmium, copper, mercury, lead and zinc. Values for these elements were between one and two orders of magnitude above those reported for uncontaminated soils in the US (USEPA 2005) and, with the exception of mercury, substantially exceeded DEQ's ESLs for shallow residential soils (DEQ 2005). Gross screening level exceedences for copper and lead were also found in soil from around 'Agingan Dump' (site 1). Submerged marine sediments in this area (site 2) were also disturbingly high in lead and at least an order of magnitude higher in copper, iron, mercury and zinc, compared with clean carbonate sediments elsewhere in Saipan Lagoon (Denton *et al.* 2001). Other site exceedences of Saipan's ESLs were noted for copper at 'Old Man by the Sea Beach' (site 20), zinc at 'Hospital Dump' (site 23), and lead and zinc at 'Banzai Cliff Dump' (site 32). Additional exceedences emerged upon weighing the data against the more conservative ecological screening levels formulated by USEPA (USEPA 2005). These are listed in Table 2 together with all DEQ's ESL exceedences.

Concluding Remarks

While the majority of dumpsites visited are reasonably far from the general population, many Saipan residents hunt and forage for food in such remote places. Therefore, the degree of metal uptake by food organisms in these areas may be of concern from a public health standpoint. This is particularly true for the more toxic elements like mercury, cadmium, silver and lead, which were found in relatively high concentrations in soils from some of the sites examined. These contaminants have no known biological function and are readily accumulated by terrestrial and aquatic animals and plants. It is therefore important to determine the metal loading of any biotic components harvested for food in these areas. Land crabs, including coconut crabs and hermit crabs, are obvious candidates for further assessment in this regard, as are wild fruits, coconuts, wild peppers, and medicinal plants used by local suruhano (healers).

The alarmingly high levels of lead found in and around the old dump site at 'Agingan Point' is another issue of concern here, especially considering the gross contamination found in sediments immediately offshore. This area and the adjacent waters of Saipan Lagoon are popular recreational and subsistence fishing spots. Local residents also harvest bivalves and seaweed for consumption from these waters. Preliminary follow-up analysis of sediments in this part of the lagoon has so far indicated widespread lead contamination that extends from the cliff face northwards along the beach for about 500 m and westwards out to the reef front, a distance of approximately 300 m. Determining the impact of this dump on aquatic communities in the area is obviously important as are the implications of the findings from a human health perspective.

Other sites of similar interest include 'Hospital Dump' (site 23), which encroaches on a public golf course and has drainage pathways into an artificial lake fished by some of the course employees, and 'Lau Lau Bay' and 'Old Man by the Sea Bay', which serve as drainage discharge points for several unspecified inland dumps and are popular fishing and recreational spots for locals and tourists alike. The relatively high levels of cadmium found inland at the old 'DPS Firing Range' (site29) and further down gradient at 'Liyang' (site 28), as well as along the coast between 'Nanasu Beach' (site 25) and 'Bird Island' (site 30), also concern us and require follow-up studies to determine impacts on aquatic fisheries and other popular food items in these areas.

Table 2: Sampling Sites Showing Soil Screening Level Exceedences (✓)

Map i.d.	Ag	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
DEQ ESL's for Saipan[a]	20	7.8	210	230	NA	2500	NA	150	200	600
1				✓					✓	✓
2									✓	
3		✓		✓					✓	✓
4	✓	✓		✓					✓	✓
5	✓	✓		✓					✓	✓
19				✓						✓
32									✓	✓
USEPA Eco-SSLs[b]	4.2	0.36	26	28	200[c]	100[c,d]	220	38	11	46
1				✓	✓				✓	✓
2				✓	✓	✓			✓	✓
3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓	✓		✓	✓
6		✓			✓		✓			
7		✓	✓	✓	✓		✓		✓	✓
8					✓					
9		✓			✓					
10					✓					
11		✓		✓	✓		✓			
12				✓	✓		✓			✓
13				✓	✓		✓			
14				✓	✓		✓			
15					✓		✓			
16		✓	✓	✓	✓	✓	✓			✓
17		✓	✓	✓	✓		✓			✓
18		✓	✓	✓	✓		✓			
19					✓		✓			
20				✓	✓		✓			✓
21		✓	✓	✓	✓		✓		✓	✓
22		✓		✓	✓		✓			
23	✓		✓	✓	✓	✓	✓		✓	✓
24					✓		✓			
25		✓			✓		✓			
26		✓	✓	✓	✓		✓			✓
27		✓	✓	✓	✓		✓			✓
28		✓		✓	✓	✓	✓			✓
29		✓			✓		✓			
30		✓		✓	✓		✓			
31		✓		✓	✓	✓	✓		✓	✓
32		✓	✓	✓	✓		✓		✓	✓
33		✓	✓	✓	✓		✓		✓	✓
34		✓			✓		✓			

[a]DEQ (2005) for shallow residential soils; [b]USEPA (2005) for most sensitive ecological receptors;
[c]after Friday (1999) and adopted by USEPA Region 4 Hazardous Waste Management (Superfund) Division;
[d]inorganic mercury only; NA = none available

Literature Cited

ACOE (2007). Revised Final Statewide Management Action Plan (SMAP) for Defense Environmental Restoration Program Formerly Used Defense Sites (DERP-FUDS) within the Commonwealth of the Northern Mariana Islands. *Prepared by the ACOE Pacific Ocean Division, Honolulu Engineer District,* June 27, 2007.

AMPRO (2005). Unexploded Ordnance, Historical Research and UXO Assessment. Saipan Commonwealth of the Northern Mariana Islands. *Report prepared by AMPRO Ordnance and Explosives Experts,* December 10, 2005.

Denton, G.R.W. and Starmer J.A. (2010). Influence of Stormwater and Wastewater Discharges on the Distribution and Abundance of Heavy Metals in Sediments from Saipan Lagoon. *104-B Project Synopsis Report*. **In**: WERI 2006 Annual Report to USGS, pp 41-48.

Denton, G.R.W., Trianni, M.S. and Tenorio, M.C. (2010a). Impact of Land-Based Sources of Pollution on Coastal Water Quality of Saipan, Commonwealth of the Northern Mariana Islands (CNMI): Arsenic, Mercury and PCBs in Popular Table Fish from Saipan Lagoon. *WERI Technical Report* No. 130: 98 pp.

Denton, G.R.W., Trianni, M.S., Bearden, B.G., Houk, P. and Starmer, J.A (2010b). Impact Determination of Unusual Mercury Source on Fisheries Resources in Saipan Lagoon, Saipan, Commonwealth of the Northern Mariana Islands: A Preliminary Assessment. *Proceedings of Island, Environment, Resources International Symposium,* Ryukyus University, Okinawa, Japan December 18, 2010 (in press).

Denton, G.R.W., Morrison, R.J., Bearden, B.G., Houk, P., Starmer, J.A. and Wood, H.R. (2009). Impact of a Coastal Dump in a Tropical Lagoon on Trace Metal Levels in Surrounding Marine Biota: A Case Study from Saipan, Northern Mariana Islands (CNMI). *Marine Pollution Bulletin,* 58: 424-455.

Denton, G.R.W., Bearden, B.G., Houk, P., Starmer J.A. & Wood H.R. (2008). Heavy Metals in Biotic Representatives from the Intertidal Zone and Nearshore Waters of Tanapag Lagoon, Saipan, Commonwealth of the Northern Mariana Islands (CNMI). *WERI Technical Report* No. 123: 50 pp.

Denton, G.R.W., Bearden, B. Concepcion, L.P., Wood, H.R. and Morrison R.J. (2006). Contaminant Assessment of Surface Sediments from Tanapag Lagoon, Saipan, Commonwealth of the Northern Mariana Islands. *Marine Pollution Bulletin*, 52: 703-710.

Denton, G.R.W., Bearden, B.G., Concepcion, L.P., Siegrist, H.G., Vann, D.T. & Wood, H.R. (2001). Contaminant Assessment of Surface Sediments from Tanapag Lagoon, Saipan. *WERI Technical Report* No. 93: 145 pp.

Denton, G.R.W., L.P. Concepcion, H.R. Wood, V.S. Eflin and G.T. Pangelinan (1999). Heavy Metals, PCBs and PAHs in Marine Organisms from Four Harbor Locations on Guam. A Pilot Study. *Water and Environmental Research Institute (WERI) of the Western Pacific Technical Report***,** No. 87, June 30, 1999. 154 pp.

DEQ (2005). Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater. Volume 1. Summary Tier 1 Lookup Tables. *Saipan Division of Environmental Quality, Commonwealth of the Northern Mariana Islands (CNMI) Report Prepared by Hawai'i Department of Health, Hazard Evaluation and Emergency Response*

Friday, G.P. (1999). Ecological Screening Values for Surface Water, Sediment and Soil. *Westinghouse Savannah River Company Technical Report No. 98-00110.* http://www.osti.gov/bridge/servlets/purl/4764-2uJvjR/webviewable/4764.pdf

Kabata-Pendias, A. and A.B. Mukherjee (2007). Trace Elements from Soil to Humans. Berlin: Springer Verlag.

Masga, R. (2009). DEQ Discusses Brownfields Super fund Law. *Mariana Variety Newspaper* Friday August 7, 2009. Story Reported by Andrew O. De Guzman - Variety News Staff

Shimmin, K. (2007). FUDS and OE Contamination in Guam, CNMI, and Off-Shore Pacific Waters: Potential Impact on an Oil-Hazmat Response & How To Get Assistance. Oceania Regional Response Team Meeting, April 24, 2007. For further information contact Kathleen Shimmin, FUDS Program Manager, USEPA-IX. Email: shimmin.kathleen@epa.gov.

USEPA (2005). Guidance for Developing Ecological Soil Screening Levels (OSEWR Directive 9285.7-55). *U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response*, 1200 Pennsylvania Avenue, N.W. Washington, DC 20460

USEPA (1996). Method 3050B. Acid Digestion of Sediments, Sludges, and Soils. http://www.epa.gov/wastes/hazard/testmethods/sw846/online/3_series.htm

USEPA (1995). SW-846 Test Methods for Evaluating Solid Waste Physical/Chemical Methods. Proposed Update III (January 1995). *Produced by the US Environmental Protection Agency, Office of Solid Waste*.

Heavy Metal Status of Soils and Stream Sediments Impacted by Leachate from a Municipal Dump in Yap State, Federated States of Micronesia

Basic Information

Title:	Heavy Metal Status of Soils and Stream Sediments Impacted by Leachate from a Municipal Dump in Yap State, Federated States of Micronesia
Project Number:	2011GU203B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Sediments, Toxic Substances, Management and Planning
Descriptors:	municipal dump, soil, sediments, leachate contamination, heavy metals
Principal Investigators:	Christina Fillmed

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Heavy Metal Status of Soils and Stream Sediments Impacted by Leachate from a Municipal Dump in Yap State, Federated States of Micronesia

Problem and Research Objectives

The main public dump in Yap, FSM, is an open, unsanitary facility located approximately 2 miles west of Colonia in the municipalities of *Rull* and *Dalipebinaw* (Fig. 1). It was officially opened by the State government in the late 1970s and has served as the main repository of non-segregated wastes from Yap Proper/Main Island since then. The dump receives around 4 tons of garbage and other residential wastes per day from Colonia town area and surrounding rural communities. Currently, it covers an area of approximately 1,460 square meters, and rises to a height of 10 meters at its highest point.

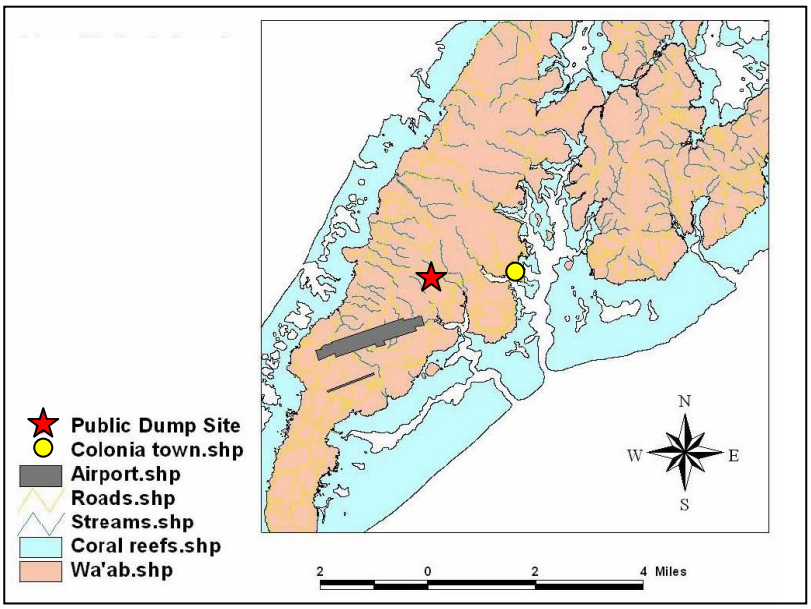


Figure 1: Yap Island showing public dump site and other landmarks

The dump is maintained by the *Department of Public Works & Transportation* who focuses largely on trash compaction and site stability. While soil cover is used to reduce odor, flies and vermin, it is applied only intermittently and largely inadequate. Of far greater concern, however, is the fact that the dump is not lined and there are no leachate retention systems in place. As a consequence, leachate that exudes at intervals around the dump perimeter during wet weather conditions flow down gradient into a nearby stream known as *Lul nu Tamthaw*.

The *Lul nu Tamthaw* flows SE for about 1 km before emptying into a forest of mangroves at the coast. Both the stream and the mangroves are popularly used by local residents for fishing, food gathering and recreational activities. The potential impact of the raw leachate on aquatic resources in these areas has been of long-standing concern to the people of Yap, both from an ecological and human health standpoint.

The purpose of this research project was to: a) determine the impact of leachate streams emanating from the Yap public dump on the heavy metal status of soils and stream sediments located down gradient of the facility, and b) provide baseline data and information, in support of Yap State's plan to rehabilitate and improve the dump site. The primary objectives were to assess the current degree and extent of the heavy contamination and determined the potential impact on aquatic resources and human health.

Methodology

Sampling is currently underway at the following locations shown in the Fig. 1 below. Samples retrieved to date are stored at -20°C and will be air freighted to WERI lab once sampling is completed for metals analysis later this year.

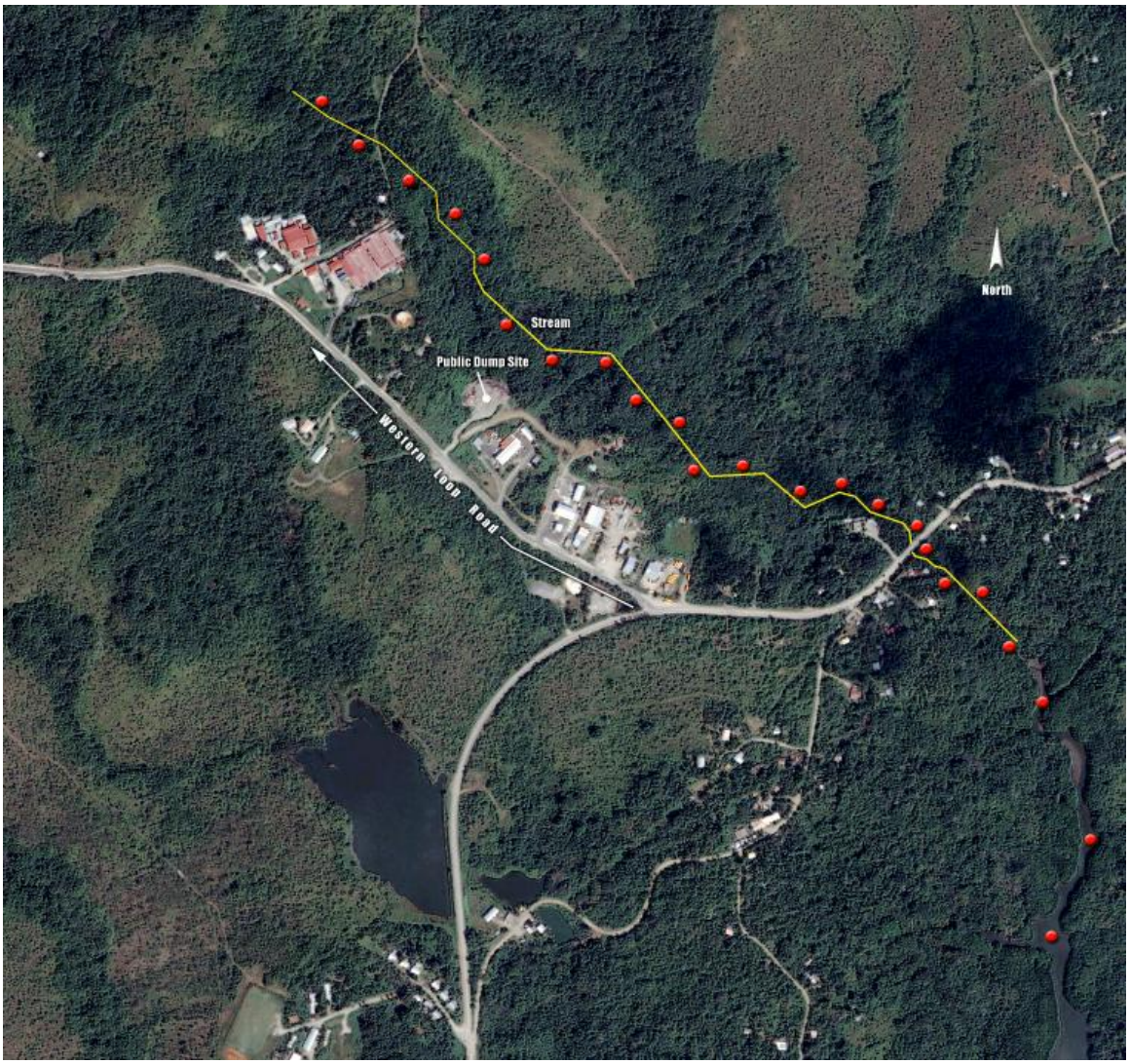


Figure 2: Arial view of study area showing location of the public dump and stream (*Lul nu Tamthaw*) sampling sites

Principal Findings and Significance

While no data is currently available the finding will provide critical information on levels and distribution of potentially toxic heavy metals in the watershed downstream of the dump. They will also provide valuable baseline information with which future findings may be compared and evaluated. Lastly, the data will assist waste disposal operators and environmental managers with any future decision making processes aimed at site remediation and rehabilitation once the dump has been closed.

