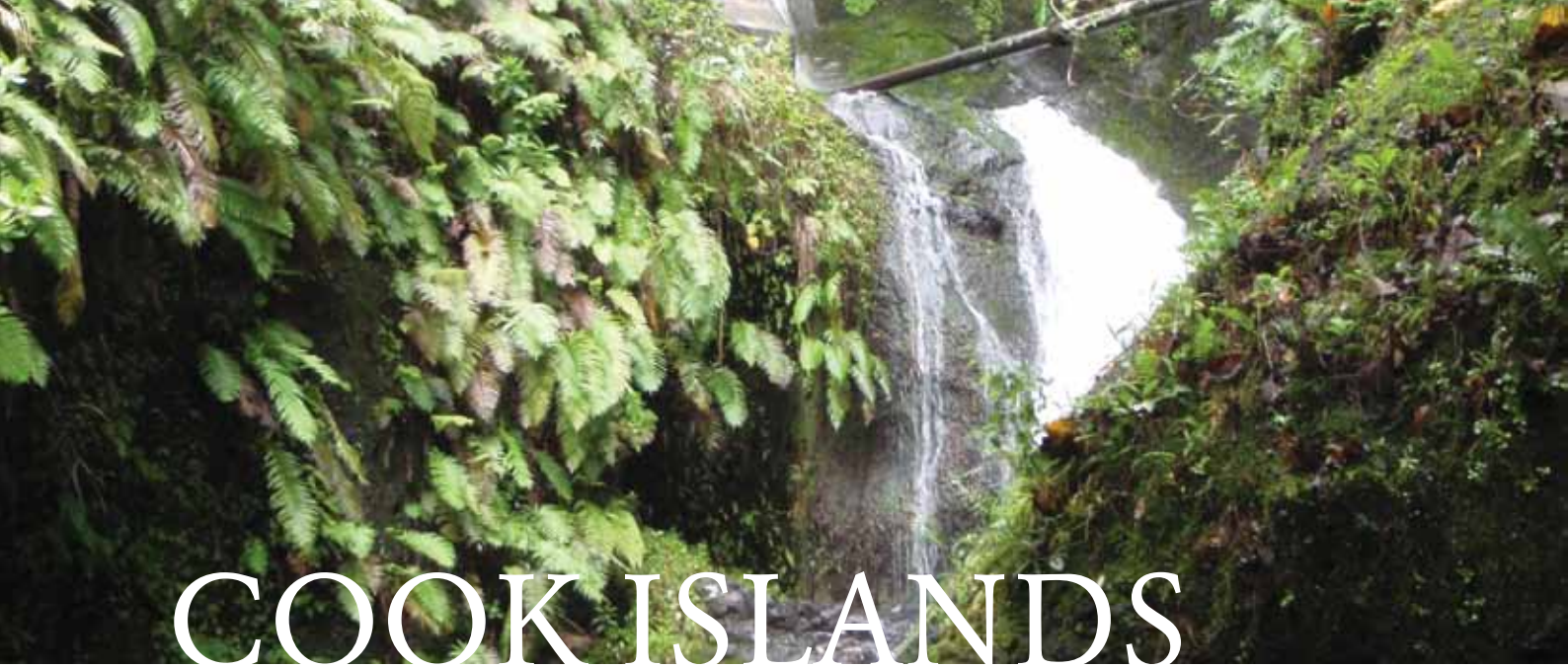


COOK ISLANDS

Wigmore's (Papua) Waterfall, Rarotonga

1. COUNTRY INTRODUCTION

Description:

The Cook Islands comprise of 15 widely dispersed islands, the Southern Group, comprising of volcanic islands (including the main island of Rarotonga) and the Northern Group comprising of coral atolls. The 2006 census data from the Statistics Office for the Cook Islands indicates a total population of 19,342, where 72% of this total population was found on Rarotonga.

Economy:

The key economic sectors include agriculture and fisheries 12%, services including tourism 78%, with industry including (black pearls, offshore banking 10%, (CIA World Factbook 2011). Like many other South Pacific island nations, the Cook Islands' economic development is hindered by the isolation of the country from foreign markets, the limited size of domestic markets, lack of natural resources, periodic devastation from natural disasters, and inadequate infrastructure. Agriculture, employing more than one-quarter of the working population, provides the economic base with major exports made up of copra and citrus fruit. Tourism accounts for an estimated 55% of the working population. Black pearls are the Cook Islands' leading export. Manufacturing activities are limited to fruit processing, clothing, and handicrafts. Trade deficits are offset by remittances from emigrants and by foreign aid overwhelmingly from New Zealand, (CIA World Factbook 2011).

Water Availability:

Surface water streams exist on the volcanic islands of the Southern Group (including Rarotonga), with groundwater and rainwater harvesting found on the coral atolls of the Northern Group. Bottled water is widely used and generally is imported. Water tankers have been used in periods of drought to transport potable water to resorts and outlying islands.

Island Vulnerability:

Droughts are of concern particularly for the smaller islands with no surface water and limited storage. Simultaneous increases in rainfall in the southern Cook Islands and reduced rainfall in the Northern Cook Islands occur during La Niña events. Cyclones are associated with La Niña events and are periodically experienced with coastal flooding when accompanied with storm surges. Aquifer saline intrusion is reported in outer islands where groundwater is utilised. Rarotonga is provided with free reticulated water and subsequently experiences high water demand. Impacts to water quality from agriculture practices including piggeries, and poorly functioning septic tanks are a major concern. Development including commercial and tourist properties on Rarotonga has lead to increased sediment and nutrient loadings entering the lagoon system, causing damage to the corals and the lagoon water quality.

Power generation:

There is no use of renewable electricity production, and due to the "flashy" nature of the streams, low baseflow, and currently limited storage, the potential for hydroelectric power generation would appear to be limited.

Health:

The World Health Organisation (WHO) reports that the standard of health in the Cook Islands is high. The infant mortality rate was 28.6 per 1000 live births in 2005. However the water supplies in Rarotonga and the outer islands are neither properly filtered nor treated and are at risk of water borne diseases. The main water related diseases are diarrhoea (835 cases in 2003) and dengue fever. A water supply and sanitation improvement programme, with the building of flush toilets in all schools and health centres on the outer islands is understood to have reduced the occurrence of infectious diseases.

