WATER AND ENVIRONMENTAL RESEARCH INSTITUTE

Guam Hydrologic Survey (GHS)

&

Comprehensive Water Monitoring Program (CWMP)

> **FY 2010 Status Report**



November 2010

GUAM HYDROLOGIC SURVEY (GHS) AND COMPREHENSIVE WATER MONITORING PROGRAM (CMP)

FY 2010 STATUS REPORT

Prepared by

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Water & Environmental Research Institute of the Western Pacific University of Guam

PROGRAM MISSION STATEMENT

The Guam Hydrologic Survey (GHS) and the Comprehensive Water Monitoring Program (CWMP) were created in 1998 by the 24th Guam Legislature under Public Laws No. 24-247 and 24-161 respectively. The Water and Environmental Research Institute (WERI) was charged with administering the annual legislative appropriations necessary to drive these two programs and facilitate, direct and implement their primary objectives. Both programs are now an integral component of the WERI water resources research, information dissemination, education and training mission, both on Guam and throughout the region.

PROGRAM GOALS

The purpose of GHS is to consolidate Guam's hydrological data gathered over the years by local and federal government agencies and consultants, and to conduct research on water related issues of local importance. GHS also funds a variety of water resource educational programs in various formats, including guest lectures and seminars at UOG and in the community, informational and training workshops for teachers and professionals from other government agencies, field trips and talks for schoolchildren, and the publication and distribution of educational posters, maps, and fact sheets.

The CWMP was created to collect data on saltwater intrusion and water lens thickness in Guam's sole source aquifer in the northern part of the island and stream flow and other parameters associated with surface waters in the south. The program builds on studies previously undertaken by the US Geological Survey (USGS) that were abandoned several years earlier because of a discontinuance of matching funds from the Government of Guam. The CWMP annual appropriations from the Guam legislature have facilitated the collaborative reinstatement of these studies with USGS under their 50-50 Federal/State-Territory cost-sharing program for water resource monitoring.

The foresight of the Guam Legislature in creating these two very important programs deserves special mention here. Through their efforts and continued support, we have consolidated and interpreted several vital water resources databases for Guam and revitalized the USGS water resources monitoring program. Our understanding of the complex physical, chemical and biological processes that influence Guam's water resources has broadened considerably and the increase in graduate student research opportunities provided by the programs has substantially added to the number of highly trained water resources professionals in the island's work force.

PROGRAM FUNDING AND FY'10 OBJECTIVES

GHS and CWMP appropriations written into each public law are \$204,200 and \$173,948 respectively. Local budgetary constraints saw a 6% reduction in funding support for both programs in FY'09, i.e., \$192, 307 and \$163,817 for GHS and CWMP respectively. These shortfalls continue through FY'11. The information presented herein summarizes all GHS and CWMP program objectives and related activities undertaken in FY'10.

PROGRAM OUTCOMES FOR FY'10

GUAM HYDROLOGIC SURVEY (GHS)

In FY'10, GHS provided funding the continued maintenance, repair and upgrading of

instrumentation in the WERI *Computer Analysis and Geographic Information System* (CA-GIS) *Laboratory*. Almost every water research project carried out by WERI involves a GIS analysis and mapping component. The GIS laboratory provides the required hardware and expertise in GIS analysis and serves as a data archive for GIS generated databases. WERI also works closely with various Government of Guam and Federal Agencies in sharing GIS data that become available.



GHS provides limited stipends and tuition fees for research by graduate students

Graduate students in WERI CA-GIS Laboratory

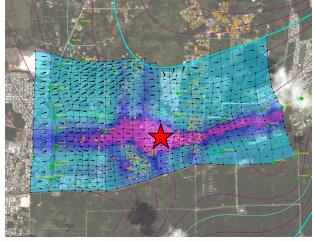
working on their MS degree in Environmental Science and partial summer salaries to WERI faculty advising those students. It also pays for undergraduate field and lab assistants working on water resources projects on Guam. Finally, GHS funds the salary of one full-time research associate charged with operating WERI's complex and sophisticated computer analysis and GIS facility.

GHS Sponsored Research Projects Completed in FY'10:

Two highly significant aquifer related projects initiated in FY'10 were: 1) the development of a contaminant transport model for northern Guam, and 2) the revision the basement volcanic topographic map. A summary report for each project is given below.

