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The University of Waikato
Te Whare Wānanga o Waikato

IGCI Technical Report

Climate Change
Vulnerability and Adaptation Assessment for Fiji

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in partnership with
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and
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Fiji — relevant departmental logo

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1 Introduction

1.1 Background

All nations, including Fiji, that are signatories to the United Nations Framework Convention on Climate Change (UNFCCC) are obliged to provide National Communications to the Conference of Parties (COP) of the UNFCCC. The COP4 stressed the need for parties to the Convention to take into account the need for establishing implementation strategies for adaptation to climate and sea-level changes. As. such, Fiji is required to submit a National Communication document that shall include information on climate change vulnerability and adaptation implementation policies and strategies.

Fiji's commitment to fulfill the requirements of the National Communication has been supported by the Pacific Islands Climate Change Assistance Programme (PICCAP) – of the South Pacific Regional Environment Programme (SPREP) - through funding from the Global Environmental Facility (GEF). This work has been extended in this present report, which provides the most quantitative vulnerability and adaptation assessment for Fiji to-date.

Fiji's contribution to human-induced (anthropogenic) climate change is considered insignificant due to its small size and development status. Nonetheless, Fiji will need to participate in international negotiations to avert the worst possible-scenarios of climate change. Even if international initiatives to limit global greenhouse gas emissions are successful, Fiji, like any other Pacific Island Country (PIC), will have no choice but to adapt to the change to which the climate and ocean system is already committed as a result of historical greenhouse gas emissions.

As an island nation, it is essential to understand how climate change and sea level rise will affect and impact on our coastal ecosystems, marine resources, subsistence and commercial agricultural developments, domestic and industrial developments, human health, water resources, population, and our national economy at large. In order to develop and implement appropriate response strategies, it is essential to establish a comprehensive baseline of the current situation in Fiji and an understanding of the effects of climate change, the degree of vulnerability and the national capacity to adapt.

This has been achieved, in this current vulnerability and adaptation assessment, by using Viti Levu for an in-depth case study, which has involved:

1) drawing on existing baseline information and previously published studies;
2) incorporating, within an integrated assessment model (IAM) known as PACCLIM, Viti Levu climate, soils and elevation data, along with a climate scenario generator, to facilitate detailed quantitative analyses of effects for selected sectors; and,
3) identifying adaptation options for each of the sectors examined.

The methodology used in this assessment is based on the Intergovernmental Panel on Climate Change (IPCC) technical guidelines (Carter et al, 1994) for assessing climate change impacts and adaptation. Firstly, the present conditions are examined and key sectors identified. Then, future climatic and non-climatic scenarios are used to examine the possible effects of climate and sea-level changes on the various sectors identified. These then form the basis for identifying possible adaptation response measures for endorsement, adoption and implementation by the Fiji government. Because of the many gaps in present knowledge, and the fact that this study is focussed only on Viti Levu, the recommendations in this report should be seen as a starting point for an on-going process of vulnerability and adaptation assessment in Fiji.

1.2 Study area and sectors

As already indicated, this study is focussed on the main island of Viti Levu. Through a process of consultation, four sectors were identified for the study: agriculture, coastal resources; human health; and water resources.

The ***agricultural sector*** contributes the most to the country's GDP and the economy at large (22%). It is also the most vulnerable to climatic variations in terms of its production capacity and capability. The recent (1997/98) El Nino drought proved the worst for the sector with the sugar industry and subsistence agriculture in Western Division being severely affected. External aid and governmental assistance were required to ensure sustenance and facilitate recovery in the worst hit parts of Fiji which included the western and northern divisions and outer islands.

The ***coastal zone*** is of vital importance to small island nations such as Fiji. It is a highly dynamic environment, which contains an assemblage of resources including reefs, mangroves and seafood. It is the location of every significant town in Fiji, most villages and the vast majority of the population as well as most activity related to industry and commerce.

Climate has many potential implications for ***public health*** in Fiji. Dengue fever outbreaks require certain climatic conditions, but are also influenced by a wide range of environmental conditions. Malnutrition can arise from times of food shortage as a result of drought and cyclones and their impact on food availability. These are just two examples of climate-related health issues in Fiji.

For the ***water sector,*** droughts and floods have significant impacts in Fiji, on both water quantity and quality. During the 1997/98 drought there were severe water shortages in the drier parts of the mainland, especially in the Western and Northern Divisions. This drought was followed by a very intense rainfall event, in January 1999, which caused record floods in the vicinity of Nadi.

1.3 Methods

There were three main tasks to complete the Viti Levu case study:

1) Development of climate and sea-level change scenarios;
2) Assessment of impacts arising from the scenarios;
3) Identification of adaptation options.

Both the development of scenarios and assessment of impacts were founded on development of an integrated assessment model for the Pacific island region, known as PACCLIM, funded through PICCAP. Application of PACCLIM, for assessment of impacts, was supplemented by more qualitative analyses using available literature and expert judgement as appropriate.

PACCLIM was initially developed as a regional scenario generator (see Kenny *et al.,* 1999a). However, this was extended to develop prototype sectoral applications for a selected high island and low island situation. Viti Levu, Fiji and Tarawa, Kiribati were identified for this purpose and data and models were integrated in the manner shown below (Figure 1.1).

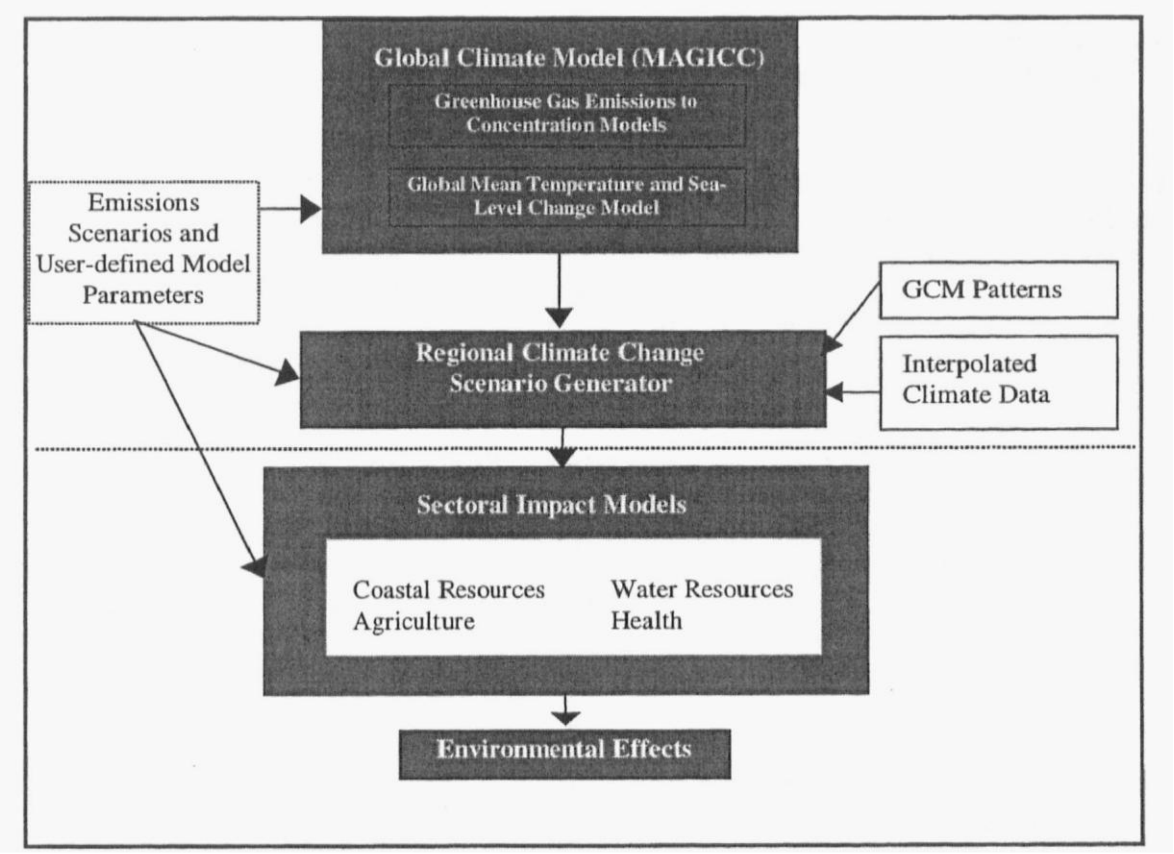

Figure 1.1. Schematic representation of the PACCLIM model system and its main components

The two main components of PACCLIM are:

1. a **scenario generator** which links together historical climate data (temperature and rainfall), patterns of climate change from complex global climate models (GCMs), and output from a global temperature and sea-level change model, called MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change; Wigley, 1994).
2. **sectoral models** for agriculture, coastal zone, human health and water resources.

The scenario generator is described in detail by Kenny et al. (1999a). For the purpose of this report, discussion will focus on developments of PACCLIM as they relate to Fiji. This involved the linking of the scenario generator together with baseline climate data for Viti Levu and sectoral models.

1.4 Viti Levu data in PACCLIM

There were three principal data-sets required for the customisation of PACCLIM for Viti Levu:

1) historical climate data – monthly climate records, for rainfall, minimum and maximum temperature, for all Fiji meteorological stations were gathered from the NIWA climate data base. Long-term averages were derived for the purposes of developing interpolated climatologies for Viti Levu;
2) digital elevation data – a digital elevation model (DEM) has been developed for Fiji at a 25 m contour interval. The data for Viti Levu were acquired from the Fiji Lands Department. These data were required for the interpolation of the climate data, to account for effects of elevation on climate;
3) soils data – digitised soil attribute data for Viti Levu, required for the Plantgro model (described briefly below), were acquired from the Landuse Planning Section of the Fiji MAFF. This group has recently established a GIS unit.

These climate data were interpolated to a 500 metre grid for Viti Levu, and the digitised soils data were re-sampled to the same grid. Unfortunately, finer resolution elevation data were not immediately available for the coastal environment, to enable assessments of inundation under different scenarios of sea-level rise. These spatial climate and soils data were then incorporated within PACCLIM and linked to relevant sectoral models.

1.5 Sectoral models for Viti Levu

Models for each of the four sectors (agriculture, coast, health, water) were incorporated in PACCLIM and linked to the Viti Levu data. However, only the agricultural, health and water resources models were applied in the present study and are described briefly here. A detailed description of models for all four sectors is provided in Kenny et al., 1999b.

1.5.1 Agriculture – PLANTGRO

The PLANTGRO model, developed by Hackett (1988, 1991) was originally customised for spatial application within VANDACLIM, a tool developed for training in climate change vulnerability and adaptation assessment (Warrick, 1998; Kenny et al., 1999b). This same customised version of PLANTGRO was incorporated in PACCLIM and linked to the Fiji data, and to the scenario generator. Within PLANTGRO, so-called notional relationships are derived for a total of 23 climate and soil factors, to develop plant files for specific crops. For each factor, the notional relationship is an expression of the plant response (suitability) to different levels of the factor in question. Output is given in the form of:

- Overall limitation rating: a composite index taking into account soil and climate conditions at each grid site;
- Greatest limitation: the most critical limiting factor at a given point in time (month) amongst 23 factors;
- Yield: Relative yield in relation to potential maximum yield;
- Growing season length (for annual crops).

1.5.2 Health – dengue epidemic potential model

Based on output from the complex process models CIMSIM and DENSIM, epidemic potential is described as a function of ambient temperature (see Patz *et al*, 1998). This relationship is the basis of the simple biophysical index model used in PACCLIM, which describes relative changes in dengue fever risk resulting from changes in ambient temperature. There is no rainfall limitation to this model. This is because the main dengue fever vector, *Aedes aegypti*, is adapted to the urban and domestic environment where breeding sites may be created by artificial containers of water. Depending on the range of human activities, such container breeding sites may be equally available under low rainfall conditions.

1.5.3 Water – flow analysis/flooding model

The flow analysis/flooding model in PACCLIM is built on a stochastic approach, which uses the generalized extreme value (GEV) distribution (described in Kenny et al., 1999b) to analyse the extreme high and low flow events. The generalized extreme-value analysis (Jenkinson, 1955) is widely used for modelling extremes of natural phenomena, and it is of considerable importance in hydrology (Natural Environment Research Council, 1975). Extreme events are defined in terms of unusual values of a sequence of observations of certain meteorological elements. The term "extreme events" is used in a broad sense, encompassing both the occurrence of extraordinary values (i.e., a record-breaking maximum or minimum) and the exceedance above or below a particular threshold level. Typically, the problem is to estimate the probability that an extreme value of a sequence of observations of a meteorological variable will be higher or lower than some constant threshold level, or alternatively, to estimate that threshold value which will be exceeded with a desired fixed, small probability. These extreme values and associated probabilities are then used in the solution of related design problems or cost-risk calculations. Historical observations of the appropriate meteorological variables are used for the identification and fitting of the desired extreme probability distributions. The utility of these estimators depends to a great extent on the length and the homogeneity of the observational record, especially in cases when the record return period of the required design value is significantly longer than the observational record.

1.6 References

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2 Fiji —an overview

Fiji is located in the south-west Pacific Ocean at a latitude of 15 to 22 degrees South, and longitude of 177 degrees West to 174 degrees East. Fiji is an archipelagic nation consisting of more than 300 islands scattered over 1.3 million square kilometers of the South Pacific Ocean. The two large mountainous islands of Viti Levu (10,400km^2) and Vanua Levu (5,540km^2), comprise 87% of the total land area.

2.1 Climate

The climate of Fiji is generally categorised as an oceanic tropical climate. The South Pacific Convergence Zone (SPCZ), a zone associated with high rainfall, fluctuates north-east and south-west of Fiji (Salinger et al, 1995). Its location relative to the Fiji islands has a strong influence on both seasonal and interannual variations in climate, particularly rainfall. The ENSO phenomenon influences the positioning of the SPCZ relative to Fiji. Fiji is also affected, often severely, by tropical cyclones.

2.1.1 Rainfall

As discussed above, the positioning of the SPCZ has a strong influence on rainfall over Fiji. During the dry season (May to October) the SPCZ tends to be positioned more to the north-east of Fiji. In the rainy season (November to April) it tends to be located over Fiji. In an addition to these seasonal variations there is also a high degree of inter-annual variability in rainfall, which is strongly influenced by ENSO and SPCZ fluctuations.

Another important influence on rainfall is the south-easterly trade wind, which carries moist air onto the islands. On the larger islands of Viti Levu and Vanua Levu, the south-eastern regions are the high rainfall areas. The mountains of these high islands have a strong influence on the distribution of rainfall, with the regions on the leeward (western) side of the mountains being much drier on average. The annual rainfall in the east of Viti Levu, where Suva is located, ranges from 3,000mm to 5,000mm, while in the west of Viti Levu, where Ba, Lautoka, Nadi and Sigatoka are located, annual rainfall ranges from 2,000mm to 3,000mm.

While the prevailing wind is from the south-east, tropical cyclones and depressions tend to track from the north and west. Thus, although the west of Viti Levu is drier on average it can experience very heavy rainfall events and associated flooding.

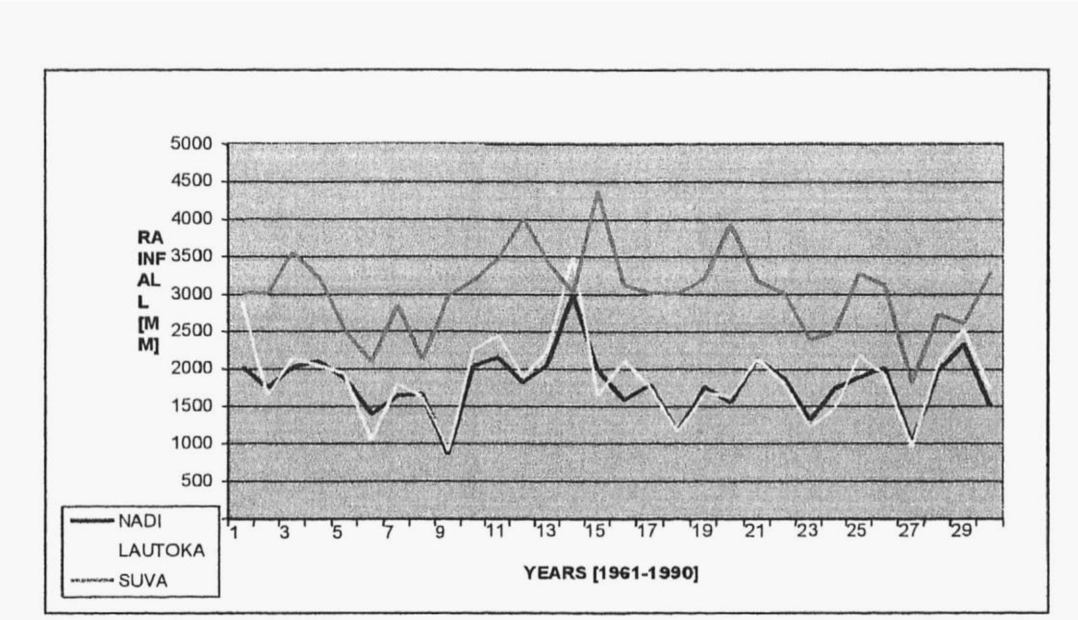

Figure 2.1. Rainfall pattern for 30 years based on data from 3 stations

2.1.2 Temperature

The average daily temperature varies seasonally, from 23°C to 25°C in the dry season and from 26°C to 27°C in the rainy season. On average, temperatures between the colder months (July-August) and the warmest (January-February) vary by about 3 to 4°C. Inter-annual fluctuations in temperature are relatively low, ranging from ±0.5°C about the long-term mean.

2.1.3 El Nino

El Nino events, which lead to a north-east positioning of the SPCZ, are the major cause of drought in Fiji. During an ENSO event, drier and hotter than normal conditions can be expected from December to February and drier and cooler conditions from June tc August. While lower than normal rainfall can be expected over most of Fiji, the moss severely affected areas tend to be in the west of the main islands.

Fiji is located in a part of the south-west Pacific region where annual rainfall anomalies are strongly correlated with the Southern Oscillation Index (SOI). The 1997/1998 ENSC event greatly influenced Fiji's rainfall pattern. It intensified from April to June of 199i where the **SOI** for June reached its lowest value since 1905 of –2.4. In September of 1997, most parts of the country recorded 20% to 50% below average rainfall. The western parts of the country recorded less than 10mm of the total rainfall, i.e. below 7°A of the average. In December, all sites recorded 50% to 90% below average rainfall. Al coastal sites in Viti Levu and parts of Vanua Levu recorded lowest ever rainfall totals for the period of 8 consecutive months from September 1997 to April 1998.

Table 2.1. SOI data for Fiji's El-Nino years

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1965	-0.5	0.1	0.2	-1.3	-0.1	-1.6	-2.3	-1.3	-1.4	-1.3	-1.8	0
1966	-1.4	-0.5	-1.6	-0.7	-0.8	-0.1	-0.1	0.3	-0.3	-0.4	-0.1	-0.5
1967	1.5	1.2	0.8	-0.5	-0.3	0.5	0	0.5	0.5	-0.2	-0.6	-0.7
1972	0.3	0.6	0.1	-0.7	-2.4	-1.6	-1.9	-1.1	-1.5	-1.3	-0.5	-1.5
1982	1	-0.1	0	-0.3	-0.8	-2.5	-2	-2.7	-1.9	-2.2	-3.1	-2.5
1983	-3.4	-3.5	-3.2	-2	0.5	-0.6	-0.9	-0.3	0.9	0.2	-0.2	-0.1
1987	-0.7	-1.4	-1.6	-2.2	-2	-1.8	-1.8	-1.3	-1.1	-0.6	-0.1	-0.6
1992	-2.6	-1	-2.2	-1.8	0.1	-1.2	-0.7	0.2	0.1	-1.8	-0.8	-0.7
1994	-0.2	0	-1	-2	-1.1	-1	-1.7	-1.6	-1.6	-1.5	-0.7	-1.3
1997	0.4	1.3	-0.8	-1.6	-2.2	-2.4	-0.9	-2	-1.4	-1.7	-1.5	-0.9
1998	-2.4	-2.1	-2.9	-2.5	0	1	1.5	1				

Source: Fiji Meteorological Service

2.1.4 Cyclones

Fiji lies in an area normally traversed by tropical cyclones mostly during the November-April wet/cyclone season. Cyclones bring about flooding and multiple land-slips, have major impacts on the economy and infrastructure, and many adverse effects for the people of Fiji. More detailed information on the frequency, severity and impacts of cyclones is provided in the sectoral chapters.

2.2 Socio-economic setting

2.2.1 Population

The Fijian population comprises several ethnic groups including Fijians, Indo-Fijians, Europeans, Chinese and others. The 1996 Population Census recorded a count of 772,655 residents - an increase of 57,280 persons over the 1986 figure of 715,375 giving an average annual population growth rate of 0.8%. Population declined in 1987 for the first time in 50 years due to a high level of emigration of Indo-Fijians. (Chandra and Chandra, 1990).

2.2.2 Population Distribution

Over 90% of Fiji's population in both rural and urban areas can be considered coastal dwellers where the vast majority of services, infrastructure, agricultural productions and social centres are located (Nunn et al., 1993). In addition to this concentration in coastal areas, the population is unevenly distributed between the islands. Over 75 % of the entire population of Fiji lives on Viti Levu. (Chandra and Chandra, 1990).

There has been an increasing trend towards urbanisation in recent years. The increasing urbanisation has led to the development of squatter settlements around the major towns in Fiji. Many of these settlements lack basic services like water, and sanitation, and houses are often of sub-standard quality. The Ministry of Housing estimated that in 1991 as many as 25% of households in Suva were located in squatter settlements and a similar situation exists in other towns. The shortage of suitable land creates pressure for urban development and limits expansion. (Bryant, 1993).

Despite the increasing urbanisation, the rural sector is still the largest sectoral component in Fiji, containing over 60% of the population. The rural sector plays an important part in the economy of Fiji. However, the sector remains the most economically depressed in terms of employment and income distribution. Rural Fijians also have limited access to services such as health care and secondary education.

2.2.3 Gross Domestic Product

Fiji's economy has a very narrow base with its performance largely determined by the success of the sugar and tourism sectors. Figure 2.2 shows the contribution of various sectors towards the national GDP as it was recorded in 1996. Over the last few years both the local and the foreign investment had been comparatively low but has started to increase. Private investment has continued but has mainly been concentrated in tourism, construction, garment and mining sectors.

Fiji's real economic growth between 1993 and 1996 averaged 2.7% per year. Following the good growth of 6.2% in 1992, real GDP grew by only 1.6 % in 1993 due to the devastating effects of Tropical Cyclone Kina. Real economic growth increased in 1994, resulting from good performances by the sugar and tourism sectors. Also, there was a higher growth recorded in agriculture, fisheries and forests sectors as these sectors recovered from the effects of the cyclone. The economy again slowed in 1995 due to a decline in sugar production by 0.6%. The GDP growth in 1996 increased to 3.1% mainly due to strong performance from tourism, mining, garment and livestock production.

The tourism sector has grown significantly over the years. Recently, a number of new tourist hotels have been built in the country. The visitor arrival has recorded a steady growth in the same period, except in 1995 when the tourist arrival declined – a decline attributed to the nuclear testing in Tahiti. However the industry remains active and is considered one of the largest foreign earners. Tourism earnings increased by 6.2% over 1995 to F$430 million in 1996.

The garment and footwear industries have been increasing since the introduction of the Tax Free Factory/Zone (TFF/TFZ scheme). Preferential access to the Australian and New Zealand markets, under SPARTECA, and the US market, under the Multi-Fibre Agreement, have both had a significant bearing on the viability of the industries.

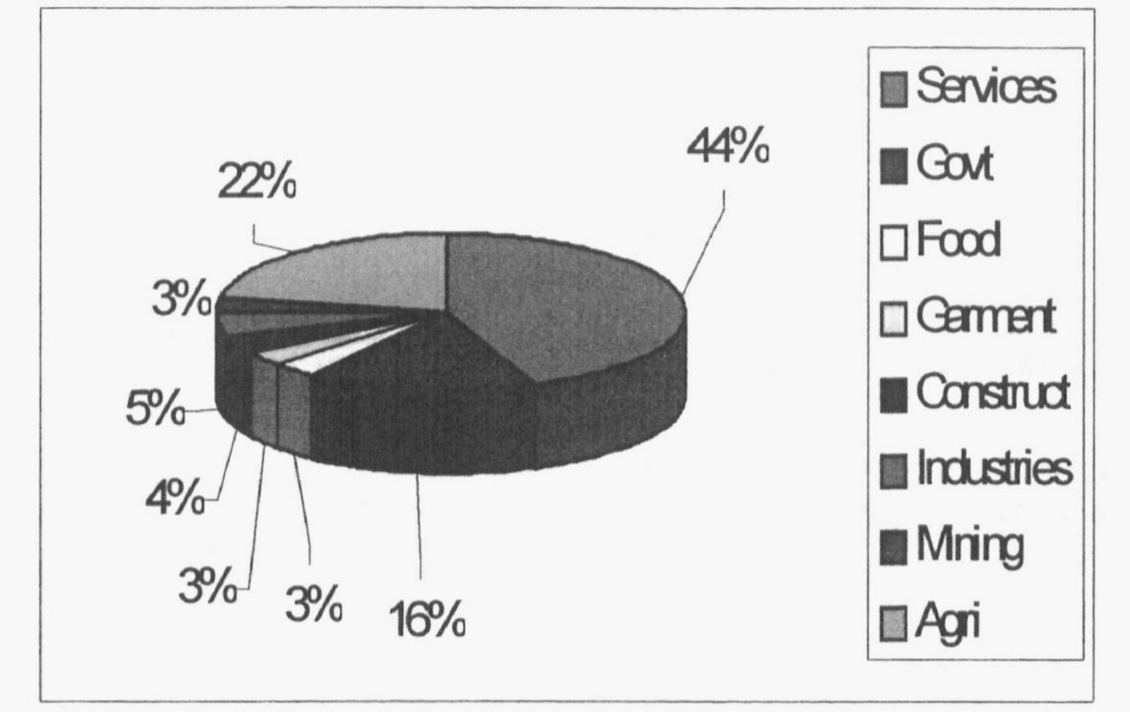

Figure 2.2. GDP by sectors — 1996

The mining industry on the other hand did not have the same success as those mentioned above. The output was low between 1993 and 1995 and then recorded a substantial increase due to improved performances of the Emperor Gold Mines and the commencement of operations at Mt. Kasi.

2.2.4 Imports and exports

External trade plays an important part in the Fijian economy. Economic growth over recent years has been possible through the adaptation of an export-led growth policy and increased facilitation of private sector development. Exports have been rising but have also been affected by the impacts of cyclones, drought and falling world prices. Domestic exports increased to F$821 million in 1996, representing an annual average growth rate of 1.4% from F$593 million in 1993. Sugar, gold and the garments remain the main export items. Recently kava and taro has increased as an export in response to increasing demand from overseas markets.

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3 Scenarios

3.1 Climate and Sea-Level Scenarios for Fiji

While the resolution of general circulation models (GCMs), used for creating scenarios of climate change, is continually improving it is unlikely that they will ever provide accurate information for Fiji, particularly relating to changes in tropical cyclones and ENSO. However, there is the likelihood of increasingly reliable information at the regional scale from which it is possible to assess implications for Fiji based on an understanding of present climate and its variability.

3.1.1 Climate model projections

Results from a number of recent GCM model runs show consistent temperature increases over Fiji of the order of 0.7° to 0.9°C per 1.0°C of global warming. However, the GCMs show variations in their projections of rainfall changes. Present rainfall patterns are strongly influenced by ENSO, which in turn has a strong influence on the location of the South Pacific Convergence Zone (SPCZ), which is a zone of high rainfall and is also where cyclones tend to develop. While existing GCM results tend to show a more El Nino-like pattern on a regional basis they show variations in the positioning of the SPCZ in relation to Fiji, ranging from a southwest shift to a northeast shift. Thus projections of rainfall change vary from increases (associated with an intensification of the SPCZ near Fiji) to decreases (associated with a northeast shift of the SPCZ).

Given this uncertainty in patterns of rainfall change, and the associated effects on variability and extremes, two differing GCM results (from the CSIRO9M2 and DKRZ GCMs) are presented here along with an analogue scenario for ENSO and tropical cyclones. The years 2025, 2050 and 2100 were selected for projecting the GCM scenarios. The patterns of change from the two GCMs were scaled, for these years, by global temperature changes from the A2 SRES and B2 SRES greenhouse gas (GHG) emissions scenarios and assuming a high climate sensitivity and 'best guess' climate sensitivity respectively. This provides an extreme (or worst case) and mid-range (best-guess) scenario for each of the GCM patterns of change. These scenarios are summarised in Table 3.1.

Table 3.1. Summary table of climate change scenarios for Fiji

GCM	**Emissions Scenario**	**2025**		**2050**		**2100**	
		Temp [°C]	**Precip %**	**Temo [°C]**	**Precip %**	**Temo [°C]**	**Precip %**
CSIRO9M2	**B2(mid)**	0.5	3.3	0.9	5.7	1.6	9.7
	A2(high)	0.6	3.7	1.3	8.2	3.3	20.3
DKRZ	**B2(mid)**	0.5	-3.3	0.9	-5.7	1.6	-9.7
	A2(high)	0.6	-3.7	1.3	-8.2	3.3	-20.3
Analogue scenario for variability and extremes: Sequence of natural disasters(droughts, cyclones, and floods) from 1992 to 1999, including 1997/98 El Nino drought							

3.1.2 Temperature changes

There is no difference in the temperature changes for Fiji from the two different GCMs. However, the choice of GHG emissions scenario has an increasingly strong influence on the amount of temperature change over time. In 2025 there is little difference between the different scenarios, but by 2100 the A2 (high) emissions scenario shows twice the temperature increase of the B2 (mid) emissions scenario.

3.1.3 Rainfall changes

The choice of GCM and GHG emissions scenario has a strong influence on the direction and magnitude of rainfall change, respectively. The CSIRO9M2 GCM shows rainfall increases over Fiji, which increase with the amount of temperature change. The DKRZ GCM shows rainfall decreases. Of the different GCMs examined, this is the only one that shows rainfall decreases for Fiji, but the possibility of this occurring should not be ignored as there could be significant impacts from such a change.

3.1.4 Variability and extremes

Given the uncertainties in the GCM results, there is at present limited understanding of the possible future changes in the frequency and intensity of extreme events such as tropical cyclones, droughts and floods in Fiji. Recent climate modelling work suggests that climate change may be associated with an increase in cyclone intensity in the region. In addition, recent experience suggests the possibility of an increased frequency of both cyclones and other extremes, such as droughts and floods, associated with ENSO fluctuations and shifts in the SPCZ. Between 1992 and 1999, Fiji has suffered from the cumulative effects of a sequence of four cyclones and two droughts–the last (El Nino) drought (1997/98) was broken by severe (La Nina) flooding in the western region (January 1999). This sequence of events is used as an analogue scenario of future changes in variability in Fiji. Such a scenario encompasses the possibility of both an intensification of the SPCZ over Fiji (higher rainfall/La Nina years) and a north-east shift of the SPCZ (lower rainfall/E1 Nino years), as reflected from the two different GCM results above. It is possible that both results may be correct, suggesting an intensification of inter-annual climate variability, and associated extremes, in Fiji.

3.1.5 Sea-level scenarios

The possibility of increased thermal expansion of the ocean and melting of glacial ice sheets as a consequence of anthropogenic climate change may result in sea-level rise. Global climate models are able to project regional change in sea level that may be relevant to Fiji, but the confidence in such regional projections remains low. Thus for the purposes of this study, the global mean projections are used as first order estimates of changes that could occur in Fiji. This was accomplished by using MAGICC in the linked model system within PACCLIM and applying the SRES global emission scenarios. The results are recorded in Table 3.2.

