PALAU

The Rock Islands

1. COUNTRY INTRODUCTION

Description:

Republic of Palau is comprised of approximately 490 islands. There are nine inhabited islands, the most populated being Koror and Babeldaob with the later being by far the largest. The remaining islands cover a range of island settings, including volcanic, raised and low coral islands and atolls. The population in 2010 is estimated at 20,518 (SPC PRISM).

Economy:

Primarily tourism, subsistence agriculture and fishing.

Water Availability:

Surface water is generally abundant and largely continuous due to regular rainfall. The Ngerikiil River and Ngerimel Dam supply the Koror/ Airai Water treatment plant on the island of Babeldaob. Approximately 90% of people living in Palau have access to piped and treated water. The inhabitants on the islands of Peleliu, Angaur and Kayangel rely on groundwater for their public water supply systems. The raised islands and low atolls, which are sparsely populated, get their water from both aquifers and household rainwater harvesting systems. There is some use of bottled water which is both produced locally and imported. Currently there is a proposal to reuse wastewater from a newly constructed sewage treatment plant, predominantly for irrigation purposes.

Island Vulnerability:

El Niño impacts on Palau can be significant, where the dry season can be extended from its usual 3 months to 5-6 months or longer. The reversal of this, the La Niña, often brings higher than average rainfall and more intense and frequent storms. Palau remains vulnerable to man-made disasters such as fires, marine oil spills, disease outbreaks, high-risk and unplanned development, and chemical and sewage pollution of water supplies. The increasing number of tourists visiting the islands is putting a strain on the existing water supply source and wastewater treatment systems. Larger hotels are generally required to have their own wastewater treatment facilities but many still rely on the public system, thus pushing the system beyond its maximum sustainable capacity.

Power generation:

There is a reliance on imported diesel fuel for electricity generation. Whilst the streams on Babaldaob are relatively small there is some potential for micro hydro electricity plants for local supply, small storage reservoirs would provide more reliable supply.

Ngerimel Dam, water supply for Koror, Palau

Health:

Because most of the water supply systems are treated, water borne disease incidence relating to the public water supply is expected to be relatively low for Palau. Of greater concern is management of water supply quality by individuals at the household and village level. The Palau Environmental Quality Protection Board tests public water supply systems on a monthly basis for presence of total coliform bacteria and disinfectant residuals. Most of the outbreaks of water-borne illness come in cluster outbreaks, where it is thought poor sanitation practices in the upper catchments may be contributing to contamination of the source, and where river water is used directly as a drinking water source without treatment. Dengue fever is at times a concern due to the large number of mosquitoes and larvae that can breed in areas of still water. According to the Division of Environmental Health, small dengue outbreaks occur at least once a year, with larger outbreaks happening every 2 to 3 years.

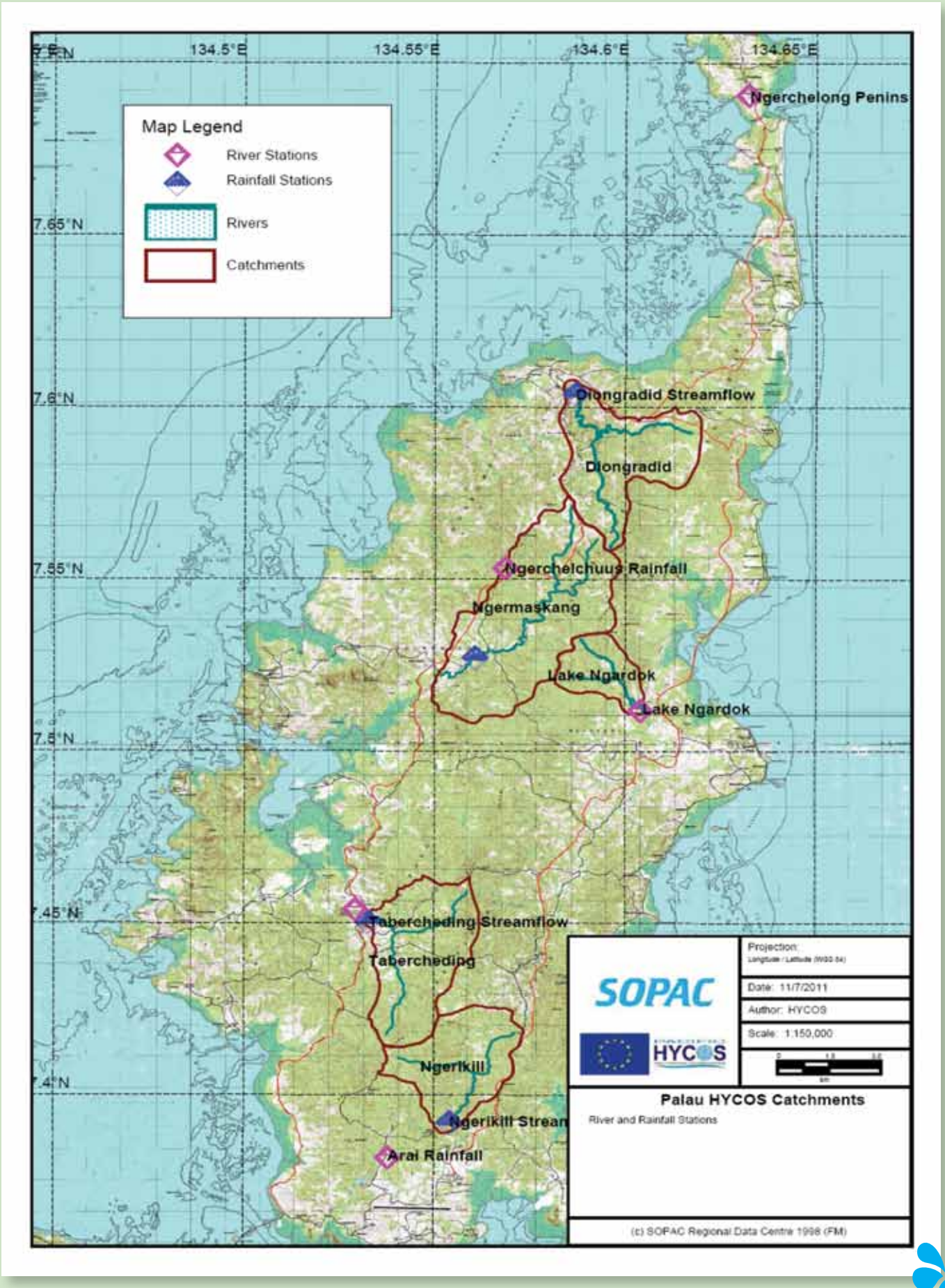
Environment and Tourism:

Palau is home to the internationally renowned 'Rock Islands'. In 2010, the number of visiting tourists was estimated as being 85,593 (Palau Visitors Authority 2011), over four times the indigenous population of Palau. Proposals are in place to develop more hotels in Koror and large resort developments on Babeldaob. Most of these proposed developments are high-end boutique markets that cater to a limited number of people per year yet have significant water demands, for example proposed golfing resorts with irrigation needs. For the most part, the developers recognise they have a vested interest in protecting the environments that tourists come to enjoy. However, there is the potential for larger-scale hotels to develop within the watersheds on Babeldaob, thus creating more wastewater and putting strain on the environment and infrastructure, (IWRM SOPAC 2007). The peak time for tourism and therefore increased stress on the water supplies is July to September as well as January to March periods (Palau Visitors Authority 2011), with the rainy season May to August.