1. Contaminant Transport Model for Northern Guam

A major realization of WERI's ongoing study of the Northern Guam Lens Aquifer (NGLA)

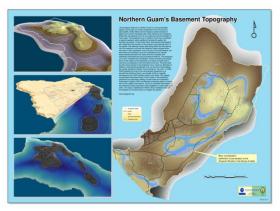


Simulated wastewater spill over NGLA

is the need to develop of a powerful three dimensional solute transport model to predict the residence times and clearance rates of chemical and biological contaminants entering the system. In FY'10, WERI began developing such a model for northern Guam using the finite element procedure. Karst limestone aquifers are highly complex with unique features that set them apart from similar aquifers in other geological formations. Their high porosity and high permeability facilitate rapid recharge rates that shorten response times needed to mitigate pollution spills over them. The development of this model will provide a valuable tool to water resources engineers enabling them to a) predict directional flow rates of contaminant plumes through the aquifer b) implement best management practices for production wells likely to be impacted in the area and c) identify best locations for remediation wells for pump and treat purposes.

2. Revision of the Basement Volcanic Topographic Map

In 2010, WERI revised and refined its earlier map of the volcaniclastic basement rock beneath the NGLA. This update incorporates more recent data on the location of the basement obtained from exploratory drilling of water wells and Installation Restoration



Revised and refined basement volcanic topographic map of northern Guam

Program (IRP) contaminant monitoring wells on current and former military reservations, and from accidental interception of the basement during exploration and installation of water production wells.

The limestone bedrock of northern Guam is a very permeable aquifer, which rests on volcanic basement rock of much lower permeability. Wells drilled into the limestone yield hundreds of gallons per minute of potable water while wells

that are accidently drilled into the basement rock do not yield economical quantities of fresh water. The basement rock of northern Guam

thus constitutes a regional aquitard, which partitions the bedrock aquifer into discrete subbasins. On the other hand, the basement topography also determines the location of the premier water-bearing zone of the aquifer: the relatively narrow strip along which the lens laps up onto the basement rock and the basement slope plunges below sea level. In this "parabasal" zone, the lens is not only thickest, but also tends to be freshest, since it is underlain by the virtually impermeable basement rock rather than the seawater that elsewhere permeates the porous limestone bedrock. The parabasal zone also constitutes the "headwater" where rainwater percolating down to the slopes of the basement rock where it stands above sea level concentrates to form the flank of the lens. The best wells are thus those placed in the parabasal zone. However, attempts by drillers to intercept the parabasal zone run the risk of intercepting the nearby basement instead, thus producing a "dry hole." The map is maintained in WERI's NGLA Database and will be updated as new discoveries or insights are gained.

GHS Sponsored Research Projects Ongoing in FY'10:

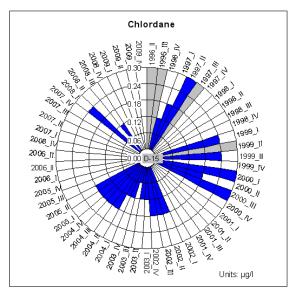
Three GHS partially sponsored research projects that are ongoing and poised to yield significant data are: 1) spatio-temporal analysis of groundwater quality on Guam, 2) reconstructing the climate history of Guam, 3) the development of a management plan for the Piti-Asan watershed. The significance and current status of each of these studies are outlined below.

1. Spatio-Temporal Analysis of Groundwater Quality on Guam

Since 1996, Guam Waterworks Authority's (GWA) has regularly monitored Guam's groundwater resources for all contaminants listed under the Safe Drinking Water Act. A substantial bank of data now exists from which certain space- and time-dependant trends are emerging. WERI has now converted all the GWA data to GIS format for further processing

and analysis. GIS can be applied to identify vulnerable wells within the aquifer. Based on the converted data, contaminant information can be displayed in GIS, and spatial query can be conducted to identify problematic wells with some kinds of contaminants.

Ongoing research at WERI is focusing on establishing a GIS model for the visualization and analysis of GWA's water quality data, in order to readily identify longand short-term temporal and spatial changes. One example shown here is the use of 'clock diagram' graphics constructed using Visual Basic for Applications (VBA). Such graphical representations may be used for any contaminant in any well and are useful for visualizing problematic and potentially problematic wells.