Table 3.2. Global sea level rise projections

Scenario/Year	2025	2050	2100
B2 (best guess)	11 cm	23 cm	50 cm
A2 **(high)**	21 cm	43 cm	103 cm

3.2 Non-climatic scenarios (Viti Levu)

Fiji is already experiencing rapid environmental and socio-economic changes which are arguably of more significance than possible climatic changes. However, the effect of such changes will significantly modify climate and sea-level change effects. Apart from the consideration of possible future climate and sea-level changes, it is important to recognise the importance of ongoing social, economic and environmental changes which are directly relevant to the determination, analysis and interpretation of possible climate and sea-level change impacts and adaptation options.

While it would be impossible to predict, with any degree of certainty, how social, economic and environmental parameters may change over the time scale of this study, it is possible to develop scenarios which may be used for the purposes of analysis and policy development. One approach would be to develop a range of well-defined scenarios which illustrate alternative development pathways in Fiji and thereby enable the comparison of such alternative development pathways in terms of future vulnerability to climate change and adaptation merit. Another approach would be to develop a best guess scenario extrapolated from present trends with explicit description of the range of uncertainty in scenario parameters. This scenario may then be used to identify and assess future adaptation measures and policy intervention options. This latter approach has been adopted in this study.

The possible future environmental and socio-economic scenarios have been developed from present day trends and patterns. In the development of the non-climatic scenario (for the years 2025, 2050 and 2100) the following have been considered as the main drivers of change:

- population growth and changing population distribution;
- economic growth and changes and likely future characteristics and activities;
- increasing limitations of available land and resources

3.2.1 Population growth

It is extremely difficult to develop reliable long-range population projections for a time scale relevant to this study. However, for the purposes of this study three scenarios for Fiji's future population growth (a high, medium and low variant) have been developed and tabulated below. Given the youthful nature of the present population, population growth has considerable momentum which will be reflected in high population growth in the medium term. All three projections provided assume an on-going reduction in total fertility rate (TFR), gradual increase in life expectancy and decreasing infant mortality rates. Migration patterns have not been included in the projections. (Projections are based on the 1996 census data and have been developed using SPECTRUM[11] demographic software).

Table 3.3. Population projections for Fiji

Projection	2026	2951	2096
High	1,210,000	1,620,000	2,300,000
Medium	1,180,000	1,480,000	1,720,000
Low	1,110,000	1,260,000	1,280,000

3.2.2 Population distribution

Currently, more than 75% of the population of Fiji lives on Viti Levu while 90% of the population of Fiji may be considered coastal dwellers. Approximately 60% of the population live in rural areas.

Based on present conditions and trends and the projections of total population size, the following have been used as scenarios of future population distribution in this study:

- It is likely that population drift from rural to urban areas, and from outer islands to Viti Levu will continue, with the result that Viti Levu as a whole, and urban and peri-urban areas in Viti Levu in particular, will experience a disproportionately higher population growth than national average.
- Other coastal areas in Viti Levu would likely experience population increase in keeping with or marginally higher than national trends and become heavily populated in the future.
- Population densities in lowland river valleys would likely increase proportionately with these trends.
- Population densities in marginal hill-land areas may show a disproportionate increase over the present low densities as coastal land and lowlands become more crowded.

3.2.3Demographic structure

As population growth stabilises and given the demographic trends typical of countries which are increasingly developed, it is likely that the population will become relatively older.

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[11] SPECTRUM — Policy Modelling System (Version 1.33) (Developed by The Futures Group International, Glastonbury, USA)

3.2.4 Economy

For the purposes of the analyses of this study, and given the impossibility of providing economic forecasts for the time scales of this study, the following scenarios describing broad economic characteristics are provided:

- Dependence on natural resources and the environment will continue to be an overriding feature of the Fijian economy.
- Agricultural production is likely to continue to be important in subsistence and formal economies and as an export earner.
- The future revenue generating capacity of the sugar industry is uncertain because of the uncertainties (fluctuations) in the global market prices and perhaps more importantly, because of the uncertainties over land tenure, lease and use. It is likely that the sugar industry will be less significant in the future and crops such as Kava and other traditional crops will become important cash crops.
- Based on past trends, the tourism sector is likely to increase. The tourism industry contributes significantly to Fiji's GDP and is expanding annually. Most of the major resorts and hotels are located along the coast. The industry is now Fiji's major foreign exchange earner. The trend for tourist developments along the coastline is likely to increase in the future and will provide employment as well as trading opportunities for the local people and companies.
- The growing cash economy is likely to continue to increase in the future. Nevertheless, the subsistence economy, while not increasing at a similar rate, will continue to play an important role, in rural areas.
- It is likely that dependence on foreign aid will continue to be a feature of Fiji's economy, particularly in response to the effects of natural phenomenon such as cyclones and droughts.

3.2.5 Infrastructure and housing

Based on the scenarios of overall population growth and population distribution and considering economic development scenarios, infrastructure and housing development is likely to increase proportionately to population growth but with the following additional characteristics noted:

- Densification of urban infrastructure;
- Spreading out or urban and peri-urban areas along the coastal margins and, to a lesser extent, inland;
- Disproportionate increase in sub-standard and squatter housing in peri-urban areas;
- Proportionate increase in coastal infrastructure - especially tourism developments and related activities.

3.2.6 Environment

In the absence of policy intervention, demographic changes, economic growth and development as described above are likely to result in a variety of adverse environmental changes of proportionate magnitude. These are noted and described below:

- Fragmentation, degradation and loss of ecosystems will increase in those areas most affected by population increase such as the coastal and lowland environments.
- Land degradation and top-soil erosion and loss will increase in these areas as well as in the marginal hill-land environments.
- Deforestation will increase and extend into the highlands as timber demand for commercial as well as subsistence purposes increases. The increase in demand for fuelwood is likely to pressurise receding forest margins.
- Sewage pollution is likely to increase in proportion to population growth and would affect the most densely populated coastal areas and associated ecosystems. Solid waste pollution is likely to accelerate with a rate of increase above that attributable to population growth as the cash economy and desire for manufactured and packaged items increases. Similar trends are likely with respect to chemical pollution.

3.2.7 Social and cultural change

The following are provided as scenarios of social and cultural change:

- There is possibly an increasing reliance on cash income while the extended family system and other traditional social structures are breaking down. These trends are all likely to continue in the future.
- The high urbanisation trend has been associated with a shift in food preference from the traditional diet of locally sourced food towards a greater consumption of imported food items such as rice, flour and canned foods. Reliance on imported food is likely to increase in the future.
- Health problems that may be associated with the changing diet, lifestyle, westernisation and behavioural patterns are likely to continue to increase and become more prominent with the ageing population.
- An increase in public health and social problems typically associated with unplanned peri-urban development, poor housing and over-crowding are also likely to increase.
- Disparities in income, standards of livings and access to health services are likely to widen. This may result in the re-emergence and increase in social and health problems prevalent in disadvantaged communities.

4 Coast

4.1 Overview of sector

The coastal zone is of vital importance to Fiji's society and its national development, containing some of its most diverse and productive resources. This is where many, if not most, of the urban centres and the vast majority of villages are located. Consequently, much of the population, together with industry and commerce, is concentrated in this area (Watling et al, 1994). Important socio-economic activities along Fiji's coasts include: tourism; fisheries; agriculture; industry and commerce; infrastructure, including ports, harbours, roads and sea walls; and the development of nature conservation sites such as the Sigatoka sand-dune natural reserve.

4.1.1 The Viti Levu coast and climate change

Anticipated impacts of climate change and sea level rise on the coast of Viti Levu include shoreline erosion (including loss of low-lying islands, atoll islands and beaches), inundation, increased storm damage and flooding, salinity intrusion into water tables and increased salinity of rivers and embayments, disappearance of wetlands, alteration to reef productivity and possible reef destruction (Kaluwin and Smith, 1997).

In efforts to identify future impacts of sea level rise and climate change it is important to note that many Pacific Islands (including Fiji) have experienced a steady increase in sea level over the past century. For example, Mimura and Nunn (1998) suggest that Fiji has experienced a rise in sea level of 1.5 mm y-1.

Perhaps of greater significance, Fiji experiences large seasonal and interannual variations in water level (+/- 0.25 m). This indicates that Fiji is naturally subject to short phases of uncharacteristically high and low water levels of the order of magnitude projected under climate change scenarios (Table 3.2).

It is not surprising therefore, that Viti Levu faces many of the same impacts as forecast with accelerated sea level rise (e.g. shoreline erosion, inundation and salinity intrusion). Over the past 100 years, these impacts are attributed to short-term, natural variability, sea-level rise and anthropogenic stresses which are compromising the natural resilience of coastal systems. Therefore, even without anthropogenic climate change and associated sea-level rise, many island nations have and will continue to experience increased vulnerability to natural hazards (erosion, inundation) due to anthropogenic stress including high population growth rates, over development, increased exploitation of biological and physical coastal resources and pollution.

A number of previous studies have examined the vulnerability of the coastal zone in Fiji to climate and sea level change (e.g. Zann, 1992; Ehlers et al., 1995; Nunn et al., 1996; Solomon and Kruger, 1996). Of interest, Ehler et. al. (1995) noted that most of these studies indicated the over-exploitation of marine resources, coastal pollution, diminished nutrient loading through intoxication and urbanization.

These have:

- *reduced the resilience of coastal systems to cope with climate variability, thus increasing its vulnerability;*
- *affected the coastal system's adaptive capacity to climate change, sea level rise and human activities;*
- *increased susceptibility of coastal population, infrastructure and property investments to natural hazards such as storm surges, tsunamis, flooding and sea level rise.*

It is expected that these impacts will be exacerbated by accelerated sea level rise and changes in storm frequency and intensity. Such changes are likely to further compromise the resilience of coastal systems.

This impact analysis focuses on the physical response of the coast to sea level rise which includes erosion and inundation. Possible reef and mangrove response are also considered in a more qualitative context. Impact analysis will be undertaken using the scenarios outlined in Chapter 3.

4.1.2 The coastal environment of Viti Levu

Viti Levu is a high volcanic island with a land area of 10,4001 km^2. It is the largest island in Fiji and is home to 75% of the Fijian population. Like other high islands throughout the Pacific much of the population infrastructure and economic activity is located in the low-lying coastal fringe. As noted by Nunn and Mimura (1997), the concentration of human activities in the coastal fringe makes these islands as socially and economically susceptible to climate change and sea level rise as low-lying atoll environments.

The interior of Viti Levu is rugged mountainous terrain which rises in elevation above 1000 m. The coastal margin is generally narrow and low-lying and has formed over the past 3000 – 5 000 years through a combination of fluvial and coastal sedimentation assisted by minor sea-level fall (approximately 3000 years ago).

Viti Levu has approximately 750 km of coastline (Fiji 1:250,000 topographic sheet). The north and east coasts consist largely of Pliocene to Pliestocene volcanics, marine elastics, limestones and old fluvial deposits (Rodda, 1982 and 1984 and **Annex C1**). Holocene emergent limestone platforms, beach rock and reef deposits also fringe the island's coastline, especially adjacent to existing reef systems.

The coastal plains of Viti Levu are of limited areal extent. Recent alluvial and reef deposits are found around the island. The main fluvial deposits include those of the Rewa, Nadi, Sigatoka, Mba and Navua rivers, with several smaller systems contributing considerable terrigenous deposits to river valleys and coastal areas.

Coral reef systems contribute considerable carbonate sediments to nearshore and beach areas. These are particularly common on the south, northwest and northeast coasts of the island.

A well-developed barrier reef system is situated off the northwest coast of Viti Levu. Over 94% of Viti Levu's coastline consists of fringing reefs with mangroves. The remaining 6% consist of open or exposed coast, without natural reef or mangrove protection.

54% of Viti Levu's coastline consists of undeveloped areas with mangroves and coral reef fringes and with low near sea elevations, in many cases less than 3 m above mean sea level. Agricultural and coastal communities occupy about 23% of the coast of Viti Levu.

About 86% of the Viti Levu coastline consists of ground with elevations less than 5m above mean sea level. The remaining 14% consist of steep and rugged terrain greater than 5m above mean sea level.

4.1.3 Biological characteristics of Viti Levu coast

According to NES (1993), Fiji's vegetation and wildlife are of exceptional scientific and genetic interest because of the high proportion of endemic forms. They have a high income-generating potential through the tourism industry.

Mangroves: The total mangrove area for Viti Levu was estimated at 23,463 ha, about 58% of the total for Fiji (Watling, 1985). The largest tracts of mangrove are located in the Ba (3,714 ha), Rewa (5,130 ha) and Labasa (1,473 ha) Delta areas. These three areas contain 40% of the total mangrove for Viti Levu.

Mangroves play an important role in the physical and biological functioning of the coast. They are important as fish nurseries, which underpin subsistence and commercial fisheries. Mangrove associated fisheries provide subsistence in the order of 8.76 Million kg of fish (Watling, 1985). This accounts for 60% of the total subsistence fisheries for Fiji, with a market price of, FJ $17.52 Million in 1983. For 1983, the total mangrove fisheries in Fiji was estimated to have a total economic return of FJ $ 21.8 million, with mangrove contributing FJ $566/ha.

Mangrove also acts as a stabilising agent for the coastal zone. The dense root networks of the mangrove act to bind and trap sediment. Thus they provide a protective buffer to the coast. Despite the importance of mangrove to the physical and biological functioning of the coast, they are experiencing significant anthropogenic pressure. Mangrove resources are highly sought after for firewood and as building materials. Mangrove areas have also increasingly come under pressure from reclamation and construction for urban development and conversion to agricultural sites. For example, large areas of mangroves have been reclaimed for sugar cultivation (1,292 ha in Labasa) and construction activities (e.g. 750 ha in western Viti Levu) (Watling, 1985). Watling (1985) also note that the

Lands Department indicated that at September 1987, 2,457 ha was reclaimed, or 6% of the original area.

Coral reefs: Fiji has well developed barrier and fringing reefs around Viti Levu. The coral reef system is a critical component of the coast of Viti Levu. In particular, it supports nearshore fisheries and other economically valuable marine species. It is the major source of sediment supply to replenish coastal surroundings; protects shorelines through dampening of waves. Coral reefs are also a source of tourism (scuba diving, snorkeling and coral viewing) and possess cultural values in terms of demarcating marine resource ownership zones.

Increasingly the reef and coast is perceived as a readily accessible source of aggregate for the construction industry.

The reefs of Fiji are under threat from coral bleaching from elevated sea surface temperatures. Information from the International Centre for Aquatic Resources Management (ICLARM, personal communication), indicate that Fiji reefs were affected by, bleaching over the past decade, and noticeable between 1987-1996. They are also subject to pollution generated from adjacent urban areas.

4.1.4 Human impacts on the Viti Levu coast

Current human activities exert significant pressure on the natural functioning of the coastal system. Such stress compromises the ability of the coast to respond to sea level rise and climate change. Particular anthropogenic stresses on the coast include:

- Deforestation – promoting increased sedimentation at the coast;
- Infrastructure development;
- Extension of agricultural development to marginal land;
- Marine pollution from unhealthy sanitation and waste disposal. Many pollutants may be retained in shallow water muddy environments, especially adjacent to and in mangrove systems. Fisheries resources in the areas, and which are harvested can become polluted, increasing the toxicological effects on humans. This is especially so for trace and heavy metals which are assimilated by shellfish;
- Destructive fishing methods and over-exploitation of the fisheries resource pose greater risks on the coral environment;
- Coral aggregate mining is a particular destructive impact on coral systems. Removal of sand, gravel and rock for construction purposes has been undertaken in Viti Levu for more than two decades. This is destructive, and can alter coastal bathymetry and circulation pattern, causing increased erosion of nearshore and beach systems. This is already prevalent along the south coast of Viti Levu;
- Reclamation of mangroves and wetland areas has deleterious effects on coastal stability and fisheries.

4.1.5 Sea Level characteristics in Viti Levu

The University of Hawaii Sea Level Centre (UHSLC) has operated and maintained a water level recorder in Suva Harbour since 1972. This record is presented in Figure 4.1. Although these data show a distinct increase in mean water level, significant gaps in the data are considered to render extrapolation of a medium-term trend dubious. Solomon and Kruger (1996) note that tide gauge records for Suva from 1987 show a general increase, but indicated that may be related to tectonic subsidence of the area or subsidence of the instrumentation site (as it is located on soft, reclaimed land). The latter has been noted by Shorten (1993). In addition, climate variability may also be responsible for these changes (Solomon and Kruger, 1996). Wyrtki (1990) and Solomon and Kruger (1996) also note that tide data for 1975 - 1986 do not show any discernible trend.

More recently the National Tidal Facility (NTF) at Flinders University of South Australia have installed a water level recorder. However, the length of record from this record is not sufficient to extrapolate any medium to long-term trends. NTF's analysis of tidal constituents for Suva does not show any significant change in tidal level for the period 1994-1999 (Mitchell, 1999).

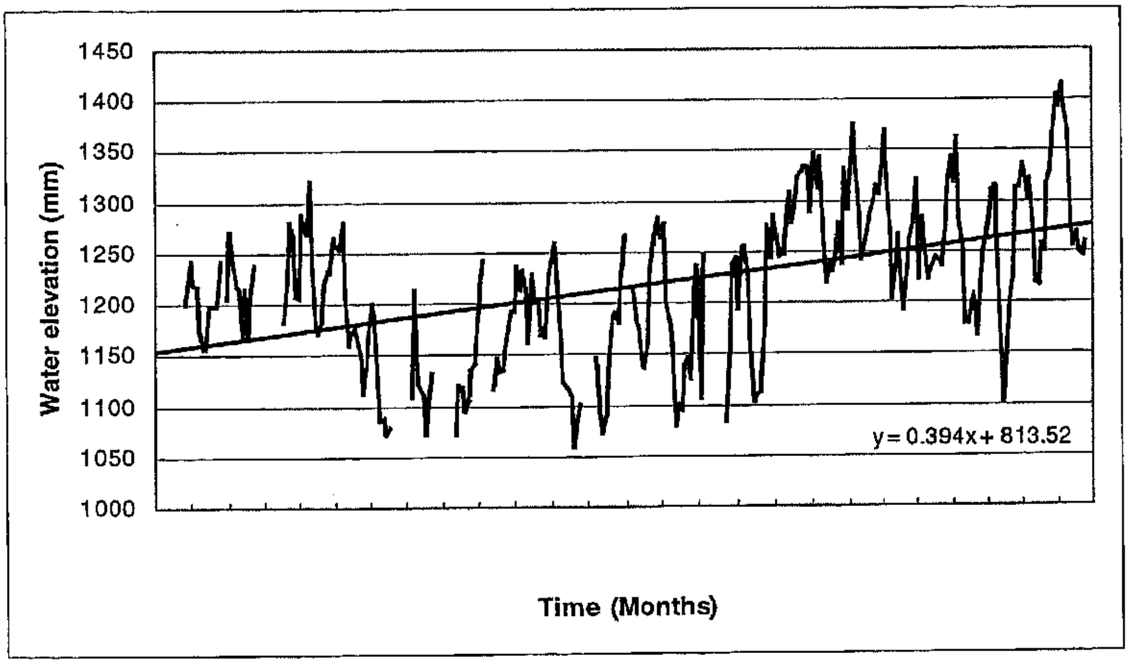

Figure 4.1. Monthly water level record Suva, Viti Levu. Source Data: The University of Hawaii Sea Level Centre (UHSLC)

Despite limitations in extrapolating long-term changes in sea level, the UHSLC record does show some significant short-term characteristics of sea level in Viti Levu. In particular the record shows strong seasonal fluctuation of 10 – 15 cm. There are also longer and larger interannual fluctuations in water level of +/- 0.25 m, which may be related to the timing of the El Nino Southern Oscillation phenomenon (Solomon and Kruger, 1996). Higher water levels were recorded between 1989 and 1994. Some of these tidal levels were associated with cyclones, e.g. Kina in 1993, with water levels of more than 1 m above the mean datum. Higher water levels are also common during the early quarters of the year, also know to be the period of higher seas, for this part of the Pacific.

4.1.6 Short-term changes in water level in Viti Levu

Apart from long-term trends, periodic fluctuations in water level occur at a range of time scales, which can also be hazardous to coastal systems. Short period surface waves, tides, storm surges and inter-annual variations in mean sea level can all elevate the water surface above its mean position and promote inundation and erosion hazards on Viti Levu. (Of interest to this study is future changes in the magnitude and frequency of such events.)

4.1.7 Wave climate of Viti Levu

Deep Water Waves: Waves impacting on the coastline of Viti Levu are generated either by local wind fields or swell originating at locations remote from Fiji (e.g. in the southern oceans close to New Zealand). Normal (i.e. non-cyclone) winds are dominantly from the east and southeast and moderate to light (trade winds) in all seasons which generate the southeasterly swell.

Barstow and Haug (1994a) analysed wave data for south and north of Fiji. Average wave heights computed for latitudes 14.5-16.5° S and longitudes 177-180° E, for this period are contained in Table 4.1.

Table 4.1. Average wave heights for Fiji

MONTHS	MEAN WAVE HEIGHT, SOUTH(M)	MEAN WAVE HEIGHT, NORTH (M)
Jan-Feb	2.14	1.89
Mar-Apr	2.40	1.80
May-Jun	2.40	1.69
Jul-Aug	2.56	1.94
Sep-Oct	2.11	1.77
Nov-Dec	1.99	1.84

In general, wave heights were 2 - 4 m with peak periods of 10 - 15 seconds. The highest swell waves (long period, generated in the south), occurred on 10 July 1993 with H_s of 5.9 m and T_p of 15 – 16s.

The maximum waves recorded by Barstow and Haug (1994a) occurred during Cyclone Joni, with a significant wave height (H_s) of 7.20 m, and peak spectral period (T_p) of 10 s.

Nearshore waves: Deep water waves impacting on the reef systems of Viti Levu will break and dissipate their energy. However some of this energy reforms across reef flats. Furthermore, wave generation inside the reefs at Laucala Bay and Suva Harbour is limited by fetch, which is typically restricted to less than 5 km. Deep-water waves break on the reef crests. According to (Commonwealth Dept. of Transportation and Construction and Caldwell Connell Engineers (1982 - cited in Dickie et al. 1991) typical trade winds in Laucala Bay of 8 m generate waves of 0.4 - 0.6 m height and 2 - 3 s periods, while stronger winds of 17 m s^{-1} generate waves of 0.8 - 1.3 m height. Hindcasts of waves at Lami indicate a very mild wave climate with a 10-year return period for waves of 0.5 m and a maximum cyclone-generated wave of 1 m (Dickie et al. 1991).

4.1.8 Storm surge in Suva, Laucala Bay, Rewa and Nausori

Storm surges are increases (or decreases) in the instantaneous water level as a result of factors other than tides and other seasonal water-level changes. They are caused by a combination of changes in atmospheric pressure, winds and waves acting on basin geometry, and local factors such as flooding from rivers.

Low pressure systems can promote storm surge. Typically for every millibar fall in atmospheric pressure the water level can rise up to 1 cm. This produces super-elevated water levels upon which wave action and associated run-up can overtop low-lying parts of coastal land causing flooding and destruction to infrastructure.

Carter (1990b) reported that for Suva, the mean pressure in January is 1010 mb and a pressure of 950 mb is expected once every 10 years as a result of cyclone activity. Thus, there is a 60 mb pressure differential with an anticipated 60 cm barometric surge.

Storm surges are also influenced by wave activity; this phenomenon is called wave set-up (Gourlay, 1993). It can contribute significantly to water levels and there is considerable uncertainty in the literature as to its magnitude in tropical reef and lagoon environments. Wind set-up also occurs as the wind pushes against the sea surface over shallow water.

Thus, the storm surge at the shoreline is a combination of barometric pressure, waves (generated both outside and inside the Harbour) and wind. The storm surges measured at the Suva tide gauge were examined by Solomon and Kruger (1996)

Eleven surge events were identified by Solomon and Kruger (1996) from analysis of the UHSLC water level records (Table 4.2). All but one of these events can be related to cyclones.

Table 4.2. Storm surges at Suva

Cyclone	*Day*	*Year*	*Surge re: LMWL (m)*	*Carter (m)*	*Pressure (mb)*	*MWL re: cd (m)*
Fay	1 March	1978	0.198	0.180		0.880
Meli	27 March	1979	0.153	0.280		0.885
Arthur	16 Jan	1981	0.163	0.550	999	0.930
Oscar	1 March	1983	0.214	0.568	983	0.896
Gavin	7 March	1985	0.323		993	0.966
Hina	18 March	1985	0.246		993	0.966
Rae	24 March	1990	0.300		993	1.038
Sina	29 Nov.	1990	0.187		986	1.038
Unnamed	21 April	1992	0.220		1001	1.024
Fran	10 March	1992	0.140		1000	1.024
Kina	4 Jan	1993	0.433		973	1.020
Unnamed	26 March	1994	0.213		999	0.997
Val	1 Jan	1975		0.320		
Betty	5 Apr	1975		0.320		
Bebe	24 Oct	1972		0.260*		
Lottie	9 Dec	1973		0.110		

NB: According to Blong and Assoc. (1994) Cyclone Bebe resulted in the evacuation of Kinoya Village on 23 October 1972 because of surge related flooding. Eric and Nigel Jan 1985 the tide gauge broke at beginning of surge (maximum observed surge before gauge broke = 0.225ttz). LMWL - local mean water level (observed WL around the surge period). Note that the mean water level as defined by Lands & Surveys is, 0.96 ni above chart datum, cd, used by hydrographers). Differences between Carter's estimates and Solomon and Kruger are attributed to different constituents used.

Based on the storm surge data presented in the previous table, the maximum storm surge recorded at the Suva tide gauge is approximately 0.4 to 0.5 m above the predicted water level. The relation between the surge and the peak wind speed is variable.

However, during Gavin and Kina (responsible for the two largest recorded surges) the wind/surge relation was very obvious. Rainfall accompanying Kina (260 mm at Nausori) produced severe floods on the Rewa River. The surge preceded the peak flood by 24 hours. The lowest pressure measured during Kina's transit of Viti Levu was 949.5 mb at Yasawa-i-rara and 972.3 mb, measured at Laucala Bay. The pressure-related surge could have been responsible for a 30-50 cm rise in water level itself.

Based on the sample of cyclone-induced storm surges presented above, it is possible to evaluate the return interval for various water levels at the Suva tide gauge. The method used was developed by Beard (1952 - as cited in Carter 1990b) and was used by Carter (1990a and b) to estimate storm-surge return intervals and to calibrate his design water level calculation.

Based on 20 years of water level records, Solomon and Kruger (1996) calculated the return period for storm surge (Table 4.3).

Table 4.3. Return intervals for storm-surge heights at the Suva tide gauge

Return Interval	Surge height (m)
1 year	0.13
2 year	0.28
5 year	0.48
10 year	0.63
25 year	0.83
50 year	0.98

Carter (1990b) and Nunn et al. (1994) estimated that storm-surge elevations in Suva and the Laucala Bay (as a result of wave set-up and barometric tide) are 1.1-1.2 in. This increase is more than two times the surge developed and recorded at the Suva gauge during Kina, which, based on a sustained wind speed of 45 knots and a minimum pressure of 972 mb, has a return period of 3-8 years. For a return period of 50 years, both reported a water level of approximately 3 m relative to chart datum (or 2.04 m relative to mean sea-level).

During high-water events at Nausori, water levels of more than 7 m have been measured (Raj and NSR Consultants, 1995). However, there should be considerable spreading of the flood waters in the lower delta mangrove region.

Obviously, water will continue to flow out of the Bay during floods, but the higher base level caused by storm-surge-induced sea-level rise could impound more water than at times of lower water level. The effects would be most pronounced along the Laucala Bay coastline.

4.1.9 Cyclones and their effect on the Viti Levu coast

Fiji lies in an area normally traversed by tropical cyclones mostly during the November-April wet/cyclone season. The following table summarises those cyclones passing through Fiji between 1961-1990.

Table 4.4. 1961-1990 Cyclone records

TYPE	PERIOD	FACTORS
Hurricane	6-7/12/64	Near hurricane force winds
Hurricane	21/12/64	Torrential rain; flooding; landslides
Hurricane	6-9/02/65	Heavy rain; flooding; landslides
Hurricane	9-10/4/67	Near hurricane force winds
Hurricane [Bebe]	23-29/10/72	Widespread flooding
Hurricane [Lottie]	9-10/12/73	Hurricane force winds
Hurricane [Val]	31/1-2/2/75	Hurricane force winds
Hurricane [Betty]	5-6/475	Tornado
Hurricane [Bob]	4-5/1/78	Possible tornado
Storm [Fay]	29-30/12/78	Flooding; storm surge
Hurricane [Meli]	26-28/3/79	Storm surge; landslides; flooding
Storm [Tia]	24/3/80	Flooding; storm surge; landslides
Gale [Wally]	3-5/4/80	Flooding; landslides
Hurricane [Arthur]	13-16/1/81	Flooding
Hurricane [Oscar]	26/2-3/3/83	Torrential rain; flooding; storm surge
Hurricane [Sarah]	25-28/3/83	Storm to gale force winds
Hurricane [Eric]	14-19/1/85	Flooding
Hurricane [Nigel]	16-20/1/85	Storm surge; flooding
Storm [Gavin]	3-8/3/85	Torrential rain; flooding; landslides
Storm [Martin]	10-13/4/86	Flooding
Hurricane [Raja]	22/12-1/1/87	Flooding; landslides; storm surge
Hurricane [Bola]	25/2-4/3/88	Gale force winds
Storm [Rae]	16-25/3/90	Torrential rain; flooding
Hurricane [Sina]	24-30/11/90	Storm to hurricane force winds

Cyclones consist of large circular depressions which can be hundreds of kilometres in diameter and generate high winds. The combination of the low pressure and high winds creates elevated water levels which are highest immediately to the left of the track of the storm. Extremely high rainfall, of several hundred millimetres in a day and winds of more than 40 m s^{-1} are common in Fiji (Solomon and Kruger, 1996).

Most cyclones which affect the SW Pacific and Fiji are spawned in the Inter-Tropical Convergence Zone during November to April when the convergence zone is between 10° and 15° S (van Loon, 1984 and Fenney, 1989). Cyclone production is dependent to some extent on sea-surface temperature, which suggests that ENSO events and global temperature changes could increase their frequency, intensity and location of formation.

A total of 73 cyclones have occurred in the past 57 years, with an average of 1.28 cyclones/year. This is significant activity for Fiji and the south Pacific, as historical data (U. S. Navy, 1996) shows that the highest concentration of cyclones in the south Pacific are found in the Fiji's territorial waters.

Examples of Cyclones and Characteristics:

- Cyclone Raja (1986). Generated waves (Hs) 8-9 m, Winds reached 11 on Beaufort Scale, maximum winds 70-75 knots;
- Cyclone Bola (1988). Significant wave heights of 5m;
- Cyclone Joni (1992). Significant wave height to 7.2 m and peak wave period a little under 10 secs. Waves promoted erosion, crop damage was noted after this event.

4.1.10 Case study area: Suva Peninsula and Rewa delta

The Suva Peninsula is the largest and most populated urban area on Viti Levu. It is on the south side of the island, adjacent to the Rewa River delta (to the east). It consists of the urbanised zone from Vatuwaqa on the east side of the peninsula to the Royal Suva Yacht Club (Korovou) on the west, an area with a coastline 18.6 km long. This area includes the downtown core of Suva along with the associated infrastructure of buildings, wharves, port and harbour facilities and tourist facilities.

The area of the peninsula likely to be subject to the direct effects of rising sea-level is land with elevation less than 5 m above Mean Sea Level (MSL). On the Suva Peninsula this is approximately 8.7 km^2 (870 hectares; Solomon and Kruger, 1996).

