

Navua River

1. COUNTRY INTRODUCTION

Description:

The Fiji Islands comprise of 322 islands, of which a third are inhabited. The two main islands of Viti Levu and Vanua Levu have significant urban areas, with the capital city of Suva located in the south east of the western main island of Viti Levu. The archipelago is comprised of volcanic peaks and uplifted oceanic sediments, as well as coral and sand islands.

Fiji is endowed with forest, mineral, fishery and water resources and is one of the more developed of the pacific island countries. Traditionally sugar exports and tourism have been the major source of foreign exchange with sugar representing one-third of industrial activity. Economic development has been restricted in recent times due to the ongoing issue of uncertain land ownership rights and recent political instability which has dampened investment and restricts development opportunities. Gold mining has made a valuable contribution to Fiji's economic development, with good prospects for additional development of mineral resources including copper and aluminium in the coming decades. In the last 10 years there has been a rapid development of mineral water abstraction and bottling, with bottled water exports to markets in North America.

Surface water is used as the main source of water supply for all cities and major towns on the larger, high islands of Fiji, as well as for industry and irrigation. Some small, low-lying islands and many villages rely almost exclusively on groundwater and rainwater harvesting.

Flooding regularly occurs throughout various parts of the country, where some larger towns including Nadi and Ba, and Labasa have developed in highly flood prone areas. These floods can cause loss of life and significant damage to property and infrastructure as well as disrupting economic activity and impacting on the lives of communities. Alteration to the floodplain for agriculture, logging, and the progressive deforestation for agriculture may cause flood peaking to become more extreme in the future.

Drought is also a regular occurrence and a serious concern, with limited storages. The 1998 drought, affected over half of the country, where no significant rainfall fell for more than seven months, and food was distributed by the government to 105,000 people. On small, low-lying islands water supplies are particularly susceptible to extended dry periods, and groundwater resources are vulnerable to over-abstraction and contamination from inappropriately located surface activities. Industrial pollution, urban drainage and sewage are cause for concern on large islands in the urban and peri urban areas.

It has been identified that 11% of the land is arable and used for cultivation while 5% is taken up by permanent crops, such as renewable forestry. The remaining 84% comprises of native



forests, grasslands, urban area and other nonarable land, (CIA World Fact book 2009).

The country's electricity supply is produced from a mix of hydropower schemes, diesel generation and other renewables. Recent data indicates that 59% of electricity was produced from renewable sources (2009, FEA), specifically hydropower including 1% solar and wind with the remainder 40% coming from diesel generation.

An estimated 70% of the population has access to treated reticulated water; however continuity of supply remains a problem, particularly during drier months.

Two catchments on the main island of Viti Levu supported by Pacific HYCOS are profiled here, the Rewa and the Navua River systems which have significance as two of the three largest rivers in Fiji. With the support of European Union funding, SOPAC has implemented hydrological monitoring and flood warning and forecasting systems in both catchments.

2. GEOGRAPHIC

The Fiji Islands are located about 4,450 km southwest of Honolulu and 1,770 km north of New Zealand. Of the 322 islands and 522 smaller islets making up the archipelago, about 106 are permanently inhabited. Viti Levu, the largest island, covers about 57 % of the nation's land area, and contains some 69 % of the population. Viti Levu hosts the two official cities (the capital Suva, and Lautoka), along with other major towns, such as Ba, Nasinu, and Nadi (the location of the international airport). Vanua Levu, 64 km to the north west of Viti Levu, covers just over 30 % of the land area and significantly less populated being home to only some 15 % of the population. Its main towns are Labasa and Savusavu. Both islands are mountainous, with volcanic peaks rising up to 1,300 m on Viti Levu, covered with tropical forests, especially on the eastern side, where heavy rains fall resulting in more dense tropical forest. Lowlands on the western portions of each of the main islands are sheltered by the mountains and have a wellmarked dry season favorable to crops such as sugarcane.

Other islands and island groups, which represent 12.5 % of the land area and house some 16 % of the population, include Taveuni southeast off Vanua Levu and Kadavu Island, south off Viti Levu (the third and fourth largest islands respectively). The Mamanuca Group (just off Nadi) and Yasawa Group (to the north of the Mamanucas), are popular tourist destinations. The Lomaiviti Group located to the east of Viti Levu, includes the island of Ovalau, and is home to Levuka, the former capital and the only major town on any of the smaller islands. The remote Lau Group is located in the Koro Sea to the east of Viti Levu and located near Tonga, from which it is separated by the Lakeba Passage.

Two outlying regions are Rotuma, 400 km to the north, and the uninhabited coral atoll and cay Ceva-i-Ra or Conway Reef, 450 km to the southwest of main Fiji Islands group. Culturally conservative Rotuma with its 2000 people on 44 sq km geographically belongs ethnically to Polynesia and enjoys relative autonomy as a Fijian dependency.

Map of Fiji Islands



Source: CIA World Factbook, 2011

Viti Levu, Geology and Land Use are shown below. The map of the main Island also shows the extent of the HYCOS study catchments of the Rewa River, Fiji's largest and the adjacent but much smaller Navua River.