Environment and Tourism:

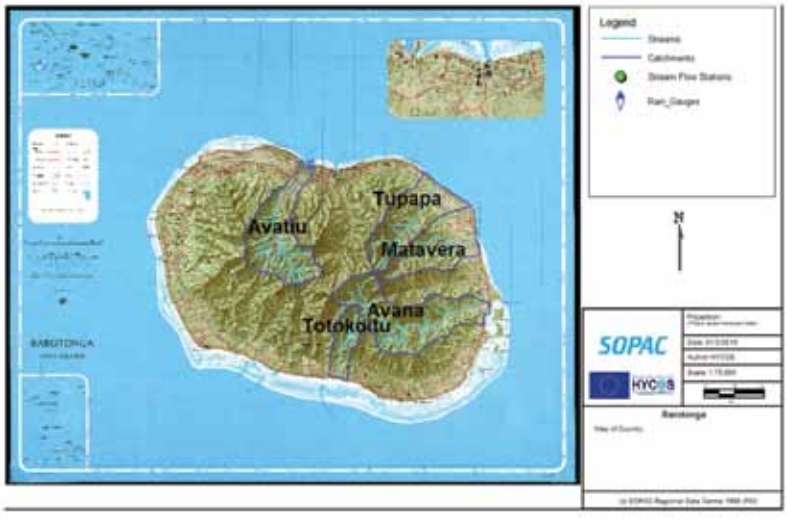
The Cook Islands economy is largely dependent on tourism, the major attraction being the clean and clear lagoon waters. The lagoon-reef systems are also important food sources for Cook Islanders and are used commercially for black pearl production on Manihiki and Penrhyn islands. Lagoon eutrophication due to anthropogenic impacts in Rarotonga is a major issue which faces the Cook Islands. Several reserves and sanctuaries have been created for habitat protection and biodiversity reasons within the Cook Islands. Suwarrow Atoll, in the Northern Cook Island group, was declared a National Park in 1978. It is a breeding ground for rare species of turtles and crabs and it is an important sea-bird breeding site not only for the Cook Islands but for the region and the world.

2. GEOGRAPHIC

The 15 islands that are the nation of the Cook Islands encompass a land area of just 241 sq km and are spread out over 2.2 million square kilometres of ocean in the South Pacific, in latitudes from 90S to 210S and 1590W and 1640W. The southern Cook Islands group comprises of nine "high" islands mainly of volcanic origin, although some are virtually atolls. The majority of the population lives in the southern group on the island of Rarotonga which is by far the largest island, densely forested apart from the coastal fringe, largely circular and rising to 652 metres on Mt Te Manga. The northern Cook Islands group comprises of six true atolls, most of which are unpopulated.

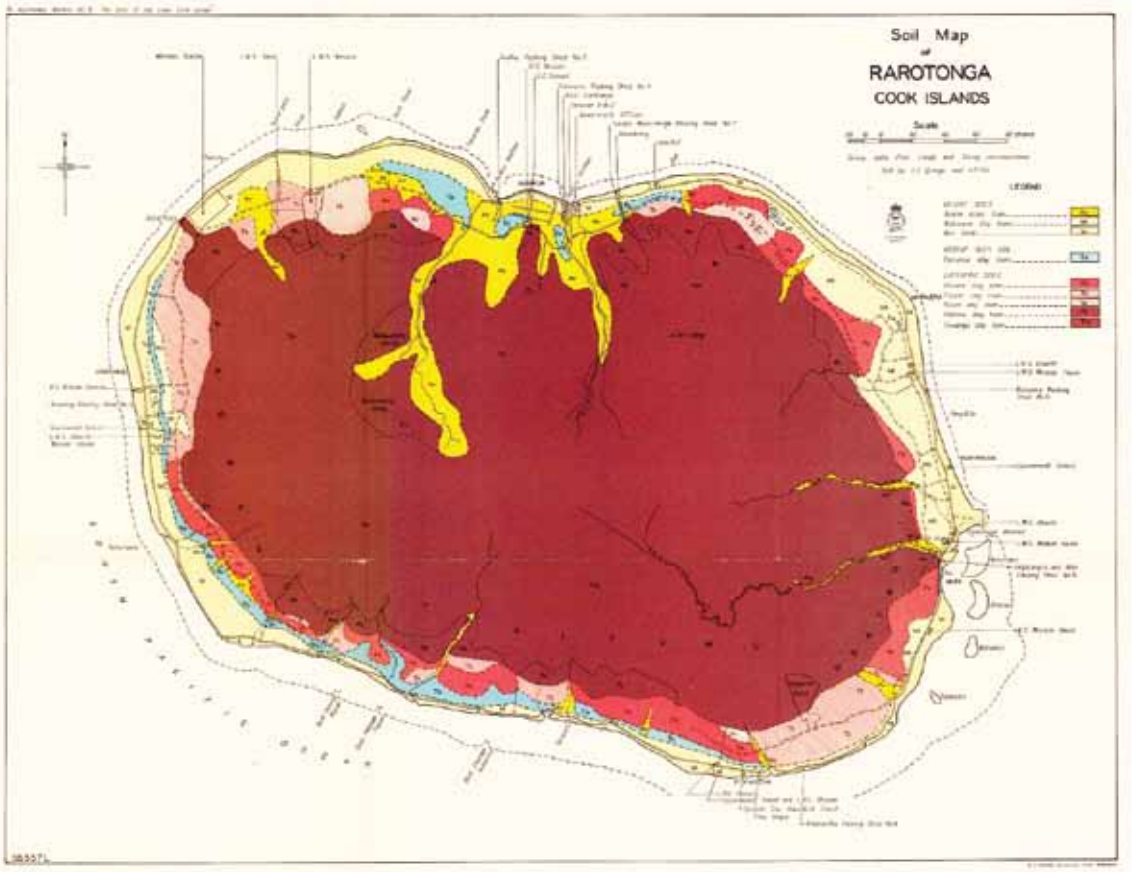
Cook Islands

Map of Rarotonga showing the major water catchments, SOPAC



Source: CIA World Factbook, 2011.