Graphical visualization of quarterly chlordane data for GWA well D-15

2. Reconstructing the Climate History of Guam (and associated projects)

Stalagmites and water samples from a cave on northern Guam are providing clues to how the climate of Guam and the surrounding region evolved over the past 22,000 years. Stalagmites

were initially collected by WERI researchers in April 2005. Laboratory work on the stalagmite has been underway for the past three years by collaborators at the Jackson School of Geosciences at the University of Texas-Austin. The project builds on a previous GHS sponsored study focused on locating and mapping the limestone rock units of Guam. The initial results are consistent with results from other islands in the Pacific and suggest, among other things, that the regional climate was much drier some 5000-6000 years ago. The western Pacific Ocean plays an important, but still poorly understood role in global climate. Results of this study will not only help to understand and predict longer-term climate trends for Guam, but for the entire western Pacific region. This study is thus an ongoing long-term study, which is now being linked to similar, collaborative regional studies. In particular it has supported two proposals for additional funding



WERI researcher, John Jocson collects drip water residues in one of Guam's many caves

from the National Science Foundation (one of which has recently been approved), which will extend the same investigation to the Philippines and Borneo. As these studies continue to progress, Guam and the surrounding region will gain an increasingly reliable understanding of long-term climate cycles and weather-related events that control the hydrologic cycle and water resources of the islands in the region.

This exciting study has drawn interest from scientists world-wide and has resulted in the subsequent development of two sister studies shown below. Both are supported in part by GHS funds and are briefly described below.

a) <u>Reconstructing Climate and Sea-Level History of Guam from Local Caves</u>

Geological field study of the coastal zone of northern Guam revealed that there is an exposed fossil coral reef in which corals have not yet completely recrystallized, as in most of the

limestone on Guam. This limestone unit forms a gently inland-sloping terrace that is up to about 20 m high and is probably coeval with previously dated Tarague Limestone deposited during the sea-level high-stand of the last interglacial, some 125,000 years ago. Its present-day elevation gives new insights to the uplift rate of this part of the island, indicating an average rate of about 0.2 mm/yr. The caves found in this limestone unit could be of great interest for future paleoclimate research. The specific chemistry of the incompletely recrystallized bedrock in which they have formed influences the chemistry of cave deposits. Preliminary chemical analysis of a stalagmite found in one of these caves, for example, shows very high concentrations of trace elements, which are proxies for prehistoric rainfall. Further analyses are needed to test the actual potential of these stalagmites for paleoclimate reconstruction, but initial results are promising, and they could potentially provide the



WERI research assistant, Blaž Miclavič, inspects Guam cave site for climate research project

means for reconstructing the ancient climate record over the past several tens of thousands of years. Understanding the past pattern of wet and dry climatic shifts on Guam will provide a basis for more reliable diagnosis or prediction of current and future climatic conditions and trends. The results from the caves on Guam will also help to better understand the paleoclimate signal in the ongoing research in the Western Pacific and East Asia.

b) <u>Reconstructing Modern Sea Surface Temperature and Rainfall-Drought History of Guam</u> The purpose of this project is to identify the rhythm and strength of past El Niño events from the coral record in Guam's coastal waters. Results from such studies of coral on Guam are of particular value because they can be compared with the cave stalagmite record from northern Guam, for which research has funded by Guan Hydrological Survey since 2008. The cave record promises to provide us the precipitation history for the past 27,000 years, at least at century-scale resolution, and perhaps decadal scale during some portions of the record. It is well known that El Niño brings lower sea surface temperature and lower precipitation to Guam. Using these two unique El Niño characteristics, we use corals to investigate past sea surface temperature history and analyze stalagmites from our cave project to obtain past

precipitation history. We expect the rhythm and scale of El Niño from the coral record will give us a means to more accurately interpret the prehistoric cave record. Currently, there are no published climate studies that use both corals and stalagmites from one region. Guam is of unique value for such studies, since it has caves and coral co-located and is small enough and far enough out into the tropical ocean that these records will have captured the oceanic climate, rather than the continental climate of East Asia. This work thus promises to be of extraordinary value. Understanding the past El Niño cycles on Guam will allow us to predict