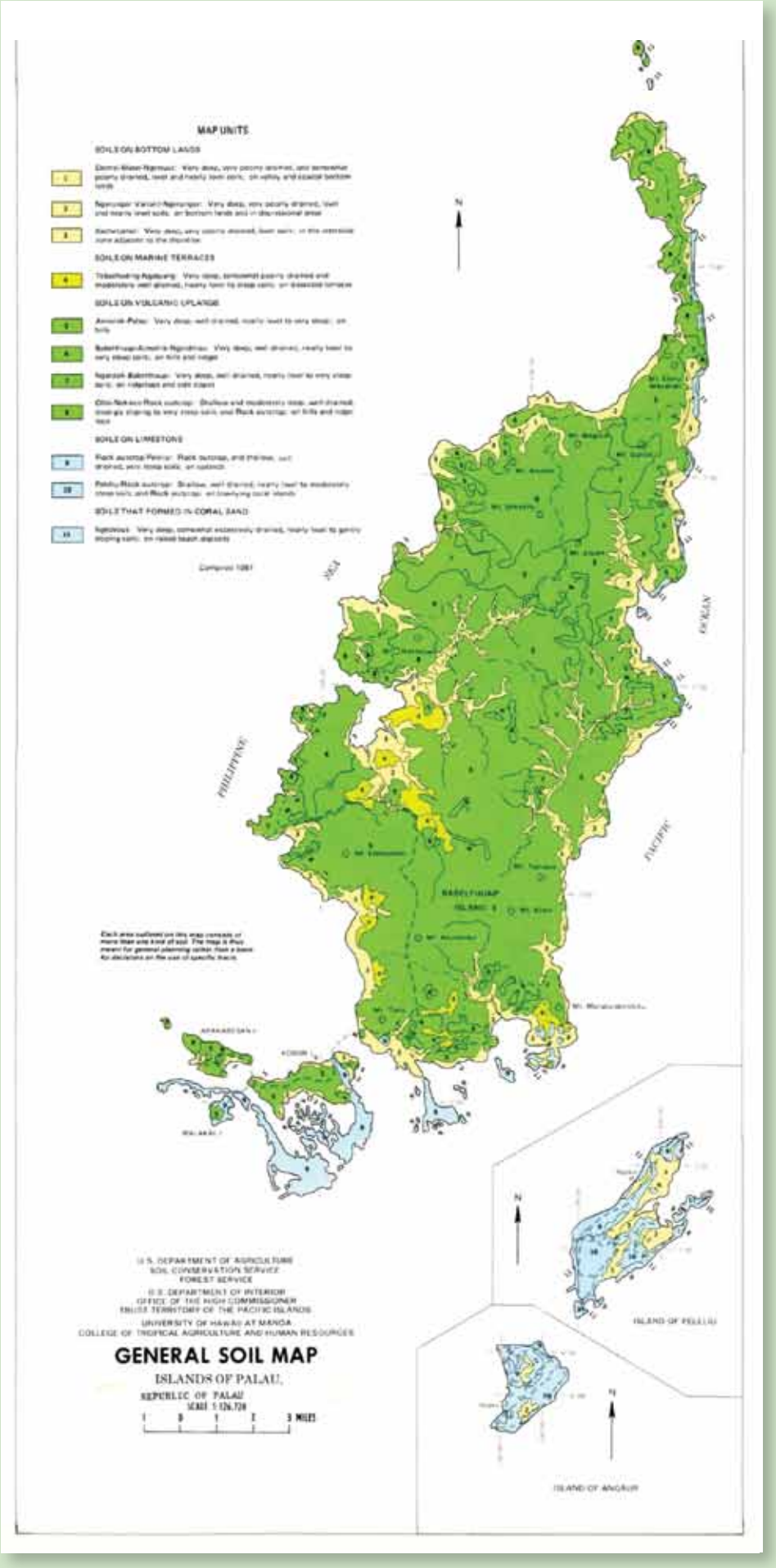
2. GEOGRAPHIC INFORMATION

Basic geographic and soil information showing the extent of the main island Group is presented in the following maps.

Map of Babeldaob showing the respective Pacific HYCOS supported streamflow Catchments



General Soil Map of Palau



http://www.lib.utexas.edu/maps/palau.html

3. CLIMATIC INFORMATION

Palau has a tropical climate and is normally humid and warm to hot. The temperature variability throughout the year varies little with an annual mean of around 28^{0}C. During the months between May through to August the Asian monsoon and Intertropical Convergence Zone (ITCZ) bring heavy rainfall to the Republic of Palau. As the ITCZ moves toward the Southern Hemisphere around September, Palau experiences semi-dry conditions for a month until the return of easterly waves bring another round of rainy months during October through to December. The months of January through to March are known for being a drier period, sometimes with prolonged periods of no rainfall depending on the strength of El Niño.

The western North Pacific is the most active tropical cyclone basin in the world, where the typhoon season extends from mid-May through mid-December. Fortunately for Palau, the majority of tropical cyclone development in this region begins in eastern Micronesia, with tropical cyclones passing mostly to the north of the island.

Apart from the National Ocean and Atmospheric Administration (NOAA) supported raingauge station in Koror, little long term rainfall data appears to be available. Data has been sourced from the USGS for the preparation of the attached table.

List of Rainfall Stations USGS/Pacific HYCOS

No	Station	Elevation	Location	Period of observations	Average rainfall#
NA	Koror - NOAA	30 m	Koror 7° 20' 34" N 134° 28' 53" E	1905 - open	3756
22523307	Arai	100m	Arai 7° 22' 54" N 134° 32' 16" E	1991-2005*	3454
27013145	Natpang	40m	Hyundai Yard 7° 27' 14" N 134° 31' 47" E	1996*	na
30373615	Lake Ngardok	30m	Melekeok 7° 30' 42" N 134° 36' 19" E	1996-2005*	3598
33353410	Mt Ngerechelachuss	150m	Ngarmaurd 7° 33' 12" N 134° 34' 07" E	1998-2004*	3755
41123750	Ngerchelong Peninsular	50m	Ngerchelong 7° 41' 26" N 134° 37' 55" E	1997-2004*	2399