Soil Map of Rarotonga



http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/asia/lists/coc.htm

3. CLIMATIC

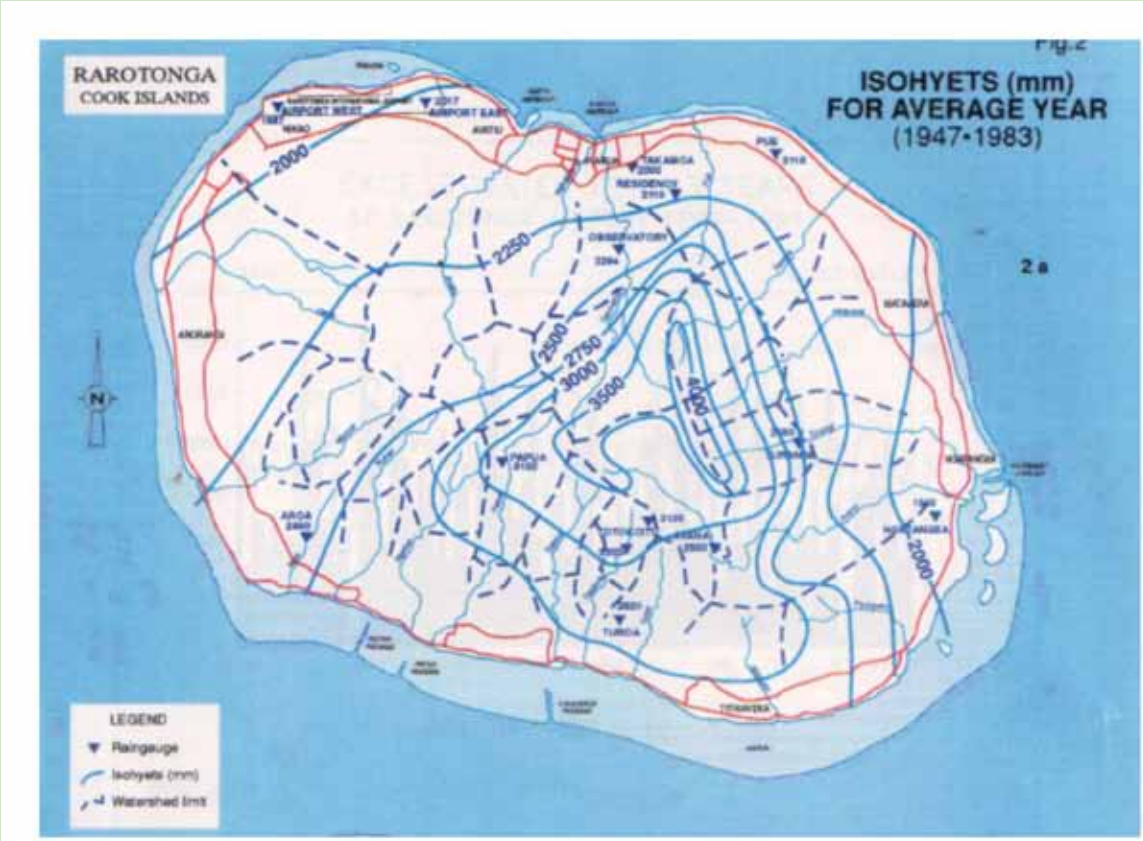
The Cook Islands weather is typically tropical. Summer, December to March, is hotter and more humid with a higher rainfall and greater risk of tropical storms and sometimes cyclones, with the winter months, June to September, generally being cooler and drier. Aitutaki and the northern islands are noticeably warmer than the main island capital of Rarotonga, which accumulates frequent cloud around its mountain peaks. Mangaia in the south is the coolest island; Penrhyn and Rakahanga in the north are the hottest due to their proximity to the equator (typically 5-7 degrees celcius warmer than Rarotonga). The summer rainy season begins in December and lasts until April. In Rarotonga the summer rainy seasons is often accompanied with average temperatures of 29^{0}C, and humid conditions, where mornings are often bright and sunny followed by late afternoon downpours. November to March is classified as the cyclone season. Heat accumulates over the Pacific Ocean during this season, depressions can form, bringing with them thunderstorms, strong winds and the occasional tropical cyclone.

May to October is the dry season with July being midwinter where average daily temperatures in Rarotonga are 25^{0}C dropping to around 19^{0}C at night. The lowest winter temperature on record was in 1965 of just over 9^{0}C

Rainfall is fairly uniform around the island, increasing with altitude with over 3,500 mm being recorded on Mt Te Kou, almost double of the 2,000 mm measured on the coast. Several automatic raingauges were installed in 1999 on Rarotonga and this network was expanded under the Pacific HYCOS project, with gauges being installed on the two outer islands of Mangaia and Aitutaki. Data collected to date is of good quality but there are some significant periods of missing data from the gauges installed in 1999. The Cook Islands Meteorological Service operates a number of manually read gauges on Rarotonga and the attached isohyetal map is based on the data collected from these.

Avana Stream, location of new hydrological station

Isohyetal map for Rarotonga



Source: Outline Scheme for Water Development 1992 WMI-BURGEAP

The stations supported by HYCOS are tabled below and some mean annual rainfall data is presented in the attached graphs indicating the annual monthly rainfall variability based on a 10 year data set with some gaps.

Flushing intake pipeline, Tupapa Stream

List of HYCOS Rainfall Stations

No	Station	Elevation (m)	Location and coordinates	Period of observations	Average rainfall
NA	Rarotonga Met Office	5	Airport 21° 12' 3" S 159° 48' 47" E	1930 open	2057
461303	Mt Te Kou	400	Mountain 21° 14' 38" S 159° 45' 33" E	2008 open	3498
427608	Avana#	107	above Weir 21° 15' 16" S 159° 45' 34" E	2008 open	NA
441306	Matavera	50	above Weir 21° 13' 32" S 159° 44' 31" E	1999 open	3011
461412	Totokoitu	46	above Weir 21° 15' 35" S 159° 46' 27" E	1999 open	2702
471301	Avatiu	89	above Weir 21° 13' 36" S 159° 46' 17" E	1999 open	2200
NA	Mangaia Island#	5	Temokomoko 21° 55' 40" S 157° 57' 10" E	2009 open	NA
428781	Aitutaki Atoll#	2	Vaitoka 18° 49' 41" S 159° 46' 19" E	2009 open	NA

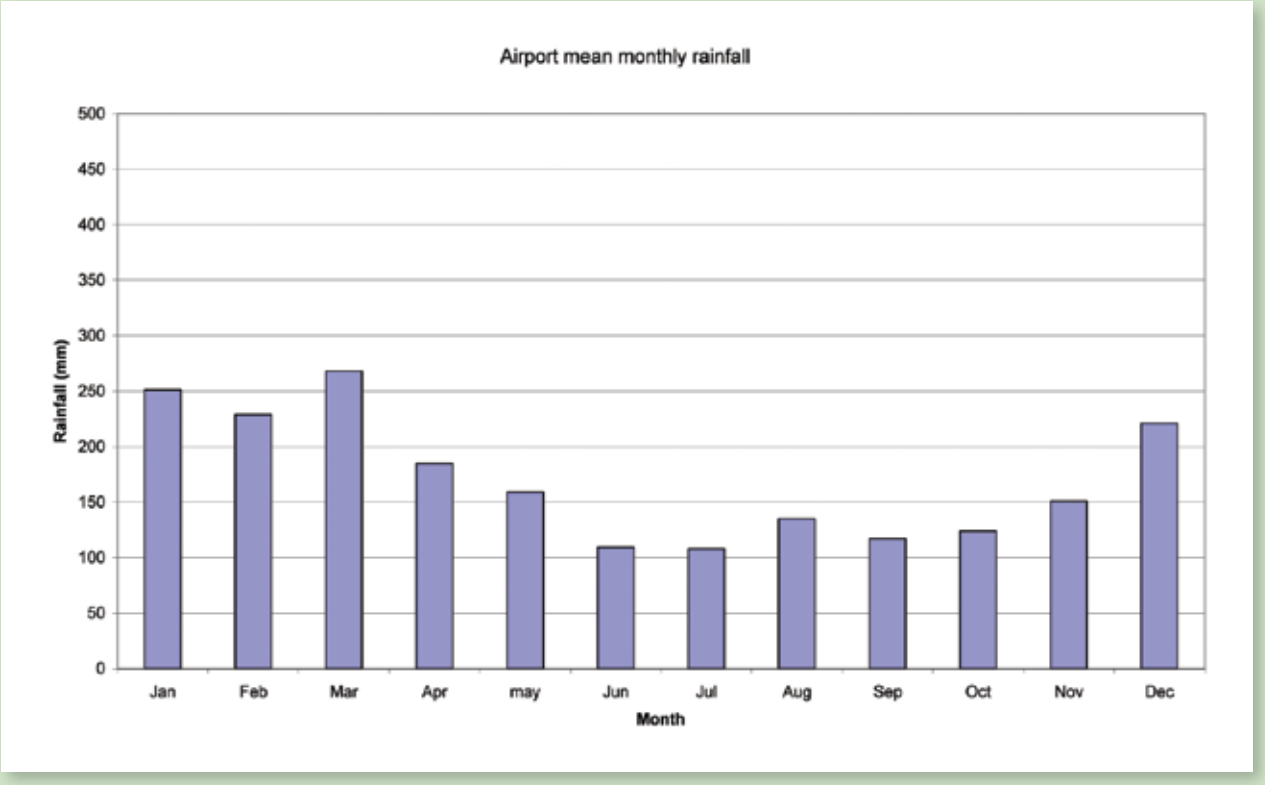
 # HYCOS sites; NA = records too short or not available