Map of Viti Levu showing the Navua and Rewa catchments

Source: Google maps and SOPAC 2010

Geological map of the Viti Levu



Source: (http://www.mrd.gov.fj/gfiji/geology.html)

Land use map of the Island of Viti Levu



Source: MRD 1991

3. CLIMATIC

The Climate Service Division of the Fiji Meteorological Service located in Nadi is responsible for meeting Fiji's needs for climatological data and for promoting the effective use of this data for weather forecasting. It is the national repository for climatological data and is responsive to user enquiries for preparation and supply of data products including aviation and marine forecasting for the region. The Nadi - Tropical Cyclone Centre was officially designated by WMO in June 1995 as a Regional Specialised Meteorological Centre (RSMC) with activity specialization in tropical cyclones tasked to provide "first-level" information in tropical cyclones (i.e., basic information covering the tropical cyclones' present and forecast position, movement and intensity) in the South-West Pacific Ocean.

Fiji enjoys a tropical maritime climate without great extremes of heat or cold. Day-time sea breezes regularly blow across the country being generally light or moderate; strong winds are far less common and are most likely to occur in the period June to November when the trade winds are most persistent. However, tropical cyclones and depressions can cause high winds, especially from November to April. Due to the influence of the surrounding ocean the average annual temperatures change only about 2° to 4°C between the coolest months (July and August) and the warmest months (January to February). Around the coast, the average night-time temperatures can be as low as 18°C and the average day-time temperatures can be as high as 32°C. Past records, however, show extreme temperatures as low as 8°C and as high

as 39.4°C have been recorded in Fiji. Rainfall is highly variable and mainly orographic, with the main islands having pronounced dry and wet zones. Little climatic differentiation occurs on the smaller islands. Fiji experiences a distinct wet season often bringing cyclonic activity, sometimes with great severity (November to April) and a dry season for the remaining year, controlled largely by the north and south movements of the South Pacific Convergence Zone, the main rainfall producing system for the region, with much of the rain falling in heavy and brief local showers. Annual rainfall in the dry zones averages around 2,000mm, whereas in the wet zones, it ranges from 3,000mm around the coast to in excess of 5,000mm at the mountainous sites.

Flooding in Fiji is experienced annually. Periodically it has been very severe and is mostly associated with the passage of a tropical cyclone or depression that results in prolonged heavy rainfall. Low lying urban centers (Nadi, Navua, Rewa and Ba), on Viti Levu, are situated near the mouth of four of the main rivers and so are flood prone. Labasa in Vanua Levu is also regularly impacted by flooding. Localised flash flooding during the wet season (November to April) is quite common. Storm tides and heavy swells can cause flooding of low-lying coastal areas especially during the passing of a severe cyclone. Droughts in Fiji are are experienced periodically and can be severe especially on the outer islands. A strong ENSO, El Niño event is most likely to result in a major drought over the country, as happened during 1982/83 and 1997/98 El Niño years. However, even in a "normal year" the rainfall in the "dry zones" of the country can be so low and a few months of an extended dry period can cause a drought impact in some places. Source: Fiji Meteorological Service.



Rainfall distribution on the Island of Viti Levu



Monthly Climate Data

The climatic summaries in the attached tables, sourced from Fiji Meteorological Service, (FMS) and show the provisional monthly mean data for rainfall and temperature, calculated from at least 10 years of continuous records but less than the standard 30 years usually required. This demonstrates the variability of the readings available from FMS synoptic stations. Such stations have been located generally in coastal areas with little penetration into the higher and wetter remote areas of Fiji. Both Nadi and Nausori Airports are located close to sea level.

Nadi at Nadi Airport

Observation Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual	Period for the Mean
Mean Temperature (°C)	27.6	27.5	27.4	27.0	25.0	24.3	23.2	24.6	25.1	26.2	26.5	27.3	25.6	1971 - 2000
Mean Precipitation (mm)	299	302	324	163	78	62	46	58	77	103	138	159	1810	1971 - 2000

Nausori at Nausori Airport

Observation Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual	Period for the Mean
Mean Temperature (°C)	26.8	27.1	26.9	25.9	24.5	23.9	23.0	22.9	23.3	24.3	25.4	26.2	25.0#	1971 - 2000
Mean Precipitation (mm)	364.5	267.8	383.4	360.9	247.7	150.5	116.7	146.7	165.5	194.7	244.8	266.8	2909.8	1971 - 2000

Monasavu at Monasavu Dam (elevation 900m)

Observation Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual	Period for the Mean
Mean Temperature (°C)	22.3	22.6	22.3	21.3	19.8	19.1	18.3	18.5	19.1	19.9	20.9	21.8	20.5	1971 - 2000
Mean Precipitation (mm)	610.4	520.7	621.9	543.3	298.9	256.9	190	261.3	270.1	327.6	444.6	535.8	4881.6	1971 - 2000

The following graphs present the mean monthly rainfall for these rain gauges which clearly identify the positive rainfall gradient from Nadi in the west to the wetter eastern side of Viti Levu at Nausori Airport (20 km from the Capital City of Suva) and to the Monasavu Hydro Electric dam located in the Highlands.

Nadi at Nadi Airport, Monthly Mean Data



Nausori at Nausori Airport, Monthly Mean Data



Monasavu at Monasavu Dam, Monthly Mean Data





In recent years with the installation of automatic raingauges in Fiji, located in remote areas, the capacity to be able to measure accurate rainfall remotely and in many cases by telemetry, has expanded greatly. FMS is significantly expanding its remote telemetered network, with additional sites installed within the Nadi, Navua and Rewa River basins under SOPAC managed early flood warning system projects. In January 2009 a massive rainfall event, (due to system convergence and not a cyclone), was experienced, being bringing the Nadi River up to catastrophic flooding levels, reputably the largest flood in living memory which bought massive damages to property and infrastructure and loss of life.