Identifying Watershed Discharge Patterns and Linkages with Ecological Assemblages in Nimpal Area, Yap State, Federated States of Micronesia

Basic Information

Title:	Identifying Watershed Discharge Patterns and Linkages with Ecological Assemblages in Nimpal Area, Yap State, Federated States of Micronesia
Project Number:	2011GU205B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Water Quality
Focus Category:	Water Quality, Ecology, Nutrients
Descriptors:	water quality, seagrass-and-macroalgae ecology, nutrients, marine protected areas, adaptive management
Principal Investigators:	Peter Houk, Yimnang Golbuu

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Identifying Watershed Discharge Patterns and Linkages with Ecological Assemblages in Nimpal Area, Yap State, Federated States of Micronesia

Problem and Research Objectives

Across Micronesia, the influence of land-based pollution upon nearshore aquatic habitats is increasing in severity (Richmond et al. 2007; Golbuu et al. 2008b; Houk and van Woesik 2008; Houk and Van Woesik 2010; Houk and Starmer 2010). Numerous management and conservation planning documents cite land-based pollution as a priority threat to marine resources, and thus call for an improved science-to-management framework, as evidenced through WERI's 2010 critical needs list. In response, the contemporary doctrine continues to improve in defining relationships between improperly managed watersheds and predictable declines in ecosystem 'health'. However, much of the insight to date remains founded in somewhat obvious comparisons between 'heavily polluted' versus 'pristine' study sites. Yet, across Micronesia the majority of priority watersheds reside somewhere between these extreme pollution endpoints, and vary with respect to their geology, human use, magnitude and nature of discharge (i.e., groundwater versus surface water discharge). Because of the unique nature of watersheds and their discharge patterns, standardized approaches for understanding their relationships with nearshore coral reef assemblages remain lacking, as insightful studies often differ in methodology (Houk et al. 2005; Richmond et al. 2007; Oliver et al. 2011). Thus, study designs must consider a broad array of approaches that best conform to the unique situations presented, despite maintaining similar overall goals of determining thresholds, which if crossed, will lead to undesirable ecological trends and resource value (Houk and Camacho 2010).

The goals of the present study are to understand the extent to which surface runoff during storm events and groundwater discharge through the subterranean bedrock may be influencing nearshore coral reef habitats associated with a vibrant, locally-managed marine conservation area in Yap State, Federated States of Micronesia. Both surface and groundwater discharge are highly influential to nearshore ecological assemblages (Umezawa et al. 2002; Golbuu et al. 2008a; Houk and Starmer 2010), however they differ with respect to their nutrient constituents, chemical forms, delivery nature and rate. Groundwater input provides a more evenly-distributed, continuous source of inorganic nitrogen that percolates through the bedrock, while surface runoff typically contains sediments with attached, organic forms of nutrients that are discharged periodically during storm events (Devlin and Brodie 2005; Paytan et al. 2006). While specific ecological responses can vary due to these differences (Duarte 1995; Lirman and Biber 2000; Houk and Camacho 2010), one consistency is that when enriched with nutrients, both types of discharge can enhance the establishment and proliferation of macroalgae in nearshore ecosystems through time, and in seagrass beds in particular (Cardoso et al. 2004; Carruthers et al. 2005; Burkholder et al. 2007; Houk and van Woesik 2008).

The Nimpal Channel Marine Conservation Area (MCA) was established through a traditional, community-driven process to address growing concerns of marine resource

depletion and coral reef integrity. Despite significant improvements in fish abundance since the inception of the MCA, concerns regarding land-based pollution and undesirable algal proliferation in the seagrass beds adjacent to the MCA remain. Thus, the present study was designed to examine the extent, causes, and consequences of compromised seagrass habitats by examining their relationships with watershed discharge patterns. Within, we first evaluate the relative influence of surface versus groundwater discharge as potential contributors of nutrients to nearshore waters. Horizontal water quality profiles suggested that groundwater discharge has the greatest influence upon the study area, and thus nutrient sampling was conducted at several sites where low salinity waters were noted, as well as reference locations nearby. In compliment, ecological assessments were conducted in seagrass beds to examine affinities between macroalgal assemblages and water quality patterns. Finally, we assessed surface current patterns to determine the boundary of nearshore waters that are associated with the MCA, to infer potential linkages with enriched waters and associated organic detritus. Collectively, these data will eventually be used to determine and the channel is shown in black.boundary for export of nutrient-rich that were not influenced, and determined to be under the influence, of g This study next evaluates

Methodology

Study area. The Nimpal Channel Marine Conservation Area (MCA) is located on the west coast of Weloy Municipality, Yap State, Federated States of Micronesia (Fig.1). While Yap Proper consists of a network of both volcanic and limestone bedrock islands, the watersheds associated with Weloy municipality are situated upon limestone bedrock. The MCA boundary was selected to protect fishery resources within the migratory channel that separates the inner and outer reef habitats, encompassing 77.5 hectares of coral-reef habitat. Despite initial success in enhancing fishery resources within the MCA, community member and elder fishermen concerns over water quality and macroalgal growth in the adjacent seagrass beds continue to grow, forming the basis for the present study. Hierarchically, our driving questions were: 1) where are the significant watershed discharges located in the study area, 2) what is the extent of nutrient enrichment, 3) what are the relationships between these identified zones and seagrass/macroalgal assemblages, 4) are there hydrodynamic linkages between these identified regions and the MCA, and 5) given the insight generated, what are some possible solutions to improve watershed-to-reef conservation practices?

Data collection completed. In order to determine the nature and extent of watershed discharge in the project vicinity we employed a water quality profiling technique, whereby an auxiliary bilge pump was used to deliver surface waters (0.5 m depth) to a continuously-recording YSI-6600 water quality instrument situated on a small boat (Fig. 2). The boat was then driven at a consistent, slow speed (1 m/s) along pre-defined nearshore, mid-shore, and offshore transects. Using this technique, data pertaining to salinity, temperature, conductivity, pH, and turbidity were collected across the study region on multiple occasions that differed lunar phase and tidal regime. For visual purposes, horizontal water quality profile data were integrated into a geographic information system (GIS) and maps were produced. In order to evaluate the magnitude and influence of surface discharge during storm events, a vertical profile was created

along a transect line extending from the largest watershed discharge point to the inner MCA boundary shortly after a significant rain event, during the rainy season (i.e., vertical casts along the pre-defined transect).

Results from water quality profiles suggested that groundwater discharge through the limestone bedrock during lunar extremes was the prominent driver of nearshore salinity patterns, as compared with surface runoff during storm events (*see results*). Using this insight, 30 locations in the vicinity of the MCA that differed with respect to watershed discharge patterns were selected for exploratory investigation of nutrients (nitrate-NO_3-N, ammonium-NH_4-N, and orthophosphate-PO_4-P). During each of three sampling events conducted to date, 30 boat-based samples were collected in accordance with the University of Guam (UOG) Water and Energy and Research Institute (WERI) standard operating procedures that included the collection, filtering, and storage of samples on ice for shipment and processing.

In order to estimate the boundaries of horizontal transfer of productive waters to the MCA we investigated surface currents using standard drogues, mounted with global positioning systems (GPS). Drogues consisted of low-profile, floating, perpendicular PVC framework with plastic sheets extending 0.5 m below the surface. This design provided for the assessment of surface currents without being influenced by prevailing wind patterns. Drogues were deployed on several occasions in associated with maximal tidal exchanges and varying weather regimes, to best capture the boundaries of horizontal transfer. For visual purposes, data were integrated into a GIS and maps were produced.

Principal Findings and Significance

Horizontal water quality profiles suggested that groundwater discharge through the limestone bedrock during lunar extremes was the prominent driver of nearshore salinity patterns (Fig. 3). Although profiling was conducted at the 0.5 m depth, the emergence of clear salinity patterns during dry periods infers that sub-surface discharge through the bedrock was the likely origin of freshwater input. Further investigations using continuously recording temperature-conductivity sensors in seagrass beds are currently underway to confirm the accuracy of this insight. In contrast, vertical profiles highlighted a minimal influence of surface discharge during storm events, as low salinity waters remained in the upper layers of the water column with minimal mixing beyond 0.5 m depth (Fig. 4). Further, vertical profiles also inferred a rapid decline in turbidity, with minimal export of sediments and organic debris beyond 100 m from shore (Fig. 4).

Exploratory nutrient analyses agreed with the noted watershed discharge patterns. Although limited, initial findings suggested that a net influx of ambient nitrogen (NO_3-N plus NO_2-N) and phosphorous (PO_4-P) from oceanic waters to nearshore surface waters may exist, supporting the notion that surface water discharge contributes less to the nutrient regimes than expected (Fig. 5). In contrast, and consistent with a slow, continuous discharge of groundwater into nearshore waters and rapid nutrient uptake and processing by the benthos, ammonium (NH_4-N) concentrations were highest in the nearshore waters adjacent to the MCA (Fig. 6). Ammonium concentrations were also elevated within a second groundwater discharge zone to the south of the MCA, however,

these two regions seemed separated by a low productivity zone. Collectively, the water quality trends suggest that prolific, and potentially compromised macroalgal assemblages exist in the two defined nearshore seagrass habitats as compared with the rest of the study region. Looking forward, ecological assessments will help to confirm these findings, and interpret the extent to which compromised assemblages might serve to export excess detritus and re-packaged nutrients to the MCA. Coupled with enhanced water quality monitoring planned for the future, ecological assessments will also provide an assessment of how much water quality and herbivory contribute to seagrass-macroalgal dynamics.

Finally, surface currents were assessed to define the spatial boundary of nearshore waters that likely influence the MCA. Surface drifter data suggested that nearshore waters within 1 km of the MCA pass through the channel during tidal exchanges (Fig. 7). Thus, the realized spatial boundaries of nearshore waters likely to influence the MCA are smaller than initially perceived, suggesting that seagrass assemblages directly adjacent to the MPA that appeared under the influence of groundwater discharge are most pertinent for detailed investigation.

Data collection and analyses during 2nd half of project period. We currently estimate that 40% of the work has been completed under this project. Remaining data collection efforts include additional water sampling at groundwater discharge locations known to have hydrodynamic affinities with the MCA. Enhanced sampling aims to improve our estimates of the nature and flux of nutrient addition to the marine ecosystem. Second, ecological assessments will be conducted across seagrass and macroalgal habitats in the project vicinity. Ecological assessments will evaluate the degree of macroalgal proliferation with respect to water quality and herbivory (i.e., the abundance of herbivorous fish). Our analytical goals will then be to: 1) assess whether or not compromised seagrass assemblages exist, 2) map their extent, 3) interpret their potential influence to the MCA in terms of detrital and nutrient export, and 4) discuss the likely causes of compromised seagrass assemblages and best approaches for improved watershed-to-reef conservation strategies.

Figures:

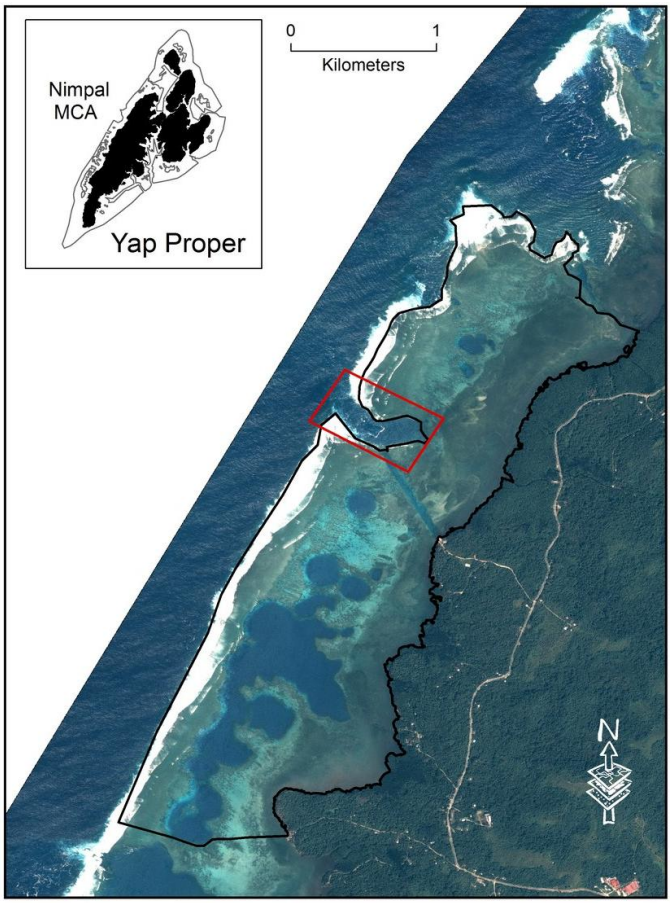


Figure 1: Map of Yap Proper (inset) and the study area. The Nimpal MCA boundary is shown in red, and the perceived extent of nearshore waters that are tidally influenced by the MCA channel is shown in black.

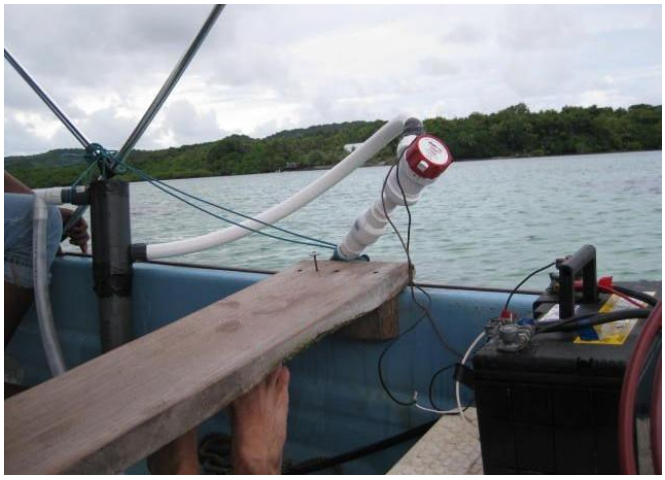


Figure 2: Photograph of the equipment used to conduct horizontal water quality profiling. An auxiliary bilge pump was used to deliver surface waters to the continuously recording YSI-6600 instrument on board a small boat that traversed slowly across pre-defined transects in the study region.