Monthly Average Climate Data for Rarotonga

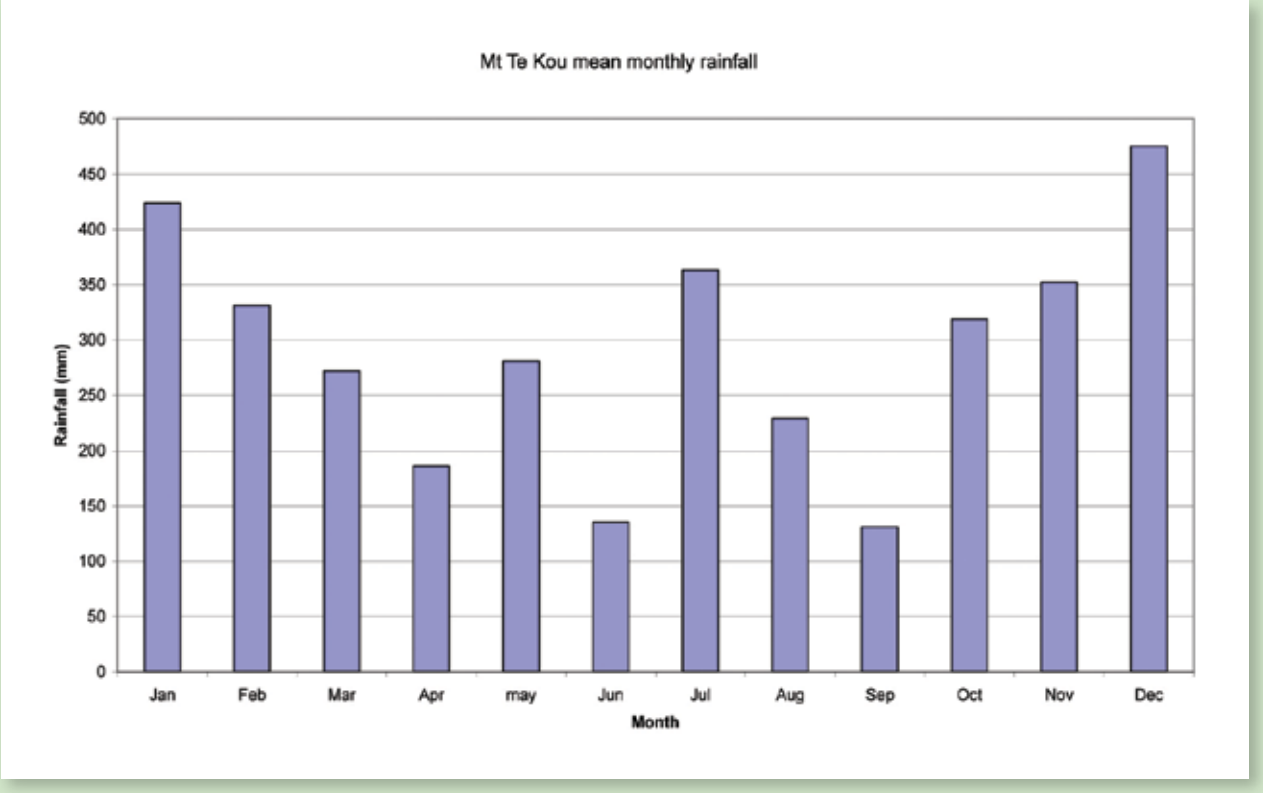
Observation Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Period for the Mean
Temperature (°C)	26.6	26.8	26.8	25.9	24.3	23.4	22.6	22.6	23.1	23.9	25.0	25.6	24.7	Jan 2000 – Dec 2008
Precipitation (mm)	251	229	268	185	159	109	108	135	117	124	151	221	3498	Jan 2000 – Dec 2008

Source: Cook Islands Meteorological Service

Variation of Monthly Precipitation Rarotonga Airport



Variation of Monthly Precipitation Mt Te Kou 400 metres altitude (short term broken dataset)



The significant effect of altitude can be seen on the plot with a strong rainfall gradient from the coastal stations to that recorded at altitude, Mt Te Kou.

Clearance of water supply weir, Avana Stream

4. WATER RESOURCES

4.1 General Description

As Rarotonga is a volcanic island, all streams generally fall from a central high point and radiate out around the island which is ellipsoid in shape. The catchments are very steep, with steep rock bound and armoured streams, more moderate in their lower channels and densely forested with a high runoff coefficient. The streams rise and fall rapidly and at times can initiate small landslides with debris, entering into the stream systems. This causes maintenance problems in the water intakes with gravel, rocks and forest material being deposited, clogging the water intake systems and degrading the quality and quantity of the water supplied. Limited storage in the form of surface reservoirs, compounded with short term dry periods, can compromise delivery of potable water. Significant savings are being made with the advent of a structured programme to reduce losses in the reticulation network. Rarotonga's water is not treated and there are some instances of water borne disease despite the source coming from generally uncontaminated natural catchments. Groundwater is not in general use in Rarotonga, however is being considered for further investigation and development. The reef environment is important to tourism, and catchment development is strictly controlled, to minimise sediment runoff and degradation of the lagoon and reef environments. Streamflow and rainfall monitoring commenced in 1999 under New Zealand Government assistance through NZAID.

4.2 Major Floods and Droughts

Floods were not measured on Rarotonga until the installation of hydrological stations in 1999 and then only for flood heights. Data is limited for flood analysis due gaps in the data and where no measurements of high level discharges have been undertaken. Flooding can affect road crossings, culverts and properties within the immediate vicinity and localised surface ponding occurs for short periods on the coastal fringe. Due to the steep nature of the island, the onset of flooding can be very rapid and destructive in the stream channel and at bridge and road crossings.

The El Nino drought event of 1998 - 1999 pre-dates the measured hydrological data. The effect of this drought was considered severe with estimates of catchment discharge approaching 50% of their normal baseflow during this period. Steep catchments and poor storage characteristics ensure the streams return rapidly to baseflow conditions shortly after wet periods with

implications for longer term water availability especially with a variable or changed rainfall distribution. The accurate measurement of low stream flows at all intakes is highly important for water management purposes, the measurement of higher flows is of a lower priority and is not undertaken at this stage.