Navua River

Upper catchment recording raingauges were inoperable at the time for the Nadi Catchment but the Tikituru raingauge located at the top of the Navua Catchment 60 km to the east, measured rainfall intensities not previously recorded in Fiji. The Tikituru raingauge, installed in 2007, measured a total of 1,280 mm over a three day period with the maximum intensity of 362 mm in a one hour period. Following this event, a calibration check was undertaken on this gauge and it was found to be within limits. The following table presents the 6 ranked maximum hourly rainfall values for this highly significant event.

Ranking	Tikituru rainfall intensity in mm/hour
1	362.0 at interval beginning 9-Jan-2009 05:40:00 hrs
2	177.0 at interval beginning 9-Jan-2009 03:10:00 hrs
3	122.0 at interval beginning 9-Jan-2009 09:10:00 hrs
4	81.0 at interval beginning 10-Jan-2009 05:10:00 hrs
5	58.0 at interval beginning 9-Jan-2009 20:10:00 hrs
6	46.5 at interval beginning 10-Jan-2009 06:10:00 hrs

Tabulation of rainfall extremes Tikituru raingauge January 2009

Though flooding was catastrophic in the Nadi River, severe flooding was also experienced in the Sigatoka, Navua and Rewa Rivers and in low lying areas.



Navua River at Nabukelevu, flood warning station





In addition to the FMS, rainfall data is also collected in Fiji by a number of other agencies;

- Water Authority of Fiji (WAF).
- Department of Land and Water Resource Management (LAWRM).
- Fiji Electricity Authority (FEA).
- Tourist resorts and private resource developers, (mining).

This data appears to be quite substantial but unfortunately it has not been possible to source and integrate this data into a National Database supported by all agencies and stakeholders.



4. WATER RESOURCES

4.1 General Description

The island nation of Fiji has among its natural and unique resources an abundance of freshwater on its larger islands where regular rainfalls ranging from 2,000mm to 6,000mm fall on the mountain catchments and into Fiji's diverse river systems. These river systems range from small mountain streams and steep torrents to that of very large mature rivers in the lowlands, meandering between flood plains and out to lagoon and ocean deltas generally sheltered by a fringing coral reef. These rivers generally assure good raw water resource security to Fiji's urban and peri-urban populations. However ageing infrastructure, limited maintenance leading to greater system losses, coupled with illegal taking of water and periodic extended dry periods can result in extended disruptions to service particularly in western provinces of Fiji.

The capital city of Suva draws its supply directly from surrounding streams, relying on system storage in small reservoirs to meet its demand. In the drier west of Viti Levu, Nadi has a significant storage reservoir in the mountains, the Vatura Dam, with some small hydro electric energy generation benefits, although demand is large, losses are significant and water disruptions are frequent. The Monasavu dam in the central highlands is Fiji's largest storage reservoir impounding 133 million cubic meters of water for Fiji's largest power station located 625 vertical meters below the reservoir at Wailoa which supplies 80 megawatts or up to 60% of the country's energy needs. This will shortly be supplemented by the Nadarivatu Hydro Electric Project at the head of the Sigatoka River which is currently under construction. Up to 41 megawatts of energy will be produced but this will be seasonal due to limited water storage. Fiji's potential for additional hydroelectric power generation on the larger islands is significant but is limited to mini and micro systems on the smaller islands with perennial streams. Likewise the potential for irrigated food production and commercial crops is very significant but remains

largely undeveloped to date. The high profile export commodity of Fiji bottled water industry is abstracted from groundwater sources located predominantly in the northern area of Viti Levu.

The larger rivers are generally monitored by hydrological stations, where flood flows commonly exceed several thousand cubic metres per second, especially in the Rewa, Fiji's largest river. Due to limited recurrent support for field operations and ongoing staff capacity issues accurate flood data in Fiji from Water Authority Fiji is limited.

Increasing pressure on catchments from expanding populations and other activities such as mining and logging has the potential for further catchment degradation which may compromise water quality with possible impacts on water supplies for major growth areas in the future. Pressures of tourism and resort development are also placing stress on supplies, particularly in the Nadi area, where already high water demands on an ageing supply system can result in reduced or disrupted services.

Smaller islands do not have high water security, many are reliant on small streams or springs which are reduced or may dry up completely during extended dry periods. In some periods of high stress, it has been necessary to use ocean barges to transport bulk water out to the communities.

Fiji can be considered in general a water rich country, with opportunities for developing a viable irrigation industry and increased potential for development of renewable energy production.

Improvements in water resource management will require a coordinated effort across many sectors including: improvements in watershed management; reductions in deforestation rates; raising public awareness of wise water use and management; controls over agricultural activities and improvements in onsite waste disposal of both domestic and industrial wastewater.



4.2 Major Floods and Droughts

Large-scale flooding in Fiji is often associated with the passage of a tropical cyclone or depression resulting in prolonged heavy rainfall. Urban centres of Nadi, Lautoka, Ba, and Labasa, situated near the mouths of significant rivers are most affected. Localised flash flooding during the wet season (November to April) is quite common. Storm tides and heavy swells contribute to the flooding of low-lying coastal areas during the passage of a severe cyclone. A comprehensive paper (McGree, Yeo & Devi; Flooding in the Fiji Islands between 1840 and 2009, October 2010), describes in detail 50 significant floods in the 13 major river systems observed during this period. This would indicate that approximately every 3 years, a notable and damaging flood can be expected in any one or more of these river systems. In January 2009, 7 of these rivers flooded simultaneously, whilst not unique, the 2009 flood caused significant damage to domestic and commercial properties as well as agriculture and infrastructure. Reduced hydrological capacity, poorly maintained stations, and limited resources within the national hydrological services of Fiji at the time precluded any actual flood measurements, or determining actual system discharge at its peak. The affect of ocean tides on the river contributed to over bank condition for many hours, resulting in significant inundation within the Nadi town area.