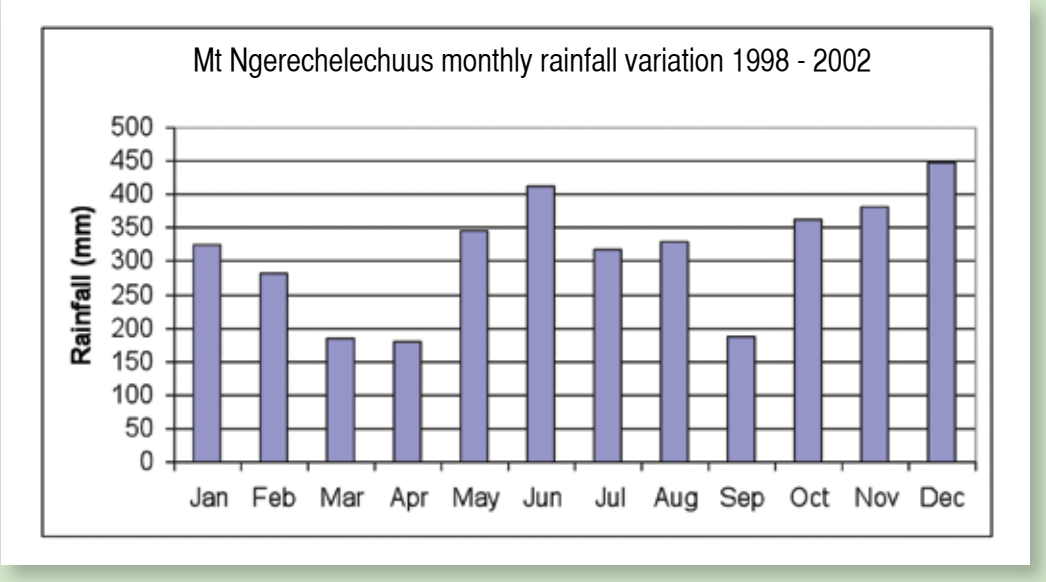
** based on limited datasets * reopened by Pacific HYCOS 2009*

Monthly Climate Data

Observation Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	An-nual	Period for the Mean
Temperature (°C)	28.1	28.0	28.1	28.5	28.3	28.0	27.6	27.6	28.0	28.4	28.5	28.2	28.1	2000 – 2008
Precipitation (mm)	324	283	186	179	345	412	317	329	188	362	381	449	3755	1998 - 2004

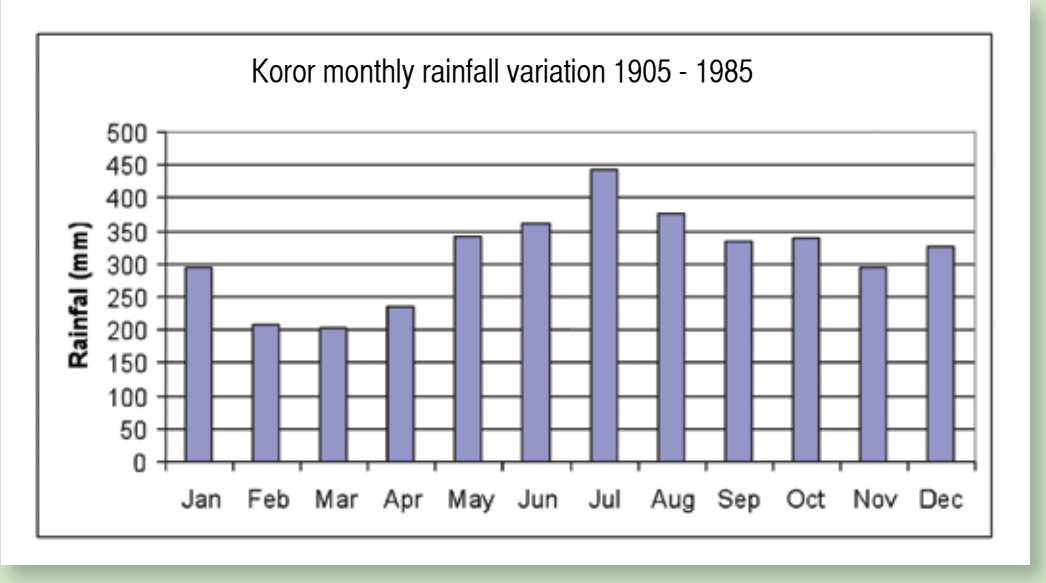
Rainfall Mt Ngerechelachuss 6 years broken data; Temperature http://www.weatheronline.co.uk/weather

Short term Variation of Monthly Precipitation Mt Ngerechelechuus



Source: USGS data – gaps and incomplete

Long Term Variation of Monthly Precipitation NOAA Koror



Source: Van der Burgh

An isohyetal map for Palau is currently not available but it is expected from the limited data available that the rainfall particularly over the main Island of Babeldaob is fairly uniformly spread due to its comparatively low altitude. Limited rainfall data available for the outer islands makes their rainfall distribution difficult to assess.

Ngerimel Dam, water supply for Koror, Palau

4. WATER RESOURCES

4.1 General Description

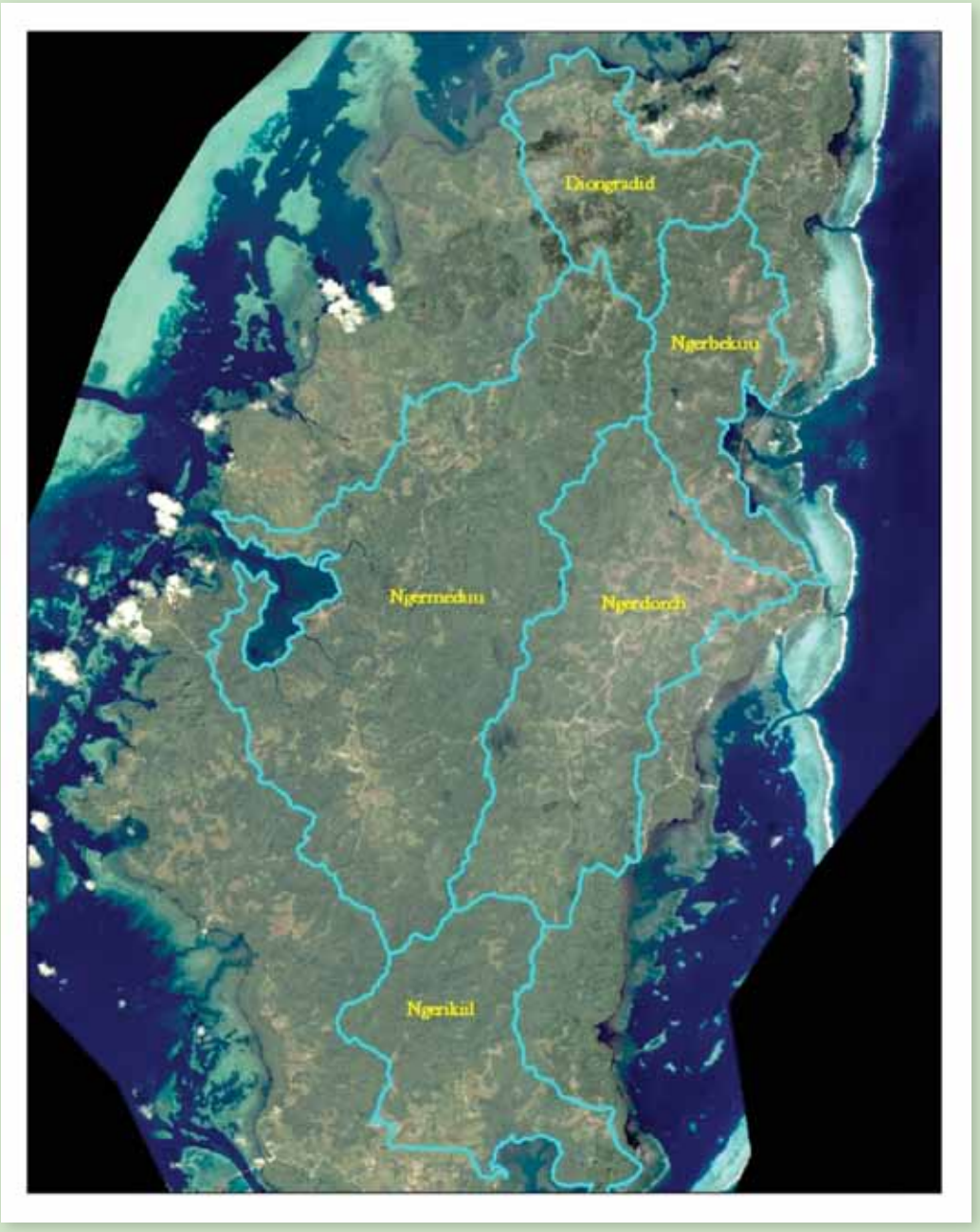
Palau has a general abundance of surface water streams and rivers on the main island of Babeldaob. There are five major watersheds in Babeldaob namely Ngermeduu, Diongradid, Ngerikiil, Ngerbekuu, and Ngerdorch. According to 2005 Census, Babeldaob, the southernmost river in Ngerikiil watershed, supplies the majority of the public drinking water system for the most populated states of Koror and Airai with 12,676 and 2,723 people, respectively. Another water source for both states is Ngerimel Dam with estimated capacity of 76ML (million litres) or (20 million gallons) of water. The largest freshwater lake Ngardok in Micronesia is located in Ngerdorch watershed and serves Palau national capital as well as Melkeok state. The Ngerbekuu watershed drains into Lletmellasech River where it serves Ngaraard state, the third most populous state in the main island of Babeldaob. It is also a future potential water source for part of Ngerchelong peninsula. The Diongradid watershed drains into Diongradid River which is a water source for Ngardmau state. The Ngermeduu watershed drains into Ngatpang, Ngermeskang and Tabecheding rivers. The Ngeremlengui, Ngatpang, and Aimeliik States, and small scale irrigation schemes, pump directly from smaller streams within Ngerdmeduu watershed.