4.3 Socio-economic characteristics

The main uses for water on Rarotonga are for reticulated urban water supply for the whole island through ring mains, and include village and market garden agriculture. Reliable water demand figures are currently unavailable but it is considered that the largest user is the tourist industry supplying resorts and the smaller tourist operations, (L Smith pers. comm. 2011). In addition, the small streams and waterfalls coupled with numerous walking tracks, offer recreation opportunities (for tourists and locals alike) in addition to the coastal reef environment. Water conservation measures are in place but are not fully effective in minimising waste of water in the urbanised areas, where water is mostly unmetered and there is no user pay system in place. Some investigations into the groundwater potential have been undertaken however there is concern that septic tanks will have impacted on the groundwater quality and reduced the potential for potable water development of groundwater. Water is highly important to the Cook islanders with concerns over downstream impacts and the potential degradation of the lagoon and marine environments due to contaminated runoffs from human and some animal wastes. Rarotonga is considered quite highly developed for a Pacific Island nation, and there is now little in stream use of water for food preparation and laundry when compared with traditional cultural use.

5. HYDROLOGICAL INFORMATION

The Cook Islands does not have a dedicated National Hydrological Service. Hydrological monitoring and assessment is undertaken by the Department of Water Works (DWW), coming under the Ministry of Works, and more recently the Ministry of Infrastructure. Under New Zealand Aid funding, and with implementation by New Zealand's National Institute for Water and Atmospheric Research, NIWA, hydrological stations (with control weirs) were installed in 1999 on the three main water intakes, along with raingauges and training provided to nominated technical staff. Visits by NIWA on an annual basis followed to further develop capacity and review operations. The Cook Islands now has a reasonably robust monitoring program with one trained technician working part time on the program. The national archive of hydrological data is accessed via the TIDEDA hydrological database system. With the ongoing support from NIWA, the Cook's are considered to have some of the most consistent recent datasets in the Pacific.

Under Pacific HYCOS additional support, and training was provided, and skills were further developed. Capital equipment for hydrological measurement was purchased and two flow sites identified and installed in order to support sustainable water resources monitoring for pilot river basins. Additionally automatic raingauges were also installed on two of the outer islands.

5.1 Hydrological Stations

The attached map shows the stream flow catchments that are currently monitored on Rarotonga. Primarily these were installed for water management and planning purposes, the Avana and Tupapa station were installed by Pacific HYCOS and unlike the three stations installed in 1999, these sites do not have control weirs. All sites are located well above the water intakes and measure the available water resource. Additional non recording water intake sites are periodically measured in times of lower than normal flows for discharge only.

Map of Stream Flow Observation Stations supported by HYCOS

List of Hydrological Observation Stations

No.	Station and number	Location	Catchment Area (km^2)	Observation Period	Observation Items (frequency)
1	*Avana 99008	Above intake 21° 15' 16" S 159° 45' 34" E	6.198 km^2	2008 open	WL, Q, RF
2	Avatiu 99001	Above intake 21° 13' 36" S 159° 46' 17" E	3.949 km^2	1999 open	WL, Q, RF
3	Matavera 99006	Above intake 21° 13' 32" S 159° 44' 31" E	5.005 km^2	1999 open	WL, Q, RF
4	Totokoitu 99012	Above intake 21° 15' 35" S 159° 46' 27" E	1.607 km^2	1999 open	WL,Q, RF
5	*Tupapa 99013	Above intake 21° 13' 13" S 159° 46' 08" E	4.186 km^2	2008 open	WL, Q

*WL = Waterlevel, Q = discharge flow RF=rainfall *Avana = installed under Pacific HYCOS*

Maximum and Minimum Discharge Statistics and Water Level

Site Names	Minimum gauged		Date	Maximum gauged		Date	Max level recorded (m)	Date	Total No of discharge measure-ments
	Level m	Flow L/s		Level m	Flow L/s				
Avana	0.315	16	17 Sept 2008	0.334	104	23 April 2008	1.441	9 May 2008	8
Avatiu#	0.059	11	18 Aug 2008	0.495	607	20 Oct 1999	1.278	08 Jan 2001	21
Matavera#	0.090	11	07 Nov 2008	0.339	145	29 Sept 2008	1.220	31 Mar 2003	21
Totokoitu#	0.093	14	15 Aug 1999	0.309	356	20 Oct 1999	0.907	7 Jan 2003	13
Tupapa	NA	10	15 Sept 2008	NA	222	29 Sept 2008	0.002	29 Sept 2008	6

 # low flow rating developed only, these sites have control weirs

Periodic discharge measurements are also undertaken on the Takuvaine, Turangi, Taipara, Ngatoe and Rutaki streams.

Discharge ratings have been developed at the three of the sites installed by NIWA and as these have control weirs, there is good confidence in the low flow data. Ratings have not been established at the HYCOS installed sites to date due to insufficient discharge measurements being undertaken.

5.2 Study Catchment Introduction

5.2.1 General Description

Two streams have been selected as the study catchments, the Avatiu which has data available since 1999, and the Avana installed by Pacific HYCOS, this being the largest catchment on Rarotonga. Both catchments are rugged, steep and heavily forested. The monitoring sites are located well above the effect of the intake weirs and measure natural catchment outflows from largely undisturbed catchments.

5.2.2 Measured Hydrological data

No hydrological data prior to 1999 has been identified for the Cook Islands however it is possible that some basic data has been collected. The Cook Islands Meteorological Service collect rainfall data from their synoptic station and archive it on their own database system. All available hydrological data has been processed and archived on the TIDEDA database and is readily accessible through DWW for water related studies. NIWA undertook a full audit on this data in 2009 producing an report on the confidence of this data and its application suitability. Currently there is data from 5 rain gauges and 12 flow stations on the archive, including 5 stations which have loggers installed.

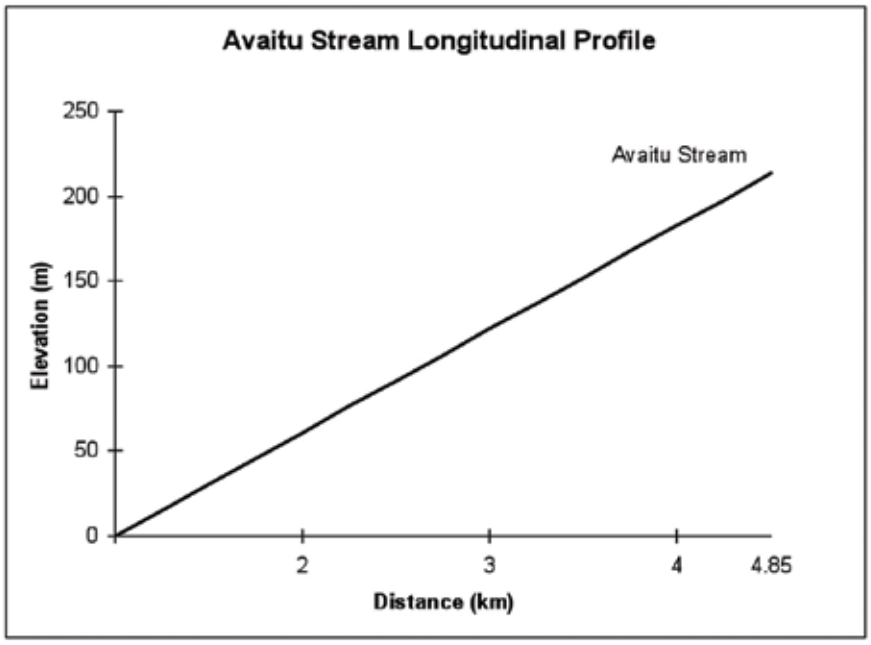
Study Catchment 1 Avatiu, above intake

The Avatiu stream rises in the central mountains and flows north through the main town area of Avatiu to the ocean. Localised flooding can occur in the town during times of heavy rain and high tides. Data collection commenced in July 1999