Upper Rewa River, culvert crossing

Fiji's annual dry season, May to October, results in subdued rainfall, which even during "normal" conditions can compromise the availability of water for hydro electric generation, or those towns and villages with limited storage and increasing populations. More extended droughts which are closely correlated to the ENSO (El Niño-Southern Oscillation) phenomenon, El Niño event, can often result in significant below average rainfall for Fiji, and can have a more severe effect on smaller water supplies at the village and small island scale, and hydro electric power generation, which in turn places greater demand on diesel generators and increases the cost of for producing power.

4.3 Socio-economic characteristics

The main river and the tributaries that form the Rewa catchment system run through the five provinces of Naitasiri, Tailevu, Namosi, Serua and Rewa which form part of the Central Division. According to the 2007 Census, the combined population, including the coastal areas, totals 346,703, just over 41% of the country's population, with the Central Division having the highest annual growth rate of population. The majority of the land in this Division is classified as "native land", owned by the indigenous people and divided among members of the landowning units according to the traditional social hierarchical system. Some land, especially in the Tailevu province, is leased out for agricultural activities such as cattle farming.



The Rewa catchment is located on the windward side of Viti Levu and enjoys high rainfall for much of the year. The forest ecosystem supports a high biodiversity of flora and fauna which in turn provides the local communities with abundant natural resources. Located close to the Rewa River and delta is the Nausori Airport, significant for flights to Nadi and outer islands and currently for limited international flights to Tuvalu, Tonga and New Zealand. On occasions the airport runway and terminal facility has been inundated by flood waters as has the town of Nausori. Nausori is an important town for commerce, agriculture and light industry.

The Navua River catchment is located within the two provinces of Serua and Namosi. The 2007 Census identifies a combined population of 25,147 people with the upper reaches of the Navua River existing as traditional Fijian villages being presided over by a chief or headman and other village elders. The river and the surrounding forest plays an important role as a primary food source for the villages. Subsistence cultivation of root crops and other vegetables is common and any surplus crops are sold in the market for extra income. Livestock-raising (such as cows, pigs and chicken) also occurs on a small scale. Logging provides the greatest influx of employment opportunities.

The Upper Navua Conservation Area is a designated protected conservation area, where there are a number of historical sites including burial caves and abandoned villages which are of high cultural significance to the people. Eco tourism is a permitted activity which provides valuable income in the form of land access royalties, guides, porters and trail maintenance to the local communities. The local communities hold intimate traditional knowledge of the river, its ecology, its biodiversity and the economic, social and ecological value of the river and its resources. This knowledge and the village social structure provides a solid foundation for the longterm preservation and sustainable use of the river and near-river resources within the catchment.

5. HYDROLOGICAL INFORMATION

Hydrological monitoring and assessment commenced in Fiji in the early 1970's in response to the need for hydrological data for the design of the Monasavu Hydro Electric Scheme. The network was established under development aid assistance and capacity was developed within suitable government departmental staff. Training was undertaken on periodic country visits by various specialists over the life of the project which was completed in 1984. Hydrological activities during this period were the responsibility of the Public Works Department (PWD) and additional stations were installed to monitor major rivers and water supply schemes.

As of January 2010, the hydrology group was transferred from the Public Works Department, to the Water Authority of Fij (WAF), a commercial entity setup by the Government to deliver potable water to the urban areas of Fiji. Water Authority of Fiji now have the responsibility and mandate for hydrological monitoring and managing Fiji's flood forecasting systems with a cooperation arrangement with FMS in regards of data sharing and in times of flooding.

Pacific HYCOS has provided considerable assistance to both WAF and its predecessor PWD, as well as FMS, supporting the rescue of national hydrological records and datasets into a national database and archive, as well as training and installing river and flood stations in both the Rewa and Navua catchments. Unfortunately considerable more investment of time and resources is required to complete this task. The datasets include various versions of the National database, as well as considerable chart and tabulated data that needs to be digitised and imported to the national database to allow it be more accessible. The national dataset (WAF stations) assembled by Pacific HYCOS shows that 45 river flow stations and 70 raingauges, (many of these raingauges being automatic), are in operation. A review of the data has identified many gaps in the record, with sometimes up to 40 or 50% of the data missing or corrupted, which restricts its use and application.



Additionally few discharge measurements are available in which to establish rating curves.

Government and donor support, technical assistance and training opportunities since the Monasavu Project however has been extremely limited for the National Hydrological Services, and they have struggled to maintain a field program to collect the basic datasets and archive the data successfully. The database requires a comprehensive review which would include assembling, sorting, digitising, reprocessing and archiving all old records and charts.