A secondary source, though only partially developed, comes from groundwater which serves the state of Ngiwal in Babeldaob and seven low lying islands. Abundant rain generally brings sufficient surface water flow, though supply can be compromised during extended dry periods, as is common during El Niño events. In addition to the local demand, tourism is considered to be a major user of water placing additional demands on water resources. Small scale irrigation and village supply is directly pumped from the numerous streams on Babeldaob.

4.2 Major Floods and Droughts

Due to the short term and fragmented nature of the datasets, there is insufficient data to be able to assess the magnitude and frequency of flood and drought events. Individual available hydrographs however indicate that the time for catchments to concentrate flow is very rapid as evidenced on the Diongradid River, with a 4 metre rise occurring in less than 2 hours. This appears quite typical of catchments on Babeldaob, where 30 minute rainfalls in excess of 50 mm are not uncommon, a 30 minute rainfall of 105 mm was registered in April 2002. Instrumentation installed under Pacific HYCOS funding will assist in the collection of datasets to better assess and quantify the impact of floods and droughts. Flooding has caused inundation problems at road and highway bridges with instances of significant sediment

Main water catchment areas Babeldoab, Palau



being transported out to the reef environment. Fatalities due to flooding is reported as up to two annually with estimation of annual flood damage estimated at $250,000.00 USD. (M. Chin pers comm. 2011).

4.3 Socio-Cultural Characteristics

Current demands on main rivers and streams, for all but the south of Babeldaob, are limited to small scale irrigation, village, public offices, and small resort water supplies. The capital city of Koror draws its water supply from the southern part of the island where the resource is highly committed especially during sustained dry periods. Potential exists elsewhere for increasing levels of irrigation, micro hydro and resort development. Some streams offer tourism potential for river boating, bush walking and waterfall and eco-tourism experiences.

5. HYDROLOGICAL INFORMATION

Palau does not have a National Hydrological Service. Hydrological monitoring and assessment activities were in the past undertaken by the United States Geological Survey (USGS); however the USGS ceased all activities in the mid 2000's. Data collection activities were undertaken on periodic country visits over a comparatively short period. As a result, datasets are short, fragmented and of limited value. The Pacific HYCOS Project, in 2009, working alongside Palau's Environment Quality Protection Board (EQPB), a Government funded agency, installed some new stations and reinstated some of the older hydrological stations that since 2000 had deteriorated into disrepair. Under Pacific HYCOS, support was provided for training, developing basic hydrological skills within a motivated team which will improve with continued exposure. Additionally capital equipment was purchased allowing the EQPB to commence hydrological data capture in pilot study areas and assist in developing a program of sustainable water resources monitoring.

5.1 Hydrological Stations

Various stations have operated over differing periods, with the resulting data generally incomplete. The attached table identifies the sites known to have operated and with data archived in the USGS Hydrological database.

List of known Hydrological Observation Stations

No.	Station and number	Location	Catchment Area (A) [km^2]	Observation Period	Observation Items (frequency)
1	Diongradid 16890600	Above compact road 7° 36' 13" N 134° 35' 14" E	11.50	1989 – 2005*	WL, Q, RF
2	Tabecheding 16890850	Above compact road 7° 27' 02" N 134° 31' 36" E	15.7	2002 – 2003*	WL, Q, RF
3	Tabecheding 16890900	Below falls 7° 27' 10" N 134° 31' 44" E	na	1989 - 2005	closed
4	Kmekumer 16891310	7° 27' 14" N 134° 31' 47" E	4.1	1990 - 2005	Reopening 2011
5	Ngerikiil 16891311	Above pump station 7° 31' 41" N 134° 33' 40" E	11.0	2009 *	WL, Q
6	Ngardok SF 16891400	na	na	1989 - 1992	closed
7	Ngardok NF 16891420	Near Melekeok na	na	1993 - 2004	closed
8	Lake Ngardok 16891425	Near Melekeok 7° 30' 42" N 134° 36' 19" E	6.3	1996 – 2004*	WL, RF
9	Ngermeskang # 16890901	Research Station 7° 31' 41" N 134° 33' 40" E	18.5	2009 *	WL, Q, RF

**reopened Pacific HYCOS 2009 # new site, Palau's largest river WL = water level; Q = discharge flow; RF = rainfall*

Water falls Tabercheding River

Assessment has shown the quantity and quality of the hydrological data to be poor and only water level hydrographs are presented in this publication. The USGS rating curves are of limited accuracy, where there is a lack of discharge measurements for calibration especially at medium to high flows. The range of discharge measurements undertaken has been presented in a table along with the maximum level recorded at the respective station to give an indication of data collected.