To the east of the peninsula are the Rewa Flats, more than 200 km^2 of alluvial deposits, which are generally less than 2 m above sea-level. Higher terraces exist at Nausori and other areas. The delta is still actively accreting with most sediment presumed to be deposited close to the mouths of the distributaries, or if suspended, it may be carried westward by the southeasterly tradewinds to be deposited in Suva Harbour.

The core of the Suva is laid out on the west side of the peninsula along a narrow fringe of low-lying, reclaimed land at the base of the steep faulted ridge which rises to an elevation of about 70 m. More modern buildings have been built along the narrow, low coastal fringe at elevations of less than 5 m above present sea-level, often on reclaimed land which has been built out over the shallow nearshore reef flats. At least 110 hectares (about 13%) have been reclaimed since 1881.

Suva has virtually no unmodified coast. More natural coastlines are found to the east (Rewa Delta) and extend to the border of Lami town (to the west).

Suva Harbour and Laucala Bay are protected by an extensive barrier reef. This reef rises steeply from more than 200 m water depth. At Suva Harbour, the reef varies from 0.5 km to more than 2 km in width and is 10 km long. Vuki (1994) and Solomon and Kruger (1996) document natural and anthropogenic stress on the reef.

Surveys performed as part of this study show that the reef-crest height varies considerably along the length of the reef, from 0.26 m to 0. 5 m above mean sea-level. The higher crests would be locations of wave refraction and would tend to concentrate wave energy resulting in larger waves and higher wave set-up and run-up (and therefore a slightly higher local mean sea-level and greater tendency for immersion than adjacent areas).

The lagoon behind the reef varies from about 3 km wide in the harbour area to less than 250 m wide off Suva Point.

A narrow fringing platform is present along the edges of parts of the Suva Peninsula except where large streams exit and where it has been covered as part of land-reclamation projects. Laucala Bay is characterised by intertidal sand and silt flats on its western and southern boundaries.

To the East barrier reefs and back-reef lagoons front the Rewa Delta. Several large reef openings allow significant wave energy to enter the lagoon. The beach at Matai-i-Suva directly faces one of these large openings and large waves can impact on it. Fringing coral reefs are uncommon along the delta front due to the large influx of fresh water and silt. Mangroves are extensive around the Suva peninsula, and the Rewa Delta hosts one of the two largest mangrove areas on Viti Levu. Sand is deposited at the mouth of the main Rewa distributary channel (Armstrong, 1993).

4.2 Effects of climate change and sea-level rise

4.2.1 Current coastal hazards

Shoreline erosion

Under the current sea-level regime, erosion has been reported in numerous locations throughout Fiji (Mimura and Nunn, 1998). Of the 29 villages surveyed by Mimura and Nunn (1994) 27 were reported to be experiencing shoreline erosion problems. In particular, Nukui Village (located at the mouth of the Rewa River) and Nabila Village (West Coast) have experienced significant shoreline retreat (15 - 20 m) over the past few decades. This erosion is attributed to the loss of mangrove that fringes the coast providing a protective buffer to incident wave energy.

Inundation

Inundation is also experienced during super-elevated water level events (cyclones, tropical depressions and high wave events).

Solomon and Kruger (1996) calibrated a simplistic, one-dimensional spreadsheet model for storm surge using existing tide gauge data, and predicting water levels at a range of sites of known elevation under a variety of storm conditions and water levels. Using the resulting water-level estimates, maps have been produced which show the location of overtopping based on the surveyed elevations. The overtopping estimates are simply based on rise of still water level and do not include the effects of waves, splash and run-up.

Water levels were estimated at a range of sites throughout the study area and calibrated using conditions generated by Cyclone Kina. At present sea level, the area from Korovou to Stinson Parade (encompassing most of the downtown) is elevated sufficiently so flooding will not occur under most storm conditions. West of the primary study area (towards Lami), overtopping of seawalls and shorelines will occur during most storms. On the southern tip of the Suva Peninsula (Nasese and Suva Point) flooding occurs along the lower-elevation shoreline and protection structures during most storms, but does not overtop the higher portions of the protection. On the east coast of the Suva Peninsula, the lower elevation shorelines are overtopped during all storms, and the mean and higher elevations are overtopped during the more severe events (e.g. 10-year events).

In the eastern portion of the Suva area, overtopping of the mean elevations occurs during all storm events and the highest elevations are overtopped during the most severe storms.

Ecosystem degradation

Mangroves: **A** study by Watling et. al. (1994) revealed that 6% of the mangrove population has disappeared as a result of human activities, paving the way for expanding development projects, agricultural land, infrastructure, residential sites, and even domestic fuel consumption.

Coral Reefs: As noted earlier coral reefs in Fiji are already subject to a number of anthropogenic (mining, over fishing, elevated nutrient levels) and natural stresses (e.g. bleaching). These stresses compromise the ability of the reefs to cope with additional stressors, such as climate change.

4.2.2 Impacts of climate change on the coastal environment of the Suva Peninsula and Rewa delta

Solomon and Kruger (1996) conducted an assessment for Suva peninsula. The following analysis is based on their assessment, of the effects on sea level rise for that area.

Drainage

In low-lying parts of the Suva Peninsula coast, rising sea level will raise water tables and affect the efficiency of in-ground septic systems and sewer pumping systems. The septic systems in the Beach Road area are already problematic in this regard and plans to replace them should proceed without delay. Groundwater is not used for drinking in the primary study area so that while salinisation of freshwater supplies could occur, it will not affect drinking-water supplies.

Shoreline erosion

Increases in water level will decrease the area of low ground around Viti Levu. This includes mangrove and adjoining low coastal plains and river mouth areas. Since this represents a large percentage of Viti Levu's coastline (86%), this is of serious concern. While all low ground is not populated, cultivated or industrialized, the 23% which is will be affected by rise in water levels. [At best current rates of erosion can be expected to continue into the future]. However, it is likely that the rate of erosion will accelerate as water level rises.

Inundation

Most of the study area has been protected by seawalls and revetments and it is inappropriate to use the Bruun rule of erosion (Bruun, 1983) to assess the changes linked to sea-level rise. In addition, sediment budgets in the area are a function of the combined inputs of terrestrial material and reef-derived detritus. The effects of rising sea-level on productivity of reef-derived sands and their movements have not yet been investigated. While the amount of material contributed to the beaches at Nasese and Suva Point from the sandy foreshore is not known, the carbonate content is currently much smaller than the terrestrial.

A rising base level due to sea-level rise will tend to trap more coarse sandy terrestrially derived material in the small estuaries at the river mouths. This suggests that a decrease in terrestrial sediment supply would accompany the slightly higher wave energies associated with higher relative sea-level, and one would expect an increase in the rate of erosion. More importantly, erosion and decreased sediment supply at the bases of seawalls and other shore protection will increase their rate of degradation and result in the need for more frequent repairs and the risk of catastrophic failures during extreme events.

The shoreline at the Rewa Delta has been described primarily as accreting, with localised rates as high as 20 m a^{-1} (east coast of Laucala Island). Under rising sea-level scenarios (average and worse case IPCC predictions), it is unlikely that erosion will replace accretion in these locations, however, the rates of accretion may decrease if sediment supply is diminished by flow deceleration due to the rising base level. This could cause increases in the sedimentation rates within channels. Currently planned river flood hazard mitigation will require re-evaluation if sea-level rise affects in-channel sedimentation rates, resulting in increased frequency of dredging and higher flood levels.

Erosion may be a problem at Nukui village where seawalls have been built on the beach. Here, the sand terminates at the low tide platform which consists of dead coral. Sand is supplied to the beach in front of the village from the small distributary channels to the east, and to some extent from the west during infrequent westerly winds and southerly swells entering through a large reef opening. Larger waves will be able to affect the shoreline under increased sea levels, but the incremental increase in wave height will be small (only a few cm) as compared with the increased water level.

Estimates of changes in the coastline arising from sea-level rise require more information on sediment transport pathways. However, the changes in the likelihood of flooding are probably a greater concern.

Flooding frequency and extent

Considerable emphasis was placed on attempts to evaluate the effects of sea-level rise on storm-surge elevations in the study area by Carter, (1990b) and to estimate the effects of sea-level rise on water levels at the Suva port facilities (Nunn et al., 1994). Solomon and Kruger (1996) extend this work using their simplistic, one-dimensional spreadsheet model for storm surge. Using water-level estimates, maps have been produced which show the location of overtopping based on the surveyed elevations. The overtopping estimates are simply based on rise of still water level and do not include the effects of waves, splash and run-up. (See **Annex C2.)**

Water levels were estimated at a range of sites throughout the study area and scenarios for future sea levels of 0.25 m, 0.5 m and 1 m above present were used. These values closely correspond to the scenarios outlined in Chapter 3.

Case 1 – 0.25 m rise: Overtopping of the shore protection in the downtown core of Suva will occur only during the more extreme events and, even then, the higher-elevation structures will be above the still water rise (though susceptible to run-up and splash).

Outlying areas will be flooded with increasing frequency, assuming that storm frequency and severity remains constant. It should be noted that Nukui village, at the Rewa Delta front, is susceptible to flooding under present sea-level conditions on a regular basis and will be severely affected by rising sea levels.

Case 3 – 1.0 m rise: Under the more extreme sea level rise scenario of 1.0 m, the area of Suva Point and east will be flooded during most cyclone events, and even the downtown core will be susceptible to flooding during moderate cyclones. As sea level rises, the frequency of overtopping from an event of a particular magnitude will increase. Essentially, the 25-year event under present SL conditions will become the 5-year event if sea-level rises by 0.5 m.

Vulnerability of the various sectors of the city to overtopping of the shore protection by storm surge is a function of the elevation of the protection relative to predicted still water level. An index of this vulnerability can be calculated based on the severity of the storm required to raise the water level over the mean elevation of the shoreline in that sector. If a 2-year storm can overtop existing coastal protection, that is an indication of high vulnerability, whereas an inability of a 50-year storm to overtop indicates a much lower vulnerability.

Four water-level scenarios (including the present) and 5 storm return intervals were considered. A site, of which the mean elevation is less than the least severe storm under present water level conditions, will be subject to overtopping for each of the 20 combinations of storm and water level. Conversely, a site, for which the elevation exceeds even the most severe storms under the highest predicted water levels, would have a score of zero overtopping. Dividing by the number of scenarios (4) gives an index which is the average number of potential flood events per scenario from 0 to 5, and thus an index of vulnerability. While somewhat biased towards the effects of sea levels higher than present, this method does indicate the relative degree of vulnerability to flooding due to storm surges.

The downtown area and the present port facilities are relatively well protected while the outlying areas are much more exposed. Not including the higher sea level scenarios would not change the ranking of the various locations because the height of the shoreline and associated structures will determine that. This method of determining overtopping vulnerability does not take into account the degree of overtopping which has major implications for flooding, since a structure which is overtopped by 1 m will be associated with significantly more potential flooding than one which is only overtopped by 0.1 m.

A second approach by Solomon and Kruger (1996) made use of the GIS capabilities. They mapped the average height of the shoreline and showed the location of the overtopped shore protection structures for each sea-level scenario for the 5-year return-interval storm surge. They also indicated the location of the damaged shore-protection structures. This method allows the identification of zones which are both vulnerable to overtopping and susceptible to additional damages. By examining the relation between the location of overtopping and disposition of the already damaged sea walls, it was possible to better allocate scarce resources to high-priority locations. (See **Annex C2.)**

The natural terrestrial coastal ecosystems in the vicinity of Suva have been drastically affected by urbanisation and are therefore not considered to be particularly vulnerable to the effects of sea-level rise. Mangroves in the primary study area are generally considered to have little value within the city and most have been slated for reclamation, so that retreat of the mangroves shoreward is not a major problem.

In the Rewa Delta front, considerable changes are anticipated which involve shoreward translation of the whole mangrove ecosystem. This will only occur in locations which are in an equilibrium condition with respect to environmental conditions, or already retreating. Where sediment supplies are sufficiently large, sedimentation and mangrove advance may still occur. Changes in the structure of the mangrove environment may also affect the abundance and diversity of the flora and fauna and thus may affect the nursery function upon which many fish species depend.

While rising sea levels will put landward-directed pressure on all species, the amount of movement is uncertain given the lack of elevation control and uncertainty as to the tolerance of the species to more prolonged submergence related to high sea-level. Equally important is the impact on lands used by villages for cultivation of cassava, taro and fruits such as papaya. Higher water levels with associated more frequent flooding and rising salinity in the water tables will reduce fertility.

4.2.3 The impact of climate change on coral reefs

El Nino Southern Oscillation (ENSO) events bring lower rainfall and increased sea-surface temperature (SST). It would be essential to undertake a correlation between ENSO events and coral bleaching, diversity and population shifts.

Increase in SST will cause significant changes in natural coastal systems. How the natural systems respond to these changes is not known at this time. It has already been noted that coral bleaching is evident in Fiji coastal areas. This is likely to increase with an increase in SST. The effects of this are damage to natural reef protection along the coastline, decrease in carbonate sediment budget for the coast, and ultimately, increase in erosion of lagoon and beach systems around the island. The specific alteration of erosion patterns will also be dependent on the response of the system to temperature increase (whether steady state or non-steady state) and the hydrodynamic alteration of coastal areas. That requires specific data analysis supported by dynamic modeling of the natural/existing environment. Since data are not available at this time, further comments on these aspects cannot be made.

The response of the reef surface to sea level rise has significant implications for morphological changes in shoreline position. Alteration to reef productivity impacts on the availability for sediment for reef islands and island beaches, and the elevation of the reef platform controls the level of wave energy impacting on the shoreline.

Geological studies show that historical rates of reef growth fall within projected rates of sea level rise, therefore, reef growth is capable of keeping pace with water level increases (Emery et al., 1954; Woodroffe and McLean, 1992). For example, the Tarawa reef flat accreted at a rate of 8 $mm.y^{-1}$ during the Holocene which falls well within the range of future projected sea level rise (Marshall and Jacobsen, 1985). This has prompted some commentators to suggest that current projected rates of sea level rise will not have widespread adverse effects on coral reefs (Nurse et al., 1998). Most contemporary reef flats have attained an equilibrium (vertical) position with respect to stable sea level over the past 2 — 3 000 years. Consequently, the productivity of these reef flats has declined with reef growth being largely horizontal in the recent past. Increased water level provides new space for vertical growth of corals at the upper regions of coral growth (Hoegh-Guldberg, 1999). Therefore, there is the potential to stimulate reef growth (Hopley and Kinsey, 1988) and in this sense sea level rise may be beneficial to reef systems.

However, recent studies have indicated that physiologically a number of coral species may struggle to adapt to warmer mean water temperatures, increased bleaching episodes associated with ENSO events and increased CO_2 concentrations in the atmosphere, all of which will inhibit the growth rate and calcification capacity of corals and reefs (Buddemeir, 1998, Hoegh-Guldberg, 1999). Coral bleaching is an important climate-related phenomenon that can lead to significant losses to coral reefs. Ideal SST conditions for coral growth and survival range between 25-29°C. Bleaching generally occurs as a result of prolonged temperature-related stresses, normally when the SST rises to 30 °C or more for a period of 10 weeks. *Zooxanthellae,* the main food source for corals, is expelled thus diminishing its food supply. Moreover, Hoegh-Guldberg (1999) suggests that changes in coral reef community structure may result with faster growing species (e.g. *Acropora sp.),* less able to cope with environmental stresses, being replaced by slower growing but more tolerant species (e.g. *Porites sp.).* Such a shift may further compromise the ability of reefs to keep pace with sea level.

Given these apparently conflicting arguments what can we conclude about likely reef response and sediment production in the Pacific?

Scenario 1 – Healthy reef response: For reefs to vertically accrete reef building organisms must increase their productivity. As noted earlier there are a number of anthropogenic stresses that have affected the health of reefs in Fiji. Based on analogues of the recovery of cyclone damaged reefs it is estimated to take between 40 and 80 years for reef surfaces to reach a viable level of production to support vertical reef accretion (Hopley and Kinsey, 1988; Harmelin-Vivien, 1994; Connell, 1997). A distinction must be made between calcification of individual coral colonies, which can be as high as 20 cm per year for branching species or as low as 1 cm per year for massive slower growing species (e.g. Porites, Done, 1999), and vertical reef flat accretion, which is one-to-two orders of magnitude less than coral colony growth.

The lag time for reef flat surfaces to expand their production will be dependent on the initial condition of the reef. Healthy reefs are expected to respond the fastest and may be able to match rates of sea level rise within 50-80 years. Changes in coral calcification and survivorship are also likely to increase the lag period for vertical reef growth.

Therefore, it is expected that the reef response will lag sea level rise by a minimum of 40 years. This lag will promote increases in water depth over the reef surface. Consequently, a `high energy window' will develop in which greater wave energy is able to penetrate across the reef surface and effect island shorelines promoting more active shoreline erosion. In situations where the reef can respond rapidly the high energy window will be small and is expected to close soon after sea level stabilises.

Changes in sediment production (available for island building) are also related to reef productivity. As reefs vertically accrete they retain a high proportion of calcified material in the reef matrix. In contrast, and as identified in the mid-late Holocene, when reefs attain their maximum vertical height in relation to sea level excess calcification is shed from the reef system as sediment, available for island building and lagoon infilling (Kench, 1998). Consequently, as sea level rises and reef flats respond by increasing productivity their is expected to be a decline in sediment production, as calcified products are required for vertical reef accretion (Kench, 1994). The reduction in sediment availability will continue until sea level once again stabilises and the reef flat reaches its maximum vertical growth position, at which time a large pulse of sediment may be generated. The reduction in sediment produced may be partially offset by the increased area of reef flat under production and increased occurrence of storms that can deliver materials from the forereef to the reef system.

Scenario 2 - Poor reef response: The worst case scenario is that reefs are unable to respond to increased water level. This may occur due to:

1. Heavily degraded reefs near centres of high population density being unable to recover due to excessive anthropogenic stress.
2. Increased frequency of bleaching episodes with insufficient recovery intervals to allow reef recovery and growth.
3. A combination of the above together with high sediment and freshwater discharges under increased rainfall.

In situations in which coral reefs do not respond to increased sea level there are a number of consequent impacts:

1. Possible depletion and collapse in reef associated artisanal fisheries (where corals become servely degraded).
2. The reef is unable to act as such an effective buffer to wave energy and storm surge. This will promote increased frequency and magnitude of waves, storm surge accelerating shoreline erosion and increasing the risk and area of flooding of low-lying areas.

4.3 Adaptation

The range of possible adaptation strategies to combat the anticipated impacts of sea level rise are discussed below. These adaptation strategies can be divided into those that try to better understand impacts and those that prescribe techniques to combat actual problems.

4.3.1 Improved understanding of the coastal system

- There is the need for adaptation technologies for assessment of the characteristics and vulnerabilities of Fiji's coastal systems to sea level change. This is extremely important, in light of the paucity of data on coastal changes in the present and factors influencing the dynamics of present day systems. This exercise is essential for the formulation of dynamic site and island-specific adaptation strategies. This includes instrumentation and monitoring systems. Some of these include tide gauges, wave gauges, current meters, salinometers, sediment traps and instrumentation devices. In some government department, where instrumentation do exist, data collection exercises and monitoring programs should be set up to assess coastal dynamics. Historical shoreline change and current spatial and temporal dynamics should be investigated.

- Detailed habitat mapping and assessments must be performed in conjunction with monitoring and instrumentation exercises. This will facilitate the formulation of optimum adaptation options for specific lengths of coastline.

4.3.2 Practical actions to reduce impacts

- For low lying, coastal communities and villages along coastal strips and in reclaimed areas, there is the need to examine various coastal protection options (including indigenous, structural and bio-engineering) for reducing the erosion risk to coastal communities. Coastal protection strategies will reduce some of the deleterious impacts of wave erosion, storm surges and structural damage by high seas and storms. However, for future development in low ground, land use and planning policies will need to be revised to discourage development in these high risk areas. From the point of view of reducing risks to communities and protection of investments, this aspect must be part of a national strategic plan for reducing deleterious impacts of sea level rise on the national economy.

- In light of the deleterious impacts of rising SST and storm frequency on coastal and marine ecosystems, there should be measures put in place to protect natural coastal ecosystems, as they are important natural protection for island systems against extreme oceanographic phenomena. Of paramount importance is mangrove and reef protection. Both these systems already show signs of deterioration due to human modification of their natural conditions and exploitation for commercial purposes. In addition, reefs of Fiji also show sign of bleaching due to elevated SST over the past decade. If these systems are not managed properly and preserved, and deteriorate in the short or long term, then the risk to adjoining coastal communities will increase. It is important, therefore to limit mangrove degradation, destruction and loss.

- For optimum coastal ecosystem preservation and management, there should also be adequate pollution control from industrial and residential areas. Organic pollution of coastal ecosystems, in particular reef communities can cause deterioration of the health of reefs, eventually killing coral species. If reefs are damaged and die, then the natural protection afforded to the coastline is removed, causing increase in erosion of beach and lagoon systems. Reduction of coastal pollution can be achieved by optimizing waste water treatment facilities at industrial and municipal facilities/sites. Reduction in suspended and dissolved solids would be highly desirable.

- The impacts of reef damage by pollution can be disastrous in insular countries like Fiji, since reefs are the main buffer between the harsh open-ocean conditions and small island systems like Viti Levu. Without reefs, small oceanic islands will be ravaged by normal sea state and storm conditions. This is already evident is many Pacific small island sates, including Fiji, where reefs fringing islands are small and are isolated pinnacles and where pollution of reefs are also evident.

- To enhance reef ecosystems, artificial reefs can be explored as a means to enhance coastal protection and increase the benthic communities in present reef sites. Artificial reefs can also act as fish aggregation devices and increase the local fisheries on reefs. As these systems become colonized with benthic dwellers, including corals, they will increase the productivity of reef communities in the local areas and act as coastal protection structures for adjacent shorelines.

- Alternative sources of construction aggregate should be sources for construction activities. In Viti Levu there is much sand and gravel mining in nearshore areas. These also impact on reef communities and cause damage to and loss of benthic dwellers and pollution among other impacts. Onshore sources of construction aggregate should be explored, as this is also a viable option for Fiji.

- There should be a reduction of reclamation activities in mangrove systems and discouragement of development (residential, agricultural and industrial) at of near the water line. This will effectively reduce the risks associated with coastal developments. This strategy can be pursued as some form of a national policy statement on land use planning and zoning for the next millennium.

- Where possible, buildings should be set back from the water line. There should also be minimal development in areas of low ground. Again, this strategy can be pursued as some form of a national policy statement on land use planning and zoning for the next millennium. "Building with nature techniques" should be explored, e.g. re-vegetation of bare or deforested coastlines with indigenous plant species.

- The cutting of mangroves should be discouraged, as these serve as an important form of natural coastal protection. National policies should be revised and incorporated which should minimize this activity.

- Mangrove rehabilitation projects can be actively pursued, with benefits similar to artificial reefs. These will increase shoreline protection, increase local fisheries and stabilize fine sediment/muddy coasts. This activity should be pursued only in areas, which are flat, low-lying and have supported this type of vegetation in recent years (but which have now been removed by human activities).

- At this time, structural or bio-engineering engineering measures for coastal protection, against sea level rise, along Fiji's and Viti Levu's coast cannot be specified. This includes the specific structural types, their dimensions and quantities. This is due to the fact that engineering measures are technical specifications, designed and built to specific environmental boundary conditions, and with some degree of tolerance appropriate for a specific design life (which varies depending on the problem, the site, finance and engineering material amongst other variables). Until site specific data and coastal boundary conditions for Viti levu have been collected and assessed, this aspect cannot be pursued.

- There is a need to regulate and control all fisheries within the artisanal-fisheries zone, based on the principles of optimum utilisation and long-term sustainability.

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5 Water resources

5.1 Overview of sector

As in any other country or nation, water is an all-round important commodity in terms of its significance and role in maintaining sustenance both physically and socio-economically. Fiji's current water resource is mostly derived from surface water run-off. Dependency on groundwater is restricted mostly to either low-lying areas outside the distribution systems, outer islands and other remote rural areas.

For the reasons noted under the headings below, Viti Levu is a suitable study area for examining the effects of climate change on the water resources of Fiji:

1. West side of the island

- the west side of the island is located in the drier part of the country which is greatly affected during droughts;
- there is a high economical significance of the assets located within the western area (such as the hotels and resorts, industries, sugar mill and expanding commercial enterprises);
- in the west are located Lautoka, the second largest city in Fiji, and Nadi the major tourist centre;
- good rainfall and stream flow data are available for a number of different rivers in the west.

2. East side of the island

- the east side is drained by the major river system of the Rewa;
- the east side has a distinctly wetter climate, facing the prevailing south east trade winds, and is therefore also prone to problems of river flooding in the wet season.

5.2 Present climate, hydrology and vulnerability

5.2.1 Rainfall

Generally, rainfall in the western division ranges from 1500mm/year to less than 2500mm/yr. As shown below, average annual rainfall from 1961-1990 for the two rainfall stations — representing the Nadi-Lautoka zone [Nadi Airport & Lautoka AES]; range from 860mm/yr to 3520mm/yr.

Table 5.1. Average annual rainfall (mm) from 1961-1990

Year/ Station	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Nadi Airport	2041	1759	2040	2115	1893	1413	1653	1676	863	2053
Lautoka AES	2911)	1654	2139	2051	1949	1064	1809	1627	896	2256

Year/ Station	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Nadi Airport	2164	1830	2077	2984	1989	1601	1802	1170	1787	1563
Lautoka AES	2455	1885	2261	3522	1669	2116	1765	1169	1695	1627

Year/ Station	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Nadi Airport	2144	1889	1323	1740	1892	2011	998	1979	2348	1498
Lautoka AES	2140	1822	1224	1463	2203	1926	956	2089	2551	1728

5.2.2 Tropical cyclones

Tropical cyclones are regular phenomena in Fiji. The following table highlights cyclones occurring between 1961-1997, with notes on areas affected and damages sustained.

Table 5.2. Record of tropical cyclones affecting the western division from 1961-1997

Period	**Nature of Disaster**
6-9 Feb, 1965 [Hurricane]	Some food crops ruined; many dwellings destroyed; severe flooding on main island caused heavy stock and crop losses; 12 deaths
23-29 Oct, 1972 [Hurricane **BEBE]**	Severe flooding in Viti Levu; extensive damage to infrastructure and root crops
5-6 April, 1975 [Hurricane BETTY]	A small tornado caused some damage in Yako village near Nadi
4-5 Jan, 1978 [Hurricane BOB]	A possible tornado demolished several houses in Sabeto, near Nadi; 1 death
3-5 April 1980 [Gale WALLY]	Flooding in all coastal villages of Viti Levu; several fatal landslides; extensive damage to main highway; considerable loss of livestock and crops; 2 missing and 14 deaths
13-16 Jan, 1981 [Hurricane ARTHUR]	Considerable damage to infrastructure; disruption to communication in some places
26 Feb-2 Mar, 1983 [Hurricane OSCAR]	Severe flood damage in towns in Viti Levu; widespread damage to dwellings and infrastructure, livestock, forestry and vegetation; disruption to water and power supply and communication; considerable coastal erosion; 9 deaths; loss estimated
14-19Jan, 1985 [Hurricane ERIC]	Destruction of villages, buildings, Nadi Airport hanger and other infrastructure; disruption of power supply, radio reception to the western Viti Levu, communication and water supply in some places; damage or destruction to forestry; crops and livestock loss due to flooding; 25 deaths; total damage estimated at F$40 million
16-20 Jan, 1985 [Hurricane NIGEL]	3 metres high storm surge at Yasawa and Viwa; substantial damage to buildings, communications, roads and coastal installations

3-8 Mar, 1985 [Storm GAVIN]	Severe widespread flooding; damage to power and communication lines, crops and vegetation; closure of several roads, bridges and both main airports due to flooding; 3 deaths; 7 missing; total loss estimated to F$lmillion
25-4 Mar, 1988 [Hurricane BOLA]	Only crop damage especially sugarcane and pawpaw; 6 presumed drowned
16-25 Mar, 1990 [Storm RAE]	Flash flooding in most parts of the country; severe flooding in Ba and Nadi towns; closure of roads and bridges; disruption to air and sea traffic, power and water supply; 3 deaths
24-30 Nov, 1990 [Hurricane SINA]	Damaged houses and buildings; power and telephone lines, crops and vegetation, sugar and pine plantations; total loss estimated to F$26 million
6-13 Dec, 1992 [Hurricane JONI]	Significant structural, crops and vegetation damages; huge loss of livestock due to flooding; 1 death; total loss estimated to F$1.5 million
26 Dec-5 Jan, 1992/93 [Hurricane KINA]	Extensive flooding in major rivers; destruction to Ba and Sigatoka bridges; major disruptions to transportation between eastern and western divisions; severe landslides; huge loss of crops and livestocks; significant infrastructure damage; 23 deaths; total loss estimated to F$170 million
4-11 Mar, 1997 [Hurricane GAVIN]	Considerable damages to infrastructure; severe flooding in Labasa and western Viti Levu; major destruction to sugarcane and other food crops plantation; 10 drowned; 2 deaths; 6 missing; total loss estimated to F$33.4 million
3-5 May, 1997 [Gale JUNE]	Damages to crops and infrastructure; total loss estimated to F$1 million

Source: Fiji Meteorological Services

5.2.3 Tropical cyclone impacts – Case study of TC Gavin and TC June in 1997

In early 1997 two tropical cyclones struck the Fiji Islands in two months, bringing high winds, heavy rainfall and river flooding. Cyclone Gavin was the first tropical storm in the 1997 wet season, lasting from 4th to 11th March (Fiji Meteorological Service 1997a), and was the most severe storm since Cyclone Kina in January 1993. The depression developed north of Fiji waters and west of Tuvalu, achieving cyclone status with storm force winds 48-63 knots[12] (89-117 km/hr) at approximately 10°S 173°E. By the evening of 5th March, Gavin intensified to a 'hurricane', i.e. with sustained winds over 63 knots (118 km/hr), and gusts to 130 knots (240 km/hr). Gavin approached the island Vanua Levu from the north during 6th March, but shortly after midnight on 7th March it altered course to the south west. The hurricane continued on this track, passing over the Yasawa and Mamanuca islands offshore to the northwest of Viti Levu. After 7th March, Gavin progressed on a southerly track away from the main Fiji group, but remained at hurricane strength until well after leaving Fiji waters. Tracks of TC Gavin and June are provided in **Annex W1.**

The second depression developed closer to the main Fiji Islands, being officially named Cyclone June at a location of 14°S 174°E early on 3rd May 1997. During most of its relatively short three-day life, June strengthened to only gale force (34-47 knot winds), except for approximately 24 hours from the early morning of 4th May when it intensified into the storm force category. Whereas Gavin travelled fairly rapidly through Fiji waters, Cyclone June displayed more erratic behaviour, making sudden changes in both direction and speed. In particular, after moving slowly but steadily on a southeast course towards the Yasawa islands during 4th May, Cyclone June then decelerated and remained almost

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[12] Wind speeds refer to sustained winds over 10 minute averaging times.

stationary to the northwest of the Yasawas the next day, before taking an unexpectedly sharp turn southwards. Unlike Gavin which left Fiji waters as an active cyclone with no signs of decay, June began to lose structure, weaken and then die out near the Fiji Islands, moving slowly northwestwards away from the coast of Viti Levu. The main differences between cyclones Gavin and June are shown in Table 5.3.

Table 5.3. Comparing the behaviour of tropical cyclones Gavin and June.