Site construction activities, Tupapa Stream

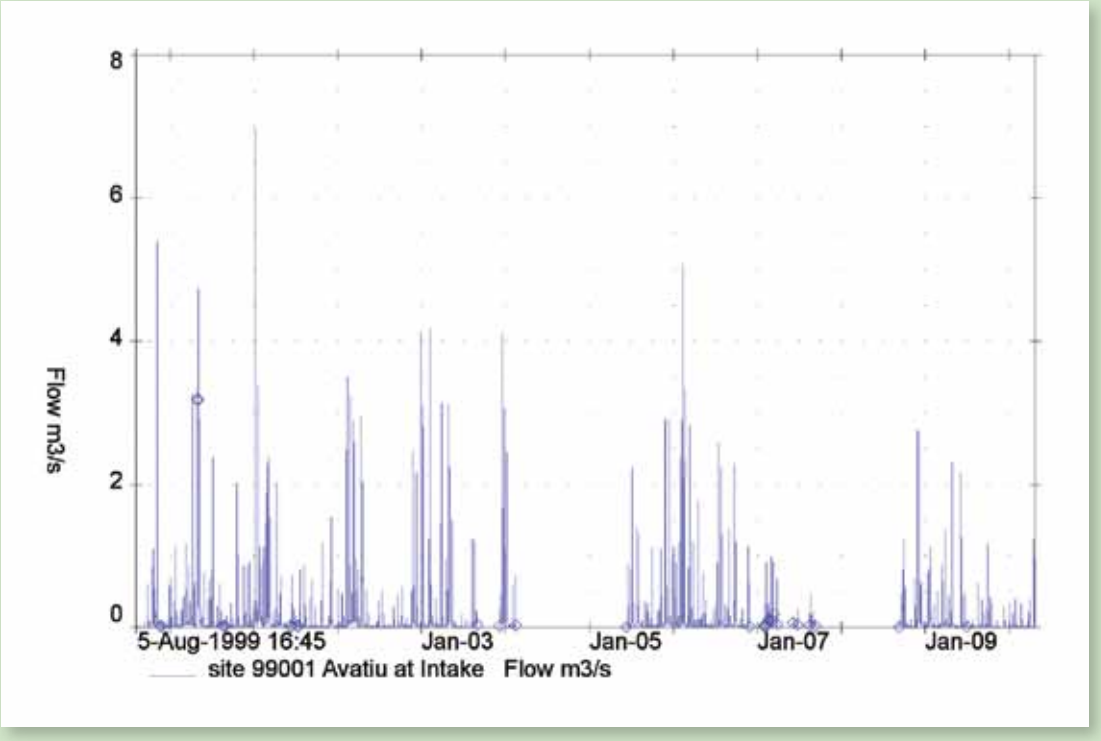
however there are some significant gaps of up to 3 months in duration. The station is located upstream of a purpose built control weir and operates a float and weight measuring system and is easily accessed from Avatu. The site measures data exclusively for water supply management purposes but will be useful for a range of catchment and environmental investigations. Discharge measurements are limited to low flows only with a maximum discharge of 607 litres/s being gauged. The stream profile from the mountains to the ocean is quite uniform with a grade of 4.5% as is shown on the attached long section.

Avaitu stream, longitudinal profile

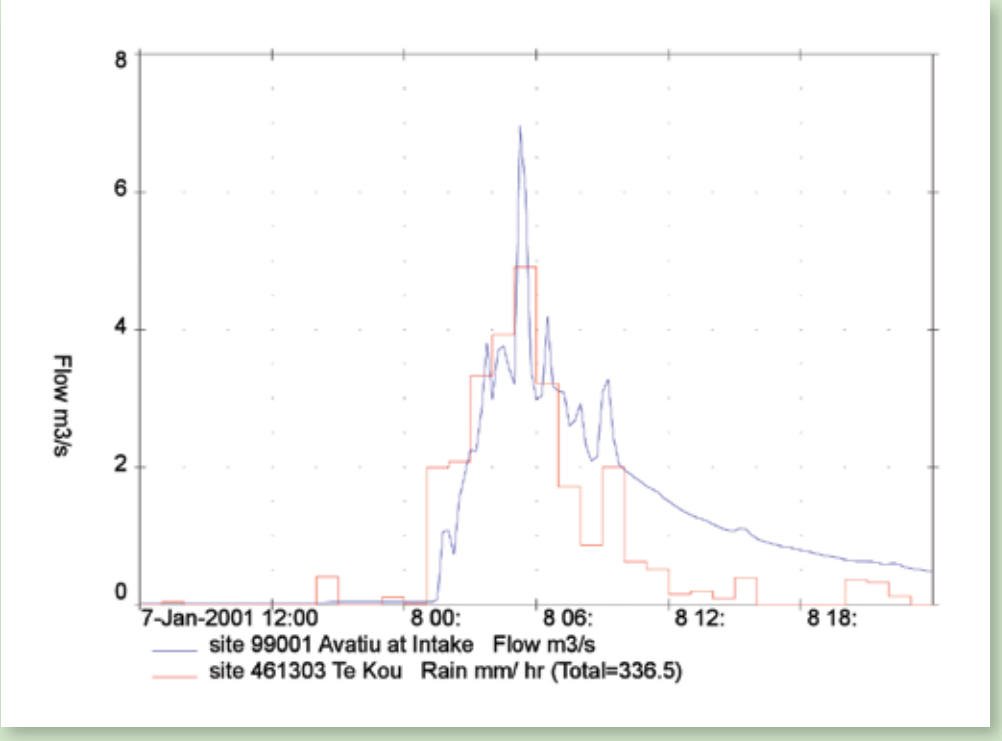


The instantaneous discharge plots have been based on the filed rating curve, however it needs to be remembered that no supporting discharge measurements have been done for the medium to high flows, the largest measured discharge flow to date was only 0.6m^3/s.

Long Term Variation of daily mean discharge Avatiu Station No. 99001



Significant storm event in 2001 with discharge and hourly rainfall plotted



The tabulation of extreme flows tabled below shows that based on the extrapolated ratings that instantaneous flood flows of close to 7 m^3/s are measured with a minimum flow of 0.003m^3/sec measured in an extended dry period in 2002. Sufficient data exists to be able to undertake informed low flow analysis at this site.