Maximum and Minimum Discharge Statistics and Water Level

Site Names	Minimum gauged		Date	Maximum gauged		Date	Max level recorded m	Date	No of measure-ments
	level m	flow m^3/s		level m	flow m^3/s				
Diongradid 16890600	0.45	0.118	08/03/90	4.69	57.70	21/01/75	4.86	30/06/00	59
Tabecheding# 16890850	2.47	0.219	21/11/02	2.76	1.22	14/07/03	6.87	11/06/03	4
Tabecheding* 16890900	0.18	0.052	02/04/92	1.08	9.12	6/10/01	2.68	29/06/01	38
Kmekumer 16891310	0.46	0.035	03/03/05	3.21	43.89	17/04/79	3.27	17/08/00	54
Ngerikiil 16891311	790	0.103	26/03/10	1.117	0.139	16/04/10	4.96	28/07/08	11
Ngardok SF 16891400	0.33	0.028	23/04/09	0.49	1.07	23/06/89	1.56	16/10/89	17
Ngardok NF 16891420	0.42	0.051	21/07/98	0.96	0.44	16/11/00	1.98	21/06/97	26
Lake Ngardok 16891425	5.84	na	26/08/98	na	na	na	6.53	18/08/99	na

*# above compact Road * below Waterfall*

Much of the known USGS data was rescued to the Palau National Hydrological Archive which uses the TIDEDA system as the Hydrological database.

Hydrologists downloading water level data, Ngermeskang river station, Palau

5.2 Study Catchment Introduction

Two sub catchments Diongradid in the main Diongradid catchment, and Tabecheding subcatchment in the Ngermduu are used to demonstrate typical hydrological features found within Palau.

General Description

The main study catchment of Diongradid a subcatchment of the Diongradid larger catchment has one of many perennial streams on the volcanic island of Babeldaob, Palau's largest island with a land area of 331 km^2. The stream flows west to the ocean from a densely forested catchment in the north of the island. The stream is relatively incised between low mountains and generally well confined between alluvial terraces with some outcropping rock bars. The USGS commenced data collection on this stream in around 1970 and collected some basic and fragmented datasets. Accessible USGS data is available from 2002 to 2004 on their website, and apart from the work done by Van der Burg in the 1980's, there appears to be limited data available for this site. Some earlier reference is made to data collected by the Germans and Japanese pre World War 2, but this data has not been sourced by this study.

The secondary study catchment, Tabecheding, is located in the south of Babeldaob with its southern catchment boundary adjoining that of the Ngerikiil River, Palau's main water supply catchment. Because of Tabecheding's relative proximity to the Arai Water Treatment Plant, it is being considered for future water supply options for Arai and Koror. Data availability is similar to that of the Diongradid River, basic and fragmented. A site located by the USGS on the lower Tabecheding below the water falls also has limited data.

5.4 Measured hydrological data

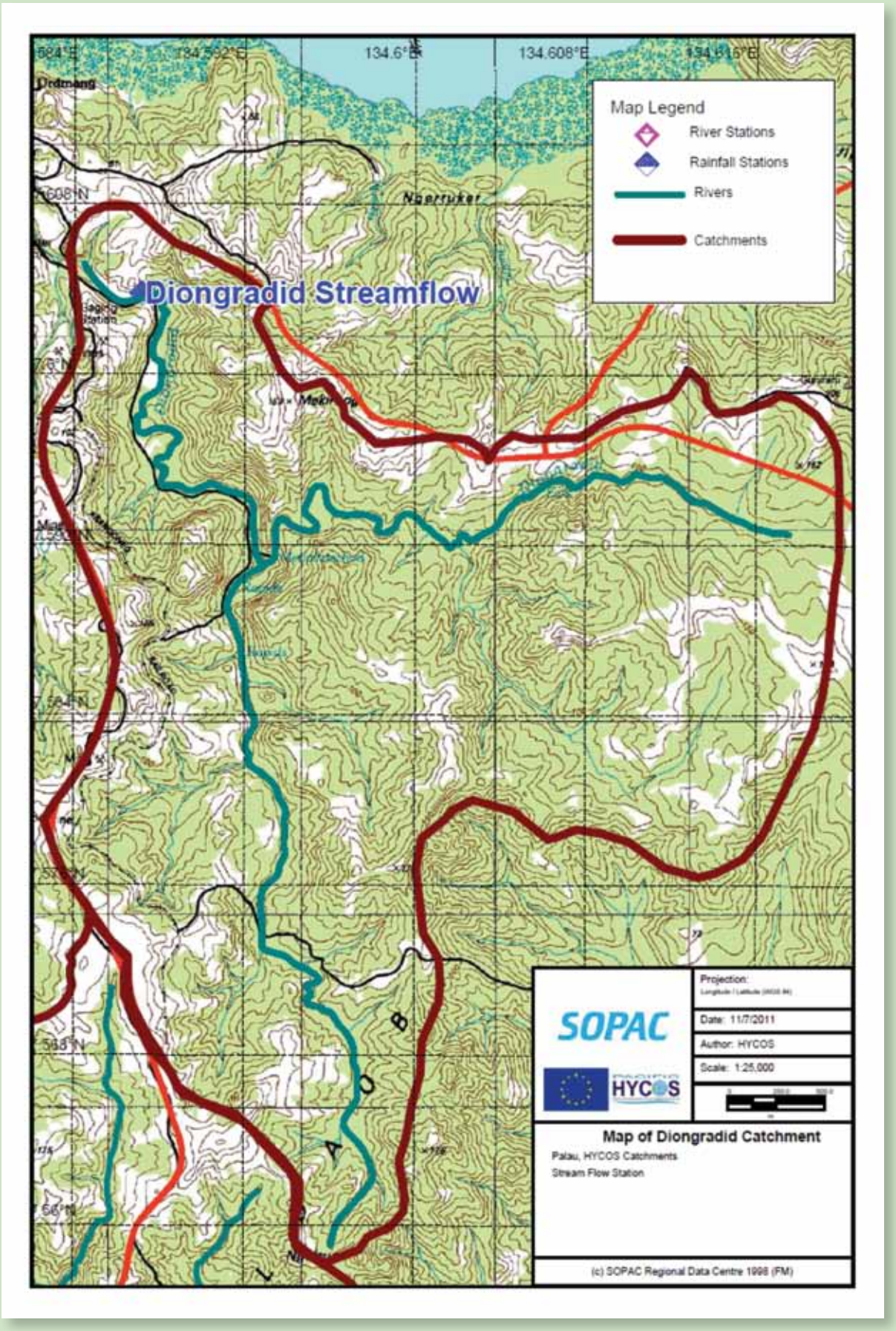
Inconsistency in the periods of hydrological data collection and lack of streamflow gaugings for higher flows limits the confidence in the application of the data in Palau. Flow measurements have in general been undertaken during low flow periods limiting the application of derived rating curves. A review of the processed data has identified discrepancies in regard to its quality which has implications for the output data. In addition to the catchment mapping, an assessment was made on the catchment gradients. This included both the main branch and secondary branches where available. Gradient or channel slope forms an important parameter in hydrological analysis, especially modelling.