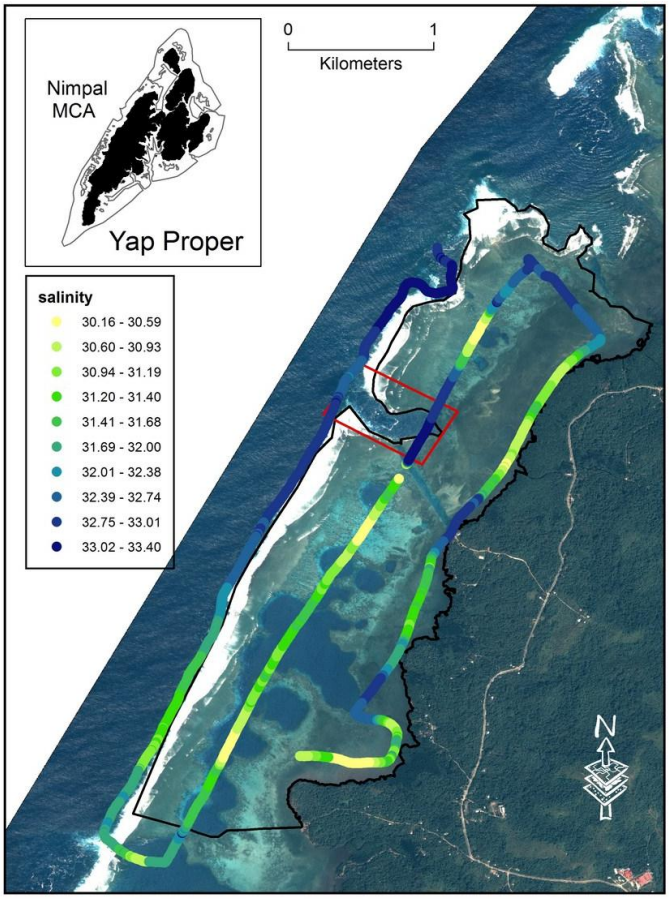


Figure 3: Salinity (ppt.) profile generated from horizontal water quality profiling during an incoming tide just before the full moon period in October 2011.

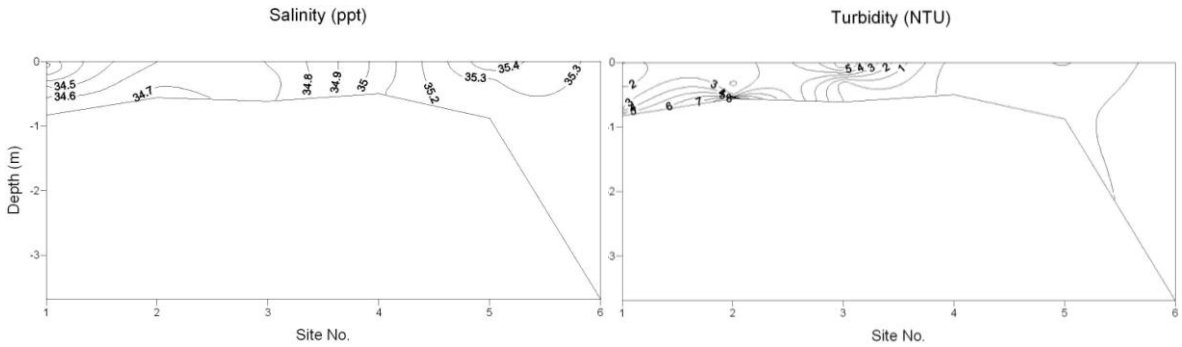


Figure 4: Vertical water quality profile of the nearshore waters adjacent to the MCA shortly after a significant rain event in October 2011. The transect originated in the mangrove habitat (site 1) and extended to the MCA boundary (site 6).

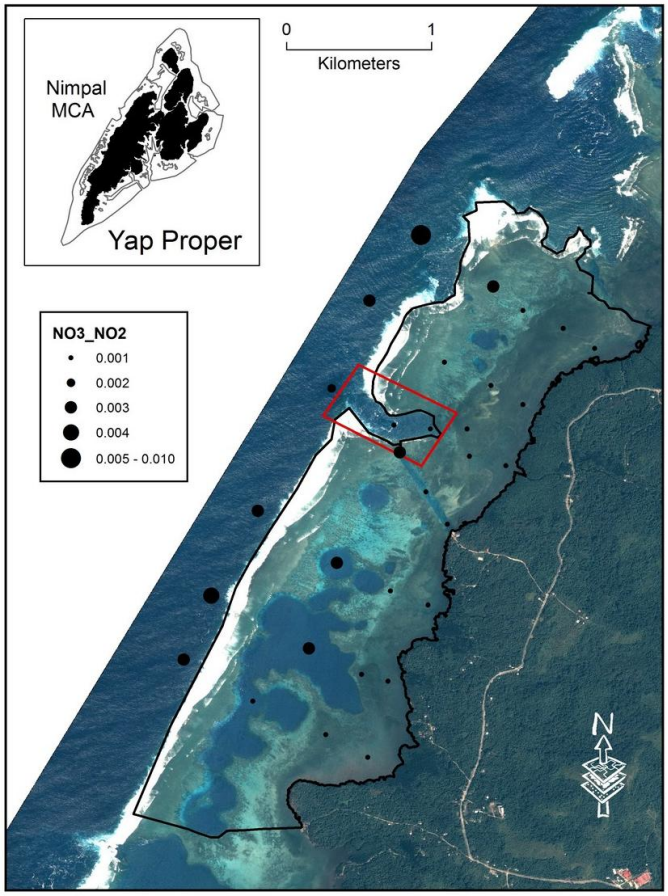


Figure 5: Mean nitrogen concentrations (µg/L NO_3-N + NO_2-N) of surface waters from three exploratory sampling events conducting shortly before the full moon periods of October – December 2011).

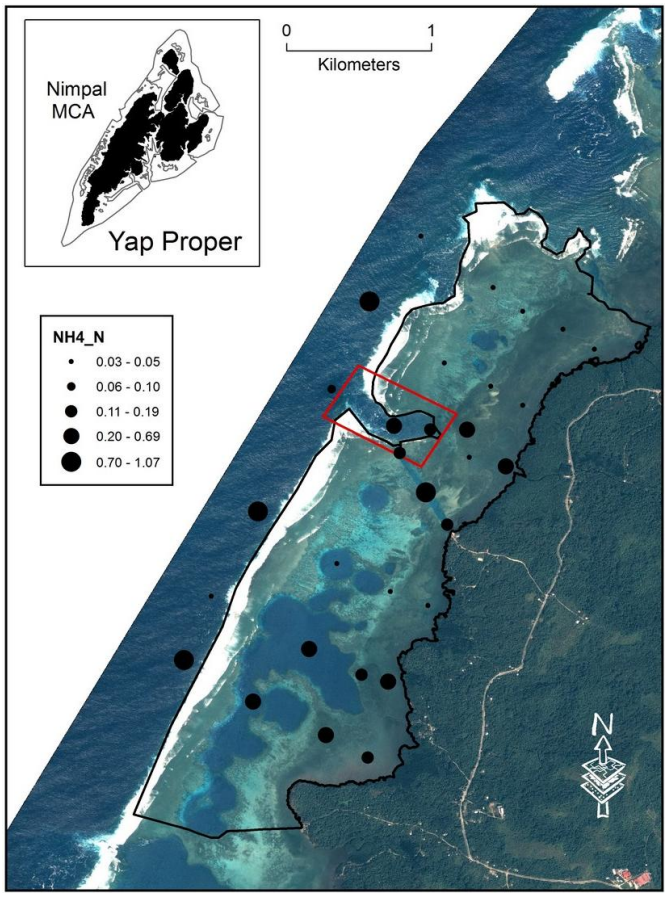


Figure 6: Mean ammonium concentrations (µg/L NH_4-N) of surface waters from three exploratory sampling events conducting shortly before the full moon periods of October – December 2011).

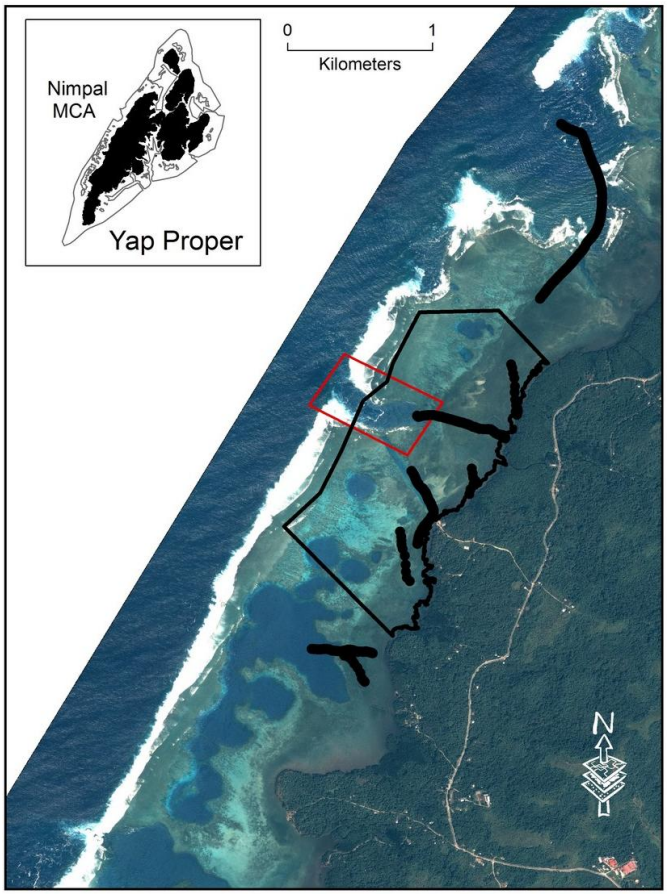


Figure 7: Surface drogue movement during several outgoing tides surrounding the full moon in October 2011. In all cases the drogue was deployed closest to shore and moved offshore at velocities ranging from 0.07 to 0.30 meters per second. The realized boundary of nearshore waters that are tidally influenced by the MCA channel is shown in black.

References

Burkholder J, Tomasko D, Touchette B (2007) Seagrasses and eutrophication. Journal Of Experimental Marine Biology And Ecology 350:46-72

Cardoso PG, Pardal MA, Lillebo AI, Ferreira SM, Raffaelli D, Marques JC (2004) Dynamic changes in seagrass assemblages under eutrophication and implications for recovery. Journal Of Experimental Marine Biology And Ecology 302:233-248

Carruthers T, Van Tussenbroek B, Dennison W (2005) Influence of submarine springs and wastewater on nutrient dynamics of Caribbean seagrass meadows. Estuarine, Coastal and Shelf Science 64:191-199

Devlin M, Brodie J (2005) Terrestrial discharge into the Great Barrier Reef Lagoon: nutrient behavior in coastal waters. Marine Pollution Bulletin 51:9-22

Duarte CM (1995) Submerged Aquatic Vegetation In Relation To Different Nutrient Regimes. Ophelia 41:87-112

Golbuu Y, Fabricius K, Richmond R (2008a). The Impact of Watershed Disturbance on Adjacent Coral Reef Communities in Babeldoab, Palau, Micronesia. American Geophysical Union, 2000 Florida Ave., N. W. Washington DC 20009 USA

Golbuu Y, Fabricius K, Victor S, Richmond R (2008b) Gradients in coral reef communities exposed to muddy river discharge in Pohnpei, Micronesia. Estuarine, Coastal and Shelf Science 76:14-20

Houk P, van Woesik R (2008) Dynamics of shallow-water assemblages in the Saipan Lagoon. Marine Ecology-Progress Series 356:39-50

Houk P, Van Woesik R (2010) Coral assemblages and reef growth in the Commonwealth of the Northern Mariana Islands (Western Pacific Ocean). Marine Ecology 31:318-329

Houk P, Starmer J (2010) Constraints on the diversity and distribution of coral-reef assemblages in the volcanic Northern Mariana Islands. Coral Reefs 29:59-70

Houk P, Camacho R (2010) Dynamics of seagrass and macroalgal assemblages in Saipan Lagoon, Western Pacific Ocean: disturbances, pollution, and seasonal cycles. Botanica Marina 53:205-212

Houk P, Didonato G, Iguel J, Van Woesik R (2005) Assessing the effects of non-point source pollution on American Samoa's coral reef communities. Environmental Monitoring and Assessment 107:11-27

Lirman D, Biber P (2000) Seasonal dynamics of macroalgal communities of the northern Florida reef tract. Botanica Marina 43:305-314

Oliver L, Lehrter J, Fisher W (2011) Relating landscape development intensity to coral reef condition in the watersheds of St. Croix, US Virgin Islands. Mar Ecol Prog Ser 427:293-302

Paytan A, Shellenbarger GG, Street JH, Gonneea ME, Davis K, Young MB, Moore WS (2006) Submarine groundwater discharge: An important source of new inorganic nitrogen to coral reef ecosystems. Limnology And Oceanography:343-348

Richmond RH, Rongo T, Golbuu Y, Victor S, Idechong N, Davis G, Kostka W, Neth L, Hamnett M, Wolanski E (2007) Watersheds and coral reefs: Conservation science, policy, and implementation. Bioscience 57:598-607

Umezawa, Y. Miyajima, T., Kayanne H., Koike, I. (2002) Significance of groundwater nitrogen discharge into coral reefs at Ishigaki Island, southwest of Japan. Coral Reefs 21:346-356

Developing Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Kosrae, Federated States of Micronesia

Basic Information

Title:	Developing Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Kosrae, Federated States of Micronesia
Project Number:	2011GU207B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Water Use
Descriptors:	Hydropower, Flow duration curves, Streams
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz

Publications

1. Heitz, Leroy F., Shahram Khosrowpanah, 2012, Prediction of Flow Duration Curves for use in Hydropower Analysis at Ungaged Sites in Kosrae, FSM, Water and Environmental Research Institute (WERI), University of Guam, Mangilao, Guam, Report No. 137, 28pp.
2. Khosrowpanah, Shahram, Leroy, F. Heitz, 2011, Abstract, Predicting Hydropower Potential on Ungaged Streams in Kosrae, the Federated States of Micronesia (FSM), Water Resources Sustainability Issues on Tropical Islands Conference, November 14-16, Water Resources Research Center, University of Hawaii, Honolulu, Hawaii.

PROJECT SYNOPSIS REPORT

Project Title: Developing Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Kosrae, FSM

Problem and Research Objectives

The cost and availability of energy resources is one key factor in the economic development and quality of life of any developing country. This is especially true in Kosrae, Federated States of Micronesia (FSM), where essentially all of the energy produced is from costly, non-renewable, and potentially environmentally damaging fossil fuel (oil) resources. The cost of fuel to operate the local power plant has risen dramatically over the past years and no doubt will continue to rise in the future. With these increases of fuel costs, it becomes more and more important to explore other means of providing energy to the islands power grid.

Kosrae is blessed with an abundance of surface water resources and because of the extreme topography of the island many of these streams have very high slopes. This combination of abundant streamflow and high stream gradient or slope is ideal for the application of run-of-river-hydropower development. This kind of hydropower development has the least environmental impact and is generally less capital intensive than typical hydropower plants built in conjunction with high dams with large amounts of water storage. While in general hydropower plants are high in first cost, the cost per kilowatt hour of energy production is lower than fossil fuel plants and has the advantage of remaining relatively stable over the life of the project. Another advantage is the hydropower plant can be operated in a running reserve capacity and therefore can be called on to easily help in supplying peak demands that occur at various times of the day.

In order to explore the feasibility of using hydropower as an additional energy source for Kosrae, it is necessary to be able to define the variability of flow available in the streams where the hydropower plants might be constructed. This is normally done by direct analyses of streamflow data for the stream in question or by applying some sort of inferential techniques from a gaged to an ungaged stream or from a gaged location on a steam to an ungaged location on that same stream. Of course, the most reliable means is to use actual stream flow data measured at the point of interest. The problem in Kosrae, as in most locations, is that streamflow information is not available for all possible sites where development could occur. In the FSM this problem is even more acute since the streamflow gaging network has been abandoned for almost 20 years. What is needed is a better means of predicting the variability of flow at ungaged locations that are likely to become candidate sites for future water resources development.

The specific objectives of this project were to: 1) develop flow duration curves for all of the previously gaged stream sites in Kosrae, 2) apply techniques for transferring the flow duration curve information available at the gaged locations to ungaged sites in Kosrae, 3) divide Kosrae's streams into homogenous streams reaches with similar flow characteristics, 4) develop a set of GIS based maps showing the location of all stream reaches and the average flows for each reach, 5) and finally Provide an Excel spreadsheet on which a user can input the average flow data provided in Objective 4 and obtain flow

duration curves for the reach and also a means to explore various turbine configurations for a hydropower plant located on the reach.

Methodology
This project was divided into several phases that are described below:

PHASE I, Develop Flow Duration Curves for Each Gage Site
The first step was to gather all the available daily streamflow data for Kosrae's streams into computer spreadsheet format. This was accomplished using WERI's Earth Info CD-ROM data base and accompanying data accessing programs. Figure 1, shows the location of the United States Geological Survey (USGS) stream gage sites in Kosrae that were used in the study. Figure 2, provides information on the period of record for each of the USGS gages.

A spreadsheet program, developed specifically for use on this project, assigned each of the daily flows into flow range categories specified by the user. The number of daily flow values greater than or equal to the upper limit of each category was then calculated. This value was divided by the total number of flows to find the percent of daily flows greater than or equal to the highest flow in that category. This term is called the exceedance percentage. An example of a flow duration calculation is shown in Table 1. A graph is made by plotting the exceedance percentage versus the value for the upper limit flow in each category. This graph is the flow duration curve. Figure 3 shows a typical flow duration curve for the Toful River in Kosrae. Note that the duration curve is normally plotted on a semi-log axis system. This is done because of the large variability between the high and low flows in the streams and to help straighten the flow duration curve for easier interpolation between values. This procedure was repeated for each of the gage sites in Kosrae. In addition to the duration values, the average annual runoff was determined for each gage site. Figure 4 shows a complete set of duration curves for all of the gage sites in Kosrae.