Cyclone Gavin, 4th-11th March 1997	**Cychine June, 3rd – 5th May 1997**
• developed away from Fiji - latitude 10°S • large storm • travelled quickly - average 20 km/hr • no erratic change in speed • no erratic change in direction • intensified to hurricane intensity (>63 knots) • long lifespan - 7 days • long track - left Fiji waters as a cyclone	• developed close to Fiji - latitude 13.5°S • 'midget' storm • travelled slowly — average 13 km/hr • showed erratic acceleration and deceleration • showed erratic changes in direction • remained mostly at gale intensity (34-47 knots) • short lifespan - 3 days • short track - decayed in Fiji waters

According to historical data since 1840, Tropical Cyclone June has the distinction of being only the fourth cyclone to threaten Fiji outside the normal cyclone season between the months of November and April (Fiji Meteorological Service 1997b). The life and behaviour of this depression are distinct in several ways from those of Cyclone Gavin two months earlier, which is a reflection of June's development at an unusually late time of the season, when sea temperatures and climatic conditions are not as conducive to sustaining a tropical cyclonic storm as earlier in the wet season. The Fiji Meteorological Service (1997c, pl) reported that "June was a midget cyclone that never really formed a visible eye due to an insufficiently favourable environment."

Cyclones Gavin and June produced widely differing rainfall patterns over the Fiji group. Cyclone Gavin produced higher overall rainfall totals than Cyclone June, mainly because it had a four day longer lifespan (Table 5.4). The distribution of maximum one-day rainfalls for both cyclones (Annex W2) reveals that the interior highlands of Viti Levu experienced the greatest deluge twice, owing to orographic lifting effects of the storms' peripheral rain bands. At an elevation of over 760m, Monasavu weather station in the centre of Viti Levu received a torrential 610 mm of rainfall on 7th March during Cyclone Gavin, and 341 mm on 4th May during Cyclone June. Associated maximum rainfall intensities, calculated over 10 minutes from rain gauge chart traces, reached 152 mm/hr and 40 mm/hr for Gavin and June respectively. **Annex W2** provides maximum one-day rainfalls produced by cyclones Gavin and June across the Fiji Islands.

Table 5.4. Coastal precipitation totals for cyclones Gavin and June

	RaidiM (mm)	
Climate station	**Cyclone Gavin**	**Cyclone June**
Nadi	396	123
Suva	222	184
Labasa	372	312

Apart from at Monasavu, however, the two storms show contrasting patterns in maximum daily rainfall. For Cyclone Gavin it was the northwest coast of Viti Levu that experienced more intense precipitation, whereas for Cyclone June it was Vanua Levu and Taveuni. Because May is normally the beginning of Fiji's dry season, several new extreme rainfall records were established for this month with Cyclone June coming at this time (Table 5.5). New one-day extreme rainfall values were set at Rakiraki in north Viti Levu, Matei airport on Taveuni, Monasavu in the highland interior of Viti Levu and Labasa on the north coast of Vanua Levu (Fiji Meteorological Service 1997e).

Table 5.5. New extreme rainfall records set by Cyclone June

Climate: station	**New one-day record (mm)**	**New monthly record (mm)**
Labasa, Vanua Levu	139 on 4th May	----
Matei, Taveuni	294 on 4th May	728
Rakiraki, north coast Viti Levu	261 on 5th May	682
Monasavu, interior highland Viti Levu	341 on 4th May	728

(data source: Fiji Meteorological Service)

The contrasting rainfall patterns over Fiji's main islands during Gavin and June led to different responses in river rises and consequent flooding. Overall, Cyclone Gavin caused more serious flooding. This was mainly because of the more prolonged duration of this storm compared to June, bringing higher precipitation totals, although the much stronger hurricane force winds must also be considered because strong winds against the shore can effectively retard the discharge of flood waters out of river estuaries.

Fiji's larger islands Viti Levu and Vanua Levu are steepland volcanic islands with mountainous interiors. Consequently, rivers on these islands with drainage basins extending inland to the windward side of the tropical storms had the most substantial flood peaks. The remaining small islands experienced less flooding due to the shorter lengths and limited catchment areas of their streams, except on Taveuni which had significant floods due to the record rainfalls received (discussed later).

For Cyclone Gavin, all the major rivers on Viti Levu responded with notable discharge peaks, although not all flooded their banks (Table 5.6). The Nadi River in the west has a catchment area of 490 km^2 and the steepest long profile for all rivers in Viti Levu with a bed gradient of 1:70. In Nadi Town near the estuary, the flood peak rose to 6.5m above sea level, which was sufficient to overtop the banks. As a result some parts of the town, particularly the market and main street, were extensively flooded to depths between 1 and 2m. The Ba River in the north also has a steep catchment, covering 930 km^2. The peak flood level surveyed at the old bridge site of Ba Town was 6.53m above mean sea level, which is only 0.25m and 2.27m below 1993 (Cyclone Kina) and 1931 record flood levels respectively. Maximum over-bank flood waters reached depths of 1.6 to 1.7m in the Ba industrial and town areas, causing substantial damage.

Table 5.6. Peak flood levels for Fiji's main rivers during some recent cyclones

Peak river height in metres*								
Viti Levu	Catchment area (km^2)	Oscar 2/3/83	Rae 29/3/90	Raja 30/12/86	Kina 3/ 1/93	Polly 27/2/93	Gavin 8/3/97	June 4/5/97
Ba	930	5.46	5.49	8.80	6.51	6.00	6.30	ns
Nadi	490	6.61	5.93	3.70	ns	7.06	6.66	ns
Sigatoka	1450	3.90	3.03	nd	4.81	ns	3.44	ns
Rewa	2900	4.54	4.99	2.82	6.66	nd	4.52	4.46
Vanua Levu								
Labasa	93	ns	5.61	6.64	1.52	ns	ns	ns
Dreketi	317	ns	6.78	11.00	1.77	ns	ns	ns

* All river levels are heights above fixed bench marks. Comparison should be made along the rows to examine the impact of different tropical cyclones on individual rivers.
nd = no data; ns = no significant flood peak

The Sigatoka River draining south western Viti Levu has the second largest catchment area of Fiji's rivers (1450 km^2) and drains from Tomaniivi (Mount Victoria) with an elevation of 1320m (Fiji's highest mountain). The upper third of the catchment is mountainous while the remainder is hilly. The average slope of the river bed is 1:134. Rainfall records for this part of the island indicate relatively low rainfall near the coast, while at higher elevations rainfall was much more substantial (e.g. 610 mm at Monasavu in 24 hrs). For this river, flooding therefore caused more damage in the middle reaches of the valley, whereas lower flood heights in the lower reaches caused less extensive inundation.

The drainage basin of the Rewa River is the largest in Fiji, spanning 2900 km^2 or almost a third of the land area of Viti Levu. The Rewa has four major tributaries: the Waimanu, Waidina, Wainimala and Wainibuka rivers. These drain southern coastal, southern interior, interior highland and north eastern Viti Levu respectively. During Cyclone Gavin, the Wainimala and the Wainibuka tributaries produced most runoff because of the high rainfalls in the highlands and on the northern coast, but the other tributaries had less significant peak flows because their catchments were more sheltered on the leeward side of the island. Consequently, below the confluence of its tributaries, the main Rewa River was able to contain the maximum 4.52m rise in water level. For Cyclone June, there was less impact of river flooding on Viti Levu because of the lower rainfall totals.

River floods generated by Cyclone Gavin in Vanua Levu were lower than previous records because of the relatively low rainfall on this island; Tropical Cyclone Raja in 1987, for example, had much higher rainfall, causing far more significant floods (Table 5.6). However, the Labasa River flooded at Labasa Town from the combined effects of rainfall in the catchment and storm surge. Rainfall on Vanua Levu during Cyclone June was higher than for Gavin, but no reports of any major flooding were made.

The island of Taveuni (430 km^2) off the south east coast of Vanua Levu has small rivers. The largest stream is the Somosomo Creek draining the northern slopes of the island. However, since it is a mountainous island with a high central volcano (Mt. Koroturaga, rising to 865m), stream catchments are steep. Streams therefore show a flashy response to heavy rainfall. During Cyclone Gavin, Taveuni received modest rainfall compared to elsewhere in Fiji. During Cyclone June, however, falls were record breaking, e.g. 294 mm on 4th May at Matei airport, causing localised flooding on the northern coast and consequent damage to infrastructure and property. Local people reported that stream flood levels were some of the highest in living memory for the island.

5.2.4 Tropical cyclones and floods in the Rewa basin

The Rewa river basin is the largest in Fiji. Details of catchment size and the main tributaries were given earlier. A total of 37 tropical cyclones occurred in Fijian waters during 1970-98, and 15 of these caused overbank floods in the Rewa system. Rainfall and river discharge records at Nabukaluka gauging station on the Waidina tributary illustrate the impact of TC Kina in late December 1993 / early January 1994. TC Kina tracked to the southeast, and the eye of the storm passed along the northeast coast of Viti Levu. The 'flashy' nature of the flood hydrograph and the rapid response of flow to precipitation reflects the intensity of the storm and the hilly terrain. See **Annex W3** (River Rewa drainage basin and major tributaries) and **Annex W4** (Rainfall and discharge associated with Cyclone Kina at the Nabukaluka gauging station, Waidina river). (Kostaschul et al, unpublished)

5.2.5 ENSO and droughts

Over recent decades Fiji has suffered several droughts, causing much human suffering and economic hardship for the nation. In the last three decades, bad droughts occurred in 1978, 1983, 1987, 1992 and 1997-98. The most recent of these is thought to be the worst drought this century. Since many rural communities are reliant on rainwater, streams and shallow wells for domestic use and watering crop gardens and livestock, these people have been especially vulnerable to periods of drought when surface water resources are at a minimum (Terry and Raj, 1999).

There are several climatic and topographic characteristics of Viti Levu that are factors in a significant drought hazard, particularly for the north and west of the island:

1. Topography

The combination of a mountainous landscape and the predominance of the south east trade winds means than the north and west are in the rainshadow of volcanic ranges that reach elevations up to 1323 m, and these areas therefore do not benefit from orographic effects. Lautoka on the north west coast, for example, receives only half the rainfall of the capital Suva on the south east peninsula.

2. Rainfall seasonality

Fiji's climate has a distinct wet-dry seasonality, with a wet season lasting from November to April and a dry season from May to October. Moreover, the leeward side receives only 20% of the annual total in the dry season, compared to 33% for the windward side. Rainfall seasonality is thus more pronounced for the dry side of the island, making this zone more vulnerable to an uneven distribution of rain days and prolonged lack of moisture in the dry months.

3. ENSO

ENSO is an inter-annual cycle of disturbance to the Walker atmospheric circulation and an associated shift in the location of warm ocean water across the equatorial Pacific (Congbin Fu et al. 1986). The strength of ENSO conditions is estimated by the Southern Oscillation Index (SOI), which is a measure of monthly atmospheric pressure differences between Tahiti in French Polynesia and Darwin in north Australia (see Ropelewski and Jones 1987, Allan et al. 1991). ENSO is known to affect climatic variability in the Pacific, and is clearly inked to the occurrence of extreme weather such as tropical cyclones and drought (Hilton 1998). Under normal circumstances, or non-ENSO conditions, Fiji tends to receive average rainfall or above. This is produced by convection along the low pressure South Pacific Convergence Zone (SPCZ), which extends diagonally from near the Solomon Islands, across to Samoa, the Cook Islands and beyond (Salinger et al. 1995). By contrast, strongly negative ENSO events, called El Nirios, are associated with an equatorward shift in the SPCZ (Hay et. al., 1993), causing rainfall failure and drought in Fiji.

5.2.6 Case study of the 1997-98 ENSO and drought in Fiji

Rainfall in western Viti Levu

Yearly rainfalls[13] from 1970 to 1998 for the coastal climate stations at Lautoka and Rakiraki are shown in **Annex W5**. These climate stations indicate the temporal rainfall pattern for western and northern Viti Levu, which are the parts of the island most vulnerable to drought. Median yearly rainfalls for Lautoka and Rakiraki are 1852 mm and 2332 mm respectively. Rakiraki receives generally more rainfall than Lautoka because occasions when the south east trade winds turn more easterly reduces the rainshadow effect of the central Viti Levu mountains for the north east coast.

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[13] These are 'water year' rainfalls, i.e. the 12 months November to October, showing rainfall over one wet and dry season cycle.

[See Annex W6 (Location of Lautoka and Rakiraki climate stations and the Teidamu and Nakauvadra creeks) and Annex W5 (Relationship between the Southern Oscillation Index, yearly rainfall and stream baseflows in the drought-prone north and west of Viti Levu).]

Fiji experienced low rainfall in 1978, 1983, 1987, 1992 and 1998. Each of these years corresponds with a strongly negative ENSO event (an El Nino), indicated by persistent negative values of the Southern Oscillation Index. In the early phase of the 1997-98 El Nino, the occurrence of tropical cyclones Freda in January and Gavin in March, prior to El Nino conditions fully developing, gave wet weather over much of Fiji. This accounts for the above average annual rainfall for 1997, despite the onset of the drought that year. The annual rainfall (November to October) for 1998 is clearly the lowest for all the drought years. Compared to the long term average, only 33% of annual rainfall was received at Lautoka and 42% at Rakiraki, which indicates the severity of the rainfall failure.

Past deficiencies in rainfall in Fiji were generally short lived. Even in the exceptional climatic conditions of the El Ninos of 1982-83 and 1987, rainfall deficiencies did not extend across a full wet season. The 1998 drought associated with the very strong 199798 ENSO episode surpasses the severity of the 1983 event, which was previously considered to be the most severe on record. During the 12 month period of September 1997 to August 1998, the western part of Viti Levu recorded the lowest rainfall since records began around a hundred years ago, and rainfall failure for the complete 1997-98 wet season is the first such occurrence. This has led some commentators to describe the 1997-98 drought as a 1-in-100 year event.

Weather patterns 1997-98

The climatic conditions that led to the 1997-98 drought in Fiji developed in early to mid-1997. Tropical cyclones Freda and Gavin produced very large rainfalls over much of Fiji in January and March 1997. However, by April the Fiji Meteorological Service was aware of a declining Southern Oscillation Index and warned of a developing El Nino event, with prospects of below average rainfall for Fiji later in the year (Fiji Met. Serv. 1997). By June 1997 the situation had worsened, with the weather summary for that month describing a strengthening El Nino, monthly rainfalls of less than half the average for the majority of Fiji's climate stations, and the possibility of a 'significant drought' (Fiji Met. Serv. op cit.). The SOI recovered slightly during the latter part of the 1997 dry season, but fell again at the start of the 1997-98 wet season. The South Pacific Convergence Zone is normally the main rain-producing weather system in the early part of the wet season, but was notably absent for November and December. Instead, sub-tropical anticyclones and persistent high pressure ridges dominated the weather pattern, giving record sunshine hours in many places but very little moisture.

By early 1998, the smaller outer islands and the western division of Viti Levu were severely drought stricken by the failure of the wet season rainfall, and were supplied by tanker with emergency water by the Public Works Department. Many sites across Fiji recorded their driest 10 months on record between September 1997 and June 1998. In

June 1998 the value of the SOI increased above zero for the first time in 15 months, indicating an easing of the El Nino conditions. However, the effects of the El Nino continued into July and August, with only a few weak frontal systems bringing scattered shower activity to the windward south east of the larger islands. The end of the 1998 dry season saw the SPCZ begin to drift southwards, closer to the main Fiji group. Associated frontal rainfall, delivered by weak troughs of low pressure traversing the country, finally brought some drought relief to the west. Conditions improved in November with widespread heavy rain at the beginning of the 1998-99 wet season.

Stream water resources

Stream discharge, even for a small stream, reflects (antecedent) precipitation over a relatively wide area – i.e. the whole of the catchment. Streamflow is therefore a form of rainfall data that has been 'naturally extrapolated' by the physiographic, geological and hydrometeorological characteristics of the catchment. This makes streamflow a good indication of the availability of water resources in rural parts of Fiji.

The Nakauvadra Creek and the Teidamu Creek are two typical water courses draining highland catchments in the drought-prone leeward zone of Viti Levu. The Nakauvadra Creek drains 38 km^2 of volcanic steeplands north of the Nakauvadra mountain range (maximum elevation 866 m) in northern Viti Levu. The Teidamu Creek drains a 56 km2 watershed which rises to 480m in the north western part of Viti Levu. Both streams have been monitored by the Hydrology Section of the Fiji Public Works Department with automatic waterlevel recorders since the early 1980s, and good stream stage-to-discharge relationships have been empirically derived by current metering at medium and low flows. These streams are therefore suitable for demonstrating the effects of the 1997-98 drought on streamflow and water resource availability compared to earlier droughts.

Annex W5 shows the minimum 10-day running means of streamflow for each monitored year between 1980 and 1998. This is a useful measure for indicating both:

1) the lowest prolonged baseflow observed during each dry season; and,
2) the deterioration of the water table, since groundwater is the main input to stream channels after a long dry spell when surface runoff is not available and a soil moisture deficit produces minimal soil throughflow (Ward and Robinson 1990).

Because of the larger and less mountainous catchment of the Teidamu Creek, the discharge for this stream is normally higher than the Nakauvadra Creek, but the pattern of changes in minimum baseflows from year to year is similar for the two streams. Years with the lowest stream baseflows generally match the years of strongly negative SOT and low rainfall described earlier, i.e. 1978, 1983, 1987, 1992 and 1997-98. The only inconsistency is the occurrence of the 1997 hydrological drought in a year of above average rainfall. As previously explained, however, much of the 1997 rainfall total was provided by tropical cyclones in January and March. The high intensity nature of these storms encouraged rapid runoff and hydrological short circuiting, giving less infiltration for soil moisture and groundwater recharge. Consequently, stream baseflows still responded to the prolonged rainfall shortage in the 1997 dry season, despite a surplus of moisture in prior months.

In 1997, the minimum 10-day mean discharge for the Teidamu Creek fell to 120 1/: during July. This low discharge is comparable to other drought years. The 199f baseflow decreased to 108 1/s, also in July, and this is the lowest baseflow on record to: this stream. For the Nakauvadra Creek, June 1997 and August 1998 recorded baseflow! of just 30 1/s and 71 1/s respectively. These flows are seen to be notably less than ari, other year since stream gauging began (**Annex** W5). In addition, the severity of I997-9 streamflow failure is further implicated by I) the occurrence of these very low baseflow! for two years in succession, and 2) the weak streamflow recovery (not shown) during the interim months, because of the failure of the wet season rainfall. It was this continuow shortage of water in streams and shallow bores, over such an extended period during the 1997-98 El Nino, that makes this drought historically one of the worst ever to affec western Fiji. Table 5.7 shows the distribution of emergency water by area for 1998 it response to this drought.

Table 5.7. Emergency water distribution in Fiji during the 1998 drought

Emergency water supply	Western Division	Northern Division	Eastern Division	Central Division
Persons	288,850	52,540	32,583	3,641
Schools	56	35	—	—

Drought case study conclusions

In spite of their location in the humid tropical South Pacific, the Fiji islands can face a significant drought hazard, especially during strong negative ENSO conditions when the rain-bearing South Pacific Convergence Zone migrates equatorward away from the group. The north and west of the main island Viti Levu is most vulnerable, because the high central volcanic mountains act as a topographic barrier to the moist trade winds prevailing from the south east. The recent 1997-98 El Nino produced one of the worst droughts to affect Fiji this century. Rainfall failure occurred across two successive dry seasons, and more significantly during the intervening wet season when precipitation is normally reliable.

From a hydrological perspective, the 1997-98 El Nino is notable for producing the lowest stream baseflows on record. In rural areas of Fiji, the population depends on streams and shallow groundwater wells to meet domestic water needs and for watering farm animals. Streamflow is therefore a better indicator than rainfall amount on the availability of water resources in periods of drought. Evidence from two streams in the leeward north and west of Viti Levu island shows that severe hydrological drought occurred even after tropical cyclones brought large rainfalls before 1997-98 El Nino conditions had fully developed. This indicates that surplus moisture in the wet season, prior to the onset of drought, cannot be relied on to sustain stream water resources later on. It is therefore important that future management of water resources on high islands in the humid tropics should consider the effects of stream hydrological behaviour, in addition to any climatic influences on rainfall receipt.

5.3 Effects of climate change

5.3.1 Climate change scenarios, floods and hydrological droughts

It is clear from the preceding sections that even under present climatic conditions, Fiji is prone to two opposite extremes of natural hazards related to surface water:

1) river floods, caused in many of the most serious of cases by high intensity and large rainfalls during tropical cyclones; and,
2) water shortage due to low stream baseflows (hydrological drought), especially in the drier western zone of Fiji, related to El Nino conditions.

Present year to year rainfall patterns in Fiji are strongly affected by ENSO, which in turn influences the location of the south Pacific Convergence Zone (SPCZ). This is a zone of high rainfall and is also where cyclones tend to develop. Results from existing General Circulation Models (GCMs) tend to predict a more El Nino like pattern on a regional basis. With regard to the Fiji locality, they show variations in the positioning of the SPCZ, ranging from a southwest shift to a northeast shift. Thus, projections of rainfall change in the future vary from annual increases, associated with an intensification of the SPCZ near Fiji, to annual decreases associated with a northeast shift of the SPCZ.

This section examines the potential changes in surface hydrology associated with projected climate change. In the tables below, the years 2025, 2050 and 2100 were selected for projecting GCM scenarios. Given the uncertainties in future changes in rainfall trends and patterns, and the associated effects on variability and extremes, two different GCM results are presented. The patterns of rainfall change are scaled by global temperature changes from the mid-case and high-case greenhouse emission scenarios, as used in the Intergovernmental Panel on Climate Change (IPCC) assessment. Tables 5.8 and 5.9 also indicate the predicted future 1-in-10 year maximum and minimum streamflows in the Teidamu and Nakauvadra creeks described in the previous section. The flows were generated using the PACCLIM water resources impact model.

Table 5.8. Predicted future 1-in-10 year low and high daily flows for the Teidamu creek, north west Viti Levu

GCM	Emissions scenario	2025				2050				2100			
		Temp (°C)	Precip %	low flow* m^3/s	high flow$^{@}$ m^3/s	Temp (°C)	Precip %	low flow* m^3/s	high flow$^{@}$ m^3/s	Temp (°C)	Precip %	low flow* m^3/s	high flow$^{@}$ m^3/s
CSIRO9M2	B2 (mid)	0.5	3.3	0.106	52.105	0.9	5.7	0.108	53.315	1.6	9.7	0.112	55.333
	A2 (high)	0.6	3.7	0.106	52.307	1.3	8.2	0.111	54.576	3.3	20.3	0.123	60.680
DKRZ	B2 (mid)	0.5	-3.3	0.099	48.776	0.9	-5.7	0.097	47.567	1.6	-9.7	0.092	45.548
	A2 (high)	0.6	-3.7	0.099	48.57	1.3	-8.2	0.094	46.304	3.3	-20.3	0.082	40.201

current high flow = 50.44 m^3/s

current low flow = 0.102 m^3/s, based on 1981-1996 stream flow data

Table 5.9. Predicted future 1-in-10 year low and high daily flows for the Nakauvadra creek, north west Viti Levu

GCM	Emissions scenario	2025				2050				2100			
		Temp (°C)	Precip %	low flow* m^3/s	high flow$^{@}$ m^3/s	Temp (°C)	Precip %	low flow* m^3/s	high flow$^{@}$ m^3/s	Temp (°C)	Precip %	low flow* m^3/s	high flow$^{@}$ m^3/s
CSIRO9M2	B2 (mid)	0.5	3.3	0.090	132.423	0.9	5.7	0.092	135.499	1.6	9.7	0.095	140.627
	A2 (high)	0.6	3.7	0.090	132.936	1.3	8.2	0.094	138.704	3.3	20.3	0.104	154.215
DKRZ	B2 (mid)	0.5	-3.3	0.084	123.962	0.9	-5.7	0.082	120.885	1.6	-9.7	0.078	115.758
	A2 (high)	0.6	-3.7	0.084	123.449	1.3	-8.2	0.080	117.680	3.3	-20.3	0.069	102.169

current high flow 128.192m3/s

current low flow 0.087 m^3/s, based on 1979-1996 stream flow data

5.3.2 Maximum flows - flood potential

Tables 5.8 and 5.9 show a contrast in the projected high stream discharge for the selected time horizons between the two GCMs. The DKRZ model suggests a decrease of up to 10% by 2050 and 20% by 2100 in high flows for both study catchments, whereas the CSIRO9M2 model projects a similar increase under the high impact scenario for GHG emissions.

Because the Teidamu and Nakauvadra creeks are small streams in comparison to other river systems in the western zone of Viti Levu, projected increased maximum flows will probably not be a major cause for concern in terms of widespread flooding (although localised damage may be severe). However, it is not unreasonable to transfer the projected flow increases to larger catchments in the west, such as Nadi and the Ba rivers, because of the similar climate, land uses, topography and geology over the west of Viti Levu. Both the Nadi and Ba rivers cause extensive damage to industrial and commercial areas when they flood (see earlier section on cyclones, and Yeo 1996), and so a possible increase of 10-20% flood volume due to climate change needs to be addressed, particularly if channel aggradation continues as a result of sediment delivery from land under intensive sugarcane land use.

5.3.3 Minimum flows - water shortage potential

Tables 5.8 and 5.9 show a contrast in the projected low stream discharge between the two GCMs. The DKRZ model suggests a decrease of up to 10% by 2050 and 20% by 2100 in low flows for both study catchments, whereas the CSIRO9M2 model projects a similar increase under the high impact scenario for GHG emissions. Low flows are useful for examining the potential for an increase in the severity of drought impacts on stream water resources with climate change. If the SPCZ tends to move away from Fiji more often with increased El Nino like conditions persisting in the South Pacific, then one implication is for stream water resources may become significantly more scarce within 50 years. In large rivers such as the Nadi, Ba and Sigatoka this may cause problems of salt intrusion in the dry season. In the 1997-98 drought, salt water intrusion because of low flow in the Sigatoka river caused problems for agricultural irrigation in the important vegetable producing region in the lower section of the valley from Sigatoka Town to upstream of the Agricultural Research Station.

Clearly, it is difficult to determine at this time which GCM projection of climate change should be applied. The two examples in Tables 5.8 and 5.9 indicate either the possibility of increased flood or hydrological drought potential, but not both within the same GCM. However, because of uncertainties of future rainfall variability linked to climate change, the best approach may be to adopt the worst combination of change, i.e. both increased flood and hydrological drought magnitude.

5.4 Meeting future water demand — a case study

This section presents an analysis of future water demand and supply in the Nadi-Lautoka area. The analysis presents an overview in broad-scale terms of estimates of future water demand (based on the population projections presented in Chapter 3) and future water supply derived from surface run-off of catchments under present climate conditions and the conditions of future climate as described by the climate scenarios used in the study. It should be noted that the intent of the broad-scale nature of the analysis is to provide indicative estimates of possible effects of climate change on water resources and not an in-depth analysis of all aspects relevant to water resource planning in the region.

5.4.1 The Nadi-Lautoka Regional Water Supply (NLRWS) Scheme

The Nadi-Lautoka Regional Water Supply Scheme – under the Ministry of Public Works and Infrastructure - is the second largest in Fiji, serving an estimated 123,000 people in Western Viti Levu (PNG Pacific Consultants, 1996). The scheme supplies both urban and peri-urban areas of Nadi and Lautoka, as well as rural areas adjacent to the two main population centres and along the Queen's Road and King's Road. In all, it covers a coastal strip approximately 40km long, reaching up to 6km inland. The scheme also includes two resorts, Beachcomber and Treasure Islands, which are located off the Nadi-Lautoka coasts and are directly connected through a submarine pipeline. Recent studies by Worley Consultants Limited (1996) and Sinclair Knight Merz Pty Ltd (1996) recommended the NLRWS scheme be extended in the long term to cater for islands as far out as Tavarau (14km North East of Lautoka) and Lomawai (30km south-south-west of Nadi). This expanded area covers some of the driest regions in Fiji, including rural areas south west of Nadi and the Momi-Lomawai area.

The NLRWS scheme is supplied by four sources: the Vaturu dam, located 30km inland from Nadi, is the main long term source; and three small sources 6-9km from Lautoka namely Buabua, Nalau and Varaqe.

The Vaturu dam, constructed between 1980-82, has a storage capacity of approximately 29 million cubic metres (PNG Consultants, 1996). The current trunk pipelines, however, are designed for a maximum capacity of approximately 45ML/day. The other three sources have a combined capacity of 14.5ML/day [Buabua – 4.8ML/day; Nalau – 5.6ML/day; Varaqe 4.1ML/day].

5.4.2 Safe yield of the catchment systems

According to the 1996 PNG Consultancy report, the assessed safe sustainable yield of the Vaturu dam and the Lautoka sources is 98ML/day. This is based on the water availability of a I in 15 year drought event.

The Vaturu dam currently supplies approximately 45ML/day and the other three sources in Lautoka supply a total of 14.5ML/day.

There are currently two water treatment plants (WTP) servicing the Nadi-Lautoka area. The Nagado WTP is sourced from the Vaturu dam and has a capacity of 45-50ML/day

(PNG Consultants, 1996). The Saru WTP is sourced from the Buabua, Nalau and Varaqe intakes and has a combined capacity of 12ML/day. The total capacity from both the treatment plants as of 1996 amounts to around 62ML/day. Water from both the Nagado and Saru WTP's is reported to be generally of high quality, although turbidity is often excessive following heavy rain.

5.4.3 Population and water consumption

The quantity of water supplied from the Nagado and Sam WTP in 1995 was approximately 46ML/day. Of this, 14ML/d was for the Nadi area and 19Mlld for the Lautoka consumption. The remaining 13ML/d, or 29% of the total water produced, was considered as "unaccounted for water." Factors contributing to the losses include leakage, illegal and unauthorised connections.

According to the 1996 PNG consultancy report, the total population served from the four sources by 1996 was 123,000. However, this analysis did not indicate relative distribution to the domestic and commercial sectors. The 1996 per capita demand, according to the JICA - Watershed Management Study report (1998), was 330l/day. It is therefore presumed that the per capita consumption rate is representative of both sectors.

5.4.4 Future projections of water demand for the Nadi-Lautoka case study

According to PNG Consultants (1996), the population of the Nadi urban area is projected to grow at a rate of 3.5% per annum over the next 10 years, and 3% thereafter. Rural growth rate is projected at 1.5%. Lautoka's population growth rate is projected to be 3.0% in urban areas and 1.5% in rural areas over the next 20 years.

However, for this case study the more conservative population estimates provided in this report have been used to calculate future water demand. The analysis assumes that the rate of population growth in the Nadi-Lautoka region is the same as the national average. Future water demand based on a more conservative **3001/day** average per capita demand was calculated and the water supply which the scheme would be required to supply were calculated (assuming a conservative **25%** loss rate). The results are shown in Figure 5.1.

5.4.5 Supply / demand analysis results

The results of this analysis indicate that, under present climate conditions and based on the calculated potential safe yield of 98ML/d from the four sources (for a 1 in 15 year drought), demand (inclusive of losses) would exceed potential sustainable supply in approximately 2051 and 2041, for the mid-range and high population growth scenarios respectively. Demand would not exceed potential sustainable supply with the low growth population scenario.