5.4.1 Diongradid Catchment

The longest term hydrological data for Palau is available from the Diongradid stream and is sourced from the USGS in the form of instantaneous water levels, (note the gaps in the dataset), identified in the figure below. The streamflow measurements and rating curve are available but cover a very limited low flow range. This is quite typical of the available datasets. The attached graphs therefore do not represent rated data, nor a measure of flood or low flows, only the water level hydrograph.

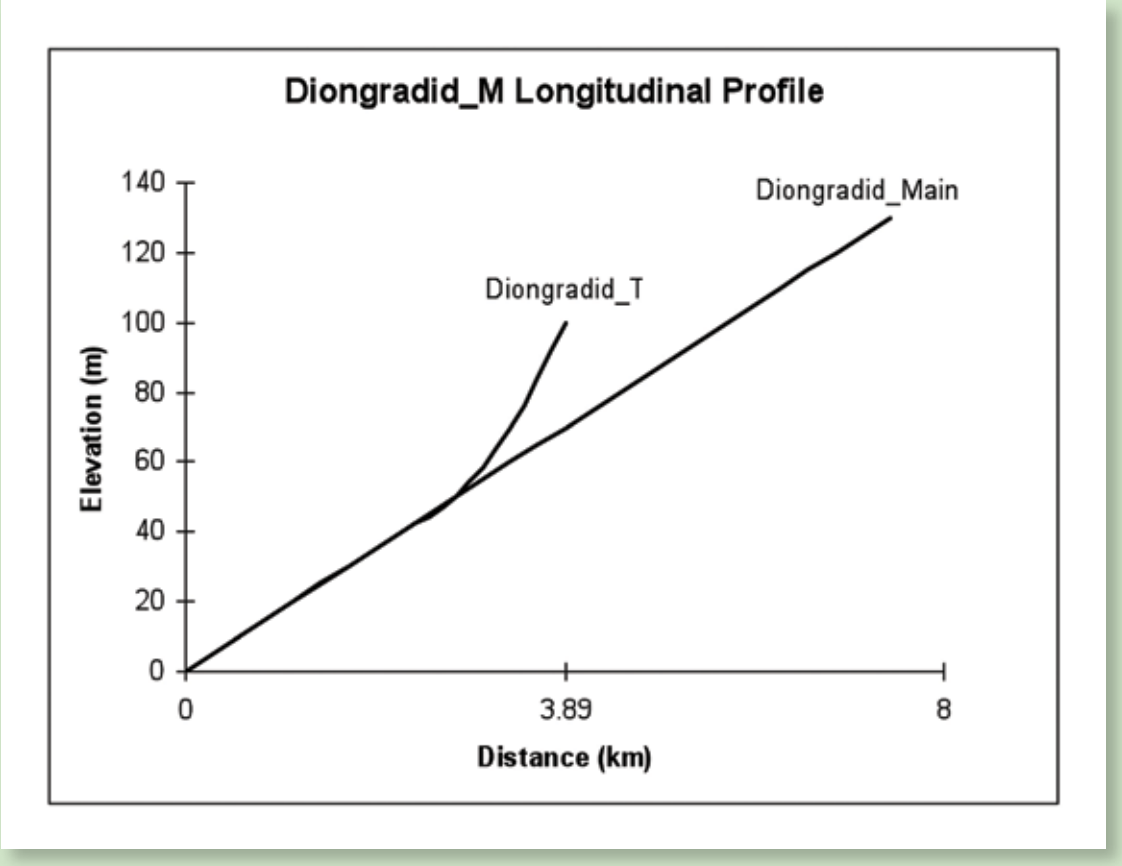
Pacific HYCOS funded installation of a new hydrological site on the Diongradid in July 2009. Improvements in developing sustainable data sets are being made, with the a national hydrological team now making regular visits. Continued support and guidance for these national efforts will improve the application of the data and increased confidence in guiding planning and management for future development for this catchment.