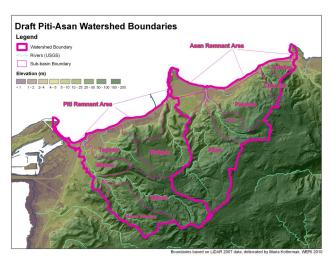
WERI research assistant, Tomoko Bell, and support team remove a 1m carbonate core from living *Porites* coral head

and model the future climate trends with much greater confidence. In August, 2010, WERI researchers extracted 1-meter long, 80-mm diameter coral core in southern part of Guam, using a uniquely designed pneumatic drill, custom-made for this project, which is much cheaper and simpler than the other drills in use. This specimen has been analyzed at the laboratory at the University of Texas, Austin since August, 2010, and we expect to reconstruct the past sea surface temperature history for the past 60 years on Guam by the end of December, 2010.

3. Piti-Asan Watershed Management Plan

The Piti-Asan watershed is a priority watershed in the need for restoration. The watershed is

adjacent to one of five marine preserve of the island. The preserve is an important recreational area for divers and snorkelers. The Piti-Asan watershed comprises of two coastal villages, housing development, conservation areas (Masso, National Parks), historic sites, and various government institutions. This project includes a watershed assessment. GISanalysis, current conservation measures, and management strategies. Plans and recommendations from other agencies and institutions like the Piti conservation action plan (CAP) are reviewed and incorporated as needed. The plan will provide an overview of the



Piti-Asan watershed: an area desperately in need of a workable management plan

area and future directions for the restoration and preservation of a healthy watershed.

GHS Sponsored Research Projects Completed in FY'10:

One GHS partially sponsored research projects completed in FY'10 was an analysis of the impact factors affecting badland dynamics in southern Guam. A summary report of this project is given below.

1. Impacts of Various Factors on Badland Dynamics in Southern Guam



Guam Badlands: A natural phenomenon exacerbated by poor land-use practices, e.g., off-roading activities uncontrolled burning and inappropriate farming methods

Erosion Soil erosion in the form of badlands is a common phenomenon throughout Southern Guam. Badlands compared to any other land cover have the highest erosion rate. Consequently, they contribute the highest amount of sediments to the marine environment. Both human and natural factors may be responsible for badland development. To manage soil erosion, specifically on badlands, in an effective way, a better understanding of the processes associated with badland dynamics is essential. This study investigates changes in badland cover between 1946, 1994, and 2006 in areas affected by human activities (off-

roading and farming) and areas not affected by human activities. The badland cover classification is based on panchromatic and color aerial photography from 1946 and 1994, respectively; and QuickBird Satellite Imagery from 2006 using density slicing. A change detection analysis of the classified images from 1946, 1994, and 2006 identifies areas of badland change. In addition, the influence of terrain attributes (e.g., slope, aspect) on badland occurrence is investigated. Based on the results of this study, management recommendations are provided to reduce soil erosion from badlands.

SUMMARY OF FY'10 EXPENDITURES FOR GHS APPROPRIATION

Below is a composite summary of all expenditures lodged against the GHS account during FY'10. As in past years, budgetary shortfalls arising out of austerity measures implemented by the Guam Legislature have so far been covered by carryover funds from GHS allotments received in previous years. As these reserves are limited they cannot be expected to sustain the program at its current high rate of activity for too much longer. This notwithstanding, we gratefully acknowledge the Guam Legislature for their continued interest in and support of the GHS program and all associated water resources related research, education and training activities carried out at WERI.

Expenditure Summary for FY'10

Expenditure Summary for FY'10						
Category	Expenditure					
1. Salaries and Wages:	\$90,222.83					
2. Fringe Benefits:	\$7,030.72					
3. Tuition Fees	\$888.00					
4. Supplies:	\$1,637.88					
5. Computer Hardware/Software:	\$9,679.69					
6. Equipment:	\$28,170.17					
7. Consultant Fees:	\$57,331.00					
8. Postage/Long Distance Phone:	\$1,178.58					
9. Printing:	\$2,787.80					
10. Travel:	\$0					
11. Administrative Fees*:	\$18,653.80					
Total FY'10 Expenditures:	\$217,580.47					
Total FY'10 GHS Allotment:	\$192,307.00					
Balance:	- <u>\$25,273.47</u>					

* University of Guam cost sharing administrative fee of 10% levied against all special appropriations received from the Guam Legislature

COMPREHENSIVE WATER MONITORING PROGRAM (CWMP)

The United States Geological Survey (USGS) has monitored our island's water resources since 1951. Unfortunately, during the 1990s they were forced to downsize this program because matching support from the Government of Guam was discontinued. This resulted in the abandonment of all deep monitoring wells needed to monitor saltwater intrusion in the north, and most of the stream gages in the south by the mid-1990s. In 1995, the USGS closed its field office at Naval Station, but continued to run a limited monitoring program (out of its Saipan and Honolulu offices).