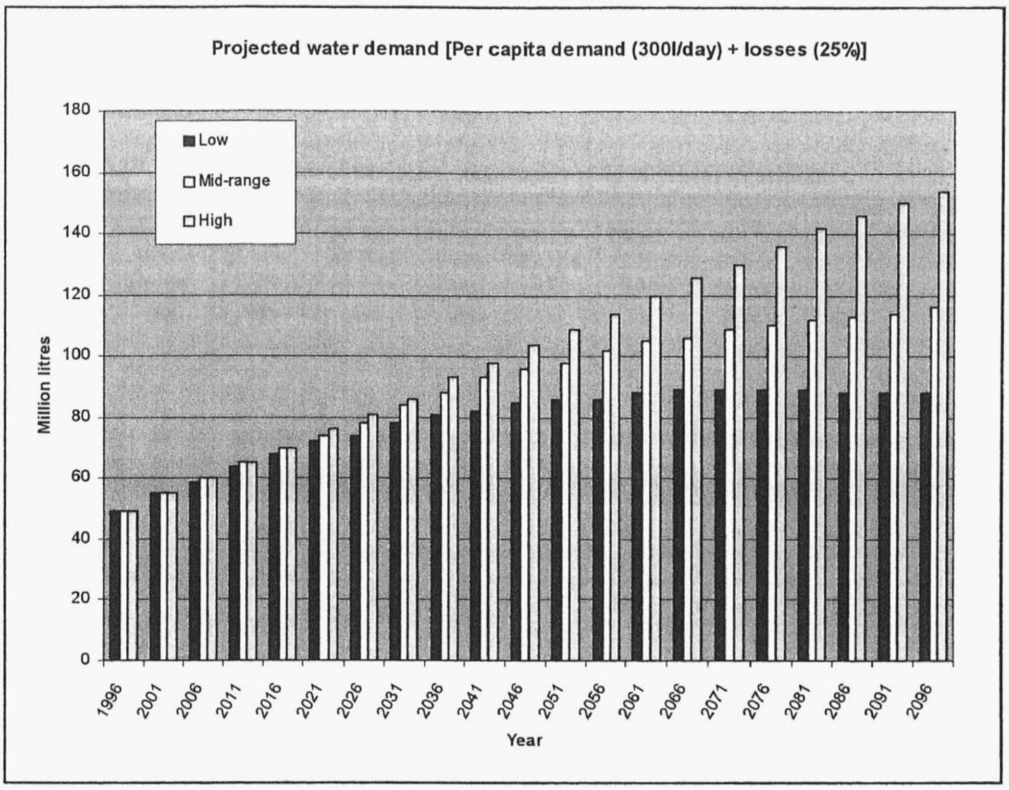

Figure 5.1 Projections of future water demand based on the population scenarios of the study

5.4.6 Impacts of climate change relevant to the NLRWS scheme case study

The three tables below provide a summary of the results of the analysis:

- Table 5.10 provides estimations of changes in the present calculated sustainable yield of 98M1/day which may occur as a result of climate change. As the PACCLIM model does not include the catchment areas of the NLRWS scheme, the assumption is made that the climate change effects on the NLRWS catchment areas would be similar to those on the Teidamu river (which is near Lautoka). The figures presented have been estimated based on the PACCLIM model results for the Teidamu river which are presented in Table 5.8.
- Table 5.11 presents broad estimates of future water demand based on the population scenarios of the study. It is assumed that per capita demand is 3001/day (not inclusive of losses) and that losses from the system are 25% of input.
- Table 5.12 presents the results of the analysis in terms of a potential water supply surplus (where projected demand is less than the projected sustainable yield) or

potential water supply deficit (where projected demand exceeds projected sustainable yield).

Table 5.10. Approximation of projected sustainable yield of NLRWS scheme

	2026			**2051**			**2096**		
Climate Scenario	**No climate change**	**DKRZ B2 Mid (-3.3%)**	**DKRZ A2 High (-3.7%)**	**No climate change**	**DKRZ B2 Mid (-5.7%)**	**DKRZ A2 High (-8.2%)**	**No climate change**	**DKRZ B2 Mid (-9.7%)**	**DKRZ A2 High (-20.3%)**
Sustainable yield(ML)	**98**	**95**	**94**	**98**	**93**	**90**	**98**	**88**	**78**

Table 5.11. Projected approximations of water demand [per capita demand (3001/day) + losses (25%)] in NLRWS scheme (ML)

Population	**2026**	**2051**	**2096**
Low	74	86	88
Mid-range	78	98	116
High	81	109	1.54

Table 5.12. Projected approximations of potential water surplus (+) / potential deficit (-) of the NLRWS scheme (ML)(presented as deviation from calculated sustainable yield of 98M1/day with no climate change and as climate change adjusted daily sustainable yield))

	2026*			**2051**			**2096**		
Climate scenario/ Population projection	**No climate change**	**DKRZ B2 Mid**	**DKRZ A2 high**	**No climate change**	**DKRZ B2 Mid**	**DKRZ A2 High**	**No climate change**	**DKRZ B2 Mid**	**DKRZ A2 high**
Low	+24	+21	+20	+12	+7	+4	+10	**0**	**-10**
Mid-range	+20	+17	+16	0	**-5**	**-8**	**-18**	**-28**	**-38**
High	+17	+14	+13	**-11**	**-16**	**-19**	**-56**	**-66**	**-76**

This analysis highlights several important points which are relevant in terms of both climate change impacts and adaptation:

- The effect of climate change appears relatively insignificant in the year 2025, but by 2050 the changes have become more apparent and climate change contributes to the magnitude of possible shortages;
- With the low population scenario climate change does not have significant impacts apart from the high climate change scenario for the year 2100;
- The amount of water lost from leakage (and other unaccounted for losses) in the system (currently estimated at 29%) is greater than potential changes in

sustainable yield attributable to climate change – even for the most extreme scenario.

5.5 Adaptation

This section summarises some of the options for the mitigation of floods and droughts on Viti Levu. First, specific structural measures are examined that directly deal with relieving these separate hazards. Secondly, a more holistic approach to adaptation based on catchment management is described. It is suggested that the second approach is more appropriate in terms of adaptation to climate change in Viti Levu as it is compatible with adaptation measures deemed appropriate in the other sectors addressed in this study.

5.5.1 Direct hazard mitigation

Flood control

A recent report compiled by JICA/MAFF (1997) on watershed management and flood control for the four major rivers of Viti Levu (Rewa, Sigatoka, Ba and Nadi) includes a thorough examination of different feasible flood control measures. Those 'structural control measures', i.e. engineering solutions, described are:

1. Diversion channels
2. Weir and retarding basin
3. Cut-off channel and retarding basin
4. Flood control dam
5. River improvement
    a) river channel widening
    b) dike construction
    c) river bed excavation

Costs of these different schemes are also calculated and case studies for a dam in the Nadi watershed and river dredging in the Rewa are described in the report. In the present context of climate change and variability, flood control dams may be the most beneficial option because they can be used for storage and water resource development to help alleviate droughts, as well as helping to control floods.

Non-structural measures, i.e. those that involve no construction, are also considered in the JICA/MAFF study. These are considered later under catchment management.

Drought alleviation

There are many options that may be adopted to relieve the severity of future droughts and attendant water shortages in Fiji.

1. Water resources management

An initial measure is to focus more effort on improving the overall management of the supply and on reducing unnecessary losses such as through leakages. On the eastern wet side of Viti Levu, for example, there should be less potential for serious drought affects. Nonetheless, in the greater Suva area during the 1997-98 El water cuts were experienced in several localities on a number of occasions, resulting in the forced closure of schools and businesses, and causing disruption to residential areas. These water shortages were, at least in part, related to problems of water management, e.g. pumping station equipment failure and vandalism. In the drier zone, the ultimate target for the Nadi-Lautoka regional water supply should be a maximum loss of 5%. It is important to note that the current loss rate of 29% is greater than the worst-case scenario of water resource reduction due to projected climate change.

2. Water legislation

There are several Acts already in place that have a bearing on future water resource availability, use and management. These are:

a) Rivers and Streams Ordinance

This provides for the granting of licences of up to 25 years to occupiers of land to take water for beneficial purposes.

b) Irrigation Act, 1974

This provides for appointed Commissioners to direct and regulate irrigation in declared areas.

c) Drainage Act

This provides for the implementation and rehabilitation of public drainage works.

These Acts may be reassessed in order to prevent the over-exploitation by large water users in times of extreme surface water scarcity. For example, licences granted for abstraction from streams and rivers may be written to include stricter conditions to conserve resources during prolonged drought.

With regard to unauthorised connections to the urban metered supply, penalties and fines may be imposed on such offenders as a deterrence means, and to those who ignore Government emergency measures in the dry season such bans on the use of hosepipes for car washing.

3. Development of alternative water resources

Much work was carried out in the 1980s by the Mineral Resources Department and SOPAC on assessing the extent and quality of groundwater reserves in Fiji. Information exists in the form of hydrogeological maps, aquifer description, water potability, etc. It has been established that there are large confined coastal aquifers in some areas that could be exploited as a fresh water resource (Maharaj, SOPAC pers. comm). Government should commit itself into looking at appropriate development of groundwater as an alternative source to relieve pressure on surface supply during droughts.

The wider use of rainwater tanks for household and school storage should also be encouraged – much of the urban and peri-urban population does not use rainwater tanks and instead relies on the metered supply. When this fails during droughts, government has to expend considerable resources carting emergency water.

4. Consumer payment

One of the largest water users in the dry zone of Viti Levu is the tourist industry.

Raising the price of water is one way of promoting conservation and wise use of this limited resource. Though the measure might be biased towards the rich, it is intended to alleviate the high rate of abuse and misuse across the community, and at the resort developments the cost would be passed on to the 'tourist consumer' .

5.5.2 Catchment management

A holistic approach to water management means to consider all the wider bio-physical and cultural factors that have an implication on this resource. In environmental studies, a practical way of dividing up the landscape is by drainage basins or catchments. A catchment is the total land area drained by a single river or stream and all its tributaries. Catchment physical features that influence the drainage pattern, channel form and stream discharge behaviour include geology, soils, vegetation and land use. A catchment approach is a valuable method because it does not separate these factors, but rather integrates them to explain the hydrolmeteorological characteristics of a defined area.

On Viti Levu, it is clear that land and water resources are closely linked. Changes **in** land use, e.g. from natural forest to intensive agriculture, especially in rugged terrain, and through urbanisation and development, will have implications for both soil and water resources. Replacement of natural vegetation will alter the water budget of an area, often leading to increased runoff, hillslope hydrological short-circuiting, a 'flashier' response of streams and higher peak discharges during storm events. This results in greater flood potential and a reduction in the moisture retention capacity of the catchment. Soil erosion on hillslopes will increase the sediment load in rivers and adversely affect channel capacity through siltation in the lower reaches.

Several reports have already been written which go some way towards addressing problems faced by Fiji's soil and water resources and/or identify catchment scale approaches to land management, e.g. Dixie, R.C. (1983), Nelson, D. (1987), JICA/MAFF (1997). A common theme in these reports is the need for measures to promote water and soil conservation. Ultimately, measures which control land degradation and soil resources also protect catchment water resources. Sound catchment management, involving all stakeholders, is therefore seen as an appropriate, environmentally friendly and 'no-regrets' adaptation measure to mitigate flood and hydrological drought severity.

Catchment-scale adaptation measures to mitigate water loss and flood potential include;

1. Maintaining and improving the water retention and storage function of watersheds by:

- increasing (natural) forest area;
- regulating land development;
- protecting land uses that retard flow, e.g. natural wetlands; and,
- maintaining river flow capacity, e.g. through soil conservation to prevent siltation.

2. Reducing the flood damage potential by:

- limiting development and urbanisation in low-lying flood-prone areas; and,
- promoting flood-proof house design where necessary.

3. Improving social infrastructure and resilience through:

- education programmes to raise community awareness of land and water conservation;
- better forecasting and communication of impending flood and drought hazards; and,
- continued support of existing disaster reduction programmes.

5.5.3 Institutional development facilitating adaptation

Catchment Authorities

If a catchment-scale approach is seen as appropriate to reduce flood and drought potential, then establishing catchment-scale management bodies, e.g. the `Ba Catchment Authority' and 'Nadi Catchment Authority' presents an option for institutional development and devolution of policy and decision-making to a regional level.

Water Authority

At present water management is divided between different Government departments (Lands, Agriculture, Public Works, Energy). An alternative is to introduce a single `Water authority', with divisions for hydrology (river monitoring), engineering (control structures, irrigation and drainage) and supply.

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6 Agriculture

6.1 Overview of sector

According to the Development Strategy for Fiji (Policies and Programmes for Sustainable Growth), agriculture remains the backbone and the largest sector of Fiji's economy; accounting for almost 43% of foreign exchange. It provides nearly 50% of the total employment and contributes 19% of Fiji's GDP. In recognition of it's importance to the economy and rural development, the Ministry of Agriculture, Fisheries & Forests (MAFF) has committed itself to the sustainable development of Fiji's agricultural base. To achieve this the Commodity Development Framework Programme (CDF) is currently being implemented. The main objectives of this programme are to accelerate the agricultural growth through greater diversification and exports, to guarantee food security and to improve the living standard of rural people.

Presently the main agricultural activities in Fiji are concentrated on Viti Levu and Vanua Levu and to a lesser extent on Taveuni. The remaining islands have a small agricultural base where traditional crop farming is practiced. Most of the suitable flat land is already under cultivation for sugarcane and subsistence crops in western Viti Levu and Vanua Levu, and for rice and other food crops elsewhere. Most of the smaller pockets of flat land and adjacent lower slopes around the southern coasts and the south-eastern coasts of the main islands are also occupied for village agriculture or small coconut plantations (Ward, 1980). As a result of the limited amount of land suitable for agricultural use, opportunities for expanding the farming area are limited (Watling et. al. 1992).

As a small island economy, Fiji faces obstacles in the development processes that are not present in larger countries. It is inherently less diversified which makes it more vulnerable to both internal and external shocks. With a small population, economies of scale are difficult to achieve on domestic markets and investment in infrastructure become more costly and often uneconomical. Superimposed on the problem of size, and its relative geographical isolation, Fiji's agricultural bases are very vulnerable to natural disasters. The situation is complicated by the land tenure system, which constrains the availability of land and its productivity.

Levels of food imports are comparatively low, and as a percentage of total imports, these have fallen slightly over the last decade. This suggests that the domestic food supply has been able to expand with increases in demand from the growing population. There are three main types of agricultural activity in Fiji: subsistence farming; semi-commercial farming; and plantation farming.

6.1.1 Agricultural systems in Fiji

Subsistence farming contributes significantly to the agriculture sector in Fiji (average of 30-40% of total agricultural GDP) thus saving a lot of foreign exchange (Agricultural Sector Review, 1996). Subsistence agriculture is practiced all over Fiji and is based upon a mixture of staple root crops (eg. dalo, cassava, yams, sweet potato) and tree crops (eg. coconuts, bananas, breadfruit, mangoes and other fruit trees), rice and vegetables. It provides a source of nutritional and economic benefits in many areas, especially in the outer islands where people have a variety of home gardens, mainly for home consumption. Farmers on the major islands are able to sell whatever is surplus thus supplementing their income. In many cases, especially in the peri-urban areas, the desire for an increase in cash has led to an increase in the cultivation of these crops at the expense of subsistence food crops because of the demand from the urban population. Farmers produce an impressive quantity and range of traditional food crops. Some, notably root crops, offer export opportunities. However, the great bulk of this production is for domestic supply, both on a subsistence and semi-commercial basis.

Semi-commercial farming is practiced to some extent in the Rewa Delta areas and the Sigatoka Valley. The crops from these regions are supplied to the urban areas of Suva and Lautoka cities and are also exported to overseas markets. As mentioned above, the subsistence farming in other regions around the country is under transformation to a semi-commercial basis but has been constrained by several factors such as the availability of land and infrastructure to market produce in some cases. Through the CDF programme the emphasis is placed on certain crops including pawpaw, ginger, and mangoes; to establish itself in niche markets for export to the Pacific Rim countries. Other potential export opportunities exist for root crops, yaqona (kava), and vegetables, provided there is a continuity of supply. Recently yaqona (kava) has found good markets with American and German pharmaceutical importers and dalo export increased due to a shortfall in supply from Samoa because of the taro blight disease.

Sugarcane and coconut are the two major crops farmed on a plantation basis. After a long decline, copra production has increased recently due to good market demands locally and internationally. Replanting of senile palms has started with high yielding hybrid varieties in the coconut growing regions of the country.

In commercial terms, sugarcane is by far the most important crop grown in Fiji. A Strategic Plan to guide the sugar industry into the 21st century has been drawn up and is set to be implemented. The Plan includes the introduction of a productivity pay system and the reorganisation of the industry's institutions, amongst other things. These changes should bring about a greater increase in milling efficiency, farm productivity and reduced sugarcane production costs.

6.1.2 Sugarcane

For more than a decade, sugarcane has been the principal agricultural crop grown in Fiji. It plays an important role in the agricultural sector and for the rural population. As such Fiji is strongly dependent on exports from sugar, which is responsible for approximately 45% of the total export earnings, around F$250 million in foreign exchange.

According to the Fiji Sugar Corporation (FSC), which controls the running of the sugar industry, there are about 22,337 cane farmers in the country. The majority of sugarcane farmers are Indo-Fijians. On average, they work on a four hectare farm leased from the native land owners. They produce about 120-200 tonnes of sugarcane per annum. The gross return from the sugarcane production from one hectare farm is about F$7 per day (Fiji Agricultural Review, July 1996).

A substantial number of people are employed in the sugar industry. About one fifth of the national workforce is involved in harvesting, transportation, milling and processing of sugar. Sugarcane production has on the average increased over the last decade due to the expansion of areas planted rather than an increased improvement in production efficiency. Much of the expansion has been on to marginal sloping land. 1996 saw a record cane production of 4.37 million tonnes from an area of 73,981 hectares (59 tonnes/hectare). Total raw sugar produced was about 462,313 tonnes at an average of 6.25 tonnes/hectare. Mill efficiency remains high by world standards. The amount of cane required to produce a tonne of sugar has increased somewhat from the outstanding levels of early 1970s (the 5 year average of tonnes of cane per sugar increased from 7.9 tonnes in 1970-74 to 8.6 tonnes in 1990-94). This can be attributed to the expansion of cane farms into less productive marginal land areas (due to lower soil fertility and less available water), which occurred in the late 1970s and early 1980s. Sugar is sold to a number of preferential markets and to the world market, with over 40% exported to the United Kingdom (UK) under the Sugar Protocol of the Lome Convention. This was supplemented in 1995 by a further quota of 40,000 tonnes sold to Portugal.

The last decade has seen fluctuating, but increasing real world market sugar prices. Medium term price forecasts, range from a small decrease to a substantial increase. However, the major concern for Fiji is the long-term future of the 172,000 tonnes sold to the European Union (EU) under the Sugar Protocol of the Lome Convention. Over the last decade the sugar has been sold at a price 2 to 3 times the world market prices, representing a net transfer of about F$90 million annually from the EU to the Fiji sugar industry. Sugar is also sold to Japan, Malaysia and China. Furthermore, there is uncertainty over the future of the sugarcane industry given the expiry of leases, which will occur over the next ten years, and the likely return of land to native titleholders.

6.1.3 Coconut

Coconut trees and copra production are found throughout Fiji but the coconut plantation are mostly found on the wetter parts of Vanua Levu, in Taveuni, Kadavu and in Lau and Lomaiviti Groups. Copra production is not intensive and requires few external inputs. The nature of its production and the final products make it one of the few possibilities for income generation in the outer islands. The two major factors affecting the distribution of coconuts are an avoidance of steep slopes and an attitudinal limit for successful cultivation. Coconuts are rarely grown above (304m) above sea level because the nuts prematurely fall if grown above 258m. Copra production varies with price. Since 1993, the trend was downhill but since 1995 an upturn in production has been noticed due to high prices.

6.1.4 Root crops

There are a number of root crops that are of economic importance in Fiji. The traditional staple crops are dalo (taro) and yams, which are alternated as wet and dry season crops respectively. Yams have been displaced to a large degree by the hardier, but less nutritious, cassava. Sweet potatoes (kumala) are of lesser importance, but still a valuable subsistence food crop. More recently, ginger has been developed as an export crop, particularly in the vicinity of Suva. Yaqona (kava), a crop of traditional importance, has also been developed as an export crop.

Dalo is commonly grown as a staple food crop, but in recent years has increased in importance as an export crop, particularly since the presence of taro blight in Samoa. Dalo is now Fiji's second major agricultural export earner due to high prices offered from New Zealand and the US. Production in 1997 was 23,350 tonnes, harvested from an area of 2,441 hectares (an average of 9.6 tonnes/ha). Approximately one quarter of the total 1997 production was exported.

Cassava, yams and kumala are grown predominantly for local consumption. For example, only 0.25% of the total cassava production was exported in 1997, yam exports were even less and there were no kumala exports.

In terms of export revenue, the other two crops of importance to Fiji are ginger and yaqona. Ginger is predominantly grown on sloping land in the vicinity of Suva, and has been encouraged as a crop to improve household income for small-holders in this area. Unfortunately a number of environmental problems have arisen from its production on sloping land, mostly related to soil erosion. Yaqona is a bush plant and is prized for its roots which, when dried and powdered, provide a traditional ceremonial drink. The consumption of yaqona is now very common in Fiji and it is increasingly being used overseas for pharmaceutical purposes.

6.2 Present climatic setting and agricultural production

6.2.1 Sugarcane

The main sugarcane areas are the relatively dry coastal lowlands in the west of the main islands, in particular Viti Levu, where there is a marked dry season. Sugarcane plantations were originally established in the wetter regions of Fiji notably the Nausori and Rewa areas near Suva, but was relocated to western Viti Levu due to lower sugar yields. It's optimum rainfall requirement is between 1500-2000mm annually. Sugarcane is normally planted in the December-March period, which is the wet season and temperatures are warmer than average. Adequate moisture and warm temperatures, in the range of 32-38°C, are required for germination. In the earlier stages of it's growth, sugarcane requires a high temperature (between 25-30°C) and a dry period is required in the months before harvesting which is normally 12 months after planting for ratoon cane and 14-18 months for planted cane. Cooler and drier conditions are preferred in the ripening period.

As indicated above, sugarcane requires an optimum temperature of 25-30°C in early stages of growth. The annual average maximum and minimum temperatures recorded for Lautoka over a 35 year period (1961-1995) were 29.6°C and 22.0°C respectively, suggests that conditions are generally well suited for sugarcane (Figure 6.1). Years with marked high temperature anomalies included the El Nino years of 1983-84, 1987-88, and the most recent 1997-98 event. These years were also associated with low rainfall anomalies, as shown below (Figure 6.2.).

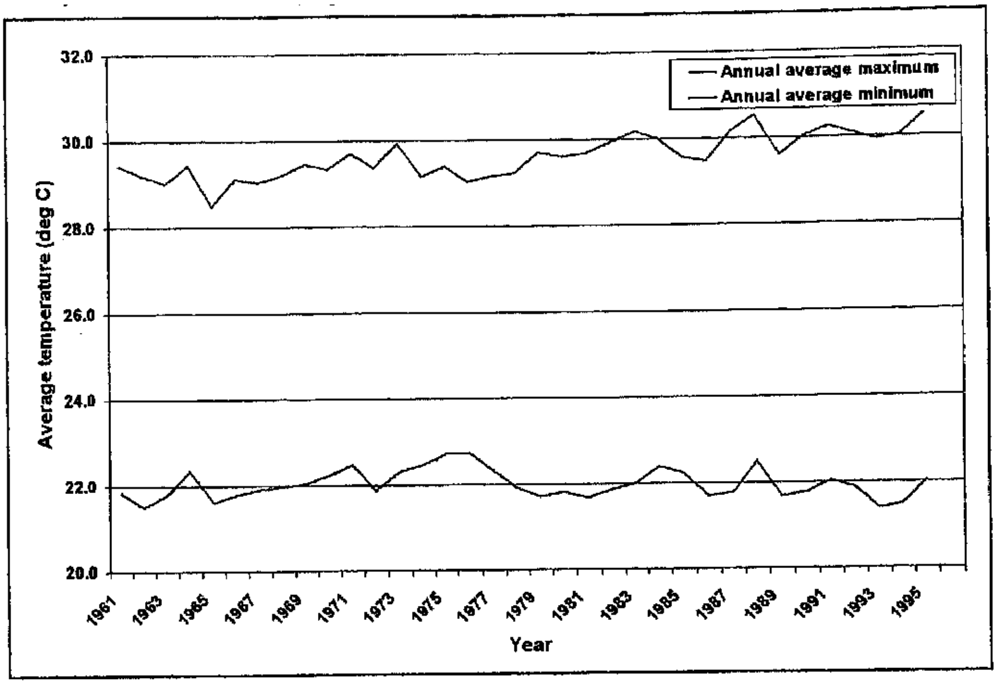


Figure 6.1. Graphical representation of annual temperature variations in Lautoka

Sugarcane requires a mean annual precipitation (MAP) of 1500-2000mm, distributed evenly through the year, to meet its water requirements. Based on the Lautoka Mill rainfall station records (Figure 6.2), the average rainfall over a 37 year period (1961-1997) recorded was 1887 mm. During that period low rainfall, and associated drought conditions, was experienced in 1978, 1983, 1987, 1992, and 1998, all of which were El Nino years.

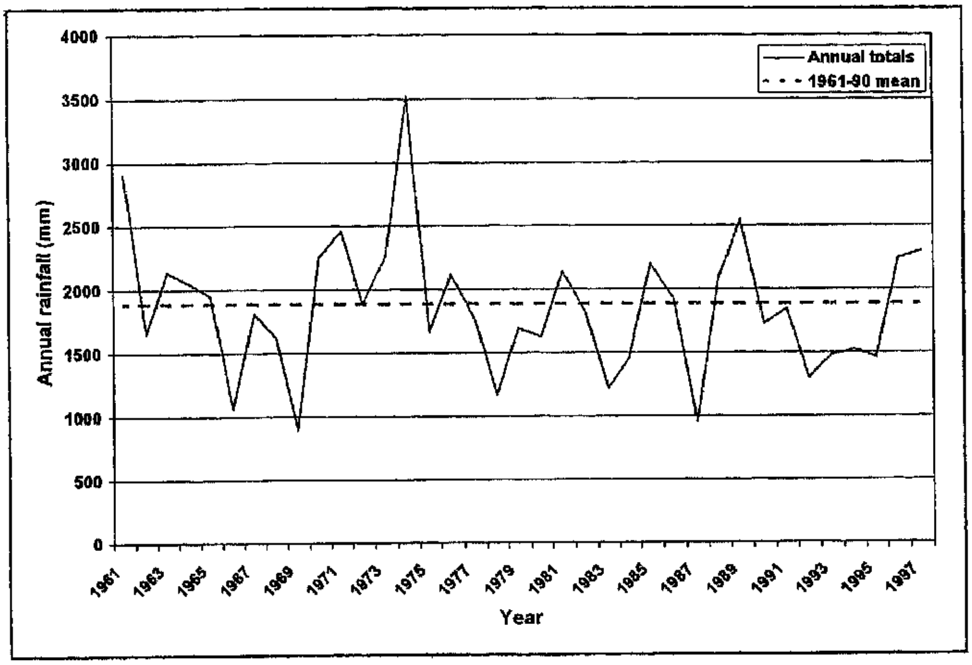


Figure 6.2. Graph representing annual rainfall variations in Lautoka.

Sugarcane production was well below average in each of these El Nino years (Figure 6.3), particularly in 1998, which stands as the worst drought on record in Fiji. The May 1998 forecast was for a production loss of 1.5 million tonnes (from an estimated production of 4 million tonnes), equating to a loss of F$104 million in revenue (UNDAC, 1998). The impacts of this drought were greatest in marginal sloping lands (greater than 12 degrees) and in sandy, coastal soils. Approximately 75% of the present land area (73,000 to 74,000 ha) used for sugarcane production is considered marginal for rain-fed production (Land Use Section, MAFF, pers. comm.). Optimal yields under rain-fed conditions in western Viti Levu are normally expected to be of the order of 60 tonnes/ha. In most years average yields are below this level, due to the lower production from marginal land areas. The Plantgro model was used to assess suitability and yield of sugarcane under present conditions. However, the model under-predicted yields in the western part of Viti Levu, where the industry is centred. Further work is required to calibrate it for present conditions, before it can be used reliably to evaluate effects of climate change.

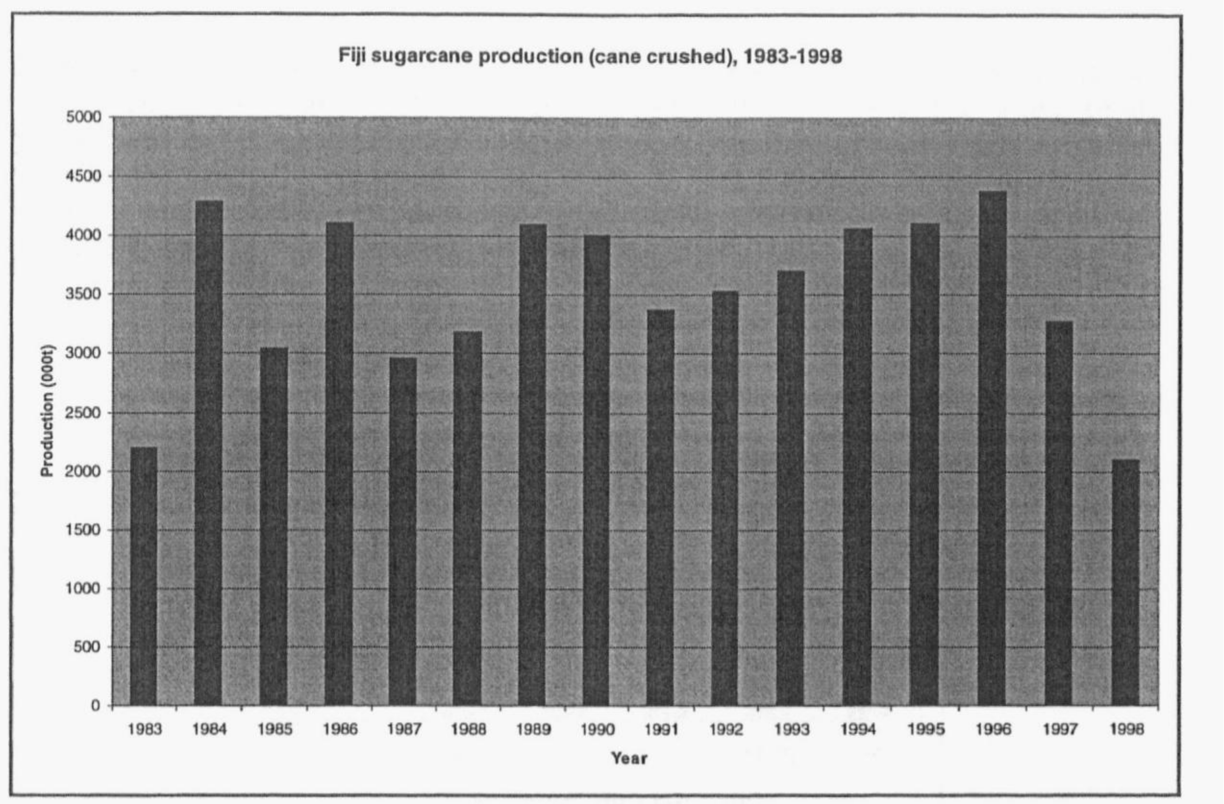


Figure 6.3. Fiji sugarcane production, 1983-1998

Aside from drought other climatic events that can adversely affect sugarcane production in Fiji are floods and cyclones. The high intensity rainfall during tropical cyclones causes problems due to water logging of young sugarcane plants, as was experienced with the extreme flooding experienced in western Viti Levu in January, 1999. Additionally, sugarcane areas on marginal to sloping land often face soil erosion problems during high intensity rainfall events, which exacerbates the situation with these marginal areas. The occurrence of high winds during tropical cyclones can also lead to sugarcane damage and yield losses, mostly by dislodging of stems.

The cumulative effects of a sequence of extreme events can be particularly damaging to sugarcane, and other agricultural crops. The 1998 drought followed a sequence of natural disasters, the effects of which were exacerbated by the severity of the drought. As a result of cyclone Oscar and the El Nino drought in 1982/83, a 46 % reduction in sugarcane production was recorded. This amounted to F$70 million loss in foreign exchange. Evidence suggests that El Nino events tend to be associated with a greater frequency of tropical cyclones of hurricane force (Pahalad and Gawander, 1999).