Diongradid catchment map above Compact Road

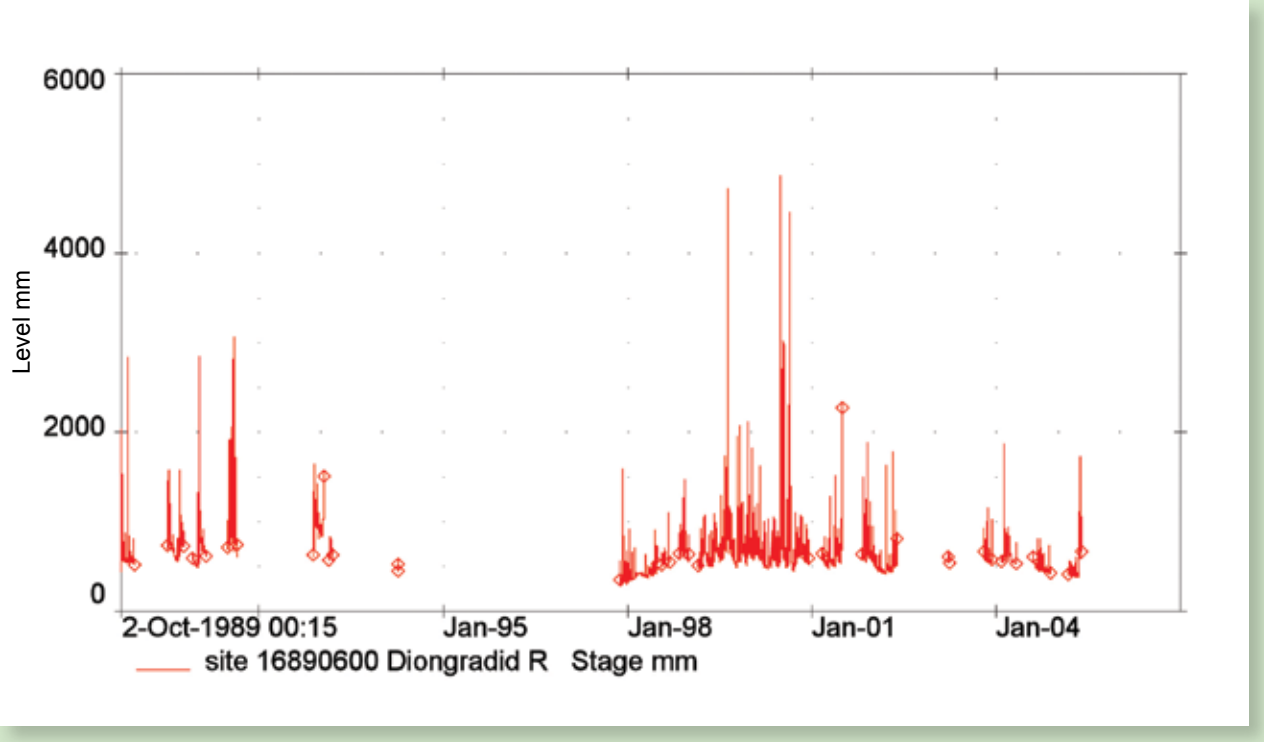


Source: SOPAC 2011

Diongradid Longitudinal Profile



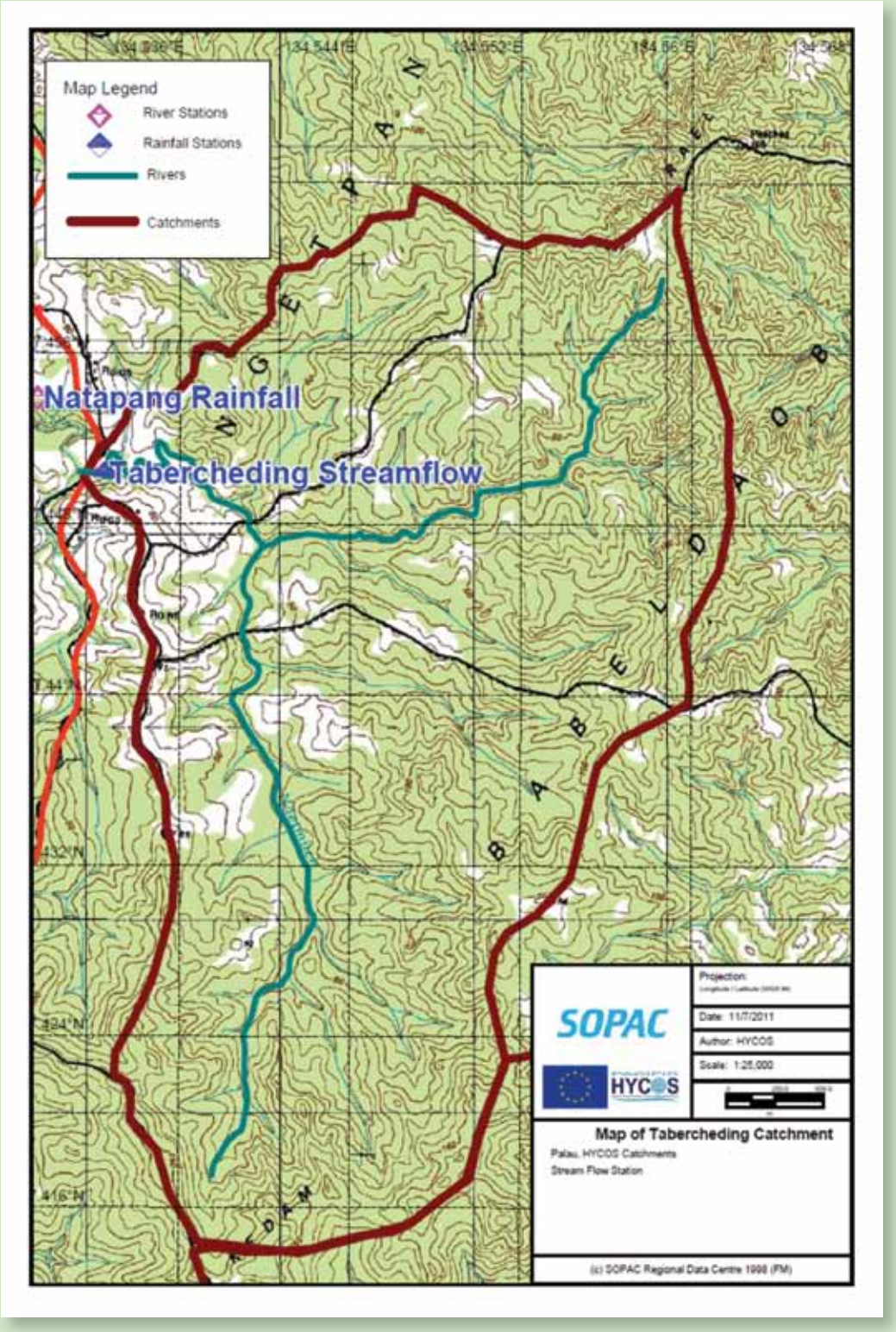
Diongradid River above Compact Road long term variation of Water Level - USGS data



5.4.2 Tabecheding Catchment

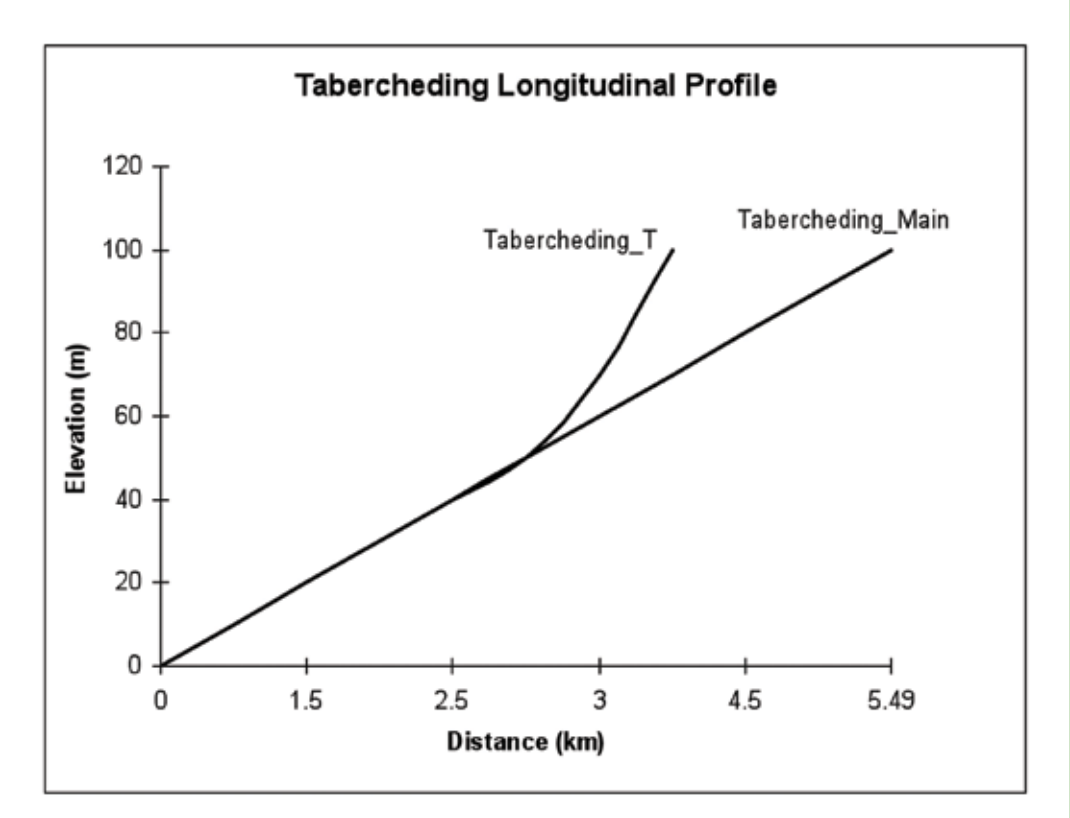
The Tabecheding River, also a Pacific HYCOS demonstration catchment for Palau has seen regular collection of the water level data coupled with increased flow gaugings in recent years which will provide a valuable data set to this significant river.