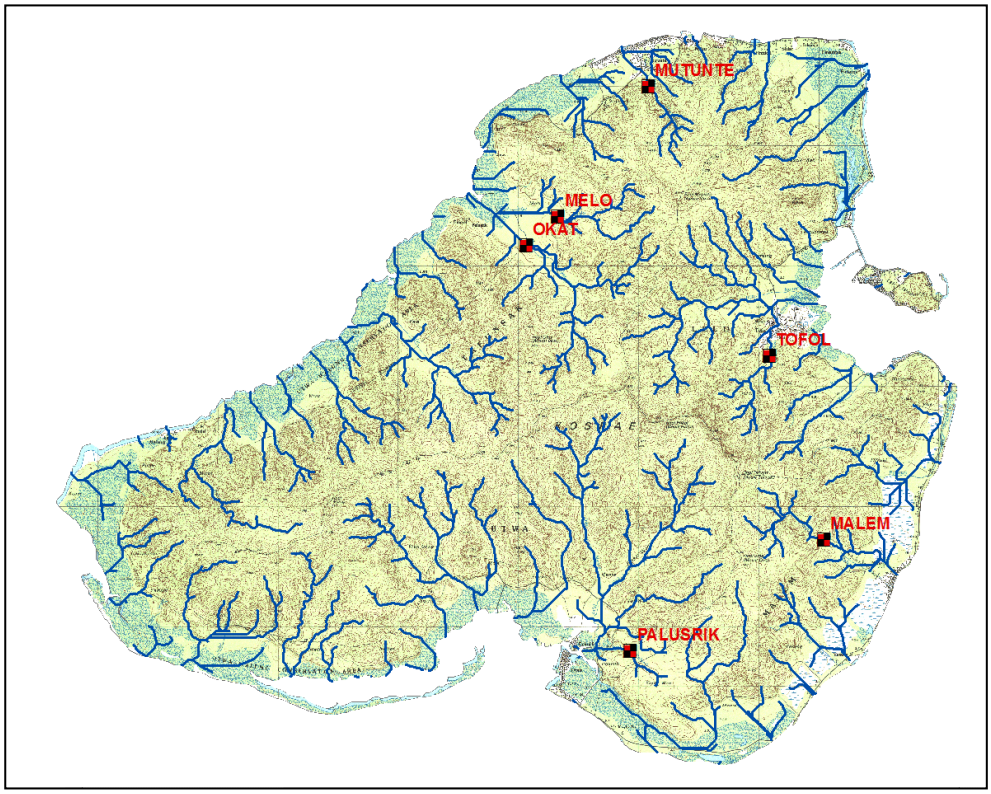


Figure 1: Streams and location of USGS stream gage sites in Kosrae

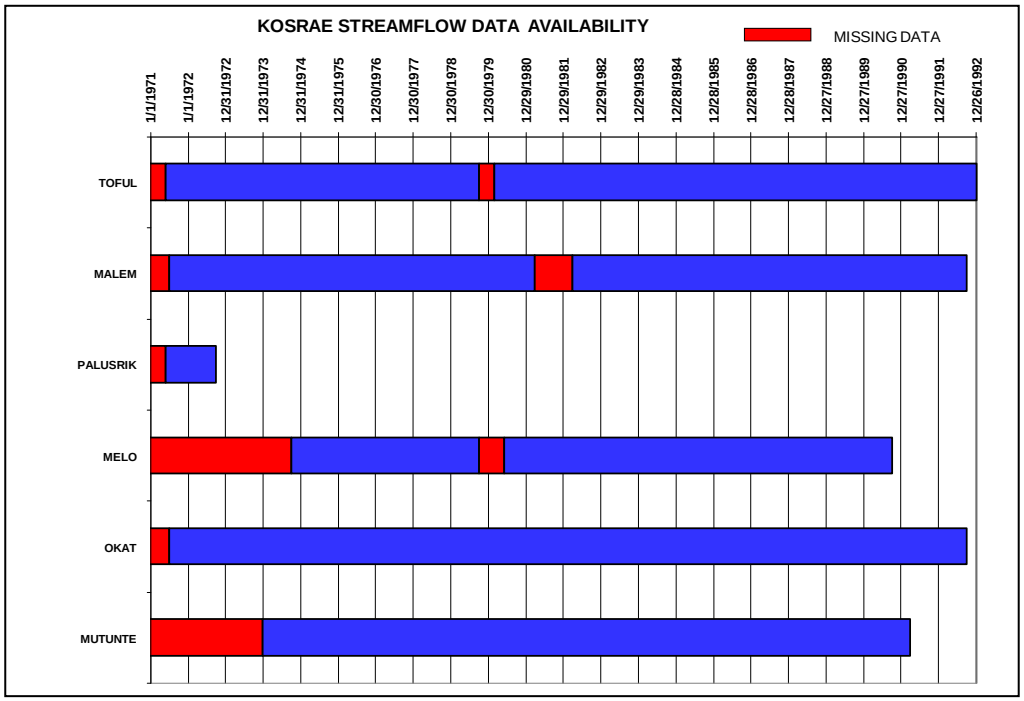


Figure 2: Availability of streamflow data from USGS gages on Kosrae

LOW	HIGH	IN BIN	NUMBER GREATER	% GREATER
0	0.02	0	6545	100.0000%
0.02	0.3	152	6393	97.6776%
0.3	0.75	360	6033	92.1772%
0.75	1	266	5767	88.1131%
1	1.25	208	5559	84.9351%
1.25	1.5	321	5238	80.0306%
1.5	1.75	192	5046	77.0970%
1.75	2	339	4707	71.9175%
2	2.25	355	4352	66.4935%
2.25	2.6	425	3927	60.0000%
2.6	3	345	3582	54.7288%
3	3.5	419	3163	48.3270%
3.5	4	369	2794	42.6891%
4	4.5	311	2483	37.9374%
4.5	5	290	2193	33.5065%
5	5.75	350	1843	28.1589%
5.75	6.75	393	1450	22.1543%
6.75	8	299	1151	17.5859%
8	10	396	755	11.5355%
10	15	373	382	5.8365%
15	50	367	15	0.2292%
50	122	15	0	0.0000%
	TOTAL	6545		

Table 1: Flow duration table for Toful River, Kosrae, FSM

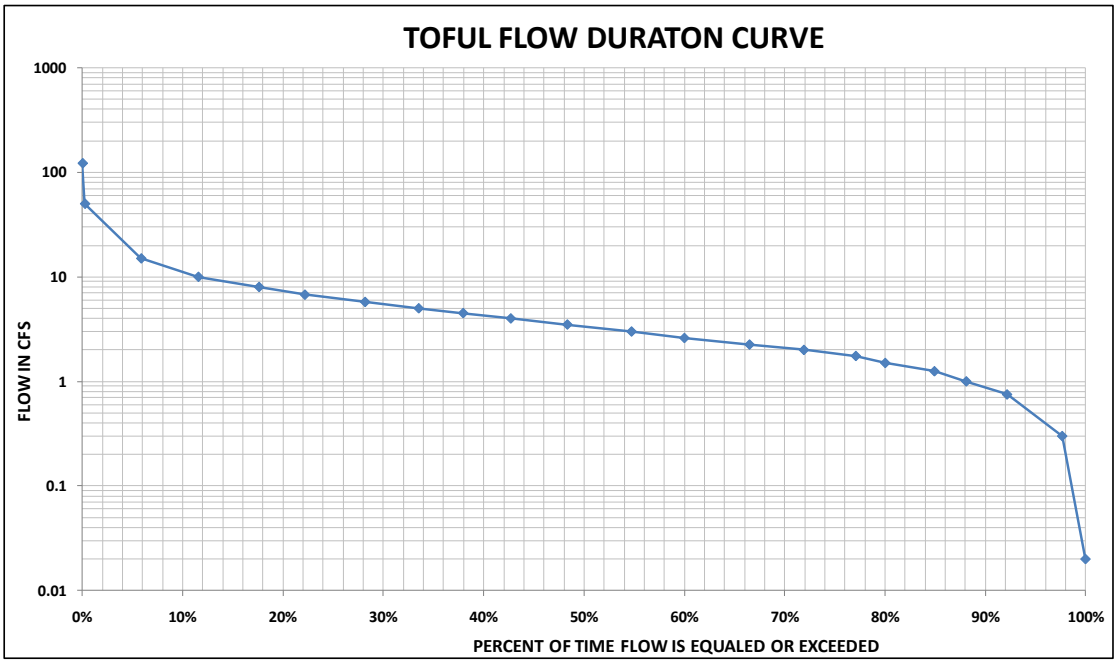


Figure 3: Flow duration curve for Toful River, Kosrae State, FSM

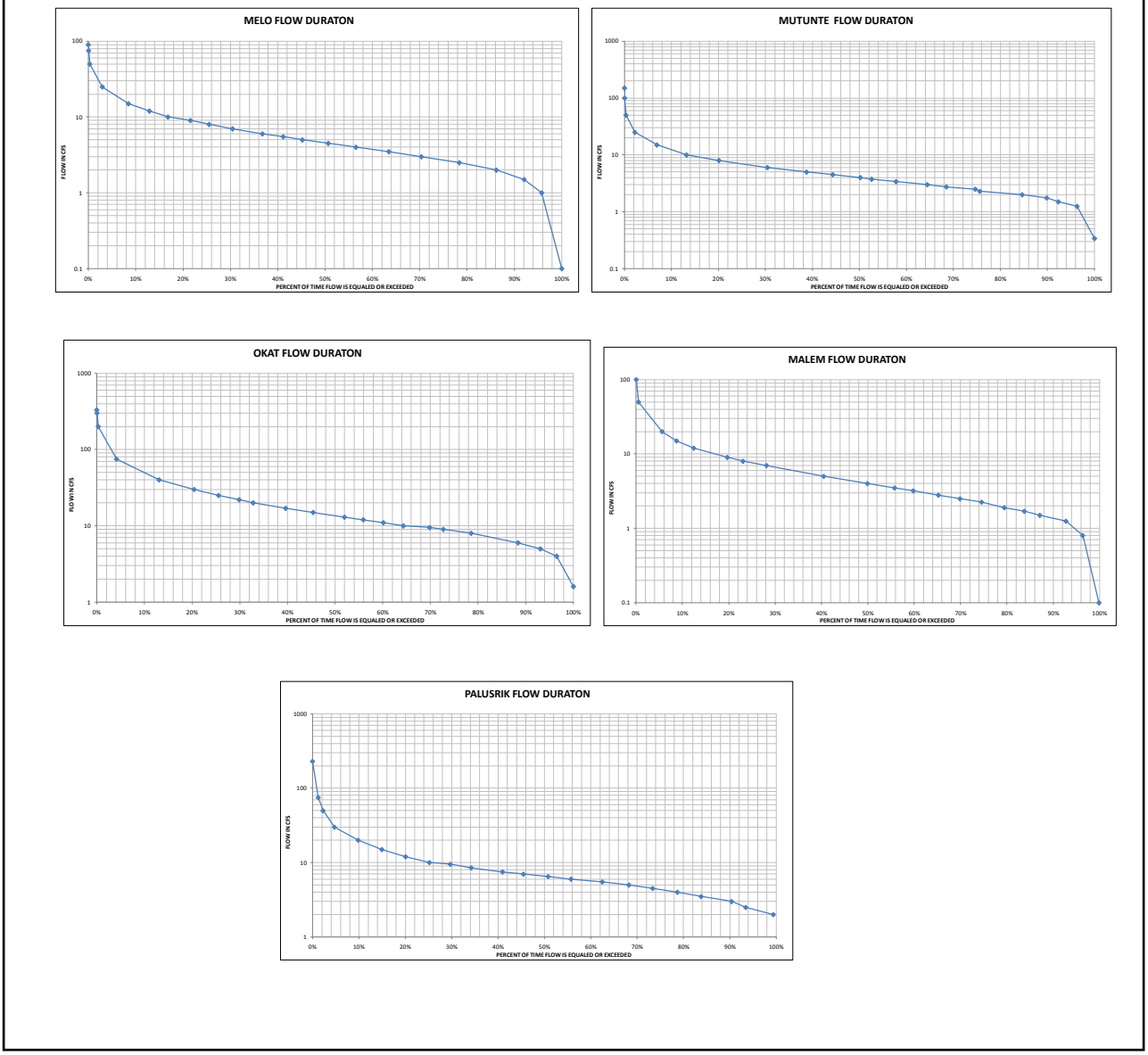


Figure 4: Duration curves for Melo, Mutunte, Okat, Malem, and Palusrik Rivers

PHASE II, Prediction of Duration Curves at Ungaged Sites

Phase II involved the application of a technique to predict duration curves at ungaged sites in Kosrae. This step is important because many of the potential hydropower sites in Kosrae are not located at or near stream gage locations. Some may be located upstream or downstream from gaged locations and some may be located on streams where no previous stream flow records are available.

The method that was applied involved the development of parametric curves of flow versus average annual flow for chosen specific exceedance percents. This method was originally developed by the co-investigator in a study of hydropower potential in the Pacific Northwest. (Gladwell, et al, 1979). The method was applied to all of the streams in Idaho to assist in determining the hydropower potential for that state.

The first step in applying the method was to take the flow values for the key exceedance percentages of Q(95), Q(30), Q(50), and Q(30) from each of the duration curves developed in Phase I. These particular exceedance values were chosen because these percentages are important in the sizing of hydropower plants. Next the average annual flow was computed for each site. The values of $Q_{(\text{exceedance }\%)}$ vs. Average Annual Flow were plotted for each exceedance value at each site and a best fit curve was matched to the data sets. An example of the resulting parametric curves is shown in Figure 5.

The best fit equations are shown at the end of the curves for each exceedance percentage. Although there were limited number of data points the high R^2 values indicates a very good fit to the data by the prediction equations. These equations were used later to predict actual flows at ungaged sites or stream reaches. Figure 5 is also shows an example of using the parametric duration curves to predict the flow duration curve values for an ungaged site with an average annual flow of 18 cfs.

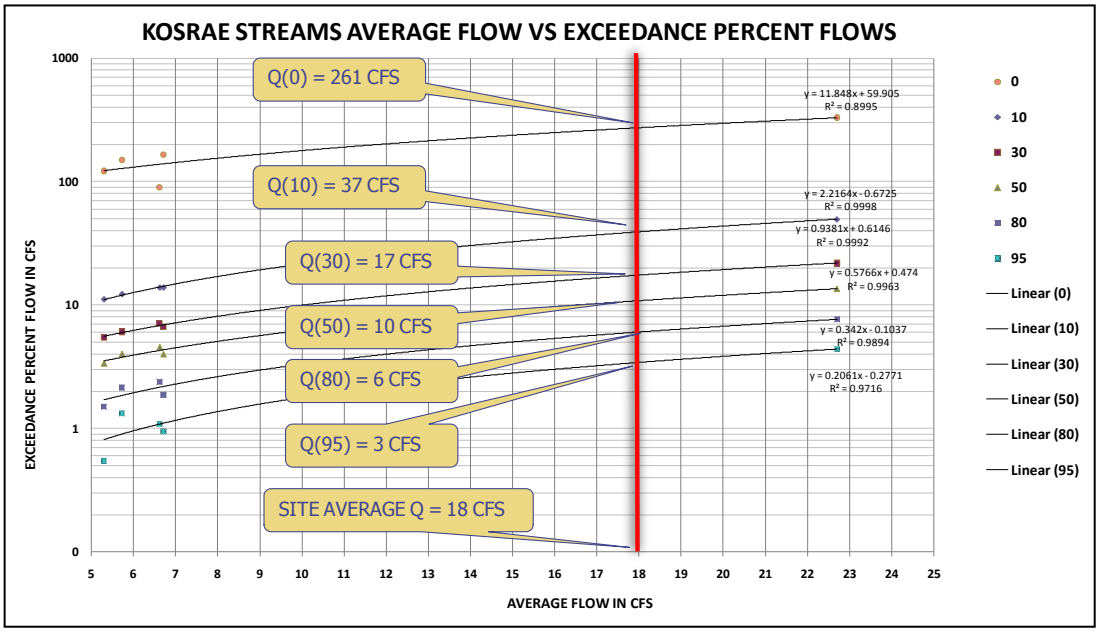


Figure 5: Parametric Flow Duration Curves

PHASE III, Develop a Means to Predict Average Flow at Ungaged Points on Streams

In Phase III we developed a means to predict average flows at ungaged points on Kosrae's streams. The technique called for the development of grid based maps of elevations and average annual rainfall and then applying various GIS Watershed functions available in the computer program ArcMap. The end product was a grid based map of average annual flow for ungaged streams in Kosrae. Since, not all the rainfall reaches the stream due to losses in the hydrological system, a correction factor called "Runoff Factor, RF" was employed. The RF factor was developed for gaged streams as shown in Figure 6. These factors were used to adjust the average annual flow for ungaged streams. Then the adjusted average annual rainfall for ungaged streams were input into the parametric flow duration curves (Figure 5), resulting in flow duration curves for ungaged sites. More details on this procedure are reported in (Heitz, Khosrowpanah, 2012).