5.1 Hydrological Stations

Water Authority of Fiji maintains a total of 88 operating hydrological and rainfall stations throughout Fiji, 64 rainfall stations and 22 water level stations, (A. Kumar pers comm. 2011). This document will restrict its presentation to the Pacific HYCOS pilot catchments of the Rewa and Navua. Data from the recently installed and upgraded sites in these pilot catchments has provided 4 years of good water level and rainfall data for the Navua catchment, and close to 3 years for the Rewa catchment, since 2007 and 2008 respectively. However very few discharge measurements have been undertaken and rating curves are still to be developed, which currently limits the application of the datasets. Many sites are relatively remote necessitating 4WD and or boat access, lack of adequate transport support

Navua River at Navua Town

for field operations is an ongoing issue, and reduces the field teams ability to undertake its field operations and collect necessary discharge measurements. As indicated earlier data held on the WAF TIDEDA hydrological database has in general been quite poor, where rating curves are limited due to a lack of substantial discharge measurements for medium to high flows. The range of discharge measurements undertaken at select sites has been presented in a table along with the maximum level recorded at the respective station to give an indication of the range of discharge data collected.

5.2 Study Catchment Introduction

Pacific HYCOS in discussion with the PWD Hydrology Unit elected to support the Rewa River catchment, Fiji's largest river system, for its pilot basin demonstration. The Rewa stations were initially installed around 1970 and upgraded to telemetry for Flood Warning System (FWS) in 1985 under development assistance from New Zealand Aid. At the time of HYCOS implementation, this system was found to be in significant disrepair and inadequate after 20 years of good service. During this time basic warnings were made but the flood model was in large uncalibrated as flood discharge measurements could not be undertaken. Pacific HYCOS focused on refurbishing the stations within the Rewa catchment, revitalising the Flood Warning System (FWS) and capacity development.





The Navua FWS was installed under European Development Funding (EDF8) in 2007 with SOPAC support. Pacific HYCOS continued to provide support to the NHS with field operations, training and resolving the difficult communication issues. Rating curves have yet to be developed for the Navua and flow data cannot be presented.

5.2.1 Measured Hydrological data Catchment 1 – Rewa River

The Rewa River is the largest fluvial system in Fiji. The basin covers 2,900 km², or approximately one third of the Island of Viti Levu. The western portion of the Rewa watershed is located on the Nadrau Plateau where the maximum elevation is 1,360 m at Mount Victoria (Tomanivi) which is also Fiji's highest mountain. Most of the north and east of the Rewa basin falls within the East Highland, characterized by hills 300-600 m in elevation. River channels are steep in their upper reaches but decrease abruptly downstream in the alluvial channels where gauging stations are located. The northern part of the basin is composed mainly of relatively young basaltic rocks and the southern part of older sedimentary and some plutonic rocks. Dense tropical rainforest is the natural vegetation, but on the floodplains this is replaced by grazing pasture and subsistence farming (Terry & Kostaschuk). The suspended sediment load in the Rewa

Navua River below Kings Highway bridge

is very high, running turbid for much of the year especially in the lower reaches, turbidity is currently not measured. The upper Waidina Catchment, a sub catchment of the Rewa, is currently being explored as a mineral prospect for copper and gold mining by a consortium of companies under the Namosi Joint Venture. Should this prospect firm up to development and production, the mine will be among the worlds largest open pit operation with consequent environment and water resource quality issues.

The main Rewa River is approximately 90 km long and the river discharges out into the Pacific Ocean via the Rewa River Delta into Laucala Bay very close to Suva.

Rainfall across the catchment is orographic and therefore highly variable. There are a total of 117 rainfall stations listed, that collect rainfall as part of Fiji Meteorological Service's monitoring network in the Rewa River catchment. Water Authority Fiji currently operates and maintains 6 of these rainfall stations and 5 operational water level stations. Of the remaining 111 rainfall stations a large number of these rainfall stations are closed and the catchment is currently left with 64 stations in operation, including the 6 WAF rainfall stations. The following map shows the HYCOS assisted stations in the Rewa Catchment.



Map of Streamflow and rainfall Observation Stations within the Rewa Catchment

The Pacific HYCOS supported stations are identified below with relevant information.

No	Station and number	Location and coordinates	Catchment area A (km²)	Observation period	Observations
1	Wainibuka 214401	Nayavu 17° 41' 02" S, 178° 21' 45" E	706	1978 open	WL, Q <u>,</u> RF
2	Wainimala 223300	Nairukuruku 17° 48' 30" S, 178° 16' 35" E	790	1972 open	WL, Q <u>,</u> RF
3	Waidina 234100	Nabukaluka 17° 58' 55" S, 178° 19' 20" E	253	1978 open	WL, Q, RF
4	Waimanu 275001	Pumping Station 18° 02' 05" S, 178° 27' 10" E	165	1971 open	WL, Q, RF
5	Rewa 264200	Navolau 17° 52' 25" S, 178° 23' 30" E	1961	1963 open	WL, Q, RF
6	Rewa 266035	Nausori 18° 01' 47" S, 178° 32' 10" E	2895	1985 open	WL, Q, RF

Details on the Rewa River main tributaries.

Source: WAF WL = Waterlevel, Q = discharge flow, RF = Rainfall



Wailoa Hydroelectric Power Plant, upper Rewa River

The attached graph on the catchment slopes clearly shows the very steep nature of the upper catchments, followed by a rapid transition to the mature channel and flood plain slopes to the ocean discharge.



Rewa Longitudinal Profile; Main channel and tributary slope of the Rewa River

This following graph shows long term monthly rainfall at the rainfall station at the Namosi Secondary School from 1979 – 2007. This station is located inland at approximately 300m above MSL in the headwaters of the Waidina River and is operated by WAF. It represents probably one of the longest consistent rainfall records in the Upper Rewa Catchment, the seasonality is distinct as is the high total mean annual rainfall of 3485 mm. The Namosi site is also close to the head of the adjacent Navua River Catchment.