In August, 1998 the CWMP was made a permanent part of WERI's program when Governor Gutierrez signed PL 24-247. This resulted in the refurbishment of the deep monitoring wells and a renewed program of water resource monitoring on Guam. The intent of PL 24-161 was to restore, and then to expand, as needed, the discontinued monitoring program in order to help Guam manage and safeguard all of its freshwater resources, now and in the future. Under PL 24-161, WERI/UOG and the USGS entered into a memorandum of understanding to administer and fund this program on a 50/50 cost-sharing basis. The CWMP is a permanent investment in Guam's future.

A well-designed long-term CWMP can save communities millions of dollars, and even human lives, by providing critical information for water-supply, culvert and bridge design, delineating flood-hazard areas, and tracking effects of climate change. The USGS started a water-resource monitoring program in Guam in 1951 with installation of stream gages at Pago, Lonfit, and Tolaeyuus and a rain gage near Fena dam. At the same time, measurements of discharge from

Almagosa Springs and water levels in Fena Reservoir started. Since 1951 about 22 continuous streamflow, 8 rain, and 16 groundwater monitoring stations have been operated, providing reliable information on the water resources and hydrologic hazards of Guam.

Currently, USGS monitoring on Guam consists of 8 continuous-recording streamflow gages, 7 continuousrecording groundwater wells, 6 groundwater wells where the thickness of the freshwater lens is measured, and 5 continuous-recording rain gages. From a broad perspective, the program provides long-term information on the hydrologic cycle of Guam so that its water resources can be understood and sustainably managed. The bulk of the monitoring stations on Guam are funded as part of a Joint Funding Agreement between the USGS and WERI.



Locations of USGS monitoring stations on Guam

Stream Gages for Water Availability and Flood Planning in Southern Guam

Most freshwater used in southern Guam comes either from streamflow or wells that withdraw water from near the banks of streams. Data from USGS stream gages provide information needed by managers and engineers to properly manage the long-term sustainability of these water resources. Statistical analysis of long-term streamflow data are needed so the effects of abnormally wet or dry years can be understood and planned for. For example, USGS gages provide information that can be used to assess and manage the sustainability of surface water from the GWA Ugum Treatment Plant. Other gages, funded in cooperation with the U.S. Navy, are used to manage withdrawals from Fena Reservoir.

Long-term streamflow information is needed for flood planning. This information is used to delineate flood zones, estimate the magnitude of floods and frequency with which they could be expected to occur, and design bridges and culverts. For example, information from 11 stream gages and 3 other sites was used to assess the flood peak magnitude and recurrence interval following Typhoon Chata'an in 2002. FEMA uses information from USGS stream gages to determine



Flow in Pago Stream has been measured since 1951

the level of financial aid from FEMA after storms. Currently, the WERI-USGS CWMP funds the operation of 5 stream gages at key locations in southern Guam.

Well Monitoring of the Northern Guam Lens Aquifer



WERI field assistant measures water levels in the Northern Guam Aquifer

Monitoring wells operated as part of the USGS-WERI CWMP provide information to assess the health and sustainability of the Northern Guam Lens Aquifer. This aquifer is the most important source of freshwater on the island. Currently, the program includes 7 wells where water level is continuously measured and 6 wells where the thickness of the freshwater lens is measured quarterly. Collectively, this information allows scientists at WERI, GEPA, GWA, and USGS to understand the flow of water through the aquifer and refine sustainability estimates of this resource. This information is used to understand how current levels of pumpage are affecting the aquifer and how future changes in climate and groundwater production may affect the sustainability of groundwater resources. Coupled with detailed geologic mapping and modern hydrologic tools such as groundwater flow models, information from this long-term program will be invaluable as additional water is needed to support increasing economic development on Guam.