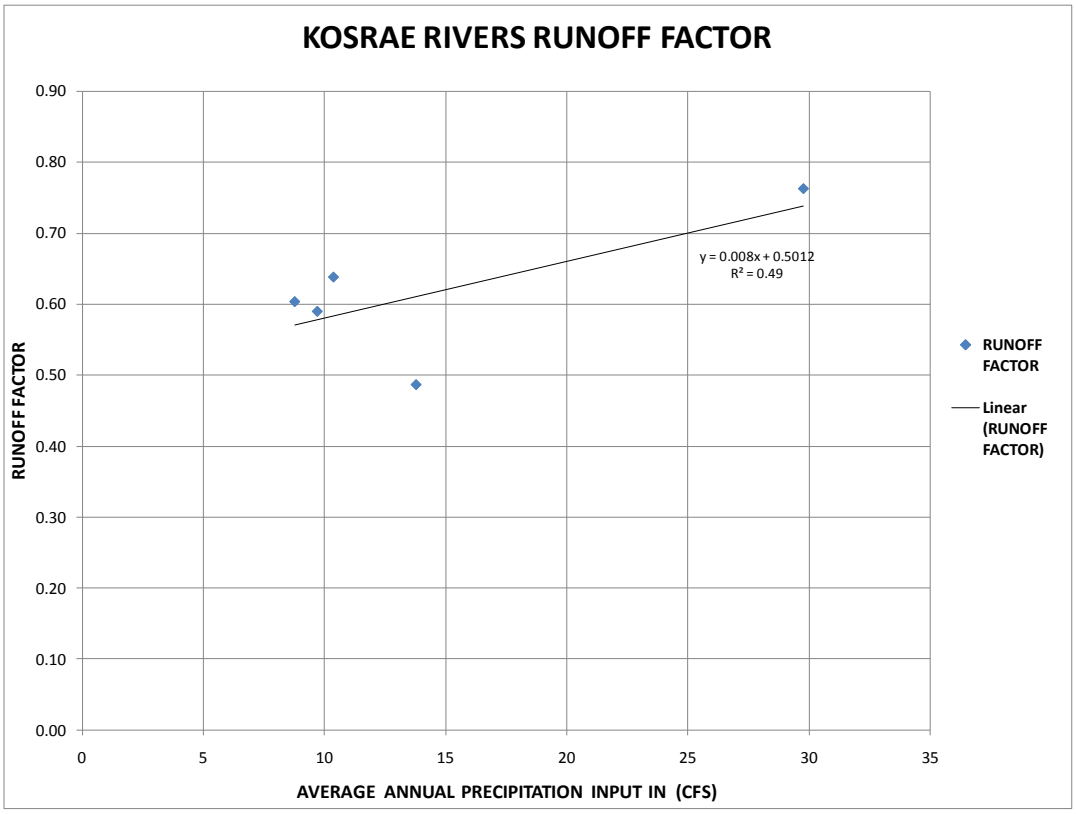


Figure 6: Runoff factor vs. rainfall accumulation

PHASE IV, Stream Reach Delineation and Average Flow

In Phase IV we divided Kosrae's streams into homogenous stream segments, called reaches, which have similar flow characteristics. This mapping was done starting with the USGS's Digital Line Graphics (DLG) hydro-coverage available for the USGS Kosrae Topographic Maps. Substantial editing was required on the Hydro DLGs to develop a good coverage showing only the streams. Figure 7 shows the entire set of streams that was developed. Figure 8 shows the RIVERS USGS DLG shape file. More detail on this procedure is reported in (Heitz, Khosrowpanah, 2012) .

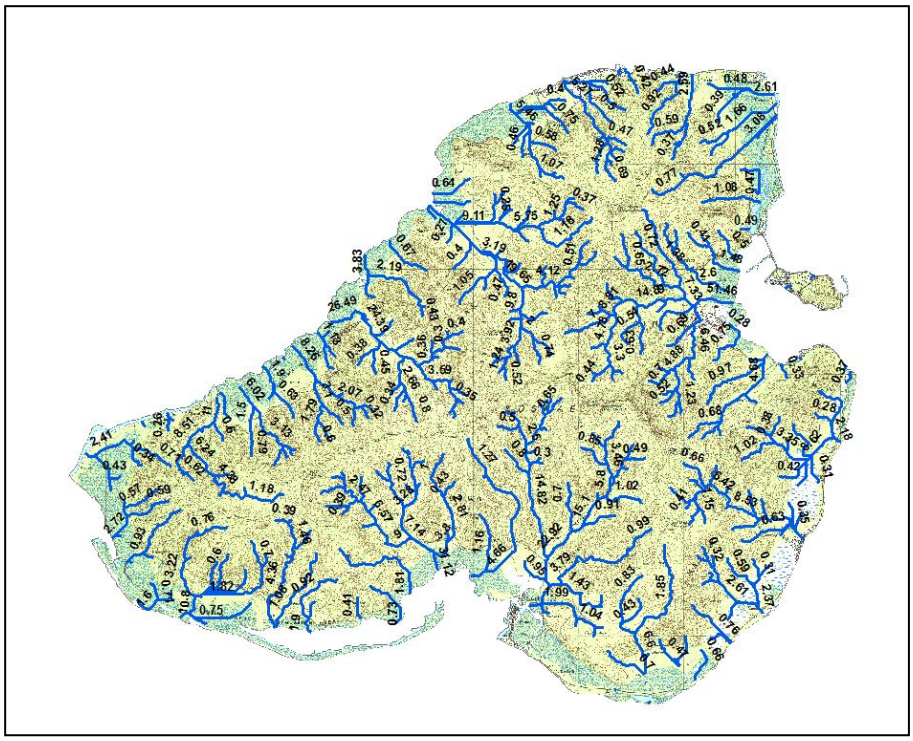


Figure 7: Kosrae streams and average flows in cfs from stream reach delineations

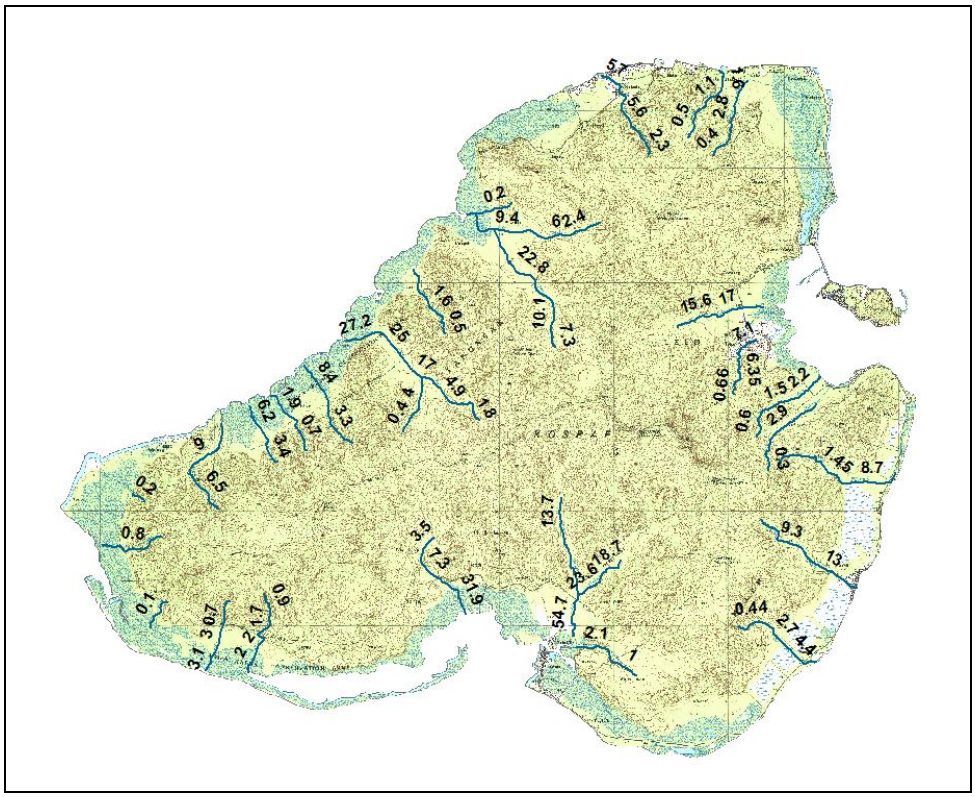


Figure 8: Kosrae stream reaches from USGS topographic map. Average annual flows in cfs

PHASE V, Hydro Power Production and Economic Analysis

In this Phase of the work a means of calculating the power potential and economic feasibility of potential hydropower sites in Kosrae was developed. A previously developed spreadsheet program (Heitz, 1982) was used as a basis for the new hydro power potential Excel application. The first worksheet of the application is shown in Figure 9. Input to this sheet is the potential site's average annual flow which comes from the previously described GIS maps. The application computes the flow duration values using the parametric duration curves described earlier. The application also plots the flow duration curve for the selected site. The second worksheet of the application, shown in Figure 10, computes the power production and economics of the site based on the flow duration curves computed on the first worksheet and the input site head, turbine sizing information and economic considerations. This application will allow the user to explore various turbine sizing and economic considerations to determine the preliminary feasibility of developing a hydropower facility at a particular site. A copy of the Excel Workbook will be furnished to those interested in carrying out their own analysis at any potential hydropower site in Kosrae.

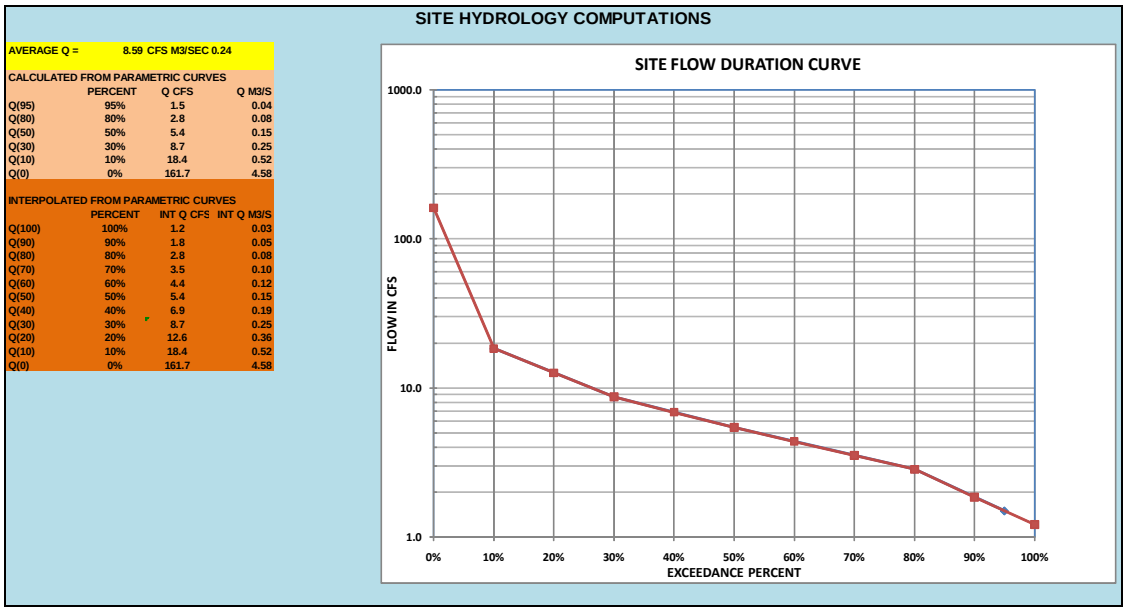


Figure 9: Hydrology worksheet of hydropower analysis application

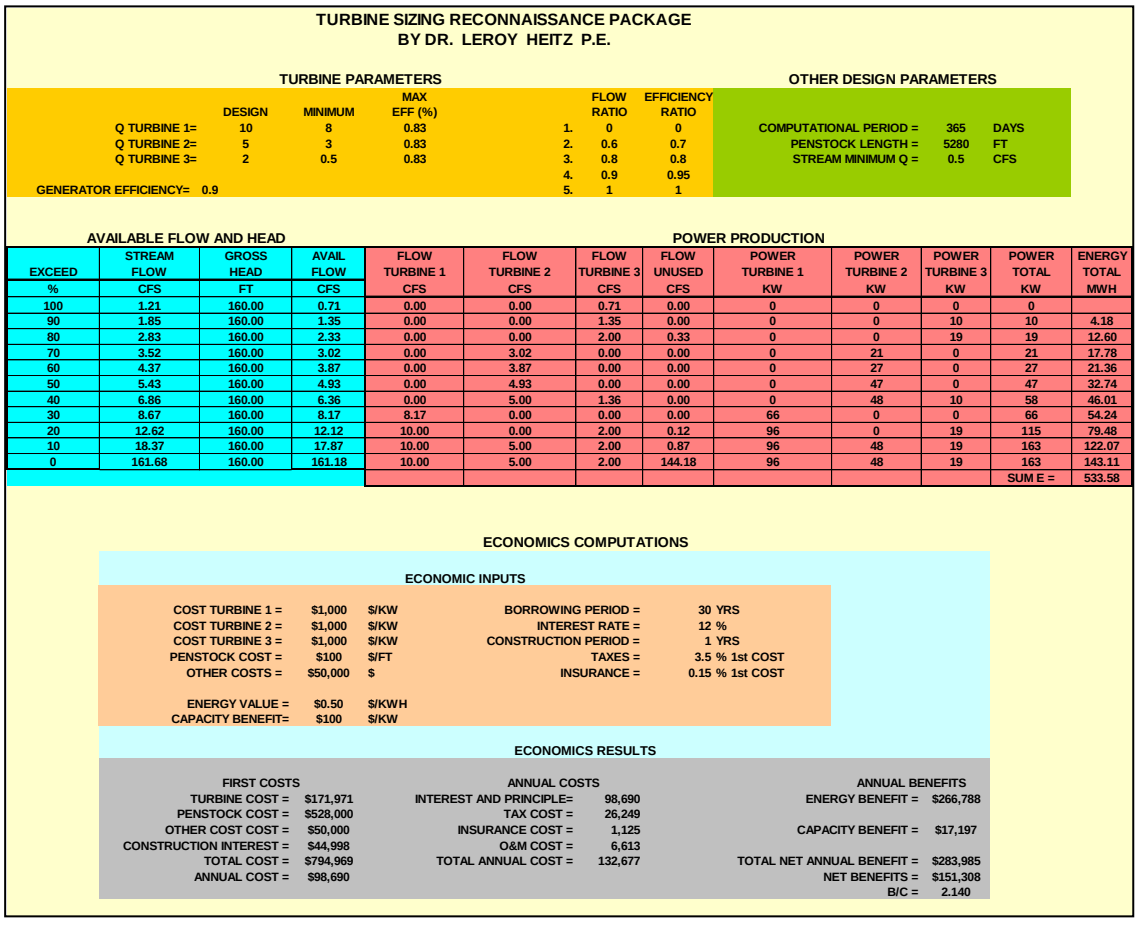


Figure 10: Hydropower output, turbine sizing and economic feasibility worksheet of hydropower analysis application

Principal Findings and Significance

This study has provided a means to evaluate the hydroelectric potential at sites and on reaches of streams in Kosrae, FSM. In order to accomplish this, average flows were developed for stream reaches on all Kosrae's major streams. A means of computing flow duration curves from these average flows was also developed.

A hydropower planning spreadsheet workbook application is provided in which average flows are input along with various hydraulic and economics parameters. A power potential and economic analysis is then performed. This analysis provides preliminary estimates of the feasibility of developing a hydroelectric project at a particular site. The workbook is available as part of the data package for this project.

The average flow data is made available through a GIS map of the stream reaches on all the major streams on Kosrae. The data for this map is available for use with the free GIS application Arc Explorer. This average flow data is useful for other applications beyond just estimating hydroelectric potential. When coupled with the hydrology worksheet in the spreadsheet application, flow duration curves can be estimated for any stream in Kosrae. This information could be used for in-stream flow requirement studies or other studies investigating man impact on the natural flow patterns in the streams.

Literature Cited

Daly, C.R.P. Nielson, D.L. Phillips. 1994. "A Statistical-Topographic Model for Mapping Climatological Precipitation Over Mountainous Terrain", J. Appl. Met. 33:140-158.