FIJI



Long Term Variation of Monthly Precipitation at Namosi Secondary School

The Rewa River at Navolau, a major station on the river, has several rating curves filed, the basis of the extrapolation is unknown and the rating has not been updated for the last 20 years. In this flow station example for the Rewa, rated discharge data is shown as an indication on the flood discharge of this significant river. It can be seen that flood discharges of 6,000 m³/s are not uncommon and a maximum in excess of 8,000 m³/s has been measured (rated flow). The frequent gaps in the data are quite evident.



Long term variation of discharge Rewa River at Navolau Station No. 264200



Annual pattern of discharge at Navolau Station No. 264200

Discharge rating for Rewa River at Navolau, Station No. 264200, note the lack of supporting discharge measurements above 8.5 meters, the basis of the extrapolation is unknown.





Navua River

Discharge statistics are important for all hydrological stations and are an important data product used in modeling, infrastructure design, environmental considerations and flood warning. The following example, a Pextreme tabulates annual minimum and maximum discharge with a summary of the stations discharge statistics for its period of record.



Source is FJ_Final.mtd Site 264200 Rewa At Navolau From 6-Oct-1970 01:00:00 to 7-Dec-2010 08:00:00 Interval = 0 Flow Cumecs

Year	Mean	Coeff. of Var.	Minimum	Date	Maximum	Date				
*1970	275.47	1.21	24.093	11-Oct-1970 01:00	2247.0	18-Dec-1970 04:00				
*1971	148.03	1.31	15.283	30-Jun-1971 08:00	1482.1	21-Dec-1971 11:00				
*1972	210.65	2.23	29.394	21-Aug-1972 18:00	8101.8	25-Oct-1972 04:00				
*1973	332.84	1.60	94.696	18-Dec-1973 21:00	5480.9	5-Mar-1973 14:00				
*1974	208.46	1.64	13.867	27-Jun-1974 13:00	3283.3	26-Apr-1974 07:00				
1975				No values for this year						
1976				No values for this year						
*1977	47.262	1.27	9.2830	19-Sep-1977 24:00	906.53	1-Oct-1977 09:00				
*1978	148.67	1.74	5.6840	11-Sep-1978 24:00	2425.4	17-Mar-1978 03:00				
*1979	138.05	1.78	21.562	8-Sep-1979 01:00	2558.9	11-Jan-1979 12:00				
*1980	181.12	2.36	15.360	7-Aug-1980 11:00	5077.2	5-Apr-1980 02:00				
1981	116.13	1.46	14.716	1-Jun-1981 01:00	1794.7	15-Jan-1981 11:00				
*1982	161.28	1.92	15.822	20-Oct-1982 10:00	3427.6	31-Jan-1982 11:00				
*1983	318.96	2.02	42.943	30-Apr-1983 07:00	4867.7	2-Mar-1983 13:00				
*1984	168.41	1.77	30.756	8-Nov-1984 09:00	3263.8	18-Mar-1984 21:00				
*1985	211.62	2.26	45.365	28-Sep-1985 01:00	4701.6	6-Mar-1985 24:00				
*1986	359.89	2.21	44.457	15-Aug-1986 13:00	5607.0	19-Apr-1986 11:00				
*1987	226.47	1.21	65.633	21-Jan-1987 22:00	2400.4	25-Dec-1987 04:00				
*1988	222.73	1.24	67.679	1-Sep-1988 01:00	2498.3	24-Dec-1988 21:00				
*1989	195.44	0.91	45.365	30-Jul-1989 20:00	1355.4	12-Feb-1989 11:00				
*1990	214.30	1.51	63.269	19-Dec-1990 20:00	3342.4	23-Mar-1990 04:00				
*1991	200.91	1.35	24.613	30-Jun-1991 23:00	2589.0	10-Jan-1991 19:00				
*1992	210.70	2.41	17.447	29-Sep-1992 20:00	3701.9	11-Dec-1992 14:30				
*1993	192.85	2.76	27.862	11-Oct-1993 01:00	7144.5	3-Jan-1993 13:00				
*1994	122.01	1.30	45.106	28-Dec-1994 21:30	1222.5	25-Mar-1994 08:00				
*1995	193.36	1.64	27.192	30-Oct-1995 10:15	3212.6	15-Jan-1995 05:15				
*1996	No mean		69.861	31-Dec-1995 24:00	69.861	31-Dec-1995 24:00				
*1997	254.75	2.05	37.382	8-Oct-1997 04:45	4526.9	5-Mar-1997 16:32				
1998	88.016	1.33 -5.	.60000E-02	9-Sep-1998 16:00	1401.8	8-Jan-1998 19:15				
*1999	243.00	1.17	56.265	30-Jul-1999 09:30	2538.9	20-Jan-1999 02:45				
*2000	199.97	1.03	30.080	10-Aug-2000 07:30	1650.4	23-Aug-2000 20:45				
*2001	152.62	1.19	38.780	4-Jan-2001 02:30	2788.4	23-Oct-2001 10:00				
*2002	119.03	0.87	44.422	15-Dec-2002 07:45	923.61	21-Nov-2002 05:45				
2003				No values for this year						
*2004	247.67	2.44	37.753	29-May-2004 23:45	4563.9	9-Apr-2004 05:45				
*2005	83.618	1.66	29.365	22-Dec-2005 01:00	2931.1	1-Jun-2005 22:00				
*2006	135.80	0.71	29.365	26-Jan-2006 20:15	242.46	15-Feb-2006 11:00				
2007				No values for this year						
*2008	235.74	0.30	150.44	7-Dec-2008 17:40	468.28	12-Dec-2008 16:20				
2009	270.14	2.02	85.212	29-Aug-2009 23:20	6453.9	11-Jan-2009 12:40				
*2010	256.81	1.40	68.749	5-Oct-2010 23:30	4325.5	1-Mar-2010 15:50				