Tabecheding catchment map

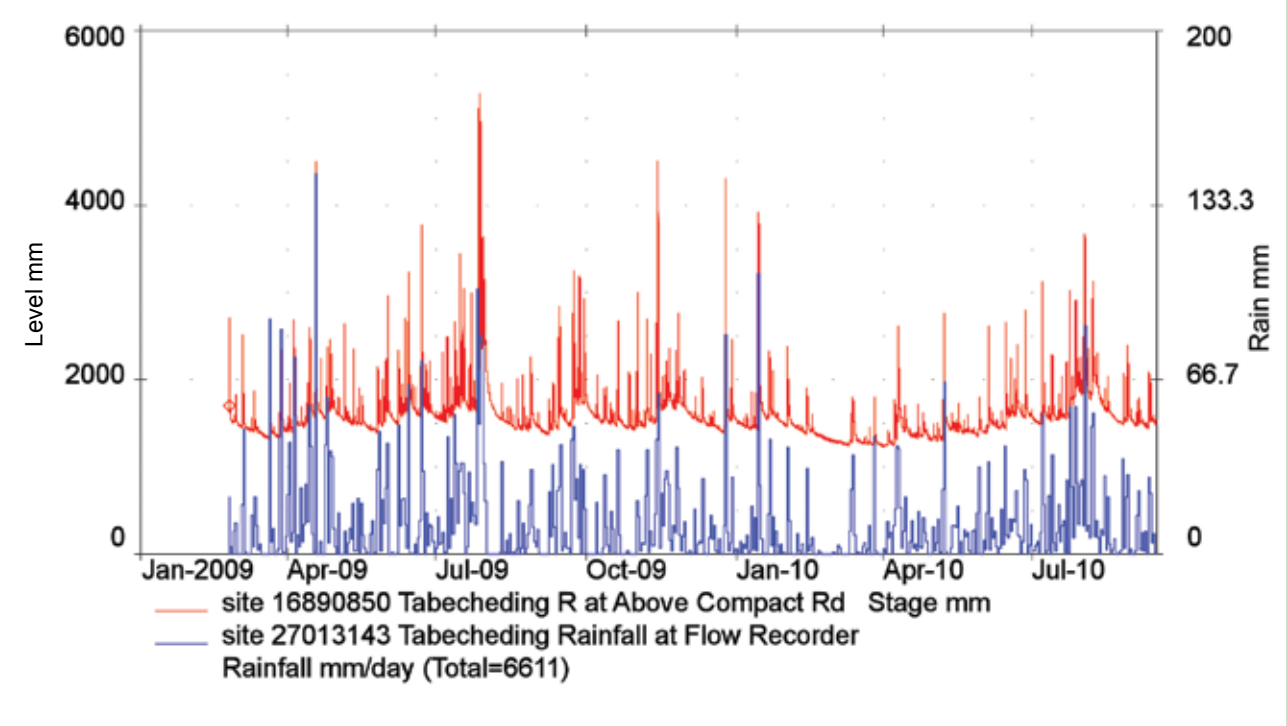


Source: SOPAC 2011

Tabecheding Longitudinal Profile

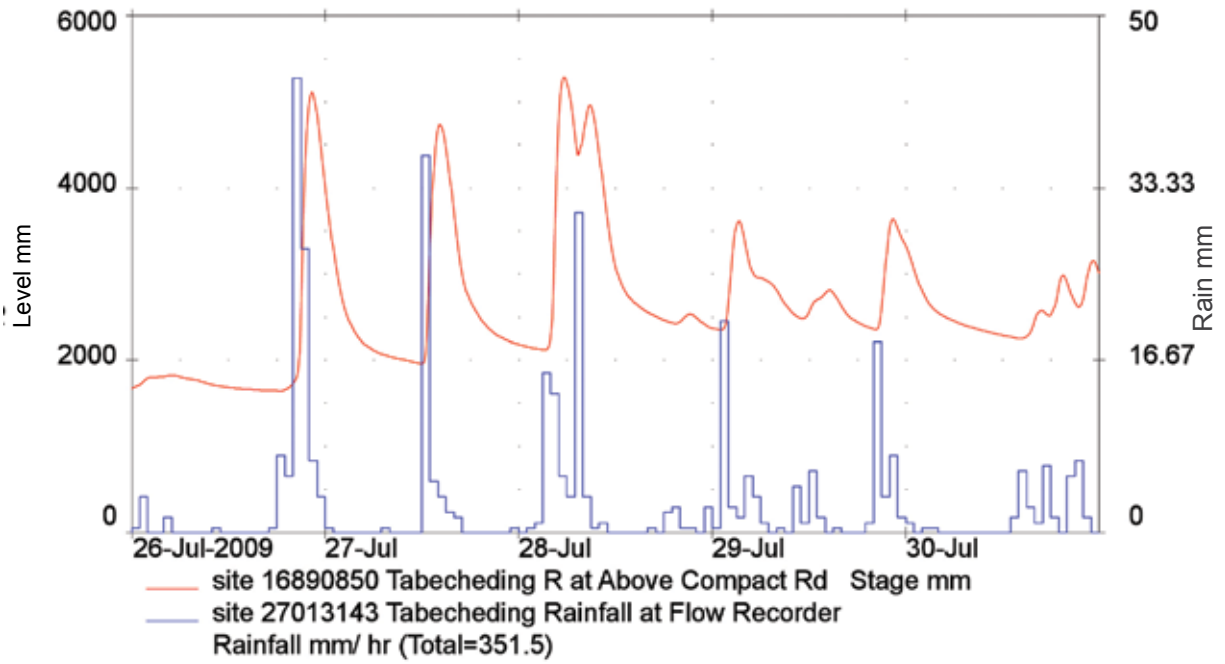


Tabecheding above Compact Road, hydrograph with daily rainfall – Pacific HYCOS data March 2009 – Sept 2010



Ngermeskang river station gauging, Palau

Hydrograph and Hyetograph of a typical recorded flood, hourly rainfalls.
Tabecheding River, July 2009



6. COMMENT

Due to short periods of record and limited streamflow gaugings, the confidence in application of the hydrological information in Palau is limited, especially for any long term or regional hydrological analysis. The data is however useful for the basic calibration of catchment models and for identification of some individual storm or drought sequences. Increased hydrological data records will improve the confidence in the flow and statistical analysis undertaken, and develop a valuable record of Palau's water resources for future development and issues. It is well recognised that a minimum of 10 years of consistent and continuous data is needed for hydrological statistics to be derived, 20 years is better. EQPB have shown a high level of commitment to this data collection program and it is hopeful that by 2015 robust datasets will be accessible by a broad range of stakeholders, providing a sound platform on which more informed assessment of the water resources Integrated Water Resources Management and long term planning can be undertaken.

Kmekumer River, above waterfall

7 CATCHMENT PHOTOS

A sample of photographs is included to demonstrate some aspects of Palau's geography, rivers and aspects of operational hydrology undertaken to date.

EQPB Hydrologist servicing the Ngermeskang Hydrological Station

Diongradid, station refurbishment

EQPB Staff undertaking cableway gauging on the Tabecheding River

Tabecheding above compact road undertaking wading discharge measurement