6.2.2 Root crops

The root crops described in the previous section (dalo, yams, cassava, ginger, yaqona) are grown under a variety of climatic and edaphic conditions. Rainfall totals, and its seasonal distribution, have a very strong influence on where, and at what time of the year, the different root crops are grown in Viti Levu, and other parts of Fiji.

Dalo is grown mostly in the wetter areas, including eastern Viti Levu, where annual rainfall ranges from 3000 to 4500 mm. In the higher rainfall areas dalo is grown all the year around and is usually planted in September to November, before the onset of the rainy season, while the off season crop is grown in March to June. Rainfall has a very strong influence on dalo yield, as shown in a sensitivity analysis of the effects of rainfall amount on simulated yield in Koronivia, Viti Levu (Figure 6.4).

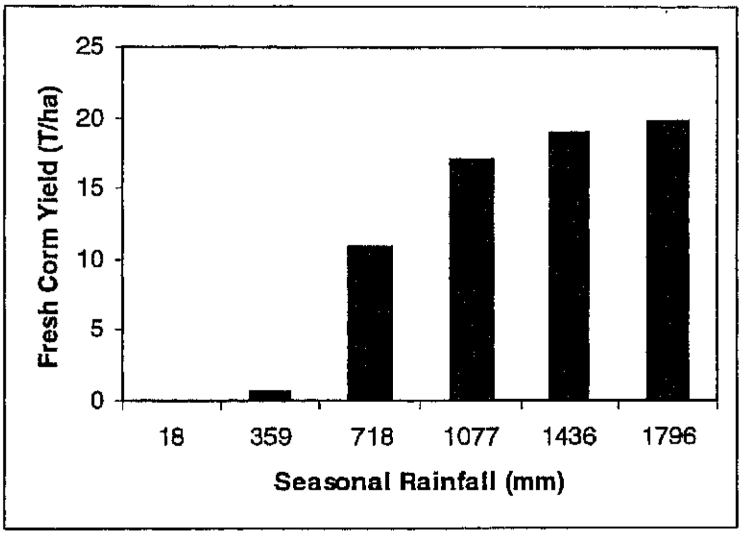


Figure 6.4. SUBSTOR-Aroid (v2.1) simulation of rainfall effect on fresh taro corm planted in September at Koronivia, Viti Levu, Fiji

Assuming optimal soil and rainfall conditions the expected average yield of dalo in Fiji is 15-20 tonnes/ha. Under subsistence conditions, it is more likely to be in the range of 515 tonnes/ha, which is the range of national average yield. However, in the more productive higher rainfall areas semi-commercial yields can be as high as 30 tonnes/ha.

Yams are traditionally grown in rotation with dalo, generally preferring drier conditions. There are some 60 different cultivars that have been trialled by the MAFF at Nausori, of which there are different cultivars suitable for different climatic zones. The normal planting time is July to August with expected yields, under optimum conditions, of 20-25 tonnes/ha. National average yields range from 5-10 tonnes/ha.

Cassava is a very hardy plant, which can grow on poor soils and under relatively low rainfall conditions. The minimum rainfall requirement is 700 nun/year, which is exceeded throughout Viti Levu on average, and in all years (including the 1997/98 drought). Cassava is planted throughout the year and is grown in most areas of Viti Levu. Expected yield is 20-23 tonnes/ha, but national average yield ranges from 3-15 tonnes/ha.

Ginger is presently grown in the high rainfall zone of Viti Levu. It is planted down the slope to avoid water-logging of the soil and associated nematode problems. This has led to some serious soil erosion problems, which the MAFF are trying to address through the encouragement of soil conservation practices. Expected yield, under optimum conditions, is 50-60 tonnes/ha. However, average yields (from the approximate 100 ha presently used for ginger production) are of the order of 26 tonnes/ha (MAFF & ALTA, 1997).

Yaqona (kava) is a traditional bush plant, which is cultivated widely in subsistence systems. Grown in a traditional agro-forestry system, it will tolerate a range of climatic condtions. Average yield in 1997 was 2.6 tonnes/ha, harvested from an area of 1263 ha (MAFF & ALTA, 1997).

The present areas of suitability and yield distribution of four root crops (dalo, lesser yam, cassava, yaqona) in Viti Levu have been mapped using the Plantgro model (Hackett, 1991) within PACCLIM (Kenny *et al.,* 1999). The results (Figure 6.5) are consistent with the brief descriptions provided above. For dalo (Figure 6.5a), a planting month of September was used, which is the main planting time. Results show a clear demarcation between the drier north-western region of Viti Levu and central and southern areas. In the more suited, high rainfall areas, the model gives yields in the range of 10-15 tonnes/ha. This is the range of national average yield, but is an underestimation of yields experienced in the southeast (up to 30 tonnes/ha). For yams (Figure 6.5b), a planting month of July was used. Most of Viti Levu, with the exception of areas limited by soil and slope, is suited for yams when planted at this time, with yields ranging mostly from 10-13 tonnes/ha. Cassava, when planted at the same time as yams (July), does not produce as well under the drier conditions (Figure 6.5c), with yields ranging from 6-10 tonnes/ha in the more suited areas. Yaqona, a perennial crop, is better suited to upland bush areas, in southern and central Viti Levu (Figure 6.5d). Yaqona yield from Plantgro is given as kg/ha (ranging from 4 to 12 kg/ha throughout Viti Levu), which probably refers to dry weight production.

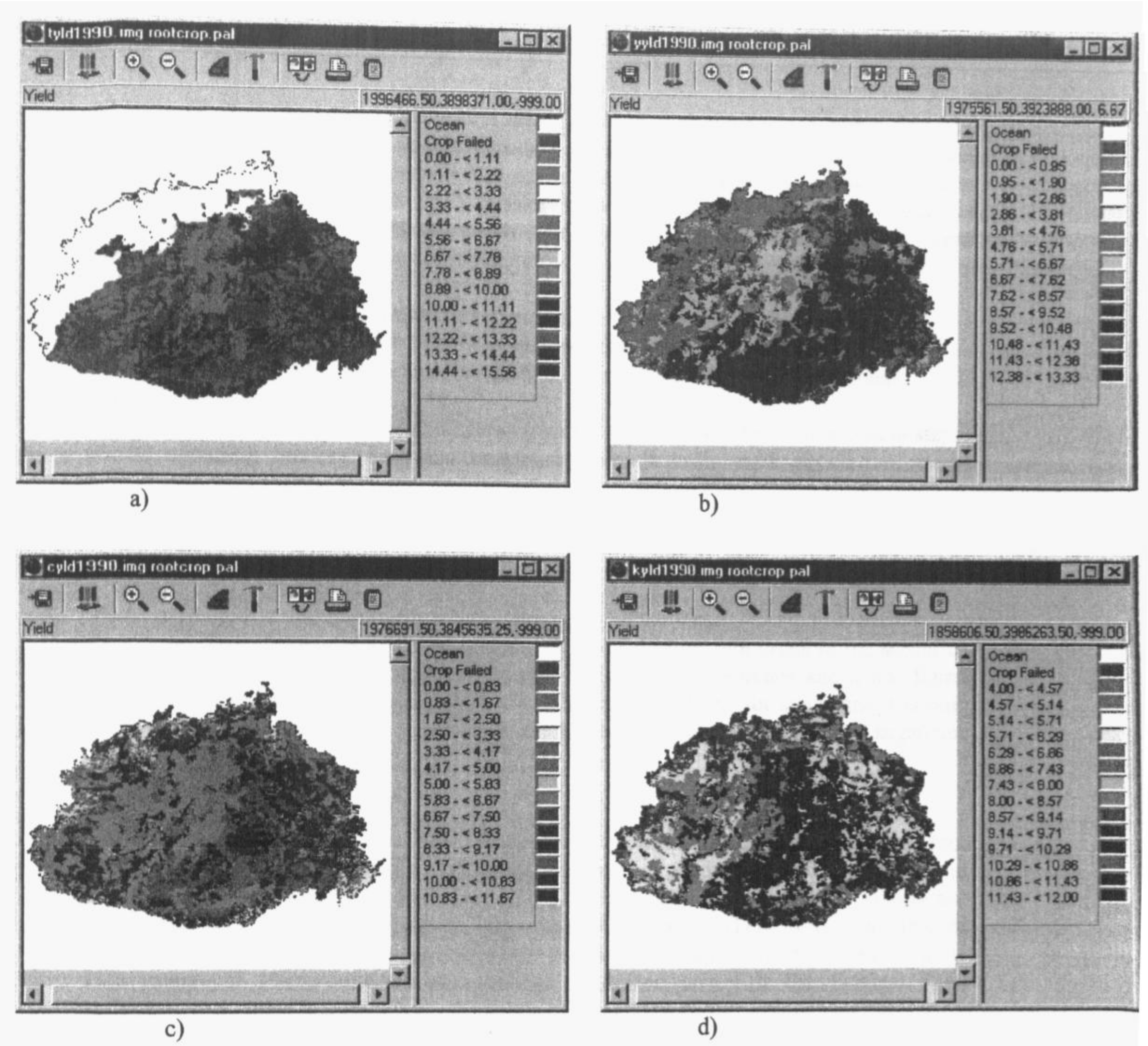


Figure 6.5. Suitability and yield of a) taro, b) cassava, c) yam, d) yaqona under present climate in Viti Levu, Fiji

It is evident that the diversity of root crops grown in Fiji is suited to a varying range of climatic conditions. With the exception of ginger, the crops described above are *all* grown for subsistence purposes and only in recent years have dalo and yaqona been developed as export crops. For this reason, the effects of climatic variations and extremes, such as droughts and flooding (largely associated with tropical cyclones), are not documented as extensively as for sugarcane. However, extensive surveys were conducted to assess the impact of the 1997/98 drought. The UNDAC report on the

1997/98 El Nino drought (UNDAC, 1998) indicated that large areas, particularly in western Viti Levu, planted in yaqona and dalo and other subsistence crops, were stricken by the drought. Crops in central Viti Levu and its south-eastern coastal belt were relatively unaffected. In the FAO mission report on the drought (FAO, 1999) the following effects on root crops, which were greatest in western Viti Levu, were documented:

1) mid-year root crop production reported to be the lowest in living memory;
2) dalo plants lacking leaf canopy, or all dried out;
3) cassava areas re-planted as many as three times without crop establishment.

As a consequence of these direct effects of the drought there was reduced access to staple foods, including cassava, dalo and kumala, by economically weak population groups (FAO, 1999).

6.3 Effects of climate change

The Plantgro model was used to determine the effects on four root crops of the scenarios described in Chapter 3. The same model was evaluated for sugarcane and it was found that further calibration is required to give reliable results. Thus, for sugarcane it is only possible to give a qualitative assessment of the effects of climate change on sugarcane production.

6.3.1 Sugarcane

The present expectation in Fiji is for an annual sugarcane production of the order of four million tonnes. As can be seen in Figure 6.3, this level of production has been attained in only seven of the last 15 years. Of the other eight years, only one (1985) was not associated with the effects of an El Nino drought period. There were a number of damaging cyclones throughout the 1983-1998 period, including a sequence of three in the first quarter of 1985, with the total damage from Hurricane Eric estimated at F$40 million.

Drought appears to be the most significant contributor to reduced production of sugarcane, the effects of which can be exacerbated by occurrence of tropical cyclones. In the absence of better information, the 1983-1998 period serves as a useful analogue for future effects. Under climate change conditions, in the good years the adverse effects of warmer temperatures (increased evapotranspiration and heat stress) might be offset by the possibility of increased rainfall, resulting in similar production levels to those experienced presently. However, it is likely that the effects of bad years might be worsened by warmer and possibly drier conditions. The 1997/98 El Nino drought, regarded as a 1 in 100 year event, may become more of the norm during El Nino years. If this were the case then in five years out of 15 (there were five El Nino events from 1983-1998) production could be halved. In summary the following might be expected within the next 25 to 50 years:

1) 47% of years with expected production of four million tonnes;
2) 33% of years with half of expected production;
3) 20% of years with three quarters of expected production (due to effects of cyclones and residual effects of drought periods).

The estimate of 47% of years attaining expected production does not account for on-going adverse effects of land degradation in marginal areas, nor does it account for the possibility that residual effects of bad years could increasingly spread to otherwise good production years.

6.3.2 Root crops

The Plantgro model was run for dalo, yams (lesser yam), cassava, and yaqona for each of the climate change scenarios specified in Chapter 3. In addition, results were generated for current El Nino and La Nina anomalies and the same anomalies adjusted by average changes in 2050. The El Nino and La Nina anomalies used were:

1) Current El Nino, +0.5°C, -50% rainfall;
2) Current La Nina, -0.5°C, +50% rainfall;
3) 2050 El Nino, +1.5°C, -60% rainfall;
4) 2050 La Nina, +0.5°C, +60% rainfall.

There were 17 images produced for each of the four root crops examined, one for 1990, four scenarios each for 2025, 2050 and 2100, and the four El Nino and La Nina anomalies described above. These images were imported into the IDRISI GIS (Eastman, 1985), they were reclassified into three yield classes (0-5 tonnes/ha; 5-10 tonnes/ha; 1015 tonnes/ha) and the land area in each yield class was calculated. The calculated land areas represent total areas of suitability for different yield classes in Viti Levu, not actual area in production. Results were graphed to highlight changes in area of the different yield classes under the different scenarios. In the graphed results presented here the four scenarios run for 2025, 2050, and 2100 are numbered such that:

1 refers to the CSIRO9M2 GCM and the B2 (mid) emissions scenario;
2 refers to the CSIRO9M2 GCM and the A2 (high) emissions scenario;
3 refers to the DKRZ GCM and the B2 (mid) emissions scenario;
4 refers to the DKRZ GCM and the A2 (high) emissions scenario.

For dalo, under average conditions, there is not much change with the different scenarios up to and including 2100, for the normal planting time of September, with the exception of scenario 4 for 2100 (Figure 6.6). On average 30% of the total land area of Viti Levu (approximately 3000 ha) supports yields of 10-15 tonnes/ha, with 45-50% (up to 5000 ha) supporting yields of 5-10 tonnes/ha and 20-25% (up to 2500 ha) supporting yields of 0-5 tonnes/ha. It is quite likely that there are changes within these yield classes with the different scenarios, which would require a more detailed site analysis for them to be quantified. Scenario 4 for 2100 gives a temperature increase of 3.3°C and a rainfall decrease of 20%, resulting in less than 15% of the total land area supporting higher yields, and an equivalent increase in the area supporting zero or very low yields (0-5 tonnes/ha).

Extreme rainfall variations appear to have the greatest impact on dalo, particularly in extreme dry years, as shown with the results for the El Nino anomalies (Figures 6.6 and 6.7), which show a dramatic reduction in total area of suitability and an approximate 30% decline in yield in areas of current suitability (primarily the southeast). The higher rainfall La Nina anomalies (current and 2050) show better than average yields for dalo.

If the pattern of climate variation of the last 15 years were repeated, and possibly intensified, in future then it might be expected that over the next 25-50 years dalo yields could be reduced significantly in 33% of years (El Nino drought years) with up to 20% of years where there are yield reductions due to residual effects of drought events. Based on the results in Figure 6.7 and the sensitivity analysis shown in Figure 6.4 it is likely that yield reductions of 30-40% could occur in years where rainfall is close to half the average. It is also likely that total production would decline in dry years, due to a combination of factors including: reduced yields; reduced area in production; reduced growing period (i.e. under normal conditions dalo can be grown year round in the highest rainfall areas, which might not be possible under drought conditions).

Yam shows quite different responses to dalo under the different scenarios, based on the present planting time of July (Figure 6.8). Under present average climate, just under 50% of Viti Levu gives higher yields, about 35% gives medium yields, and just over 15% gives zero or low yields. Warmer, wetter conditions lead to an increase in land area with zero or low yields, increasing to about 30% under Scenario 2 in 2100. Warmer, drier conditions lead to an increase in land area with medium yields, increasing to just over 40% under Scenario 4 in 2100, and a decrease in the land area with zero or low yields, down to about 10% of the land area with the same scenario.

The El Nino and La Nina results for yam are very interesting. Under the El Nino anomalies the total area with zero or low yields decreases to its lowest level out of all of the results (Figures 6.8 and 6.9), with the land area producing medium yields increasing significantly under El Nino drought conditions. In contrast, the La Nina anomalies show a dramatic decline in area suitable for yam (Figure 6.9), with significant increases in the land area producing zero or low yields (Figure 6.8).

In general it might be said that under climate change, yam yields might be lower but production the same or higher (more land suitable) in about 33% of years (El Nino), yields might be comparable to the present in about 20% of years, and yields and total production could be reduced in La Nina or wetter than average years (up to 50% of years). This is more-or-less the opposite to what would be expected with dalo, which is consistent with the traditional use of dalo and yam as wet and dry season crops respectively.

Although cassava is grown year round it was evaluated for a single planting time, July, to provide a contrast with the results for yam. Because it is grown year round it is difficult to draw too much from the results presented (Figures 6.10 and 6.11). However, it is evident that cassava is generally less productive than yam when planted at the same time. Results also indicate that productivity generally worsens with climate change, with significant increases in land area with low yields under the high temperature increases experienced with Scenarios 2 and 4 in 2100. Productivity also worsens under both El Nino and La Nina conditions, compared to the average, particularly under an intensified La Nina situation.

The results for yaqona show no change from the present, for all scenarios including the El Nino and La Nina anomalies. This may or may not reflect the actual sensitivity of the plant. Reports from the 1997/98 drought indicated that yaqona failed in drought affected areas. However, the Plantgro results (see Figure 6.5d) indicate that yaqona is most suited to upland areas in central and southeastern Viti Levu, which was least affected by the drought. This suggests that, with increased commercialisation and expansion into less traditional areas, yaqona production could become increasingly susceptible to variations in climate in Viti Levu (and throughout Fiji). However, given the lack of response of the model for yaqona it is not presently possible to quantify such effects.

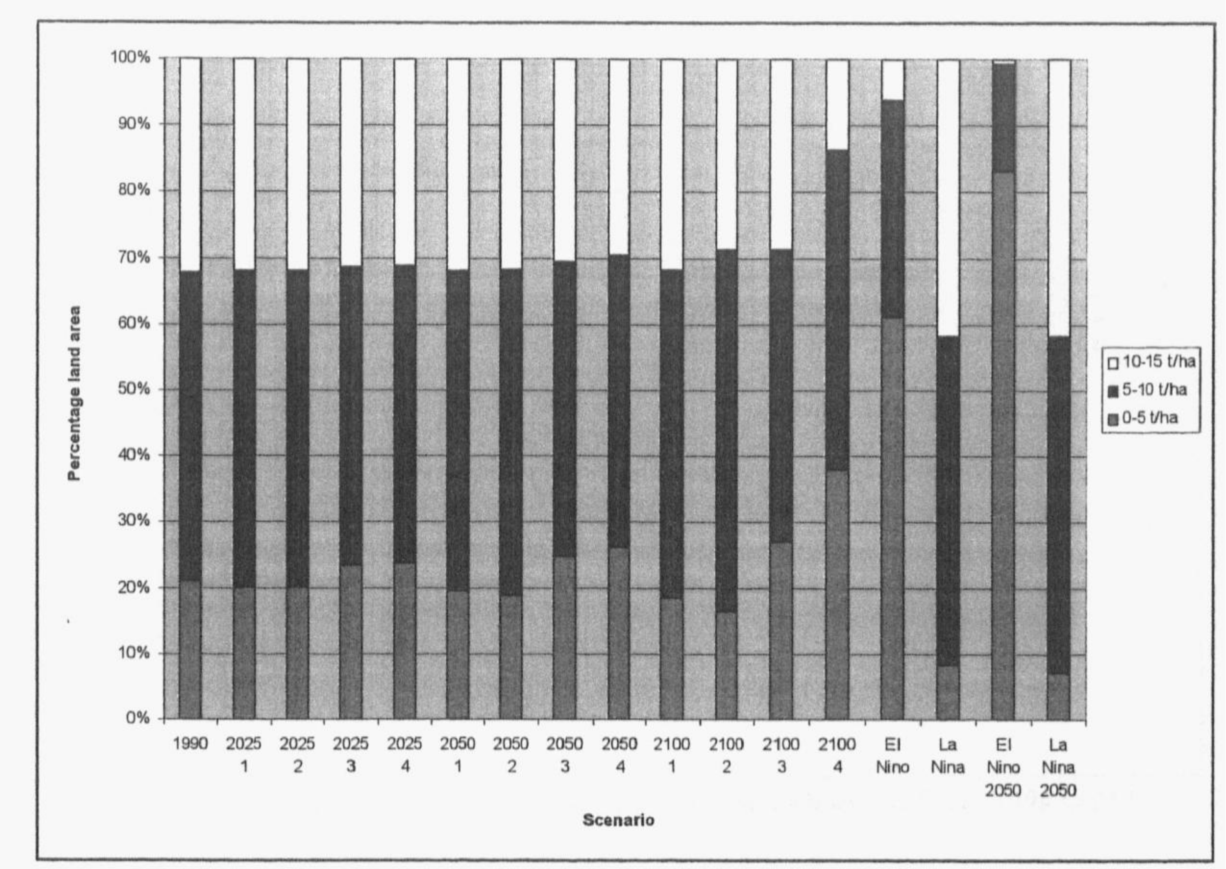
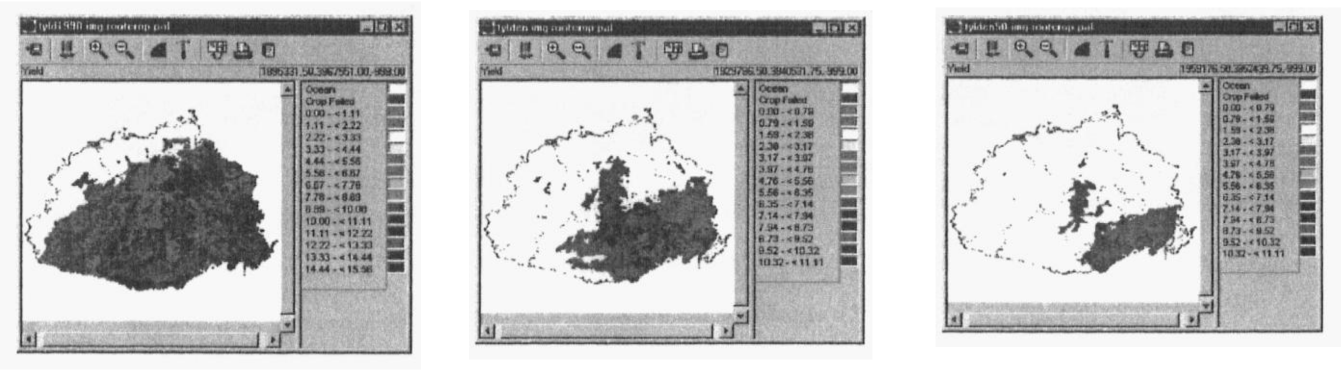


Figure 6.6. Change in areas of suitability, and yield for dalo in Viti Levu, 1990 to 2100



1990

Current El Nino

2050 El Nino

Figure 6.7. Effect of El Nino drought (present and 2050) on areas of taro suitability and yield in Viti Levu

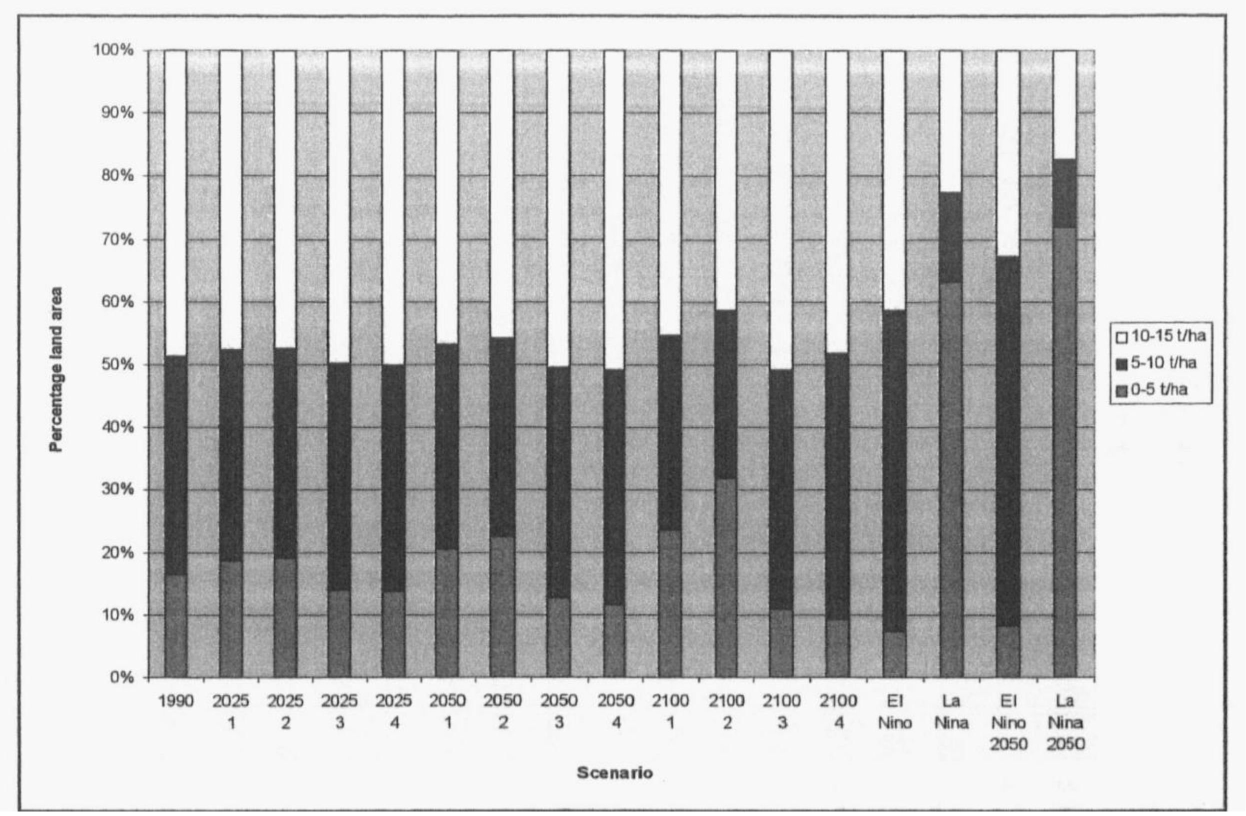
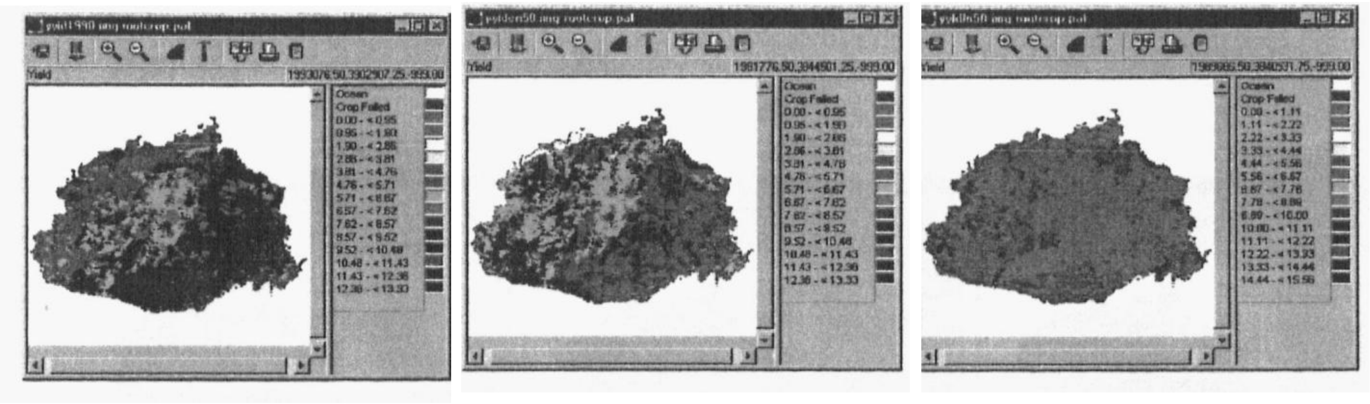


Figure 6.8. Change in areas of suitability and yield for yam in Viti Levu, 1990 to 2100



1990 **El Nino 2050** **La Nina 2050**

Figure 6.9. Effect of El Nino and La Nina anomalies (2050) on areas of yam suitability and yield in Viti Levu

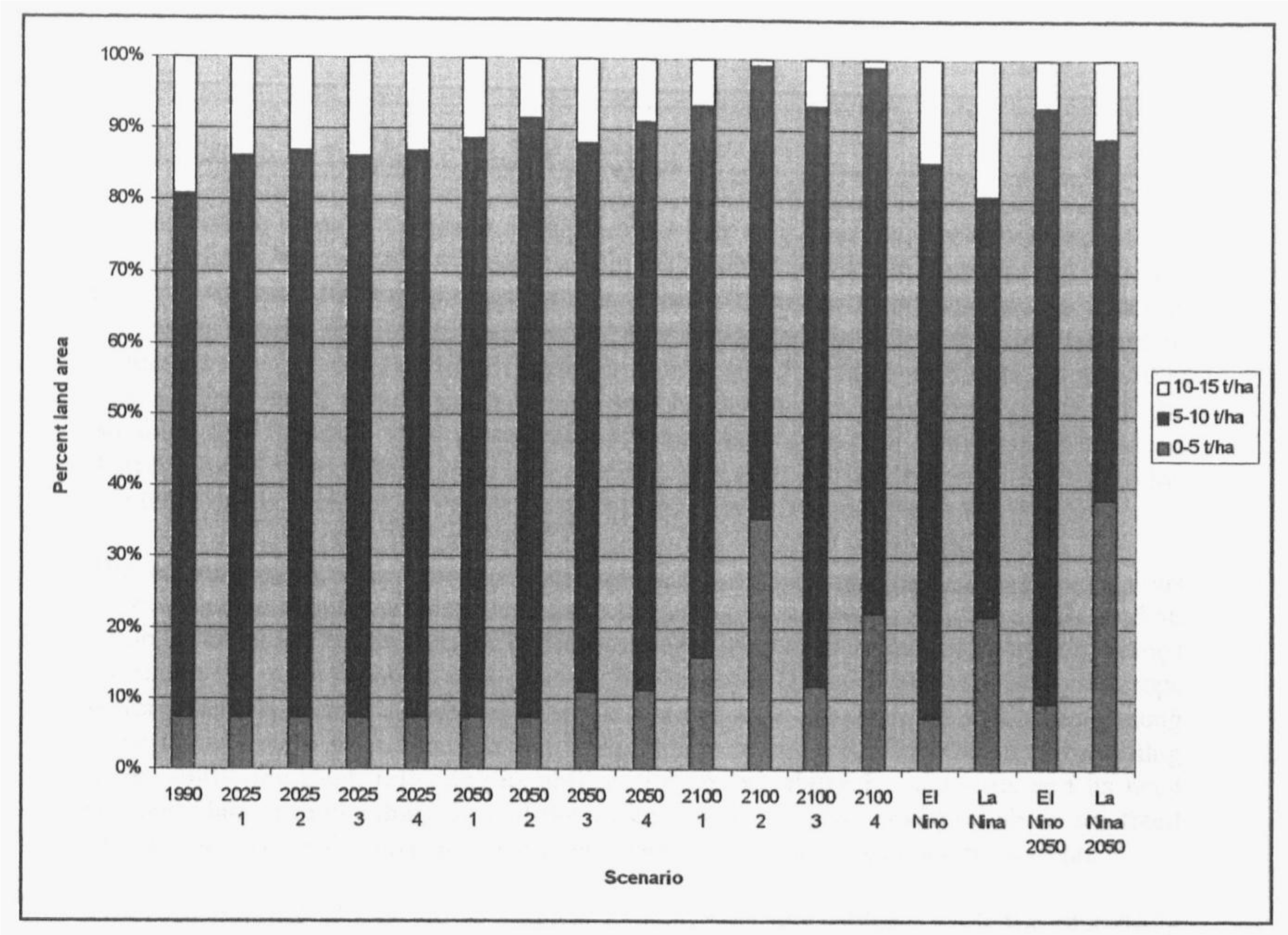
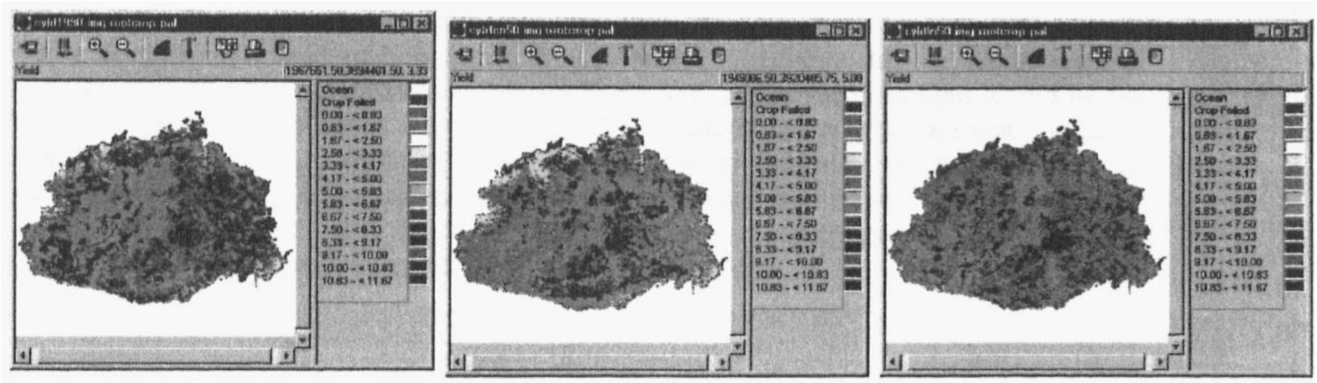


Figure 6.10. Change in areas of suitability and yield for cassava in Viti Levu, 1990 to 2100



1990 **El Nino 2050** **La Nina 2050**

Figure 6.11. Effect of El Nino and La Nina anomalies (2050) on areas of cassava suitability and yield in Viti Levu

Box 1. Effects of Tropical Cyclones on Crops

The effects of tropical cyclones on agriculture can vary considerably depending on the characteristics, such as wind speeds, amount of rainfall and storm surge height, of each event. As well, different types of crops have different responses to the extreme conditions caused by tropical cyclones. Comparable and consistent data on damage to different types of crops is difficult to obtain. One event for which such data are available was Cyclone meli which caused considerable devastation throughout much of the Southern Lau Group in 1979. As Figure A, which shows the path of the cyclone and the distribution of wind speeds, indicates, some islands such as Nayau were subjected to the full force of the event while others, such as Ogea only experienced gale force winds.