Hydrological station, Matavera Stream

~~~ NIWA Tideda ~~~ SOPAC 26-MAY-2011 15:23
~~~ PEXTREME ~~~
Source is Rarotonga.mtd Site 99001 Avatiu at Intake
From 5-Aug-1999 16:45:00 to 26-Apr-2010 09:00:00
Interval = 0
Flow m^3/s

Year	Mean	Coeff. of Var.	Minimum	Date	Maximum	Date
*1999	4.66965E-02	2.76	4.00000E-03	21-Sep-1999 16:00	5.4040	4-Nov-1999 07:45
*2000	5.84941E-02	2.37	1.10000E-02	13-Oct-2000 20:45	4.7290	4-May-2000 06:45
*2001	7.50711E-02	2.33	7.00000E-03	15-Nov-2001 15:30	6.9680	8-Jan-2001 05:15
2002	5.48603E-02	2.35	3.00000E-03	29-Aug-2002 12:15	4.1350	28-Dec-2002 08:30
*2003	8.43976E-02	2.15	5.00000E-03	9-Aug-2003 23:00	4.1790	10-Feb-2003 03:00
*2004	6.50363E-02	1.63	1.20000E-02	29-Jan-2004 15:00	2.4490	4-Jan-2004 07:00
*2005	6.93779E-02	1.91	9.00000E-03	13-Jun-2005 17:45	2.9250	29-Nov-2005 15:00
*2006	7.07787E-02	2.24	8.00000E-03	24-Nov-2006 13:15	5.0850	10-Feb-2006 03:15
*2007	5.63716E-02	1.02	1.40000E-02	9-Feb-2007 15:00	0.99600	5-Mar-2007 20:00
*2008	6.73876E-02	2.70	6.00000E-03	15-Sep-2008 16:15	2.7640	2-Dec-2008 17:30
*2009	4.16160E-02	2.27	5.00000E-03	31-Dec-2009 23:45	2.3090	28-Apr-2009 05:45
*2010	3.67614E-02	2.21	5.00000E-03	5-Jan-2010 16:30	1.2310	20-Apr-2010 18:15

Average Annual Minimum 3.00000E-03 Maximum 4.1350 (complete yrs)

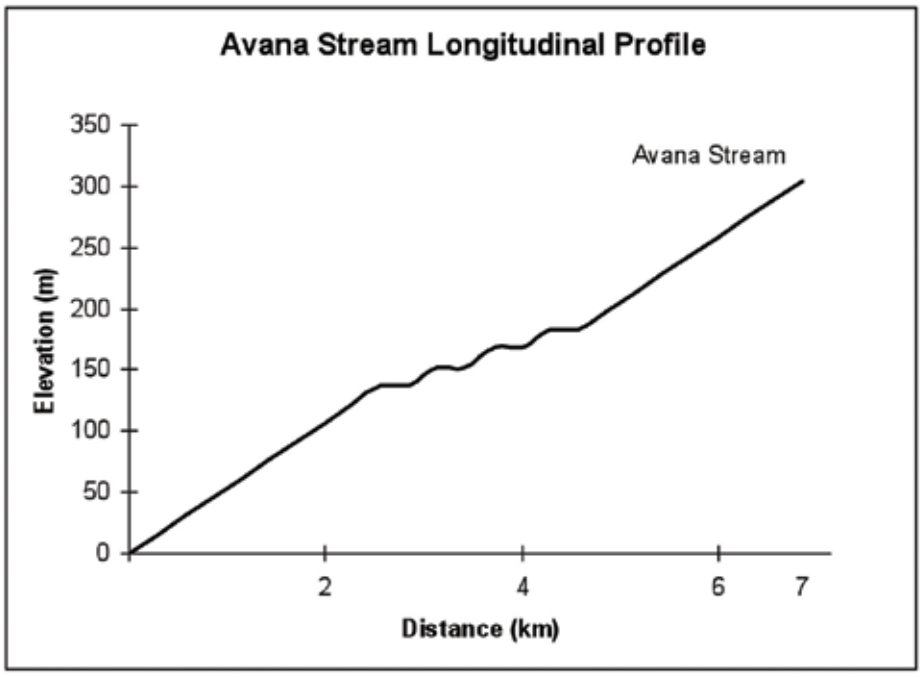
'*' denotes years with gaps in the data or incomplete years
Coeff. of Var. = sd/mean

Minimum is 3.000000E-03 at 29-Aug-2002 12:15:00
Maximum is 6.96800 at 8-Jan-2001 05:15:00
Mean is 6.165184E-02
Std. Dev. is 0.142899
Coeff. of Var. is 2.32