Average Annual Minimum 33.291 Maximum 3216.8 (complete yrs) **' denotes years with gaps in the data or incomplete years

Coeff. of Var. = sd/mean

 Minimum is
 -5.600000E-02 at 9-Sep-1998 16:00:00

 Maximum is
 8101.76 at 25-Oct-1972 04:00:00

 Mean is
 187.738

 Std. Dev. is
 360.676

 Coeff. of Var. is
 1.92

The statistics tabulated above demonstrate the annual minimum and maximum discharge and discharge statistics for the Rewa River at Navolau. The data is somewhat complete for Fiji, but gaps are still evident and are the result of the failure of instrumentation since 1985, with a telemetry system failure in 2003 and 2007. A * denotes missing data in that particular year and it should be noted that all years have some period of missing data. Rating curves were developed in the early years of operation with 18 curves being developed since 1978 when good frequencies of discharge measurements were undertaken. The last filed rating curve is in 1991 and 50% of the rated data is based on this curve. The highest gauged discharge was 2,168 m³/s with the highest rated flow being 8,101 m³/s measured in 1970. Only 46 discharge measurements have been undertaken since 1991 with only 13 being done in the last 10 years and at low flows only. Most of the total 173 discharge measurements undertaken were undertaken pre 1991. Regular discharge measurements are required to provide confidence in flow data determination.

The flood in December 2009 brought on by Cyclone Mick resulted in a significant flood (rated not measured) of 6,300 m³/s. The attached plot shows the 3 hourly rainfall plotted with discharge, the rainfall does not truly reflect the flood as it is from the flow station and not from the upper catchment where rainfalls were most probably much higher.



Rewa River at Novolau Discharge and rainfall December 2009 flood.

The table appended below shows the discharge statistics for the Rewa River discharge stations. Most were undertaken over 20 years ago and many at low flows. For this reason, the rating curves most probably do not reflect the current level and discharge relationships for any flow range.





Waidalice River

	Site Names Station	Minimum gauged		Date	Maxi gau	mum Iged	Date	Max level	Date	Total No of discharge	
Number	Number	Level m	Flow m ³ /s	Date	Level m	Flow m³/s	Date	recorded (m)	Date	measure- ments	
	Wainibuka at Nayavu 214401	0.95	6.025	22/09/92	5.250	412	9/11083	19.82	11/01/09	226	
	Wainimala at Nairukuruku 223300	0.29	8.976	31/12/71	5.58	1672	30/01/72	14.50	18/03/72	569	
	Rewa at Navolau 264200	-0.16	9.829	28/03/81	8.42	2168	16/03/78	18.36	3/01/93	173	
	Waidina at Nabukaluka 234100	0.33	4.400	24/06/99	1.60	768	25/08/99	10.27	15/03/06	33	
	Waimanu at Pump Station 275001	-0.31	4.500	11/06/69	5.560	238	1/04/87	10.48	17/04/86	716	
	Rewa at Nausori 266035	Tidal river system, no rating developed									

Maximum and Minimum Discharge Statistics and Water Level.

Table showing extremes of discharge statistics and water level at monitoring stations in the Rewa catchment



Catchment 2 – Navua River

The Navua catchment is located in south eastern Viti Levu. With a drainage area of 1,070 km², this is Fiji's third largest river system with a river length of 91 km draining out into the Pacific Ocean at the Drakeilobi Bay within the Beqa Lagoon. At the highest point, the catchment is 1,084 m above sea level. Average annual rainfall in Navua town is 3,500 mm (Mataki, et al, 2006). The geology of the catchment comprises of Navua Mudstone containing well defined mudstone and fine-grained sandstone, minor limestone and basal conglomerate (Viti Levu Sheet 18 MRD).

The settlement of Navua has an estimated population to be around 7,000 persons, Mataki (2006). Commercial rice farming in the floodplains of the Navua River used to be an important agricultural activity until around 1990 when this was no longer profitable due to the import of cheaper rice from abroad and flood damage to the water off take, and irrigation channel system. Current agricultural activities are limited to small-scale commercial and subsistence farming of vegetables and cash crops as well as cattle and goat grazing. There is also significant logging of mahogany in the upper catchment. Mining of river gravel in the Navua River gorge where it exits onto the flood plain is also significant where it is causing major channel degradation. The Upper Navua Gorge is an area of high ecological significance and has been designated a conservation area to protect it from logging, mineral explorations and other ecologically damaging land use activities. The river is a source of tourism income with cultural river and village tours and river rafting being established. The river provides an important transportation route in an area of very few roads.

A flood warning system was installed in the Navua River in 2007 under European Development Fund EDF8 for providing advanced warning for the communities living on the flood plain and Navua town. This involved an upgrade of the Nakavu discharge station at the gorge, the installation of two new up stream hydrological stations and three additional raingauges.