Rainfall Data to Estimate Water Supply Recharge and Flood-Water Distribution

The USGS currently operates 6 rain gages on Guam, 4 of which are funded by the WERI-USGS CWMP. Rainfall data are fundamental to understanding the water supply and threats from flooding. Information from these gages is used to evaluate the extent of drought during El Nino events and the severity of flooding during typhoons. Information from rain gages is also essential in determining how much freshwater infiltrates past the ground surface to reach the water table. This water, known as recharge, is the source of freshwater in the Northern Guam Lens Aquifer and only by measuring rainfall can its abundance be accurately estimated.

Sediment Measurements for Watershed Management



Ugum River after heavy rains transports large amounts of sediment to the coast and severely impact coral reefs. Knowing the sediment sources and amounts discharged can assist managers in the design and implementation of mitigation strategies.

Coral reefs on Guam are thought to be damaged by sediment carried in runoff from watersheds. Managers are trying to understand the sources and amounts of sediment moving from watersheds to coral reefs so that this problem can be addressed. Successful watershed restoration may result in reduced soil erosion and sediment transport to coastal waters, thereby increasing compliance with the Clean Water Act. Streams may also become better habitats for native stream organisms if sediment load is reduced. As part of the WERI-USGS CWMP, two stream gages in southern Guam have been upgraded with specialized equipment that automatically collects water samples so that the amount of sediment flowing to the ocean can be measured.

What does it cost to operate a stream flow and other gages?

In fiscal year 2011, the cost to operate a continuous-record streamflow gage will be \$22,850. This includes all operation and maintenance, site visits, field data collection, data analysis, and computation of the flow record. Gage operations are frequently reviewed and upgraded as improvements become available. Determining the suspended-sediment load at a gage increases the annual cost an additional \$27,420. Other gages, such as rainfall (\$10,970) and groundwater (\$6,850), require less funding. With over 100 years of experience, USGS procedures ensure that data are reliably collected, analyzed, and publicly available

How can one get USGS water resource information?

Most data from USGS gages are readily available on the internet. As part of CWMP between WERI and the USGS, historic data and other hydrologic information for Guam are consolidated and made publicly available at: <u>http://hi.water.usgs.gov</u>.

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Government of Guam Fiscal Year 2012 Budget Program Fiscal Summary

FUNCTION:EDUCATION & CULTUREAGENCY:UNIVERSITY OF GUAMPROGRAM:WATER AND ENVIRONMENTAL RESEARCH INSTITUTE (WERI)

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Budget Account Allocation		FY2009		FY2010		FY2011			
FUND TITLE	Fund		Percent of Program	Authorized Appropriation	Current Service	Program Plan	Governor's Recommendation	FY20012 Projected	FY20013 Projected
General Fund Appropriation		\$956,825		\$982,453	\$982,453	\$1,008,850		\$1,036,038	\$1,064,043
Guam Hydrologic Survey (Local)		\$192,307		\$192,307	\$192,307	\$204,200		\$204,200	\$204,200
Guam Water Monitoring Project (Local)		\$163,000		\$163,000	\$163,000	\$173,948		\$173,948	\$173,948
Guam Water Monitoring Project (Federal)		\$139,020		\$139,020	\$139,020	\$173,948		\$173,948	\$173,948
USGS Water Institute Program (Federal)		\$277,005		\$277,005	\$277,005	\$277,005		\$277,005	\$277,005
ENSO Application Center (Federal, National Weather Service		\$150,000		\$200,000	\$200,000	\$200,000		\$200,000	\$200,000
Total Program Appropriations		\$1,601,152		\$1,753,785	\$1,753,785	\$1,837,951		\$1,885,139	\$1,893,144
FTE Positions									
Performance Indicators	Туре								
Undergraduate Courses Taught	WKLD	3		3	3	3		3	3
Graduate Courses Taught	WKLD	10		8	8	8		8	8
Thesis Committees served (chaired)	WKLD	21(11)		15(9)	15(9)	15(9)		15(9)	15(9)
Projects Initiated	WKLD	15		12	12	12		12	12
Projects completed	WKLD	11		12	12	12		12	12
Technical Reports	WKLD	10		5	5	5		5	5
Journal Articles/Conference Proceedings.	WKLD	17		10	10	10		10	10
Professional Presentations	WKLD	12		10	10	10		10	10
Workshops/Conference Presentations	WKLD	3		2	2	2		2	2