The accompanying table shows the effects of the cyclone on crops grown on various islands located at different distances from the path of the storm. The table tells us that, while, at the storm centre damage is nearly total, at even short distances away some crops are relatively more resistant than others. In particular, the table shows that some crops suffer relatively serious damage even some distance from the storm centre. Chief among these is cassava, a crop which is not a traditional cultivar, but one which is becoming increasingly prevalent, reflecting its ability to grow on relatively poor soils and its need for lower labour inputs than some of the traditional crops. Thus land and labour are freed up for other economic activities including cash tree crops such as copra production.

The high liability of cassava to tropical cyclone damage, coupled with the increasing dependence upon it as a subsistence cash crop, increases the likelihood of heavy dependence upon food rations as a result of tropical cyclones. In most cases the best strategy for food security in cyclone prone areas is a diversity of crops and the maintenance of traditional crops where possible.

In a scenario of increased tropical cyclone intensity, it is likely that the trend towards increasing cultivation of cassava will result in greater food crop losses than would be the case if traditional root crops were maintained. An adaptation programme that sought to promote the farming of traditional crops would need to determine the reasons, such as falling soil fertility and competing demands for labour, that have contributed to the emergence of cassava as a major crop. From this perspective, promoting sustainable agriculture may be seen as a useful adaptation to climate change.

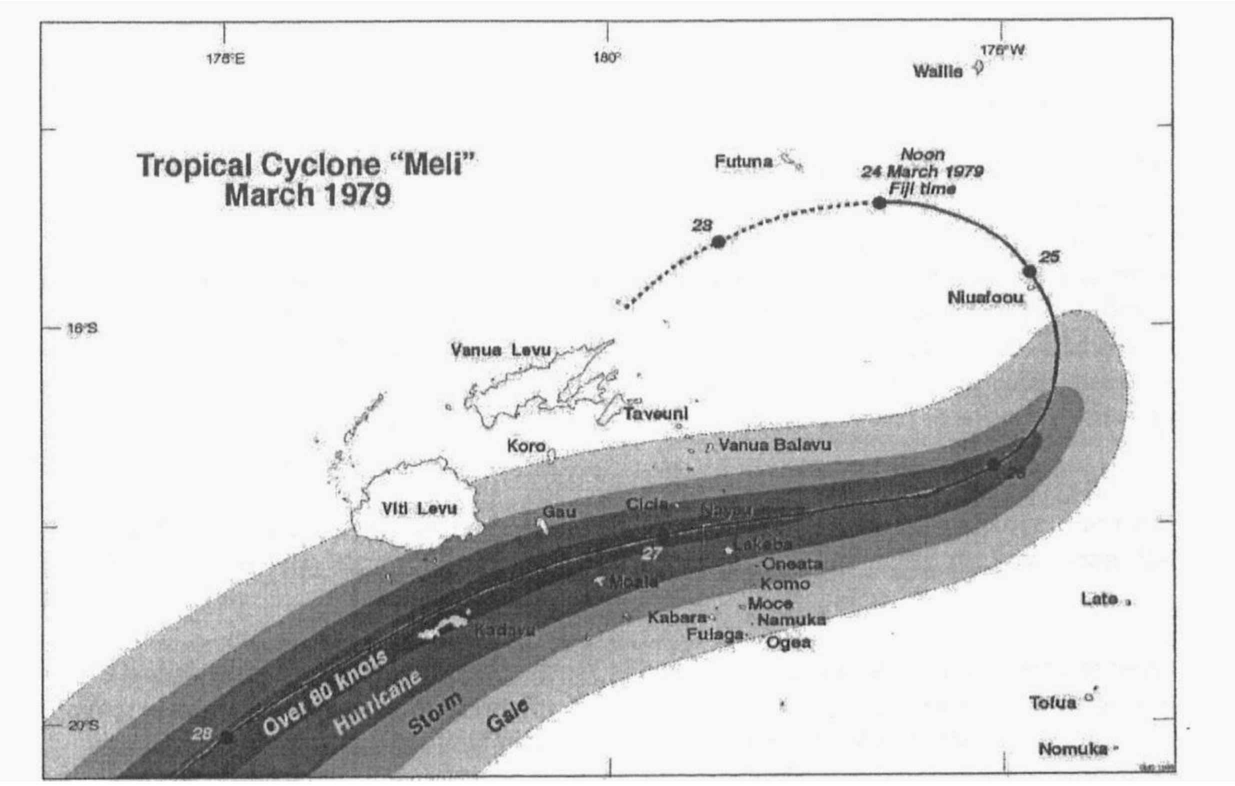


Figure A. The path of Cyclone Meli through the Lau Group showing the distribution of wind speeds (After, Krishna, 1981)

	Distance	**Root Crops**			**Tree Crops**		
Island	**From Nayau (km)**	**Cassava**	**Taro**	**Yam**	**Banana**	**Coconut**	**Breadfruit**
Nayau	0	100	100	80	100	100	100
Cicia	30	100	96	54	100	91	100
Lakeba	30	94	55	48	82	75	50
Vanuavatu	45	75			75	60	50
Oneata	67	60		10	50	40	40
Komo	86	60			40	30	40
Moce	88	60		10	50	40	40
Namuka	99	50			50	15	30
Kabara	99	60		10	50	40	
Fulaga	129	50			40	10	30
Ogea	142	50			40	10	30

Source: Campbell (1985)

6.4 Adaptation

Given both the present vulnerability of agricultural systems in Fiji to variations in climate and the likelihood that this could be exacerbated by climate change, there is a strong case for advocating a no regrets approach to adaptation for agriculture. Such an approach has not only been endorsed by countries in the region, but is also supported by the FAO (FAO, 1999a). The approach suggested by the FAO is to place greater emphasis on *"research and the extension of more flexible farming systems that are tolerant to climatic stresses and variability"* (FAO, 1999a). The development and extension of such systems should be part of a holistic and integrated approach, which takes into account the multiple inter-dependencies (i.e. between the coast, land and water resources and the interaction of people with their resource base) in PICs, and needs to be consistent with national policies, specifically those related to environmental management, and involve community participation and ownership.

Specifically, although not exclusively focussed on adaptation to climate change, the FAO (1999b), propose the development of sustainable production systems involving the following actions:

- *"Traditional or moderate input systems. Develop sustainable agro-forestry systems to: raise and diversify production, improve soil fertility, prevent soil loss and environmental degradation, and reduce dependence on external inputs;*
- *Intensive high-input agricultural systems on lowlands. Introduce short-duration cover crops and legumes to improve soil fertility and structure, conserve moisture, reduce build-up of weeds and pests, reduce reliance on imported chemicals and fertiliser, minimise environmental degradation, and increase green fodder availability;*
- *Farming systems research. Appraise socio-economic issues and feed this information into cropping trials and extend technology to the farming community using a farmerto-farmer approach."*

The foundation for the above has already been put in place in Fiji, by recent developments including:

1) the preparation of a comprehensive draft land use policy for Fiji, which contains recommendations aimed at the sustainable management of Fiji's land resource;
2) the establishment of the Commodity Development Framework (CDF) aimed at increasing the economic robustness of subsistence communities;
3) the recent merger, within MAFF, of the extension and research divisions which will provide greater opportunities for farming systems research;
4) the existence, within the Landuse Planning Section of the MAFF Research Division, of a CDF programme aimed at introduction of sustainable land use practices particularly in erosion prone sloping land areas;
5) the establishment of a Geographical Information System, within the Landuse Planning Section, aimed at providing accurate information on matching crops to the most suited soil and climatic conditions.

At present, some of these activities are given relatively low priority. For example the conservation work (item 4)) has received relatively low funding through the CDF. The establishment of a national land use policy (item 1) ought to provide the basis for strengthening the other listed activities. However, this could be further enhanced by placing a much stronger emphasis on reducing adverse effects of extreme events and taking account of the possible effects of climate change. The experience of the 1997/98 El Nino drought, which followed a sequence of natural disasters, has heightened awareness of this need.

Some more specific measures, relating to the effects identified in the previous section include:

1) sugarcane – as recommended in the UNDAC Mission Report on the Fiji Drought (UNDAC, 1998) serious thought should be given to the following measures for sugarcane:
   i. cease sugarcane production on marginal sloping and coastal lands and introduce alternative crops in association with more sustainable land-use practices;
   ii. intensify sugarcane production in the better land areas through the introduction of irrigation. As suggested in the UNDAC report, if the sugarcane area were reduced from 66,700 ha to 40-45,000 ha and yields increased, under irrigation, to at least 90 tonnes/ha then the national production goal of four million tonnes could be attained annually.

   The sugarcane situation in Fiji is a complex one, given the physical setting (large areas of production on marginal land in a drought prone part of the country), the land lease issue, and the likely end to preferential prices in the near future. The cessation of sugarcane production on marginal land areas, and introduction of alternative crops, is a highly feasible option that is already being discussed within Fiji. However, implementation of such measures is likely to be impeded in the short-term given high uncertainties with the land lease situation. This uncertainty provides little incentive for the Fiji-Indian leaseholders to diversify crops and to implement soil and water conservation measures.

   Indications are that there are large untapped groundwater reserves in the west. However, the potential benefits of these reserves need to be balanced against the costs of establishing an irrigation scheme, the likely rate of extraction, and the potential for salt-water intrusion. In addition, the possibility of a decline in economic returns from sugarcane (if preferential prices are removed) needs to be taken into account. An alternative adaptation measure in the better land areas would be to encourage diversification to higher value crops. The situation is complicated by continued uncertainty over land leases. If the land reverts to the native Fijian landowners, it is possible that crop diversification could become a more readily adopted option.

2) root crops – in general it appears, from available knowledge and the results of the previous section that there is a high adaptive capacity with root crops. A number of measures could be implemented, including:

i. strengthening the role of the Landuse Planning section in identifying areas most suitable for the different root crops;
ii. breeding more drought tolerant dalo varieties;
iii. enhancing the yam breeding programme (at least 60 varieties have been evaluated) and encouraging a reintroduction of traditional yam and taro crop rotations.

Adaptation measures for dalo, assuming a possibility of future El Nino droughts that are at least comparable to that experienced in 1997/98, are explored in more detail in the example below. This example highlights the fact that, while there is a high adaptive capacity when the root crops are considered as a whole, there could be significant costs to drought-proofing specific crops. A more feasible approach might be to encourage the development of flexible land management strategies, coupled with seasonal forecasting systems, to ensure that the most suitable crops are planted in particular years and seasons. One difficulty with this approach is the increased importance of dalo as an export crop, and thus a preference for its cultivation.

Options for dalo are examined in more detail in the attached example.

Box 2. **An adaptation strategy to maintain dalo corm production as climate changes**

Under current weather conditions at Koronivia on Viti Levu, a rainfed dalo crop planted in September yields approximately 20 tonnes/ha with individual corms weighing about 1 kg. In a scenario where rainfall is reduced to 50% of the current level and temperature rises by 1.5 °C, yield drops to 13 tonnes/ha and each corm is only 0.7 kg. If corm weight is too low the entire crop may be unmarketable. Choosing proper management strategies to maintain dalo production under adverse changes in climate must account for yield and corm size.

The major cause of the low yield and corm weight is the lack of water. The solution is to provide more water to the dalo plant by increasing the soil volume each plant has to extract water (i.e., lessening the plant density) or adding water to the soil. Simulations show that decreasing plant density from 2 to 1 plant/m^2 in a rainfed crop can raise the corm weight from 0.7 to 1 kg (Figure A). Because the plant density is low, corm yield is only 10 tonnes/ha (Figure B). To maintain a dalo corm output of 20 tonnes, a field would need to be 2 ha instead of I ha needed before climate change. Alternatively, adding 440 mm of water (4.4 million liters/ha) over the season would increase dalo yield to 20 tonnes/ha and corm weight to 1 kg (Figures A and B). Additional strategies that maintain dalo production include simultaneously adjusting plant density and irrigation as suggested in Figures A and B. Adapting dalo production to climate change will require large resource allocation. At most, land area devoted to dalo will double or water resources to deliver 4.4 million liters per ha must be developed.

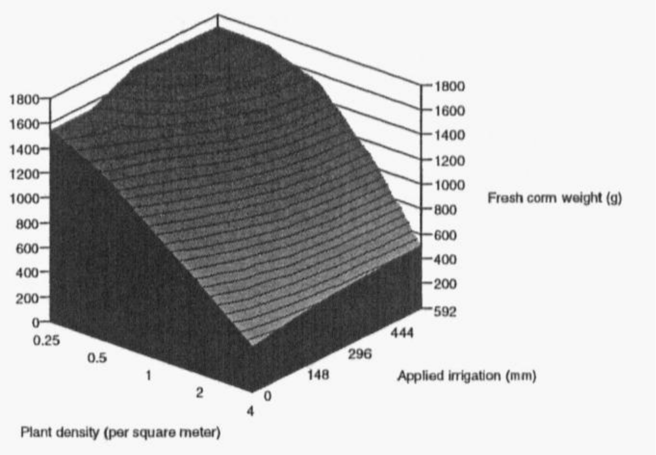


Figure A. Fresh corm weight increases as irrigation is applied and plant density is lowered under reduced rainfall and higher temperature conditions at Koronivia, Viti Levu.

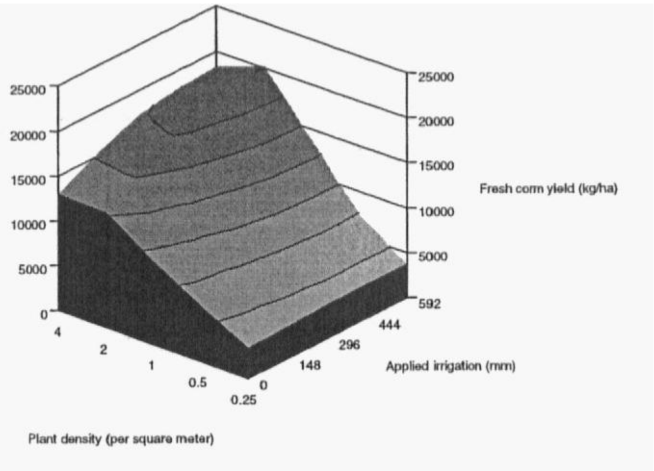


Figure B. Dalo yield increases as irrigation and plant density increase under climate change scenario at Koronivia, Viti Levu.

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7 Human Health

7.1 Overview of sector

Fiji has made significant progress in the last 25 years in improving the status of public health. This is reflected in the downward trend in the Infant Mortality Rate (IMR) which has fallen from 41.4 in 1975 to 16.3 in 1994 and an increase in Life Expectancy which in 1996 was estimated to be 68.7 for females and 64.5 for males.

While many of the improvements in the public health status of Fiji have been achieved through the improvement of medical services such as hospital services, primary health care and the successful immunization programmes, it is evident that social and economic changes have also contributed to this process through improvement in living conditions, sanitation, nutrition and improved water supplies. Overall, the result has been that Fiji, like many other developing countries, has been experiencing an epidemiological transition in public health characterised by a downward trend in infectious diseases and increase in non-communicable diseases. Changing life-styles, levels of affluence, diets and urbanisation have possibly contributed to the rising trend in the prevalence of chronic and non-communicable diseases more typical of a developed country.

Not all sectors of society in Fiji have benefited from socio-economic trends and improvement of health services which have contributed to the overall improvement in public health indicators. In fact, paradoxically, it would appear that some sectors of society and communities might be worse off than before. Social and economic change has also been associated with loss of traditional social structures, rapid urbanisation and increased disparities in income and standards of living. Recent years have seen the increase in peri-urban squatter settlements, worrying levels of poverty, increased levels of pollution and environmental degradation and the continuation and possible resurgence of conditions, such as malnutrition and diarrhoeal diseases, which are frequently related to poverty, poor living conditions and poor sanitation. These trends and factors indicate the present vulnerability of certain communities and the likelihood that the effects of climate change may result in significant impacts on human health in Fiji.

The possible impacts of climate change on human health and well-being highlight the fact that it is critically important that action is taken today to ensure that development in Fiji follows a trajectory which reduces the vulnerability of all sectors of society through the promotion of policies which are socially, economically and ecologically sustainable and which increase the resilience of society and the ecological systems on which society depends for health and livelihoods.

7.2 Climate change concerns for public health in Viti Levu

This section presents a preliminary risk analysis of climate change effects on public health in Fiji in order to identify those conditions and factors that are likely to be most important and warrant further analysis. Determinants of human health are extremely diverse ranging from genetic and biological factors through to environmental, social and economic factors. Climate is one of the important determinants of human health. Average climate conditions, climate variability and climate extremes influence human health in Fiji either through direct mechanisms (such as flooding), indirect mechanisms (such as the distribution of vector-borne diseases) or through cumulative mechanisms (as exemplified by the effects of a cyclone or drought on the national economy and living standards).

Consequently, the effects of climate change on human health may be considered as 1st, 2nd, 3rd order effects depending on the pathways or mechanisms involved.

Potential first order health effects include injury and illness due to more frequent heat waves, storms and floods.

Expected second order effects include altered distribution of communicable diseases including vector-borne diseases (dengue, malaria), waterborne diseases (viral and bacterial diarrhoea) and diseases related to toxic algae (ciguatera).

Nutrition-related illnesses (especially malnutrition, and possibly chronic diseases such as cardiovascular disease and diabetes, related to western diets) are a major category of potential second-order health effects.

More diffuse and ill-defined, but certainly important third order health impacts include the effects of poverty, inequality, unemployment and other more severe forms of social disruption such as forced migration. Vulnerability to all categories of climate change impacts is expected to be strongly influenced by associated social, economic and ecological factors.

The scope of this study does not allow in-depth analysis of the effect of climate change on all aspects of human health risks. However, considering the present public health concerns in Fiji and the degree to which aspects of human health are sensitive to current climate conditions in Fiji, a short-list of conditions which may be important in terms of climate change in Fiji has been developed. It should be noted from the outset that the scope of this study is constrained by data availability and the technical tools available for the assessment of climate change impacts. Those impacts of climate change which are discussed are those that are easier to understand based on the present experience of climate effects and known mechanisms of disease. Consequently, the more ill-defined, downstream and cumulative impacts of climate change, which may indeed prove to be the most important, are not analysed in depth.

Dengue fever

Dengue fever is a significant and possibly increasing public health concern in Fiji with the most recent epidemic in 1998 involving an estimated 24 000 cases and resulting in 13 deaths (Basu et al, 1999; WHO, 1998). Changes in rainfall, ambient temperature and humidity influence the life-cycle of the mosquito vectors and are powerful determinants of the distribution and size of vector populations.

Temperature also influences the biting rate of the mosquito vectors and replication rate of the dengue virus in the mosquito vector and consequently influences epidemic risk.

Dengue fever has therefore been identified as a significant public health risk in Fiji which will be influenced by climate change and is further analysed in this chapter.

Malaria

Malaria, like dengue fever, is a mosquito-borne disease and as such the mosquito life cycle, distribution and population size and epidemic risk are also closely linked to climatic variables. However, while malaria is endemic in other Melanesian countries, the *anopheles* mosquito species responsible for malaria transmission are not found in Fiji. Apart from imported cases of malaria (numbering about 10 – 20 per year), Fiji has remained malaria free (Fiji MoH, 1997; Koroivueta, pers. comm.).

It is well recognised that suitable climatic, ecological and environmental conditions for *anopheles* species do exist in Fiji and that if introduced, there would be a high likelihood that a capable vector population would become established in Fiji and present the possibility of endemic transmission of malaria (Prakash, pers. comm.). Strict port control and quarantine measures to prevent the introduction of *anopheles* mosquitoes have thus far been successful.

Several factors suggest that the analysis of the effect of climate change on malaria in Fiji is important:

- The literature suggests that the global distribution and prevalence of malaria is likely to increase with climate change (WHO, 1996);
- Similarly, the incidence of malaria on other Melanesian countries may increase posing additional risks of introduction to Fiji especially in the context of increasing travel within the Pacific region;
- Notwithstanding significant advances in vector control technology, control of *anopheles* species would prove difficult in the ecological milieu in Fiji.

However, notwithstanding the factors described above, several factors indicate that the climate change related risk of malaria in Fiji may be not be significant:

- A preliminary analysis of the suitability of climatic conditions in Fiji for malaria and malarial vectors suggests that the present climatic conditions are already near optimal for mosquito populations and the transmission of the disease. (See **Annex Hl** and **Annex H2.);**
- Changes in epidemic risk attributable to climate change, *per se,* are therefore possibly relatively small and of low significance in the populated coastal areas. With the more extreme climate change

scenario, there may even be a slight decrease in malarial risk by the year 2100. **(See Annex H2.);**
- Given that malaria is not present in Fiji, interpretation of the significance of changes in malarial risk attributable to climate change is extremely difficult without this baseline reference;
- The fact that Fiji has, remarkably, remained malaria free, suggests that it is possible that there are unknown ecological or other factors which preclude the establishment of a capable vector population for malaria in Fiji;
- Quarantine and border control measures have been successful to date and while the risk of introduction may remain high, that component of risk specifically attributable to climate change is likely to be small and would not be easily defined.

Therefore, while changes in malaria risk may occur as a result of climate change, these have been considered beyond the scope of this study and have not been further analysed.

Filariasis

Filariasis is another mosquito-borne disease, present in Fiji, which is likely to be influenced by climate change (Prakash, pers. comm.; WHO, 1996). Villages in coastal areas are often the most likely to have high incidence rates of filariasis as the primary mosquito vector, *Aedes polynesiensis,* is salt water tolerant and breeds in a variety of coastal habitats including crab holes and marshlands. It is therefore possible that inundation associated with sea level rise will alter the distribution and population densities of this vector. Another vector of filariasis in Fiji, *Aedes fijiensis*, breeds in rainwater collected in leaf axils of banana plants and therefore would also be influenced by land use and climate change. *Aedes pseuodscutellaris* is another competent vector of filariasis and is found in Fiji.

Fiji is presently involved in a comprehensive programme which aims to eradicate filariasis. As control of filariasis vectors is very difficult, the programme which commenced in 1996 relies on mass drug administration (diethyl carbamazine and albendazole). Through this programme, it is anticipated that filariasis will be eradicated from Fiji within 5 – 10 years (Koroivueta, pers. comm.).

Therefore while it is theoretically possible that the incidence of filariasis is influenced by climate and would be expected to change with climate change and sea-level rise, it is unlikely that it would remain a significant public health risk in Fiji and relevant to the time horizons of this analysis. For this reason, filariasis has not been analysed further in this study.

Diarrhoeal diseases

Diarrhoeal diseases remain a significant problem in Fiji and are particularly important in terms of child health. In general, the case incidence rates of infantile diarrhoea have improved in the last 25 years, as sanitation and water supplies have improved. However, the data from the last three years suggest that this may be a re-emerging problem and current rates suggest that diarrhoeal diseases are a significant cause of childhood morbidity. There are observed associations between climate and diarrhoeal outbreaks in Fiji which relate to both seasonal effects and extremes of rainfall. The possible effects of climate change on diarrhoeal diseases will be analysed and discussed further.

Ciguatera

Ciguatera (fish poisoning) is the most frequently occurring human illness caused by ingestion of marine toxins, affecting perhaps 50,000 people per year in tropical and subtropical countries (Baden et al. 1995). The disease is caused by the ingestion of reef fish which have been contaminated by ciguatoxins. Ciguatoxins are produced by marine dinoflagellates (particularly *Gambierdiscus toxicus)* that live on the surfaces of marine macroalgae. Herbivorous reef fish become contaminated when feeding on the macroalgae. The toxins are concentrated on moving up the food chain, as when larger carnivores including Barracuda, Snapper, Grouper and Moray Eel prey on herbivorous fish (Baden et al. 1995). Ciguatoxins have been estimated to have a half-life of about 260 days, similar to the period over which outbreaks of ciguatera are said to occur (Lewis 1992; Lewis and Holmes 1993).

Ciguatera has substantial adverse health impacts in Pacific Island countries which rely on fish as a major protein source (Lewis 1992). Lewis (1992) suggests that a small increase in several countries may have been related to an El Nino event. Other authors have previously noted a seasonal increase in Fiji, American Samoa and New Caledonia in spring (Sorokin 1975; Dawson 1977; Bagnis 1979). The seasonality of ciguatera may be related to rainfall runoff from high islands, in which case a seasonal relationship would also be expected in Vanuatu (Lewis, 1992). Unfortunately, it is not possible to confirm this since reports of ciguatera from Vanuatu have been erratic until recently. While there has been much speculation about a role for climate factors in ciguatera and other diseases caused by harmful marine algae, the evidence to date has been qualitative and anecdotal (Hallegraeff 1993; de Sylva 1994; Tibbetts 1998).

It is likely that climate is only one of several important factors affecting ciguatera incidence. For example, ciguatera has been associated by several authors (Ruff 1989; Lewis 1992; de Sylva 1994; Baden et al. 1995) with disturbance of coral reefs. Hallegraeff notes that while harmful algal blooms are a natural phenomenon, "... in the past two decades the public health and economic impacts of such events appeared to have increased in frequency, intensity and geographic distribution" (Hallegraeff, 1993).

Various explanations have been suggested, including increased awareness, contamination of coastal waters, transport of dinoflagellate cysts in ships' ballast water, and global climatic changes. A study of ciguatera in 8 Pacific Island countries found positive correlations between the annual incidence of ciguatera and local warming of the sea surface in one group, all of which experience warming during El Nino conditions (Hales et al, 1999b). In the remaining islands, there were weaker negative correlations between ciguatera and local sea surface temperature. In Fiji, there was essentially no correlation between ciguatera and sea surface temperature ($r = -0.05$, $p = 0.81$). Therefore, whilst global climate change is likely to increase the incidence of ciguatera in some regions, it is not possible to make quantitative forecasts of effects in Fiji on the basis of this study and the effect of climate change on ciguatera will not be further analysed in this report.

Nutrition related illness

Drought conditions in Fiji have in the past resulted in severe food shortages and provide an indication of the vulnerability of certain communities to the effects of climate extremes. Some of the nutritional problems that have been associated with drought conditions include inadequate dietary intake of protein and carbohydrates as well as micronutrient deficiencies. These are discussed further in this report.

In summary, therefore, while it is recognized that climate may have a wide range of direct and indirect effects on human health and that human health may be considered an integrating unit of a wide range of climate effects, only those public health concerns with clear climate linkages have been considered and those which are more amenable to quantitative or qualitative analysis. The following will be analysed in more detail:

1. Dengue fever;
2. Diarrhoeal diseases;
3. Nutrition related illness.

The linkages between socio-economic, environmental factors and human health are also discussed in the context of the vulnerability of individuals and communities to climate variation and future climate change.

7.3 Present conditions: Today's climate and human health in Viti Levu

7.3.1 Dengue Fever

World-wide, dengue fever epidemics have increased in number, frequency and distribution over the last 40 years and consequently dengue fever has come to be considered one of the most important emerging public health problems (WHO, 1996; WHO, 1997). Currently, dengue fever is the most important mosquito-borne disease in Fiji. Clinical manifestations range from mild fevers to severe and potentially life threatening haemorrhaging disease.

Dengue fever – biomedical profile of the disease

Dengue fever is caused by one of four serotypes of the dengue virus (DEN-1, DEN-2, DEN-3 and DEN-4). It is an arboviral disease which in Fiji is transmitted predominantly by *Aedes aegypti*. The mosquito vector becomes infected when it bites and feeds on a viraemic human. The virus infects and replicates in the gut tissues of the mosquito from where it disseminates and becomes detectable in the mosquito saliva. At this point, the mosquito is able to infect the next human it bites. The time period from when a mosquito is infected to when it becomes infectious is known as the extrinsic incubation period and may vary from 6 – 39 days (Patz *et al*, 1998). A non-immune human bitten by the infected mosquito is likely to develop the disease after a period of 5 – 6 days. (See Figure 7.1.)