There are a total of 6 rainfall stations in the Navua River catchment that are maintained by the Water Authority Fiji, WAF. The only climate station in the Navua catchment is found in Tokotoko which also records other parameters such as atmospheric temperature and evaporation. There are no other synoptic stations in the catchment.





Map of Streamflow and rainfall Observation Stations within the Navua Catchment.

List of Hydrological and Rainfall Observation Stations

No	Station and number	Location and coordinates	Catchment area A (km²)	Observation period	Observations	
1	Cabe 1871710	18° 07' 09"S, 177° 42' 59" E	na	2007 open	RF	
2	Wainimakutu 1789010	17° 58' 25"S, 178° 05' 33" E	na	2007 open	RF	
3	Tikituru 1870915	18° 00' 00"S, 177° 54' 22" E	na	2007 open	RF	
4	Navua 311801	Nakavu S 18°11'30"S,178°06'06" E	1,016	1971 – present	WL, Q, RF	
5	Navua 312703	Sabata 18°06'59" S, 178°04'16" E	963	2007 – present	WL, Q, RF	
6	Navua 310704	Nabukelevu 18°07'31" S, 177°57'57" E	375	2007 – present	WL, Q, RF	

WL = Waterlevel, Q = discharge flow, RF = Rainfall, na not applicable

The attached graph on the catchment slopes clearly shows the steep nature of the upper catchments, followed by a rapid transition to the flood plain slopes to the ocean discharge.



Longitudinal profile of the Navua River main channel and tributaries

The table appended below shows the discharge statistics for these stations. Whilst a significant number of measurements have been done at Nakavu, only 20 measurements are listed as being done over the past 10 years and none at high flows. The most recent rating curve developed in 1998 does not represent the current level discharge relationship.

Site Names	Minimum gauged		Date	Maximum gauged		Date	Max level	Date	Total No of discharge		
	Level m	Flow m ³ /s	Date	Level m	Flow m³/s	Date	recorded (m)	Date	measure- ments		
Navua at Nakavu	0.38	9.51	31/12/02	3.78	580	20/03/69	12.01	4/04/80	173		
Navua at Sabata		No discharge measurements or rating curve listed on the database									
Navua at Nabukelevu		No discharge measurements or rating curve listed on the database									

Navua River sites, Maximum and Minimum Discharge Statistics and Water Level.

Navua River sites, Maximum and Minimum Discharge Statistics and Water Level



Gravel extraction - Navua river

There is concern that the 1998 rating curve, the last filed, for a water level of 11 meters shows a rated discharge of 22,576m³/s which would appear hydrologically impossible for this catchment and exceeds the rated discharge of the much larger Rewa Catchment. The maximum rated discharge of 30,044 m³/s was estimated in April 1980. For these reasons discharge data is not presented for the Navua River and a full re-evaluation of the data is essential. The attached rating curve shows an absence of supporting discharge measurements above 4 meters with two distinct sets of curves being evident with significant discharge differences evident.



Navua River at Nakavu, discharge rating curve Station No. 311801

The Navua at Nakavu station was installed in 1971 with relatively good data collected for many years until the mid 1980's when more gaps are evident at an increasing frequency in the data. It can be noted since 2000 the effect of gravel extraction at this site, which has reduced measured water levels each year, now to below the zero level on the gauge. The site is important for flood warning purposes and future water projects and there are no realistic options for moving it up or downstream. Use of the data is limited to measuring flood levels only and this extends to much of the historic data also.



Navua at Nakavu, water level hydrograph Station No. 311801

6. COMMENT

In general, Fiji has poor and fragmented records, with few discharge measurements undertaken in the last decade, especially at medium and high flows for the larger rivers. There is significant uncertainty in the application of any rating curves which have been developed for current water level data due to the lack of recent gaugings particularly at higher flows, despite Fiji commencing hydrological monitoring over 40 years ago.

The data that is available is useful for the basic calibration of catchment models and for identification of some individual storm or drought sequences only. In many cases, important storm and extreme events have been missed. A minimum of 10 years of consistent and continuous data is needed for hydrological statistics to be derived and a review of the data has shown this to be lacking.

Confidence in the datasets which are accessible can assist government and stakeholders alike

to make a more informed assessment on the development and sustainability options of the nation's water resources. In particular the need for data for disaster risk management and mitigation in regards to large floods and droughts.

However there has been little in the way of formal training programs developed or made accessible to the Hydrology Unit staff either within PWD or WAF since the Monasavu Dam Project, unsurprisingly there are no professional hydrologists within WAF or PWD. As a result, and without considerable investment in its staff and their operations, hydrology in Fiji will struggle to advance any further than past its current field capabilities. Without some form of sustained investment to build capacity and leadership, ideally through focussed mentorship, demanding a minimum standard of professionalism, the application of the data will be limited and the quality assurance and overall confidence in the datasets themselves will continue to be undermined.



7. PHOTOGRAPHS



Flooding in the lower Rewa River September 2005



Hydrological monitoring site for Rewa River at Navolau (housing station is upbill)



Navua residents watch Navua River flood waters from the main highway bridge in January 2009 (Fiji Sun Online 14/01/09)



Disaster Management Committee visit to the Navua Flood Forecasting station at Sabata, Navua Catchment



Tikituru raingauge at the head of the Navua catchment, this gauge measured 360 mm in a one hour period in January 2009 during the Nadi Floods.



Undertaking river current meter flow measurement from a boat on the Navua River at Sabata.