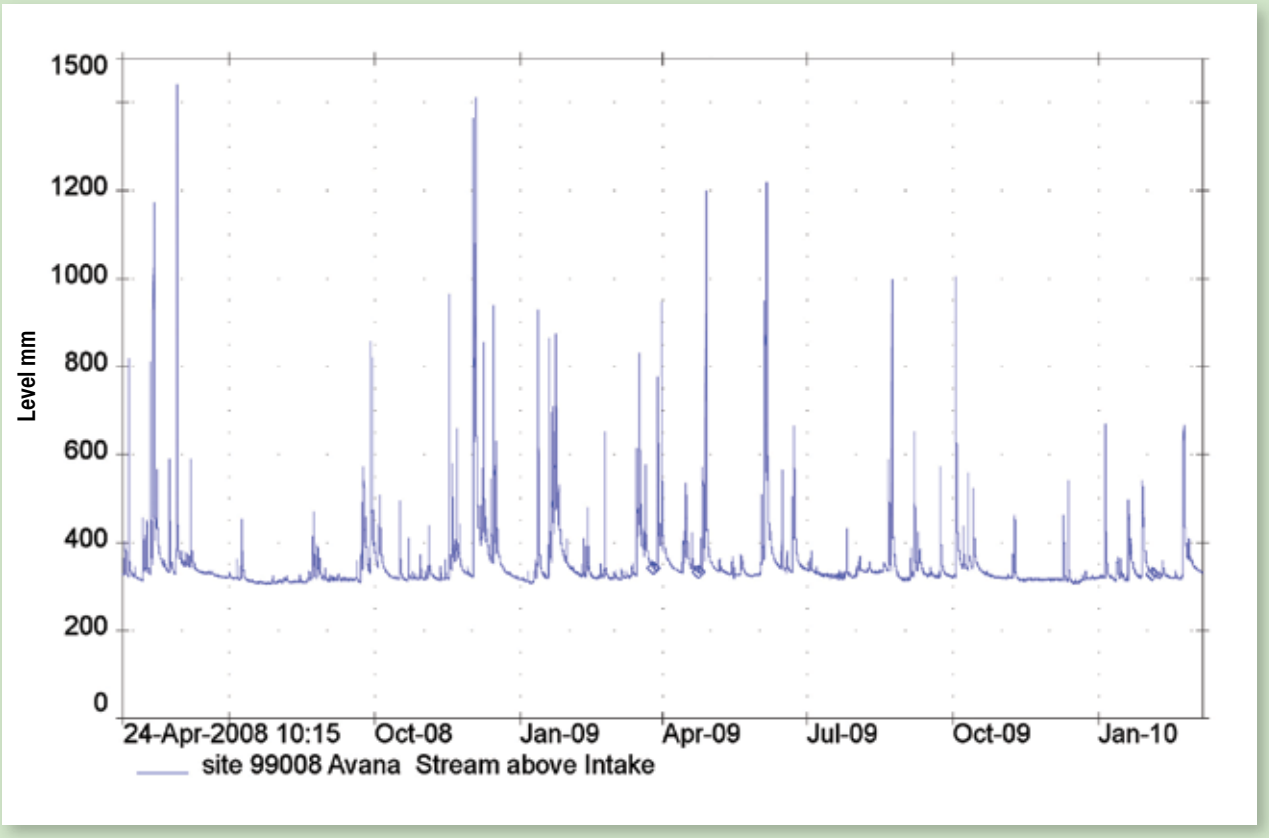
Study Catchment 2 – Avana above Intake

The Avana stream rises in the central mountains on the southern slopes of Mt Te Kou and flows easterly to the ocean. It is Rarotonga's largest catchment with no previous hydrological data being measured. Data collection commenced in April 2008 with the installation of the site under Pacific HYCOS. The station is located upstream of a purpose built control weir and operates a bubbler measuring system. Access is by 4WD and is 2.5 km inland from the coast necessitating many stream crossings, for this reasons it is difficult to access to measure medium to higher flows. As the site is located mid catchment, lower catchment inflows are not included nor measured. The site currently measures data exclusively for water supply management purposes and is available for a range of catchment and environmental investigations in the future. Discharge measurements undertaken are to few to allow the development of a useful discharge rating curve. The stream profile from the mountains to the ocean is quite uniform, with an average grade of 4.3%, apart from the flatter mid section as shown on the attached long section.

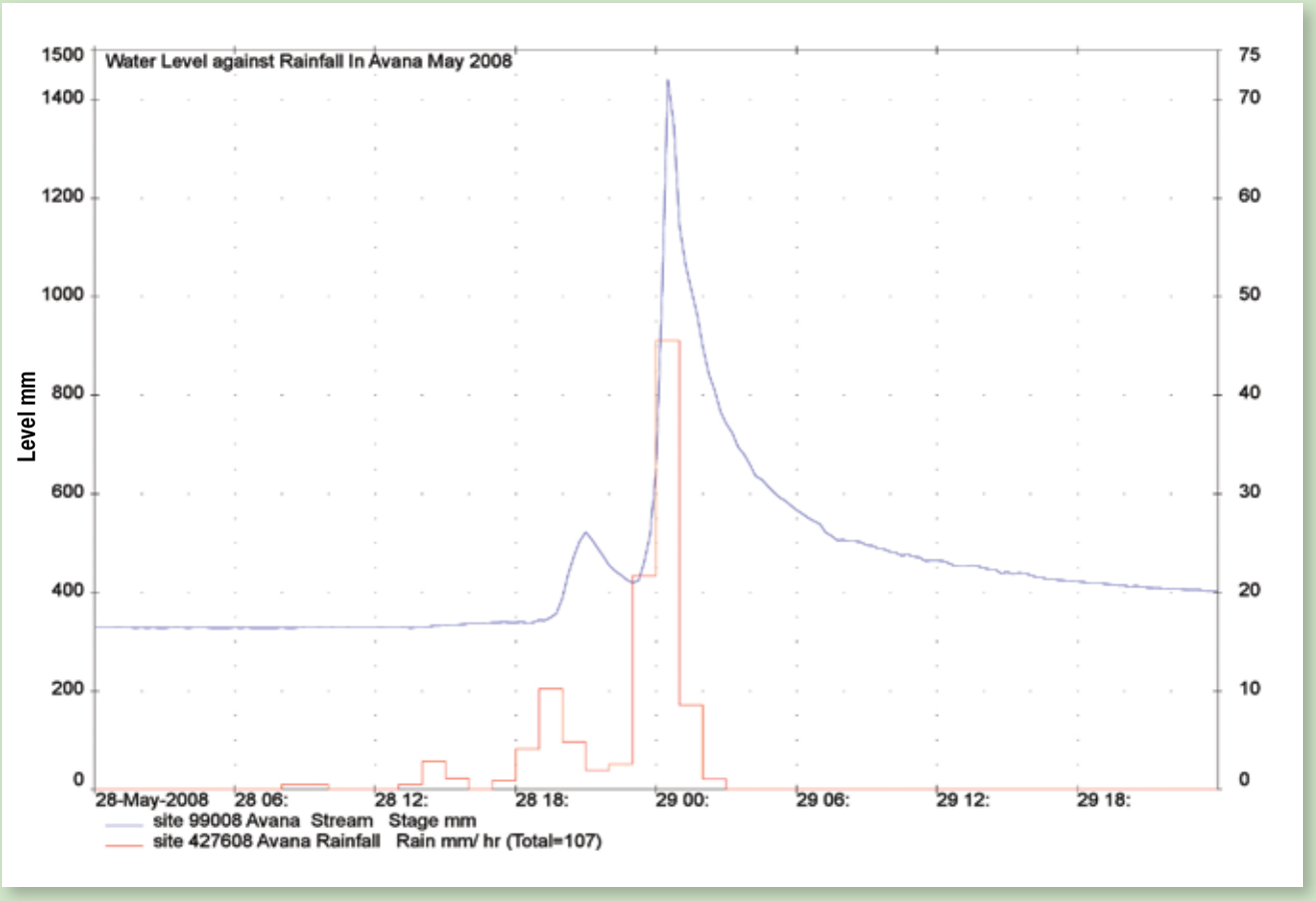
Avana stream , longitudinal profile



Long Term Variation of Water Level (Instantaneous), Avana Stream, Station number 99008



Avana Stream typical flood Hydrograph showing the rapid response to hourly rainfall



6. COMMENT

The Cook Islands was fortunate in obtaining donor funding in 1999 from NZAid to allow for the installation and operation of a modest hydrological network. Pacific HYCOS was able to build on this and further develop the network and capacity within Rarotonga. There is now adequate coverage on the significant streams and additional rainfall stations for rainfall measurement within Rarotonga. Records are mostly complete with periods of missing data occurring when priorities were elsewhere rather than servicing the hydrological network. The data that is now available is extremely useful for resource assessment and analysis of dry events since 1999 allowing for better management and planning and the basic calibration of catchment models for some individual storm or drought sequences. In this respect the Cook Islands has the most robust recent hydrological datasets of all of the Pacific HYCOS surface water countries. The DWW and staff have shown a very good level of commitment since 1999 to the collection of hydrological data and it is hopeful that by 2015 some robust gap free longer term datasets will have been collected. These datasets will further assist government and stakeholders alike to make a more informed assessment on the development and sustainability options of Rarotonga's water resources and develop confidence and skills for additional water resources monitoring and management in outer islands.

7. PHOTOGRAPHS

Avana Stream at gauging site, typical Rarotongan stream environment, well cobbled and bouldered bed, heavily forested and well developed incised channels.

Avana streamflow station setting up instrument housing, bubble sensor and logging equipment. Note the steep mountains typical of Rarotonga.

View from Mt Te Kou showing the fringing reef, reef channels, urban fringe forest and natural grassed clearings surrounding the island, and the typically steep nature of the stream catchments.

Servicing Te Kou automatic raingauge, the highest raingauge on Rarotonga

Matavera streamflow station, typical of the sites with control weirs

Site construction works setting up Tupapa Stream flow station