Gladwell, J.S., L.F. Heitz, C.C. Warnick, C.C. Lomax, P.C. Klingeman, & A.B. Cunningham, 1979, "A Resource Survey of Low-Head Hydroelectric Potential at Existing Dams and Proposed Sites in the Pacific Northwest Region, Phase II", University of Idaho Water Resources Research Institute, Report No. (197905).

Heitz, L.F., 1982, "Hydrologic Analysis Programs for Programmable Calculators and Digital Computers for Use in Hydropower Studies", University of Idaho Water Resources Research Institute, Report No (198207), 127 pages.

Heitz, L.F., Sh. Khosrowpanah, 2010, "Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM", University of Guam/WERI Technical Report No. 129, 24pp.

Heitz, L.F., Sh. Khosrowpanah, 2012, "Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Kosrae, FSM", University of Guam/WERI Technical Report No. 137 (under printing), 28pp.

USGS Award No. G11AP20225 Hydrogeological Database for Northern Guam

Basic Information

Title:	USGS Award No. G11AP20225 Hydrogeological Database for Northern Guam
Project Number:	2011GU214S
Start Date:	9/1/2011
End Date:	8/31/2012
Funding Source:	Supplemental
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, None, None
Descriptors:	Groundwater database, aquifer management
Principal Investigators:	John Jenson, John Jenson

Publications

1. Bendixson, Vivianna, 2011, 3-D Groundwater Database for the Northern Guam Lens Aquifer, American Water Works Association, Hawaii Section 37th Annual Conference, May 5, 2011, Honolulu, Hawaii.
2. Rotzoll, Kolja, Stephen B. Gingerich, John W. Jenson, and Aly I. El-Kadi, 2012, Estimating Hydraulic Properties from Tidal Attenuation in the Northern Guam Lens Aquifer, Territory of Guam, USA, Hydrogeology Journal (in review)

PROJECT SYNOPSIS REPORT

Project Title: Hydrogeological Database for Northern Guam

Problem and Research Objectives

The objective of this ongoing project is to construct a comprehensive database of all the hydrological, hydrogeological, and engineering data related to the Northern Guam Lens Aquifer, which will be accessible and useful to groundwater resource professionals, including scientists, engineers, managers, and regulators. For the immediate future, the database supports the ongoing 3.5 year collaborative Guam Groundwater Availability Study, the objectives of which are to (1) obtain a better understanding of the regional groundwater flow system, (2) estimate groundwater recharge, and (3) estimate the effects of selected withdrawal scenarios using a numerical model that will be supported by the database.

Methodology

Phases of the study include (1) a review and analysis of existing data from previous studies, drilling records, production records, water quality records, observation wells and other hydrologic data collection stations, maps, imagery, and all other data related to the occurrence, production, and quality of water from the aquifer, (2) ongoing collection of hydrologic data from existing platforms and installation and collection of data from new platforms, (3) water budget computation and, (4) development of a numerical groundwater flow and transport model.

Principal Findings and Significance

Findings: This is an ongoing study now in its second year. To date, a large amount of data has been collected and assembled in electronic formats. These include scans of historical records, spreadsheets containing hydrogical data on existing and new wells. Numerical data are assembled in spreasheets that are being organized for easy search and access. Geographical data are being assembled in GIS formats for ready access and construction of maps and geo-spatial analyses of aquifer properties. Emphasis is now being given the completeness and accuracy of data on the elevation of the volcanic basement rock beneath the aquifer.

Significance: This project directly supports ongoing development of the aquifer in anticipation of the planned military buildup on Guam as well as continued improvements in water production to support growth of the civilian economy and improvements in quality of life for the island's entire population.

Information Transfer Program Introduction

WERI's research activities focus predominantly on local water resources problems and issues identified largely through discussions with regional stakeholders at our annual advisory council meetings. Disseminating the results of these investigations to appropriate governmental agencies, environmental managers, policy makers and other local decision makers in the water resources business, has the highest priority and is accomplished in various ways. Institutional technical reports remain a strong vehicle for transmitting such information to our target audiences, many of whom are remotely situated and do not have access to the scientific literature, or require a greater degree of detail than is normally permissible in a standard journal publication. WERI faculty have also become increasingly more interactive with audiences overseas in recent years by sharing their research findings at professional meetings, conferences and workshops at the national and international level. Our recently improved website is gaining increased popularity among professional circles, both at home and abroad, and is now accessible to the great majority of our stakeholders throughout the region. Our annual Advisory Council meetings in Guam, the CNMI and the FSM are highly effective information transfer mechanisms, bringing together people who typically have little to no contact with one another during the rest of the year. These meeting serve as a valuable forum of information exchange and discussion on common issues, problems and needs in the water resources arena. We remain strong in our commitment to teaching and training the up-and-coming water resources professionals of tomorrow, in addition to conducting workshops, courses and seminars for those currently employed in this area. WERI faculty also continue to be major and effective participants in water related law and policy making on Guam by serving as committee members and chairs on numerous governmental boards and by giving testimony at legislative oversight hearings.

Presenting 'Guam Water Kids': Private, DoDEA School Outreach/Teacher Relations Program

Basic Information

Title:	Presenting 'Guam Water Kids': Private, DoDEA School Outreach/Teacher Relations Program
Project Number:	2011GU193B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Non Point Pollution, Conservation
Descriptors:	Water resources, aquifer, groundwater, surface water, watershed, Guam, hydrological cycle, ground water, non-source pollution, non-point pollution, conservation.
Principal Investigators:	Arretta Ann Card, Arretta Ann Card

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Presenting 'Guam Water Kids': Private, DoDEA School Outreach/Teacher Relations Program

Problem and Research Objectives

With the assistance of a grant from WERI and the USGS, environmental educational materials addressing water resource issues in a context familiar to Guam children and educators were developed. These materials and accompanying illustrations and images address basic features of Guam's fresh water resources and the critical need to protect and conserve them on a level appropriate to students age 9-12. The island's unique needs were taken into consideration and an understanding of the importance of Guam's fresh water as a key resource in our daily lives and a sense of stewardship were addressed with age appropriate information packaged in a "kid friendly" and "teacher friendly" format called "Guam Water Kids."

As these materials became available and were approved for use in the Guam public school system at the superintendent's level, it became apparent that further steps were needed to introduce and demonstrate use of the educational presentation, lesson plans and other accompanying materials to school principals, librarians and classroom teachers. In Fall 2010, an initial presentation of the "Guam Water Kids" to public school 6th graders and their teachers served to provide support for teachers to integrate the materials into their curriculum each school year and created better awareness of WERI as an educational resource. Some 1,150 *public* school students and 40 teachers were engaged in these presentations.

However, students and teachers in *private* schools—which serve a significant proportion of the school children on Guam including military dependents— were not addressed. In addition, private school teachers who saw the program at various conferences and teachers' meetings requested that this population be accommodated with a presentation and demonstration of the "Guam Water Kids" materials. In order to meet this need and also in an effort to reach the children of military familes who attend Department of Defense Educational Activity (DoDEA) schools, funding of additional on-site presentations at six schools was granted under the 104-B WRRI Program.

Methodology

All Guam private schools serving 6th grade students were invited to schedule a presentation. The presentations were scheduled on a first-come, first-served basis. Procedures included:

1) Contact and present flyers and other materials to the principals of private schools on Guam serving sixth graders and, upon principals' approval, contact appropriate head teachers to schedule presentations to sixth grade sections. Presentations were scheduled for the fall 2011 and spring 2012 semesters.
2) A special effort was made to contact the superintendent of the DoDEA schools, Dr. Maria Rubio, who approved of the program and assigned a staff member to facilitate

both scheduling and base access. The DoDEA Instructional Support Specialist for Math & Science, for grades 4-12, Dr. Cheryl R. D. Sangueza, Ph.D., reviewed the "Guam Water Kids" materials and briefed teachers as well as coordinating the visits to the U.S. military facilities of Andersen Air Force Base and Guam Naval Base.

3) Ann Card and Jennifer Berry conducted six team presentations of the "Guam Water Kids" program with Phil Card serving as technical resource. Participating teachers and/or school's media resources librarian received a packet of the educational materials including the CD presentation, printed copies of the two related Lesson Plans and Activities, and WERI contact information.
4) A survey of participating educators was conducted and analyzed to evaluate the "Guam Water Kids" presentation and related lesson plans. Contact information has been preserved in order to facilitate future communication with educators.

Principal Findings and Significance

The following presentations were made at six private schools in Fall 2011. Participants included 384 private school students including 196 students attending DoDEA schools. Twenty-three teachers attended including the DoDEA Instructional Support Specialist for Math & Science, for grades 4-12.

		Attendance	
Middle School	Date	Students	Teachers
Guam 7th Day Adventist	09/29/2011	17	1
McCool Elementary, Navy, DoDEA	11/22/2011	93	5
Harvest Christian Academy	10/21/2011	24	1
St. John's School	11/03/2011	41	2
Bishop Baumgartner Memorial	11/03/2011	106	7
Andersen AFB Middle DoDEA	11/15/2011	103	7
		384 Total	23 Total

Following is a selection of images of the materials presented and photographs from the presentation in the schools and the community. *Figures 1-11 follow.*

Figure 1: Title Slide "Guam Water Kids," A 20 minute narrated slide show

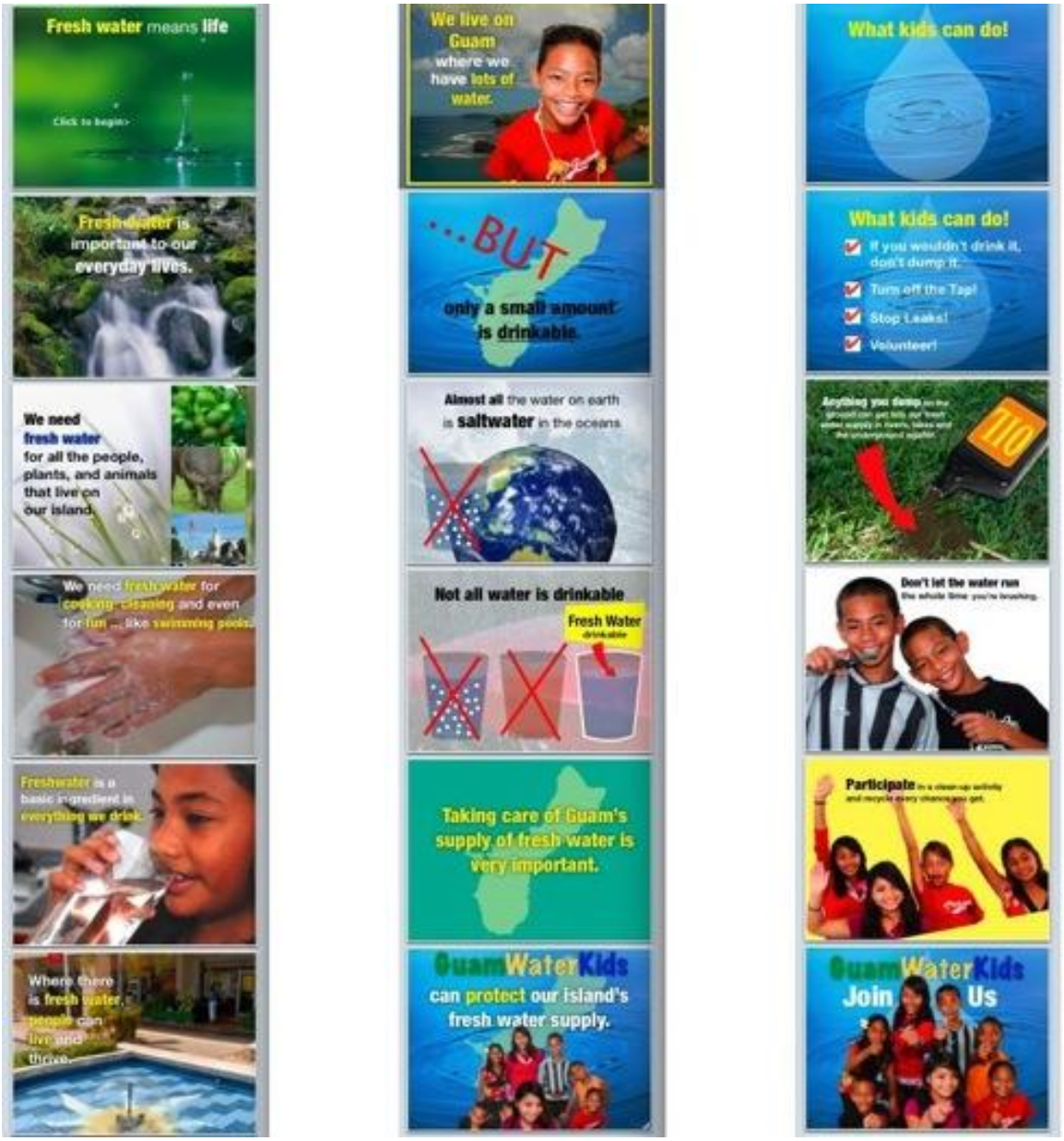


Figure2: Selection of slides from the presentation.

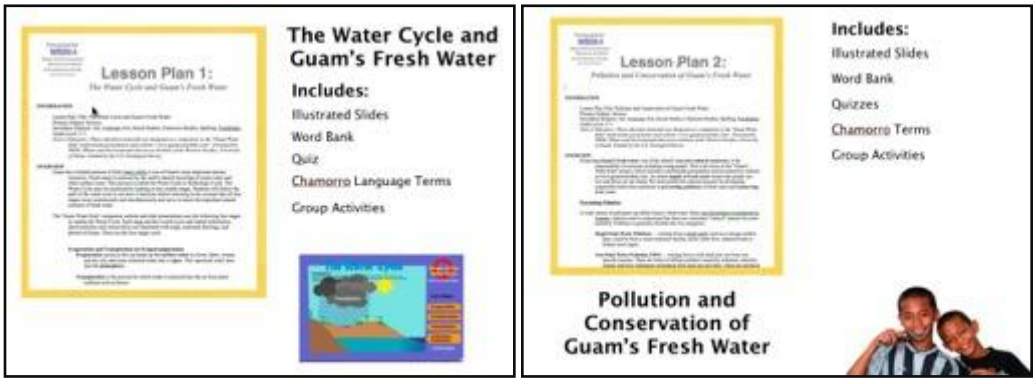


Figure 3: Teacher materials are downloaded from the website and a CD of the presentation and master copies for duplication were also left with each school's media librarian.

Figure 4: Students at Bishop Baumgarner Memorial Catholic School

Fig. 5 Jennifer Berry, Ann Card, St. John's School students

Figures 6 & 7: Ann Card (above), Jennifer Berry instructing students in Harvest Christian Academy classroom.

Figure 8: McCool Elementary School, Department of Defense school located inside Naval Base Guam.

Figure 9: McCool Elementary School, students are dependents of active duty military and federal employees associated with Naval Base Guam.

Figure 10: Andersen Middle School, located inside Andersen Air Force Base, Guam.

Figure 11: Andersen AFB Middle School, assembly in enclosed courtyard. Students are dependents of active duty military and federal employees.

Presenting 'CNMI Water Kids': Public School Outreach/Teacher Relations Program

Basic Information

Title:	Presenting 'CNMI Water Kids': Public School Outreach/Teacher Relations Program
Project Number:	2011GU198B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Non Point Pollution, Conservation
Descriptors:	Water resources, aquifer, groundwater, surface water, watershed, CNMI, hydrological cycle, ground water, non-source pollution, non-point pollution, conservation.
Principal Investigators:	Arretta Ann Card

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Presenting 'CNMI Water Kids': Public School Outreach/Teacher Relations Program

Problem and Research Objectives

With the support of a 104-B WRRI grant from WERI and the USGS, environmental educational materials addressing water resource issues in a context familiar to Commonwealth of the Northern Mariana Islands (CNMI) children and educators were developed. These materials and accompanying illustrations and images address basic features of the fresh water resources on Saipan, Tinian, and Rota, and the critical need to protect and conserve them on a level appropriate to students age 9-12. The island's unique needs were taken into consideration and an understanding of the importance of fresh water as a key resource in daily life and a sense of stewardship were packaged in a "kid friendly" and "teacher friendly" format called "CNMI Water Kids."

When similar materials were developed for use in the Guam public school system, it became apparent that further steps were needed to introduce and demonstrate use of the educational presentation, lesson plans, and other accompanying materials to school principals, librarians and classroom teachers to encourage adoption. An initial on-site presentation of the "CNMI Water Kids" was offered to public school 6th graders and their teachers to help integrate the materials into their curriculum, and created awareness of WERI as an educational resource. Commissioner of Education of the CNMI Public School System, Dr. Rita Sablan, lent enthusiatic approval and the invaluable support of her staff to assist in scheduling school visits. She graciously made room on the agenda of the the October 2011 professional development program to accommodate a workshop for teachers as well. At the school level, principals and teachers also responded enthusiastically to the offer of the presentation and demonstration of the "CNMI Water Kids" materials.

Eleven on-site presentations and travel to Saipan, Tinian and Rota was granted and the grantees made 13 presentations visiting all 12 public elementary schools in the Commenwealth of the Northern Mariana Islands (10 on the island of Saipan and one each on the islands of Rota and Tinian).

Methodology

The project was designed to introduce and demonstrate materials developed in the "CNMI Water Kids" project to the teachers and students at CNMI public schools. Six graders and their teachers had the opportunity to see the narrated multi-media presentation and a team presentation conducted by Ann Card and Jennifer Berry. The presentation was intended to serve as an example classroom use of the animated illustrations and photos to convey the basic concepts of the importance of fresh water in daily life with emphasis on the water cycle and how it sustains surface and ground water resources on these islands as well as helpful habits that children can develop that protect fresh water resources.

The project's educational consultant Jennifer Berry discussed the resource materials with each teacher and the school librarian during the site visits and left copies behind. These support materials include two lesson plans with activities, relevant vocabulary in English, Chamorro and Carolinian languages, and a companion website where the teacher materials are also downloadable. Also, an additional online quiz, and slide shows about the key concepts that learners can review at their own pace. Local place names and maps were used.

At most schools, all sixth grade students and their teachers attended a combined group assembly. In several schools, students fifth graders and sometimes third and fourth graders also attended. Two back-to-back presentations were made at one school to accommodate class schedules. Educators attending often included language specialists.

The project included the development of a list of participating teachers to be retained for future use and a survey assessment of the materials presented. Questions inquired about the potential value for use in their classrooms and ongoing incorporation of the materials into curriculum. Educators were given the opportunity for opened ended questions regarding other needs and were asked to indicate their willingness to participate in teacher training courses that may be developed and introduced int the *Critical Water Resources Research, Teaching and Training Needs for the CNMI* assembled by the WERI-CNMI Advisory Council at their future annual meetings.

Principal Findings and Significance

The following presentations were made in Fall 2011 and Spring 2012 semesters. From the CNMI Public School System, 1,063 students and 36 teachers participated.

		Attendance:	
School	Location	Students	Teachers
Dandan Elementary	Saipan	86	4
Kagman Elementary	Saipan	159	8
Koblerville Elementary	Saipan	54	3
Garapan Elementary	Saipan	125	5
San Antonio Elementary	Saipan	48	2
Sinapalo Elementary	Rota	90	8
Oleai Elementary	Saipan	81	3
San Vicente Elementary	Saipan	114	4
G. T. Camacho Elementary	Saipan	63	3
Wm. S. Reyes Elementary	Saipan	100	4
Tanpag Elementary	Saipan	22	1
Tinian Elementary	Tinian	98	6
		1,063	36

Following is a selection of images of the materials presented and photographs from the presentation in the schools and the community. *Figures 1-15 follow.*

Figure 1: Title Slide "CNMI Water Kids," A 20 minute narrated slide show

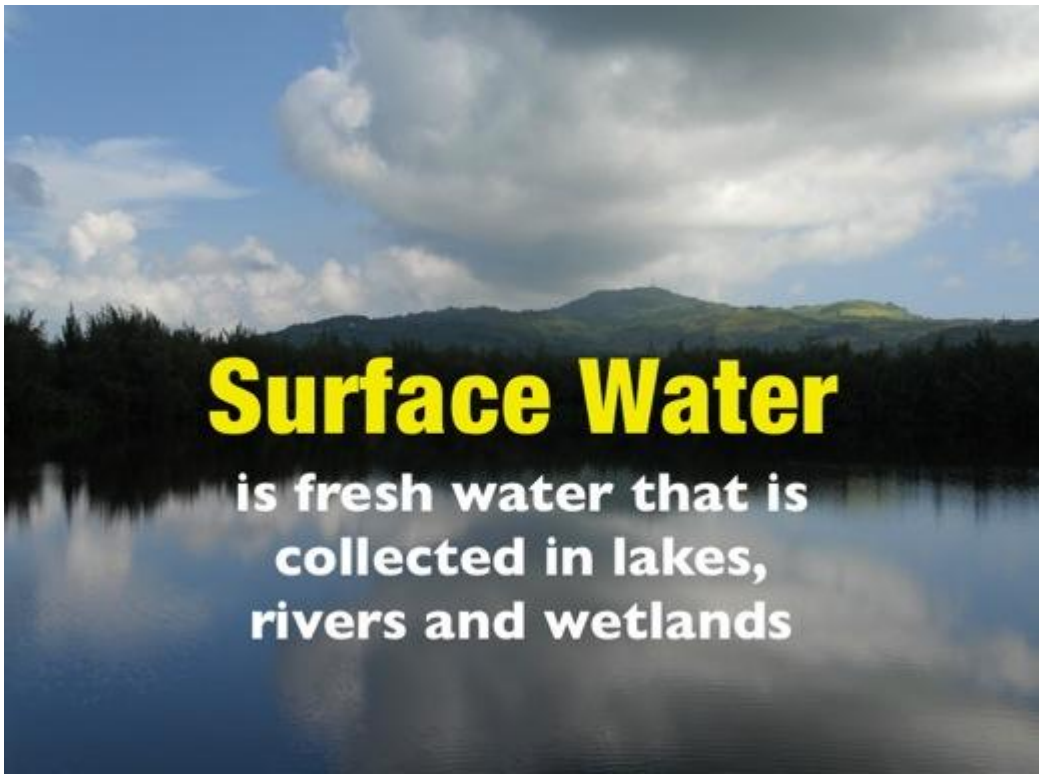


Figure 2: Surface Water slide featuring Lake Susupe, Saipan.

Figure 3: Selection of slides from the presentation

Figure 4: Teacher Materials

Figure 5: Website home page

Figure 6: Dandan Elementary School, Dandan Village, Saipan, CNMI.

Figure 7: Students and teachers at Dandan Elementary School, Saipan

Figure 8: Garapan Elementary School, Garapan, Saipan, CNMI.

Figure 9: Vice Principal Marj Pangelinan welcomes Ann Card, Jennifer Berry, and Phil Card (not pictured) to William S. Reyes Elementary in Chalan Kanoa, Saipan.

Figure 10: Students gather at Willam S. Reyes Elementary, Chalan Kanoa, Saipan, CNMI.

Figure 11: Tanapag Elementary in the northern Saipan village of Tanapag.

Figure 12: Jennifer Berry with Tinian Elementary students, San Jose, Tinian, CNMI.

Figure 13: Tinian Elementary students volunteer ways they can take personal action to conserve and protect fresh water on the island of Tinian.

Figure 14: Sinapalo Elementary School, Sinapalo, Rota, CNMI

Figure 15: Students and teachers at the "CNMI Water Kids" presentation on Rota.

Water System Leak Detection Training for Saipan, Commonwealth Utilities Corporation (CUC)

Basic Information

Title:	Water System Leak Detection Training for Saipan, Commonwealth Utilities Corporation (CUC)
Project Number:	2011GU202B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Water Supply, Management and Planning
Descriptors:	Water Resources, Training, Education, Operations and Maintenance
Principal Investigators:	Shahram Khosrowpanah

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

Project Title: Water System Leak Detection Training for Saipan, Commonwealth Utilities Corporation (CUC)

Problem and Research Objectives

Water system leakage is a serious problem for all utility agencies throughout the Western Pacific. It reduces the performance of the system and a big money lost for utilities. The development of the modern water distribution system for most of the islands in this area started in 1970. Since then the system has been upgraded through a series of United State (US) sponsored capital improvements projects. However, the system leakage for some of these islands is as high as 60%. Utility agencies are suffering from lost revenues and are not able to provide 24- hour water service to their customers. Leak detection is one of the most cost effective and efficient ways to reduce non-revenue water. In fact, a leak detection program should be the highest priority with each utility agency. It is cost effective, and has the immediate result of increasing the system performance.

A stated goal of the Commonwealth of the Northern Marianas Islands (CNMI) government is to provide 24-hour water to all residents served by the Commonwealth Utility Corporation (CUC) water system. Over the years the CUC water distribution system has grown and new wells have been added to the system. One of the problems that CUC is facing is lack of trained leak detection personnel. In the past, CUC had 5 people from water division that were trained for carrying the leak detection program. However, most of this crew has been retired or left the CUC. The need for water resources related training continues to be given a high priority by the CNMI advisory council. In response to these unique circumstances, a special training program was designed for CNMI. The training concentrated on the water system leak detection training for the CUC. The specific objective of this training was to increase the technical understanding of system leakage theory, application of leak detection, how to manage the leakage, and use state of the art leak detection equipment. Since other utilities in CNMI such as islands of Rota and Tinian were experiencing similar problems, the training gave an opportunity for other utility personnel to attend the training. This specific training was requested by the CUC as part of the WERI advisory council meeting held in October 2010.

Methodology

The training project consisted of a one week long workshop that provided an understanding the leak detection theory, causes, and how to find leaks and fix them. As can be seen from the schedule below, the training provided a balance of classroom, laboratory and field activities that provided students with a solid theoretical background of the current state-of-the–art leak detection technology as well as hands-on activities in the field. The CUC provided the required classroom and shop space required to carry out the training.

The instructor who led the training was Mr. Scott Wicklund, Director of field services/training from ‘Utility Services Associates.’ This company is based in Washington and specializes in leak detection technology and instrumentation.

Training activities

A. Classroom Training covering the following topics (Approximately 1.5 day):

1. Introduction to a leak detection program / theory.
2. Explanation of how leak sounds originate. Discussion of leak sound transmission through different types and sized of pipe.
3. Explanation of "Acoustic Leak Survey" & each type of survey including permanent monitoring. Introduction to survey tools/ equipment and the benefits of each.
4. Leak sounds exercise – (class did very well with this test)
5. Discussions and recommendations of paperwork / reporting practices that may be utilized in the field. Distributed field forms to attendees for consideration.
6. Hands on experience to cover the operation of the LD-12 leak detector
7. Started discussion on correlation theory and explained how a correlator locates water leaks.
8. Discussed three rules of correlation, best contacting practices, and the correlation formula that enables the correlator to measure time delay.

B. Field Training covering the following topics (Approximately 3.5 days):

1. Demonstration use of equipment.
2. Hands on training and field practice on pinpointing leaks, estimating leakage, reporting, and review.

C. Equipment

The following equipment was used during the training:

1. Subsurface Leak Detection LC2500 leak noise correlator
2. Fluid Conservation System S-30 leak noise surveyor
3. Subsurface Leak Detection LD-15 leak noise detector
4. Subsurface Leak Detection LD-12 leak noise detector
5. Subsurface Instruments PL-2000 pipeline locator
6. Subsurface Instruments ML1 Ferrous locator
7. Probe rods
8. Audio and visual media presentations

Principal Findings and Significance

A total of fifteen (15) people working at the CUC completed the training. The training covered leak detection theory, and how to determine when a leaky survey is required, economic benefits of a leak detection survey, how to incorporate a leak detection survey and/or permanent leak detection crew for your water facility, how to become familiar with various sounds created by leaks and type of leaks encountered, types of leak detection surveys and proper record keeping, get familiar with various leak detection equipment and techniques, and field demonstration and actual leak detection scenarios and exercises.

The net result of this training was to increase CUC personnel water conservation capability through leak detection technology. This will in turn reduce costs incurred with the production and treatment of non-revenue generating water and lead to better management of Saipan's groundwater resources. Ultimately, then it will help the Saipan government provide local residents with safe drinking water on a 24-hour, 7 days a week basis.

After the training, Mr. Scott Wicklund, lead instructor submitted a written report of his observations and general recommendations for future leak detection activities on the Saipan water distribution system to the PI and CUC chief engineer.

Figure 1. Class room lecture presentations

Figure 2: Students during the class work

Figure 3: Hands-on practice in the field

Figure 4: Participants learn to differentiate between signal sounds detected

Figure 5: Participants awarded 'Certificate of Completion' at end of training

Atoll Water Budget Modeling: Information Transfer and Training for the Federated States of Micronesia

Basic Information

Title:	Atoll Water Budget Modeling: Information Transfer and Training for the Federated States of Micronesia
Project Number:	2011GU208B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	Atoll islands, groundwater management, Federated States of Micronesia
Principal Investigators:	John Jenson

Publications

1. Bailey, Ryan T., John W. Jenson, and Danko Taboro¨i, 2012, accepted, Estimating the Freshwater Lens Thickness of Atoll Islands in the Federated States of Micronesia: Hydrogeology Journal
2. Ryan T. Bailey and John W. Jenson, 2011, Groundwater Resources Analysis of Atoll Islands in the Federated States of Micronesia Using an Algebraic Model, WERI Technical Report No. 134: Mangilao, Water and Environmental Research Institute of the Western Pacific, University of Guam, 29 pp.
3. Ryan T. Bailey and John W. Jenson, 2011, Abstract, Analysis of Groundwater Resources on Atolls in the Federated States of Micronesia, Water Resources Sustainability Issues on Tropical Islands, 14-16 November, Water Resources Research Center, University of Hawaii at Manoa, National Institutes for Water Resources, Honolulu, HI.

PROJECT SYNOPSIS REPORT

Project Title: Atoll Water Budget Modeling: Information Transfer and Training for the Federated States of Micronesia

Problem and Research Objectives

In response to the interests expressed by FSM residents and government officials, WERI researchers have developed an atoll aquifer model for the Caroline Islands (Bailey et al., 2008a). The model provides a tool for managers and planners to estimate how the fresh water lens in specified atoll islands in the FSM may respond to given changes in recharge. Specifically, the model provides a means of calculating lens thickness, and hence the groundwater reserve that can be expected for the size and geology of the island as well as specified amounts of seasonal rainfall. Due to the success in using the model in the FSM, there is a request to train the designated users in government agencies and educational institutions of the FSM on how to operate the model to apply its results to water resource management problems, such as the conjunctive use of surface and groundwater.

Methodology

The model runs on lap-top or notebook computers, and comes with a published WERI technical report that serves as an operator's manual for the model (Bailey et al., 2008a) and with another that serves as an educational text on atoll island hydrology and modeling (Bailey et al., 2008b). The technical reports are also available on CD and on-line on the WERI website (www.weriguam.org/v2 /index.php).

Principal Findings and Significance

In October 2011, WERI instructors took the model to Chuuk State and presented a workshop on it in conjunction with WERI's annual Advisory Council Meeting for the Federated States of Micronesia. The workshop covered the basic aspects of atoll hydrology, the threat to atoll island water resources, an analysis of atolls within the FSM and the state of Chuuk, and the procedures for using the model.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2011GU211B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	N/A
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, None
Descriptors:	Information Transfer, Education, Water Resources
Principal Investigators:	Gary Denton

Publications

There are no publications.

PROJECT SYNOPSIS REPORT

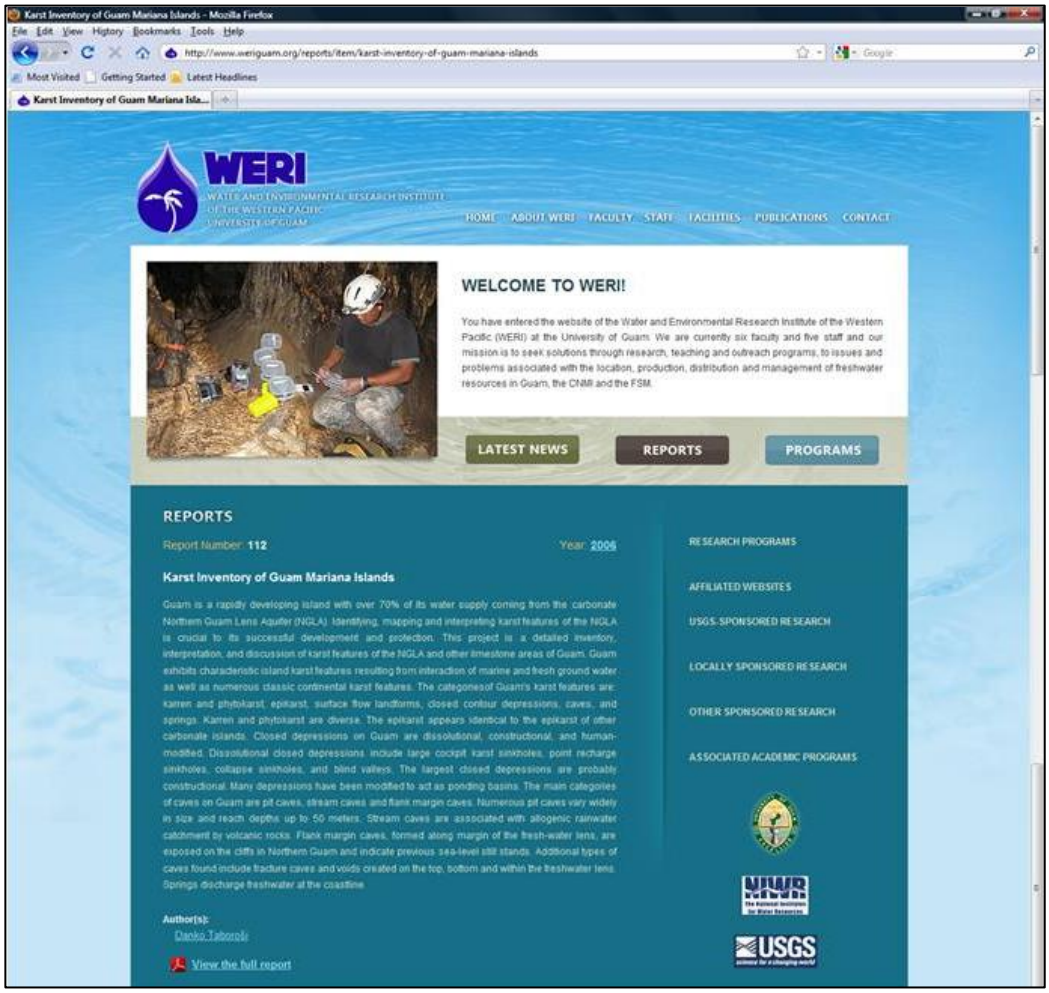
WERI's mission involves a large information transfer-dissemination component. Key elements include written forms such as brochures and pamphlets, a web site, technical reports, journal articles, newspaper columns, and book chapters. The audience for the results of USGS sponsored research is widely varied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

The WERI web-site is the Institute's primary Information Transfer/Dissemination mechanism. The home page, shown below, is located at http://www.weriguam.org/. It features informational links to WERI faculty, staff and Institutional facilities, our current research, education and training activities, primary sponsors and most recent publications. The user friendly format is intended to increase visibility of the Institute's research programs and associated projects particularly for our stakeholders in remote locations where state-of-the-art internet services and computer technology are often lacking

WERI Web-site Home Page

This project also funded the design, layout and printing of four (4) major technical completion reports resulting from USGS funded research projects. Fifty (50) hard copies of each report were printed. All WERI technical completion reports are available in downloadable pdf format on the WERI web-site at http://www.weriguam.org/reports/list.

The technical completion report library was updated with several new additions bringing the total volume number up to 136. The improved database search engine process for accessing these reports on line utilizes a composite 'Abstract' database for key word searches. Searches based on 'Author' now search all authors in the author string not just the lead author as before. Upon selection of a particular report, site users are presented with the complete abstract, which may be viewed prior to downloading the main report. An example is shown below.



WERI Reports Page

Because of Guam's remote location, and the escalating costs of air travel, it is difficult and costly for researchers to present their findings at technical conferences and symposiums in other parts of the Globe. A portion of the current Information Transfer Project was earmarked for off-Island travel expenses for PI's and graduate students presenting refereed professional papers summarizing all or a portion of current or past USGS 104-B projects.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	0	0	1	1
Masters	4	0	0	2	6
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	5	0	0	3	8

Notable Awards and Achievements

For the fourth year in a row, WERI conducted the highly popular Groundwater Resources Management Training Course specifically for the inhabitants of island atolls in the FSM. This year the 104-B sponsored course was an adjunct to the WERI-FSM Advisory Committee meeting held in Chuuk State in early October. Once again, the workshop attracted island leaders and government officials and was well received by all. Participants were trained in the use of a high-resolution computer model of an idealized atoll aquifer to predict the sustainable management of their groundwater resources under various climatic scenarios. As with the previous offerings, the training continues to be well received. WERI has committed to offering additional workshops in conjunction with the next advisory meeting. The model is now being expanded to incorporate rain catchment use and storage, in addition to groundwater.

During the summer and fall of 2011, WERI offered a professional development course, at the request of the professional water resources community on Guam: The Northern Guam Lens Aquifer—Geology, Hydrology & Professional Tools. The course was attended by 16 engineers and other water resources professionals from Guam Waterworks Authority, Naval Facilities Command Marianas, and the private sector. This was an intensive course with 48 hours of contact time, including a day-long field trip of the aquifer, in which participants were shown the major rock units that comprise the aquifer, and the karst terrain features that are relevant to recharge and aquifer protection. Much of the materials used were derived from past USGS 104-B sponsored projects.

WERI faculty continues to engage both graduate and undergraduate students in their research activities. During this past year we are pleased to announce that two WERI students, Ms. Tomoko Bell (spring 2011) and Ms. Christine Simard (spring 2012) have graduated from the Environmental Science MS Program. Ms. Bell’s thesis project entitled 'Coral and Speleothem in situ Monitoring and Geochemical Analysis: Guam, Mariana Islands' was initiated with USGS 104-B funds and has so far produced two technical reports, one on the results of the project, and a second on the novel tool developed to drill meter-length cores of 8-cm diameter. The thesis provided the first documentation of the local record of sea surface temperature in a shallow-water coral enclosed in Guam’s Apra Harbor. A manuscript for the professional literature is in preparation. Ms. Bell was awarded a graduate scholarship by the University’s Micronesian Area Research Center to cover travel to a professional meeting.

Ms. Simard’s thesis, 'Salinity Trends in the Northern Guam Lens Aquifer', was also 104-B funded and won the University of Guam President’s Award for the outstanding graduate thesis of 2012. Local interest is high. So far she has presented her results to the Guam Legislature’s Committee on Natural Resources, Guam Environmental Protection Agency, Guam Waterworks Authority, and the Consolidated Commission on Utilities, and has been invited to present it to the governor and his staff as well. She will also be presenting her results to other carbonate island researchers at the 16th Geology Conference at the Gerace Research Center in San Salvador, Bahamas, in June 2012. Technical reports and manuscripts for the professional literature are underway.

Pioneering work on the carbonate island karst model by WERI's senior groundwater hydrogeologist, Dr. John Jenson, and his colleagues, has recently been incorporated in a new textbook, 'Speleothem Science', by Fairchild and Baker (2012), bringing it into the mainstream literature of karst geology and hydrology. Almost all of Dr. Jenson's work cited in the text was initiated with either 104-B or 104-G funding.

Publications from Prior Years

1. 2007GU95B ("Mercury Contamination in Garapan Lagoon, Saipan: An Evaluation of Potential Drainage Pathways and Impact on Fisheries Resources") - Book Chapters - Denton, Gary R.W., Michael S. Trianni, Brian G. Bearden, Peter Houk, John A. Starmer, 2010, Impact Determination of Unusual Mercury Source on Fisheries Resources in Saipan Lagoon, Saipan, Commonwealth of the Northern Mariana Islands: A Preliminary Assessment, in Maekado, M., Umemura, T., Fujita Y. and Hirose, T., eds, Learning from the Pacific Islands: Environments, Resources and Developments of Micronesia. Tokyo, Japan, Sairyusha Co., Chapter 10, p. 155-176 (in Japanese).
2. 2008GU140B ("Watershed Management for Pohnpei Island in the Federated States of Micronesia") - Book Chapters - Khosrowpanah, Shahram, Leroy F. Heitz, 2010, Watershed Management for Pohnpei, the Federated States of Micronesia, in Maekado, M., Umemura, T., Fujita Y. and Hirose, T., eds, Learning from the Pacific Islands: Environments, Resources and Developments of Micronesia. Tokyo, Japan, Sairyusha Co., Chapter 10, p. 155-176 (in Japanese).
3. 1999GUC-09 ("Island Karst Hydrology of Guam and Its Incorporation into a General Carbonate Island Karst Model") - Articles in Refereed Scientific Journals - Taboro¨i, Danko, John W. Jenson, John E. Mylroie, 2012, in review, Coastal Discharge from an Uplifted Carbonate Island Aquifer: Northern Guam, Mariana Islands: Journal of Coastal Research
4. 2004GU31B ("Persistent Contaminant Assessment of Food Fish from Tanapag Lagoon, Saipan") - Articles in Refereed Scientific Journals - Denton, G.R.W., 2011, Good Fish, Bad Fish: The Mercury Dilemma, Journal of Micronesian Fishing, Spring 2011 Issue.
5. 2007GU95B ("Mercury Contamination in Garapan Lagoon, Saipan: An Evaluation of Potential Drainage Pathways and Impact on Fisheries Resources") - Articles in Refereed Scientific Journals - Denton, Gary R.W., Michael S. Trianni, Brian G. Bearden, Peter Houk, John A. Starmer, 2011, Impact of a Medical Waste Incinerator on Mercury Levels in Lagoon Fish from a Small Tropical Island in the Western Pacific, Journal of Toxicology and Environmental Health Part A, 74, 823–827.
6. 2007GU94B ("Land Cover Accuracy Assessment for Southern Guam") - Articles in Refereed Scientific Journals - Wen, Yuming, , Shahram Khosrowpana, Leroy F. Heitz, 2011, Land Cover Change of Watersheds in Southern Guam from 1973-2001, Environmental Monitoring and Assessment, 179, 521-529.
7. 2009GU156B ("Impacts of Land Cover Change on Groundwater Quality in Guam") - Articles in Refereed Scientific Journals - Wen, Yuming, 2010, Impacts of Human Activities on Groundwater Quality in Guam, Mariana Islands. The International Journal of Environmental, Cultural, Economic and Social Sustainability, 7, 243-256.
8. 2009GU154B ("Reconstructing the Ancient Rainfall-Drought History of Guam") - Articles in Refereed Scientific Journals - Partin, Judson W., John W. Jenson, Jay L. Banner, Terrence M. Quinn, Frederick W. Taylor, Daniel Sinclair, Benjamin Hardt, Mark A. Lander, Tomoko Bell, Bla¸ Miklavič, John M.U. Jocson, Danko Taboro¨i, 2012, Relationship between Modern Rainfall Variability, Cave Dripwater and Stalagmite Geochemistry in Guam, USA: Geochemisty, Geophysics, Geosystems, v. 13, no. 3, pp. 1-17.
9. 2009GU154B ("Reconstructing the Ancient Rainfall-Drought History of Guam") - Articles in Refereed Scientific Journals - Sinclair, Daniel, Jay L. Banner, Frederick W. Taylor, Judson W. Partin, John W. Jenson, John E. Mylroie, Ethan Goddard, E., Terrence M. Quinn, John M.U. Jocson, Bla¸ Miklavič, 2012, in press, Magnesium and Strontium Systematics in Tropical Speleothems from the Western Pacific: Chemical Geology, v.294-295, pp. 1-17.
10. 2010GU170B ("Continuing Calibration and Application of LUOM in Southern Guam Watersheds ") - Water Resources Research Institute Reports - Lou, Qiang (Charles), Shahram Khosrowpanah, 2012, Continuing Calibration and Application of Luom in the Southern Guam Watersheds, Water and Environmental Research Institute (WERI) of the Western Pacific, Mangilao, Guam, Technical Report No. 131, 68pp.

11. 2010GU175B ("Development of a GIS Data Base for Saipan's Drinking Water Delivery System ") - Water Resources Research Institute Reports - Heitz, F. Leroy, Shahram Khosrowpanah, 2011, Development of a Geographic Information System for the Commonwealth Utility Corporation, Saipan Water Distribution System, Water & Environmental Research Institute (WERI) of the Western Pacific, University of Guam, Mangilao, Guam, Technical Report 132, 17pp.
12. 2011GU207B ("Developing Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Kosrae, Federated States of Micronesia") - Water Resources Research Institute Reports - Heitz, F. Leroy, Shahram Khosrowpanah, 2012, Prediction of Flow Duration Curves for use in Hydropower Analysis at Ungaged Sites in Kosrae, FSM, Water and Environmental Research Institute (WERI), University of Guam, Mangilao, Guam, Report No. 137, 28pp.
13. 2007GU95B ("Mercury Contamination in Garapan Lagoon, Saipan: An Evaluation of Potential Drainage Pathways and Impact on Fisheries Resources ") - Conference Proceedings - Denton, Gary R.W., Michael S. Trianni, Brian G. Bearden, Peter Houk, John A. Starmer, 2011, Tracking Down an Unusual Source of Mercury Enrichment in Fish from Saipan Lagoon, Saipan, Commonwealth of the Northern Mariana Islands, in Progress in Environmental Sciences and Technology, Vol. III, Science Press USA Inc., 983-997.
14. 2009GU156B ("Impacts of Land Cover Change on Groundwater Quality in Guam") - Conference Proceedings - Wen, Yuming, 2011, Application of Multi-temporal and Multi-source Data for Land Cover Change Detection in Guam, USA, Proceedings of the 19th International Conference on GeoInformatics, June 24-26, 2011, Shanghai, China.
15. 2009GU154B ("Reconstructing the Ancient Rainfall-Drought History of Guam") - Conference Proceedings - Miklavič, B., John E. Mylroie, John W. Jenson, Richard H. Randall, Jay L. Banner, Judson W. Partin, 2012, Evidence of the Sea-level Change since MIS 5e on Guam, Tropical West Pacific, in Onac, B.P., Fornos, J.J. (Eds.), Sea Level Changes into MIS 5: from Observations to Predictions, Studia Universitatis Babeş-Boylai, Geologia (Special Issue 2012), Cluj University Press Cluj-Napoca, Romania, p. 30-32.
16. 2009GU154B ("Reconstructing the Ancient Rainfall-Drought History of Guam") - Conference Proceedings - Miklavič, Bla¸, John E. Mylroie, John W. Jenson, Richard H. Randall, Nata¨a Zabukovec Logar, Danko Taboro¨i, 2012, Denudation of Eogenetic Limestone During the Last Glacial Cycle in a Tropical Environment, 20th International Karstological School "Classical Karst": Karst Forms and Processes; 18th to 23rd June, 2012; Karst Research Institute, Postojna, Slovenia, accepted.
17. 2009GU154B ("Reconstructing the Ancient Rainfall-Drought History of Guam") - Conference Proceedings - Miklavič, Bla¸, John E. Mylroie, John W. Jenson, Richard H. Randall, Jay L. Banner, Judson W. Partin, 2012, Evidence of the Sea-level Change Since MIS 5e on Guam, Tropical West Pacific, NSF Workshop: Sea Level Changes into MIS 5: From Observations to Predictions, April 10-14, 2012, Palma de Mallorca, Mallorca, Spain.
18. 2009GU154B ("Reconstructing the Ancient Rainfall-Drought History of Guam") - Conference Proceedings - Miklavic, Bla¸, John W. Jenson, Jay L. Banner, John E. Mylroie, Judson W. Partin, Logar, N. Zabukovec, Benjamin F. Hardt, Daniel Sinclair and Eric James, 2011, Diagenesis and trace-element geochemistry of cave drip-water and a stalagmite in MIS5e limestone, Guam, Mariana Islands, 6th International Conference: Climate Change - The Karst Record: University of Birmingham, Birmingham, England, U.K., 26 - 29 June 2011, p. 94.
19. 2010GU171B ("Applications of LiDAR Data for Inarajan Watershed Management ") - Conference Proceedings - Wen Yuming, Shahram Khosrowpanah, 2011, Application of LIDAR Data For Delineation of Inarajan Watershed In Guam, USA, Proceedings of 1st International Workshop on Surveying and Geospatial Information Systems (SGIS2011), May 21-22, 2011, Fuxin, Liaoning, China.
20. 2008GU146B ("Comprehensive Survey of the Current State, Infrastructure, and Usage of Freshwater Resources on Low Islands of Pohnpei State, Federated States of Micronesia") - Other Publications - Tabaro¨i, Danko, M. Martin, 2009, Pakein Atoll Freshwater Resources and their Usage, State, and

Infrastructure, Island Research & Education Initiative 2011 Publication, 95 pp.

21. 2008GU146B ("Comprehensive Survey of the Current State, Infrastructure, and Usage of Freshwater Resources on Low Islands of Pohnpei State, Federated States of Micronesia") - Other Publications - Tabaro¨i, Danko, M.S. Collazo, 2009, Mwoakilloa Atoll Resources and their Usage, State, and Infrastructure, Island Research & Education Initiative 2011 Publication, 129 pp.
22. 2009GU164B ("Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM") - Other Publications - Heitz, F. Leroy, Shahram Khosrowpanah, 2011, Abstract, Prediction of Flow Duration Curves for use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM, Water Resources Sustainability Issues on Tropical Islands Conference, November 14-16, Ala Moan Hotel, Honolulu, Hawaii, Section 8-75.
23. 2010GU174B ("Impact of Urban Runoff, Wastewater Discharges and Past Solid Waste Disposal Practices on Contaminant Profiles in Fish from Saipan Lagoon") - Other Publications - Denton, Gary R.W., Michael S. Trianni, Michael C. Tenorio, 2011, Abstract, PCB Status of Popular Table Fish from Northern and Central Sections of Saipan Lagoon, Abstract, Asia Pacific Academy of Science, Education, and Environmental Management General Meeting, November 29-30, 2011, American Memorial Park, Auditorium, Saipan.