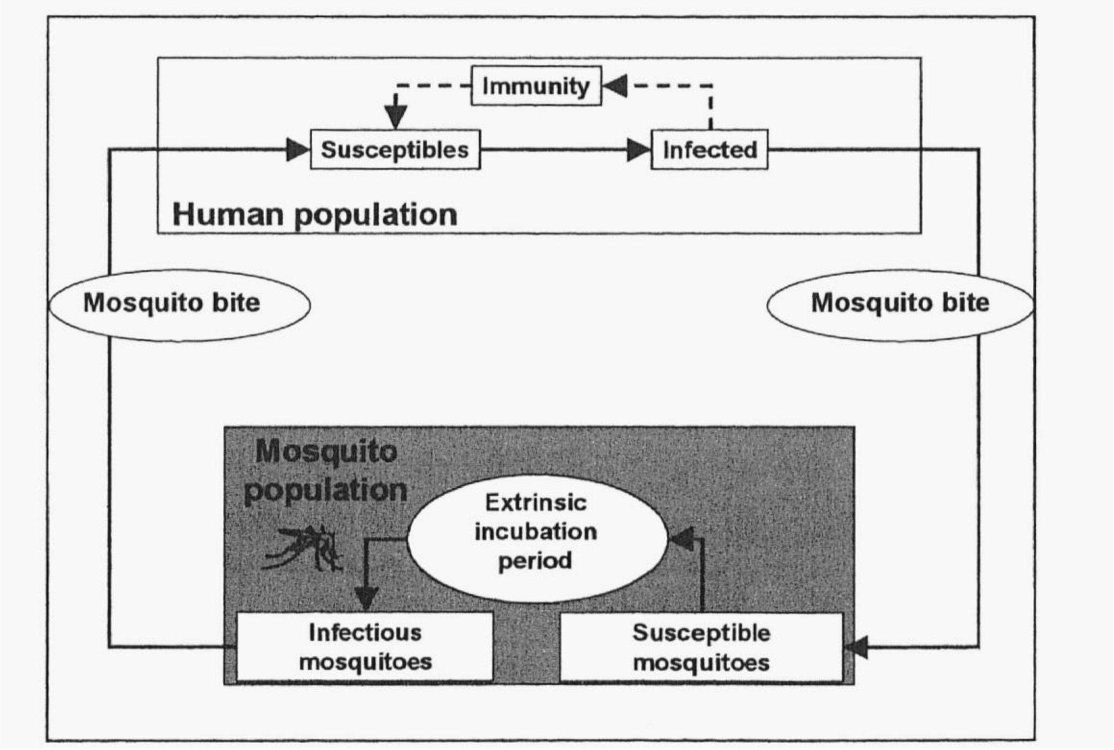

Figure 7.1. Schematic of dengue fever transmission cycle

The prodromal period of approximately 2 days is typically characterised by malaise and headaches. Classical dengue fever (DF) is characterised by a high fever and a range of constitutional symptoms including muscle pains, joint pains, headaches and weakness. Fever and symptoms last about 7 – 8 days. Classical dengue fever is usually self-limiting and rarely fatal. However, convalescence in adults may be slow with the patient experiencing prolonged fatigue, weakness and depression (WHO, 1997).

Dengue haemorrhagic fever (DHF) is a more severe form of the disease and is characterised by haemorrhagic phenomena and plasma leakage due to increased vascular permeability. Some of these patients may progress to Dengue Shock Syndrome (DSS) and develop severe circulatory failure. Mortality rates of the more severe forms (DHF and DSS) range from 1% to 20% depending on the medical expertise and services available. Convalescence is otherwise usually short and complete.

Treatment for all forms of dengue is symptomatic and supportive. Depending on the clinical manifestation of the more severe forms of the disease, supportive therapy ranges from intravenous fluid replacement, to blood transfusion to more advanced circulatory support measures. No specific therapy is available. In general, children tend to make a more rapid recovery from DF than adults do. However, they are also more likely to develop the more severe forms of the disease.

While infection usually confers life-long immunity to the serotype of the virus which caused disease, it does not provide cross-over immunity to the other serotypes of the dengue virus. In fact, infection by one of the other serotypes is more likely to result in the more severe forms of the disease, DHF and DSS. Consequently, repeat epidemics caused by different serotypes of the virus, mixed epidemics caused by two or more of the serotypes simultaneously, and highly endemic areas, predispose to a higher occurrence of DHF and DSS.

Dengue fever vectors in Fiji

Four mosquito species found in Fiji are capable vectors of dengue fever:

- *Aedes aegypti;*
- *Aedes albopictus;*
- *Aedes polynesiensis;*
- *Aedes pseudoscutellaris.*

Aedes aegypti is the most efficient vector of dengue fever, and the vector implicated in epidemic transmission of dengue fever in Fiji. It is has a high affinity for the domestic and human environment, breeding in water-filled artificial containers within and around homes and human settlements. Such containers typically include discarded tyres, tin cans, car bodies and manufactured container items, water drums, vases, coconut shells, roof gutters, flower pots, drinking troughs and so on. Water storage drums in rural areas without piped water are well known breeding sites while areas of informal or squatter housing have also been found to provide an abundance of breeding sites. In Fiji, tyres and drums are the most important and productive breeding sites. Although tyres and drums together make up only about 10% – 20% of the total number of container breeding sites, they are responsible for producing 83 – 99% of adult container-breeding *Aedes* mosquitoes (Kay et al, 1995 cited in Basu et al, 1999).

As *Aedes aegypti* is highly domesticated, breeds in the domestic and urban environment, is day-biting, feeds preferentially on humans and has the characteristic of taking several short feeds from different people to make up a full meal, it has become known as the dengue fever vector *par excellence*. *Aedes aegypti* is presently distributed throughout Viti Levu and is found in close association with humans in both rural and urban areas.

Epidemiology – the making of a dengue epidemic

The occurrence of dengue in Fiji has been characterised by epidemics – a pattern typical of small island countries. The appearance of a dengue outbreak requires several elements:

- the introduction – usually by one infected person (or infected vector) – of one of the four types of dengue viruses;
- the existence of a large enough population of suitable vector mosquitoes (such as Aedes *aegypti);*
- a large group of susceptible people, without immunity to the introduced dengue virus;
- appropriate environmental conditions favouring the contact between infected persons and the vectors, and vice-versa. These will include weather conditions such as temperature as well as social conditions, including sanitation, housing and overcrowding.

The record of dengue fever epidemics in Fiji is presented in Table 7.1 below.

Table 7.1. Historical record of dengue fever epidemics in Fiji

Year	Serotype	Reported number of cases	DHF/DSS	Number of deaths
1885	Unknown	Thousands	None	?
1930	Unknown	Thousands	None	?
1943/4	Unknown	Thousands	None	None
1971/2	Den-2	4000	None	None
1974/5	Den-1	20 000	Yes	12
1980	Den-4	127	?	?
1981	Den-1	Hundreds	Yes	1
1982	Den-2	546+	?	?
1984/6	Unknown	490+	?	?
1989/90	Den-1 and Den-2	3686	Yes	40
1998	Den-2	24000	Yes	13
				Adapted from Basu et al, 1999

The 1997 / 1998 dengue epidemic in Fiji

The most recent epidemic of dengue fever in Fiji was caused by the Pacific strain of the DEN-2 virus. It is thought that the disease was introduced in Nadi as it first appeared in this region before spreading across to Suva where the epidemic rapidly escalated before spreading across to Vanua Levu and some of the outlying islands (Koroivueta, pers. comm.). The 1997 / 1998 epidemic was the worst in Fiji's history with an estimated 24 000 cases, 1700 hospital admissions and 13 deaths. The lower death rate as compared to the 1989/1990 epidemic has been attributed to the efficiency and quality of the medical response and clinical treatment.

Interestingly, the epidemic occurred during a severe drought period related to the 1997 / 1998 El Nino event. This highlights the significance of the ability of *Aedes aegypti* to adapt to the human environment (making use of the household water storage containers and facilities employed during the drought) as opposed to relying on the need for rainfall to provide breeding sites.

Economic impact of a dengue fever epidemic in Fiji

Apart from the loss of human life, dengue fever epidemics incur a range of costs including direct and indirect economic and social costs. Some of the more overt categories of costs include (Basu et al, 1999):

- Costs of hospitalisation, medical treatment and laboratory services;
- Loss of productivity due to illness;
- Emergency vector control costs;
- Loss in tourism revenues;
- Cost incurred at the household level in coping with ill family members.

While no detailed or rigorous estimation of costs for dengue fever epidemics in Fiji has been undertaken, the broad estimates available are indicative of the magnitude of potential costs:

- One estimate of the economic impact of the 1997/1998 epidemic reckons the cost at F$ 6.5 million. This estimate only accounted for hospitalisation costs, personnel costs, vector control costs, treatment costs, medication and IV fluid costs and the cost of laboratory services (Koroivueta, pers. comm.).
- Another crude estimate of the cost of the 1997/1998 Fijian epidemic arrived at a value of F$12 million. This estimate was derived from a cost analysis of the 1981 Cuban epidemic and included the cost of medical care, hospitalisation, loss of salaries, loss of productivity and costs of vector control (Basu et al, 1999).

It is suggested that the analysis of an epidemic presented in the table below would be a useful basis from which to estimate epidemic costs.

Table 7.2. A framework for cost analysis of a dengue epidemic

Nature of epidemic	1000 cases of classical dengue 10 cases of Dengue Haemorrhagic Fever 1 death
Medical costs	100 hospitalisations for 1 week 10 intensive care cases for one week (with a further 2 hospitalisation weeks)
Time off work (assuming all cases are working adults)	500 for 1 week 400 for 2 weeks 100 for 3 weeks 9 for 4 weeks (1 death)
	(modified from **NZMoH,** 1996)

Vector control

In Fiji vector control for dengue fever is aimed at source reduction of breeding sites through community participation (Prakash, pers. comm.) in order to achieve overall reduction in mosquito population numbers. In the past extensive use was made of chemical control methods. Cost, ineffectiveness, environmental and health risks and the emergence of better alternatives have contributed to a reduction in the use of chemicals in vector control. It is increasingly recognised that the key to vector control is the physical eradication or limitation of breeding sites, especially within and around the home environment. This approach to vector control is increasingly devolving responsibility to communities and relying on community involvement and motivation to achieve reduction in available breeding sites.

Innovative approaches to vector control such as the use of biological control agents including *Toxorhynchites* mosquito species and the crustacean *mesocyclops* have been examined in limited field trials. These initial field trials have produced promising results, however, limited resources have thus far precluded further research and experimentation into biological vector control.

Fiji has a well developed and innovative vector control programme which adopts a highly integrated approach including *inter alia* vector surveillance, clinical and laboratory surveillance, community education and awareness raising, community clean-up campaigns, international port quarantine measures, clinical refresher courses for health workers, epidemic readiness measures, primary health care improvement and targeted chemical vector control.

Overall it would appear that the integrated approach adopted and developing in Fiji which maximizes the involvement of communities and devolves a significant responsibility for vector control to communities, has the potential to be highly successful, granted that it receives sufficient political and financial support.

However, the challenge of vector control is considerable. Present surveillance measures employ a range of sampling techniques and measurement indices. The Breteau Index, although a crude measure of vector abundance, is used as a guide in determining the magnitude of vector control response. The Breteau Index is defined as the number of containers per 100 premises inspected which contain *Aedes* species. WHO guidelines indicate that where the Breteau Index is less than five the likelihood of an epidemic is low, while where it is 50 or above there is a high risk of epidemic outbreaks. The experience in Fiji is that the risk of a dengue fever outbreak is high if the Breteau Index reaches 35 and it is this threshold that initiates an aggressive vector control response (Prakash, pers. comm.).

The current annual budget for vector control activities in Fiji is F$53 000 (Basu et al, 1999). As this limited budget funds all vector control activities (the most important being control of filariasis and dengue vectors), there are significant financial constraints to achieving a more effective or desirable level of control of dengue vector populations and the recent outbreaks highlight the need for improved resourcing of vector control initiatives in Fiji.

Present climate and dengue fever risk

As a disease transmitted by a poikilothermic mosquito vector, the epidemiology of dengue fever is strongly influenced by climatic conditions. Climate is an important determinant of, and influence on, vector distribution, life-cycle, feeding patterns, longevity, reproductive rate and the efficiency with which vectors transmit the dengue virus.

Rainfall

For its role in the life-cycle of the mosquito vector in the provision of breeding sites, rainfall is recognised as an important factor in the development of an epidemic. Indeed the rainy season in Fiji which is from November to April is known to be the time of year with the highest risk for dengue fever outbreaks, while dengue fever transmission is rare during the dry season (May to October). During the rainy season the abundance of container items provides an abundance of breeding sites and the population of *Aedes* mosquitoes may rapidly increase in size. However, it should not be assumed that high rainfall is the key mechanism predisposing to dengue outbreaks or key predictor of epidemic risk. The unique characteristics of *Aedes aegypti* as a domestic container-breeding mosquito allow it to adopt breeding sites which relate to human activities rather than rainfall *per se.* This is clearly exemplified by Fiji's 1997/1998 dengue epidemic which occurred under severe drought conditions and illustrates the importance of water storage drums as breeding sites. In Fiji, the need to store water arises during droughts, after cyclones and is on-going in some rural areas. Thus, because of its adaptation to the human environment *Aedes aegypti* populations in Fiji may escalate under both dry and wet conditions, or where there are unreliable or disrupted water supplies as may occur during a drought or cyclone event.

Temperature

Epidemiological studies of dengue fever in Mexico identified temperature as the key determinant or predictor of dengue fever infection (Koopman et al, 1991). This study showed a four-fold increase in risk with a rise in temperature from 17°C to 30°C. No evidence of dengue infection was found where average temperature in the rainy season dropped below 19.3°C. This would suggest that temperature is a better predictor of dengue fever risk than rainfall.

Temperature strongly influences several factors in the transmission of the disease. It has been shown that as temperature increases the biting rate of the mosquito increases and the extrinsic incubation period decreases (that is, the viral multiplication rate increases). These two factors have the effect of increasing the epidemic potential or the efficiency with which the disease is transmitted in a human population. This relationship between temperature and epidemic potential has been modelled by Patz *et al* (1998). According to this model, epidemic potential is negligible below 23°C from which it starts increasing, escalates rapidly from about 30°C and drops precipitously at about 40°C due to a rapid increases in mosquito mortality at this threshold.

It is appreciated that a range of biophysical factors including rainfall, microclimate, habitat availability and availability of breeding sites would influence the distribution and abundance of vectors in Fiji. However, although, by no means, the only determinant, it is suggested that temperature is a key determinant of epidemic risk where a capable vector population is present (Patz *et al,* 1998; WHO, 1996; Koopman *et al,* 1991; Halstead, 1990) and therefore a key determinant of epidemic risk in Fiji.

The relationship between temperature and epidemic potential (Patz et al, 1998) is the basis for the dengue fever epidemic potential model in PACCLIM. Analysis of present day epidemic potential in Suva and Nadi, based on the month of the year, would support the argument that temperature is an important determinant of dengue fever risk. Results shown in **Annex H3,** identify December, January, February and March as the months of highest risk – a finding that is substantiated by the Fijian experience of seasonal changes in risk. It is recognised that this warmer time of year coincides with the rainy season and hence the association between higher model-predicted epidemic potentials and the recorded experience of dengue fever epidemics may be co-incidental and that rainfall is indeed the underlying factor predisposing to a higher epidemic risk at this time of year. However, this is not supported by the experience of the 1997/1998 epidemic which occurred under severe drought conditions. During the 1997/1998 epidemic, breeding sites for *Aedes aegypti* would have been reduced from the full range of potential containers and limited to those containers (such as 44 gallon drums) used for household water storage. Thus human activities and the unique breeding preferences of the *Aedes aegpti* mosquito created the conditions necessary for the epidemic and not rainfall *per se.* This demonstrates the potential for epidemics to occur independent of rainfall conditions or indeed, the rainy season.

In summary, therefore, given the presence of vectors and a susceptible human population, the evidence and literature suggest that there are two key components to epidemic risk in Fiji – both of which are climatic or climate related:

1. **Ambient temperature.** The literature supports the view that temperature is a key predictor of epidemic risk and has a well defined and substantiated relationship with epidemic potential as described by Patz et al (1998) and borne out by the model predicted results for current epidemic potential in Nadi and Suva and the experience of dengue fever epidemiology in Fiji.

2. **Abundance of breeding sites.** The abundance of breeding sites is a function of a wide range of social, economic, environmental and climatic conditions. Rainfall patterns, either directly - through the provision of breeding sites- or indirectly, through human activities when water supplies are disrupted - may influence vector population densities and hence epidemic risk.

Both these components are important in terms of the effects of present and future climate on dengue fever risk. As *Aedes aegypti* breeding sites (and therefore mosquito population abundance) may occur and increase under a range of high and low rainfall conditions, experience has shown that rainfall, *per se,* is not a useful predictor of epidemic risk. Therefore, it is argued that the ambient temperature risk component relates more closely to the possible change in epidemic risk which may occur as a result of climate change, while the second risk component – the abundance of breeding sites – relates more closely to management of this risk, that is, it is important in terms of adaptation to climate change.

7.3.2 Diarrhoeal disease

Despite overall trends suggesting a phase of epidemiological transition in Fiji, diarrhoeal diseases are an important public health problem. While diarrhoeal diseases affect all age groups, they are of particular significance in the under five and infant age groups where diarrhoeal disease is associated with higher morbidity and mortality. Diarrhoeal diseases are caused by a variety of pathogens. However, water supply and sanitation are two important underlying environmental factors which contribute to the outbreak and spread of diarrhoeal disease. Consequently, poorly serviced rural areas and peri-urban squatter areas are at risk.

Table 7.3. Access to water

Percentage of population with access to safe water and sanitation(Fiji MoH, 1999[a])	
Urban	90
Rural	80
Total	85

In rural areas of Fiji, communities are dependent on unprotected water sources such as rainwater catchments, shallow open wells and streams. Water from such sources is not treated and in many cases prone to bacterial contamination from 'upstream' settlements.

In rural areas only 12% of houses have flush toilets as compared with 61% in urban areas (Watling and Chape, 1992). Those areas most vulnerable to health problems associated with sewage waste are the squatter settlements in urban and peri-urban areas and also the rural areas (Porter, 1994).

In Fiji, diarrhoeal diseases have a marked seasonal pattern, with most cases occurring in the summer months. This could be due to changes in monthly average temperature and/or rainfall. There is also considerable anecdotal evidence of an effect of extremes of rainfall on diarrhoea.

The 1997/1998 drought was one of the most severe which Fiji has experienced. It resulted in a complete failure of the wet season and many areas in Fiji experienced the driest 10 months on record between Sept 1997 and Jun 1998 (Terry and Raj, 1999).

The 1997/1998 drought was associated with an increase in reported cases of infantile diarrhoea. During the first 3 months of 1998 the case numbers of infantile diarrhoea were markedly increased above the mean monthly totals for the preceding five-year period. In 1998 reported case totals for January, February and March were 2263, 1398 and 1053 respectively while the mean of the monthly totals for the previous five years was approximately 630. While this is normally a time of year which shows an increase in the number of cases occurring in association with warmer and wetter conditions, the monthly case numbers during this drought period exceeded even that which would normally be anticipated for this three-month period of 'normal' rainfall years. The mean of the monthly totals of reported cases of infantile diarrhoea for these three months for the previous 5-year period is 891.

Overall in 1998 reported cases of infantile diarrhoeal disease reached a record high of 12,272 (Fiji MoH, 1999[b]). It was also noted that both adult and infantile diarrhoeal disease increased and that this was likely to be associated with poor water quality during this drought period as indicated by unsatisfactory water quality in 37% of samples taken during the first 3 quarters of 1998 (OCHA, 1998).

Fiji has a high rainfall variability and is prone to floods and cyclones. Such events may also be associated with outbreaks of diarrhoeal disease. In rural areas most households and villages are not connected to sewage systems, and pit latrines are the predominant means of excreta disposal. Heavy rainfall for prolonged periods which is associated with a rise in the water table may lead to leakage of these systems and contamination of groundwater sources, other water sources and rivers and streams. Similarly, floods may also result in widespread bacterial contamination of water sources and waterways which are used for a wide range of purposes.

In urban areas similar bacterial contamination may occur where there is flooding or overflowing of septic tank systems and in squatter areas with poor sanitation conditions. Overflowing of septic tanks and other non-reticulated sewage systems is a particular problem in Suva as the soils have a very low permeability. The result is that heavy rainfall and flooding often results in contamination of Suva's waterways and immediate coastal areas and leads to a range of public health risks (Porter, 1994).

With the high number of pit latrines in rural areas and often poor sanitation facilities in urban areas, as well as with the use of septic tank systems, heavy rainfall and floods may result in escalating rates of diarrhoea) disease.

Analysis of monthly reports of diarrhoea 1978-1998 confirm a "U-shaped" relationship with estimated monthly average rainfall as shown below.

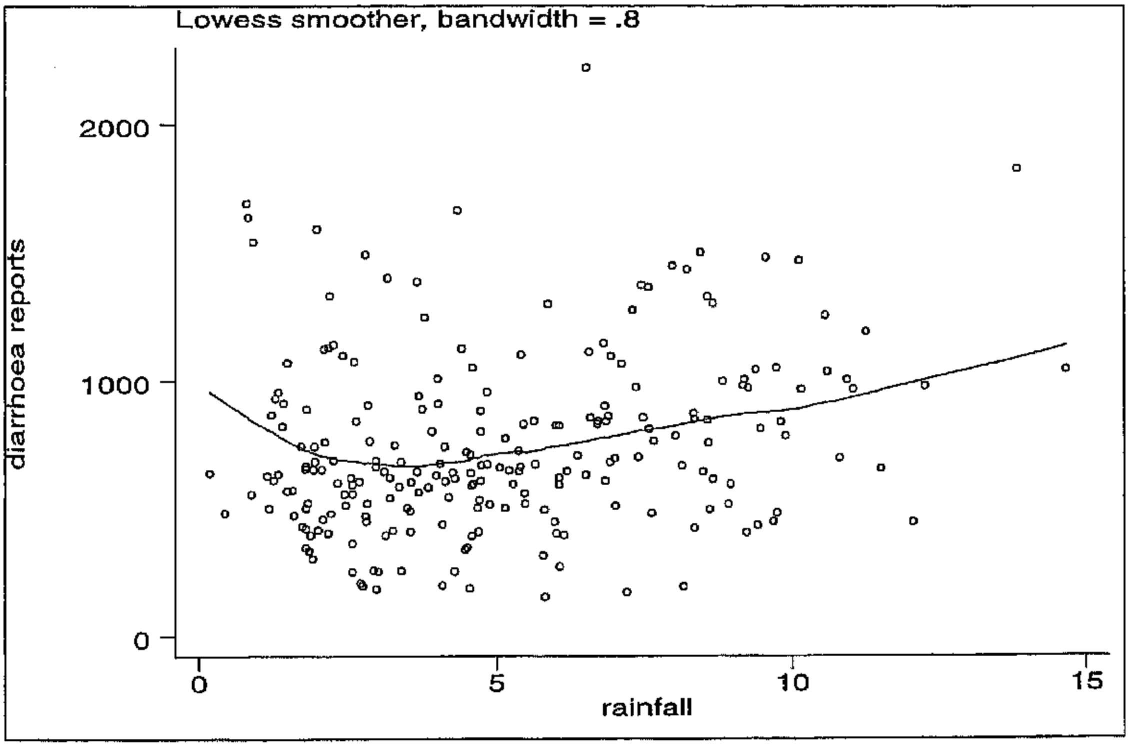

Figure 7.2. Relationship between estimated monthly rainfall and monthly reports of diarrhoeal disease

7.3.3 Nutrition related illness

The drought which was experienced in the Western division in 1987 was associated with nutritional problems. A reduction in both subsistence and commercial agricultural activities was greatest in the inland areas of the Western division and it was in these areas where dietary intakes were most affected and nutritional deficiencies the most severe (Porter, 1994). Between 28% and 90% of people in the Western division had, in their own opinion, experienced deterioration in their health because of the drought (Parkinson, 1990 cited in Porter, 1994).

Nutritional deficiencies, in terms of protein and energy intake, as well as micronutrient deficiencies such as iron and vitamin A deficiency, also increased during the drought period of 1997/1998. This has been attributed to failure of crops and household gardens, as well as failure of household income. This resulted in not only a decreased dietary intake but also the need to purchase or rely on food of lower nutritional value (OCHA, 1998).

The effect of the 1997/1998 drought on subsistence agriculture and household gardens in the Western division was severe. The impact of this was particularly significant for poorer communities and those that relied heavily on subsistence activities to maintain food security (OCHA, 1998). Indirect effects on food security in the Western division arose from loss of income associated with other drought impacts such as the decrease in casual employment opportunities in the sugar cane industry.

Western Viti Levu and the Yasawa group were the two areas worst affected by the 1997/1998 drought and up to 90% of the population in these areas required emergency food and water rations.

The 1997/1998 drought was associated with an increase in malnutrition in the under-5 age group which showed a shift to the lower percentiles of weight-for-age (OCHA, 1998). Downward trends in nutrition in the under 5 age group and the associated nutrient deficiencies such as iron deficiency and Vitamin deficiency were likely to have been significant contributors to the increase in diarrhoeal disease. Vitamin A deficiency is also associated with increase in the incidence and severity of respiratory infections in childhood as well as in the severity of measles cases which are more likely to experience complications.

Micro-nutrient deficiencies among primary school children in the Western division were noted to increase. One large survey noted a 10-fold increase in iron deficiency (measured by clinical paleness in primary school children) as compared to the preceding two years (OCHA, 1998). Apart from reduced dietary intake of nutritional food, the possibility of increased incidence of intestinal parasites as a cause of iron deficiency has also been suggested (OCHA, 1998). Nutritional deficiencies in the early childhood years may have long term and irreversible effects on both physical and mental development.

Possible contributors to malnutrition in this period would have been an overall reduced dietary intake as well as the reduced availability of important weaning foods such as dalo, sweet potatoes, cassava in the Fijian diet and cereals and legumes in the Indo-Fijian diet (OCHA, 1998).

Apart from the under-5 age group, another group that were affected by the drought were pregnant women (and their unborn children). The rate of cases of pregnant women who presented with obstetric conditions that could have been related to decreased nutritional intake increased from 10% to 25% from the first quarter to the second and third quarters of 1998 (OCHA, 1998). In this group there was also an increase in anaemia which may have been related to iron deficiency resulting from dietary insufficiency.

7.3.4 Climate variation, environmental quality, poverty and human well-being

Poverty is a major problem in both urban and rural areas in Fiji. The overall proportion of households existing below the poverty line have been estimated by a range of studies to be between 12% and 20% (UNDP, 1997) while the percent of households which are below the poverty line in the urban fringe areas of Suva has been estimated to be as high 37% (Bryant, 1993 in UNDP, 1997).

In Fiji, poverty is linked to landlessness. There is an inverse relationship between ownership of land (or usufruct rights over land) and poverty (Bayliss-Smith et al, 1988). Ownership of land or usufruct rights over land is important as at a bare minimum, it provides access to subsistence production. Subsistence activities are extremely important in Fiji and it has been noted that where subsistence activities are ongoing, the degree of absolute poverty that may be expected from an assessment of household incomes does not exist (UNDP, 1997).

Those households and communities most vulnerable to the effects of climate variation are those that are economically disadvantaged. Infectious diseases, including diarrhoeal diseases, and disorders related to nutritional deficiencies are more likely to affect poor households, and such households are more likely to experience hardship as a result of climate extremes such as droughts and floods. Public health outcomes of climate variations and extremes, are the result of complex interactions between diverse factors including living conditions, water supplies and sanitation, food security, nutrition, immunity, exposure and susceptibility to infections, severity and clinical course of infectious diseases and access to medical services. Poverty and environmental degradation are important underlying factors which increase the vulnerability of individuals and communities to health problems associated with climate variability.

Poverty may therefore be seen both as a factor contributing to vulnerability to climatic effects as well as an outcome of climatic effects. However, the analysis of these complex "feedback" effects of climatic variations on poor households is beyond the scope of this study.

7.4 Effects of climate change

7.4.1 Possible effects of climate change on dengue fever risk and incidence

The epidemic potential model used in PACCLIM is based on work by Patz et al, (1998) and has been used in the analysis of possible changes in dengue fever risk in Fiji which may be attributed to climate change. Patz et al applied climate model outputs to estimate epidemic potential of existing populations of *Aedes aegypti,* using climate-related parameters previously used in dengue transmission simulation modelling. These parameters were linked to monthly averaged outputs of temperature generated from GCMs.

The major factor affecting epidemic potential in this model is the extrinsic incubation period - the time taken for viral replication in the host mosquito. The model cannot account for the range of climatic, environmental and ecological factors affecting mosquito abundance or distribution, or effects specific to vector species other than *Aedes aegypti*. Social aspects of transmission dynamics such as human population density, travel, immunity and housing conditions are also likely to have important influences on disease transmission (Hales et al. 1999a) and are not represented in the PACCLIM dengue fever model. These are definite limitations of the modelling approach, however, the dengue fever model in PACCLIM is the best available semi-quantitative tool to aid analysis of the possible effects of climate change on human health in Fiji. See **Annex H4.**

The dengue fever epidemic potential model within PACCLIM was used to analyse the present monthly patterns in epidemic potential for Nadi and Suva and present spatial characteristics of dengue fever epidemic potential in Viti Levu. These same parameters were analysed under future climate conditions projected for the years 2025, 2050 and 2100. The scenarios as described in Chapter 3 formed the basis for analysis. However, as the epidemic model is driven by temperature changes alone and considering that both GCM patterns showed a high degree of convergence regarding the magnitude of temperature changes, only the CSIRO pattern was used for scenario construction.

Thus scenarios for the study years were based on the CSIRO GCM pattern and:

1. the B2 SRES emission scenario using the Mid-range value for climate sensitivity; and,
2. the A2 SRES emission scenario using the High climate sensitivity.

Changes in the frequency and severity of extreme events and future climate variability were not considered in this analysis.

Epidemic potential in Nadi and Suva

The most populated areas of Fiji are the urban and peri-urban areas of Viti Levu. These two areas, therefore, are arguably the most important to consider in terms of present and future dengue fever epidemic risk.

The PACCLIM dengue fever model was used to generate site-specific values for epidemic potential for these two towns under present climate conditions (1990 baseline climate). Values of epidemic potential were calculated for each month of the year and are presented in **Annex H3.**

Based on these results and considering the current seasonal epidemiology of dengue fever in Fiji, it is possible to assume a model predicted threshold value below which the risk of an epidemic is low. The results presented in **Annex H3** indicate that such a possible threshold value may be assumed to lie between 0.1 and 0.15.

The results from this analysis show that the dengue fever epidemic potentials are highest from November to April in both Nadi and Suva. This finding closely resembles the seasonal nature of dengue fever epidemics which have been experienced in the past in Viti Levu. Model derived epidemic potentials range from 0.11 to 0.21 for Nadi and from 0.07 to 0.18 for Suva.

Monthly epidemic potentials were calculated for the years 2025, 2050 and 2100 under climate conditions as projected by the two scenarios. These results are shown in **Annex H3.**

In 2025 model predicted epidemic potentials for both projections are similar, ranging from 0.12 to 0.24 for Nadi and from 0.08 to 0.19 for Suva. These results suggest the seasonal patterns of epidemic risk will still be a characteristic of dengue fever epidemiology in the year 2025.

In 2050 the projections show slightly diverging results. The B2Mid projection shows epidemic potentials ranging from 0.13 to 0.25 in Nadi and from 0.09 to 0.22 in Suva. The A2High projection describes epidemic potentials for Nadi ranging from 0.15 to 0.28 and for Suva ranging from 0.09 to 0.24. This suggests that the length of the high-risk season for epidemics would extend to all 12 months of the year for Nadi and possibly continue to show seasonal patterns in Suva although the high-risk season for Suva is extended. The epidemic potentials in the wet season for both towns are significantly higher than for the present conditions.

In 2100 model predicted epidemic potentials describe a high all-year-round risk for both climate change scenarios. In Suva the length of the high-risk season also extends to the full year with the high scenario, while the mid-range scenario suggests a similar outcome, although the two months of July and August have relatively low epidemic potentials of 0.1. Epidemic potentials for Nadi range from 0.15 to 0.29 and from 0.23 to 0.41 for the mid-range and high scenario respectively. In Suva model-predicted epidemic potentials range from 0.1 to 0.25, and from 0.15 to 0.35 for the mid-range and high scenario respectively.

Spatial changes

The spatial characteristics of dengue fever epidemic potential were analysed for Viti Levu using PACCLIM. The same scenarios were used as before, however, instead of analysing epidemic potentials by individual months of the year, epidemic potentials were derived as predicted annual means. Figure 7.3 and 7.4 show the spatial characteristics of dengue fever epidemic potential for Viti Levu for present conditions and for the years 2025, 2050 and 2100.

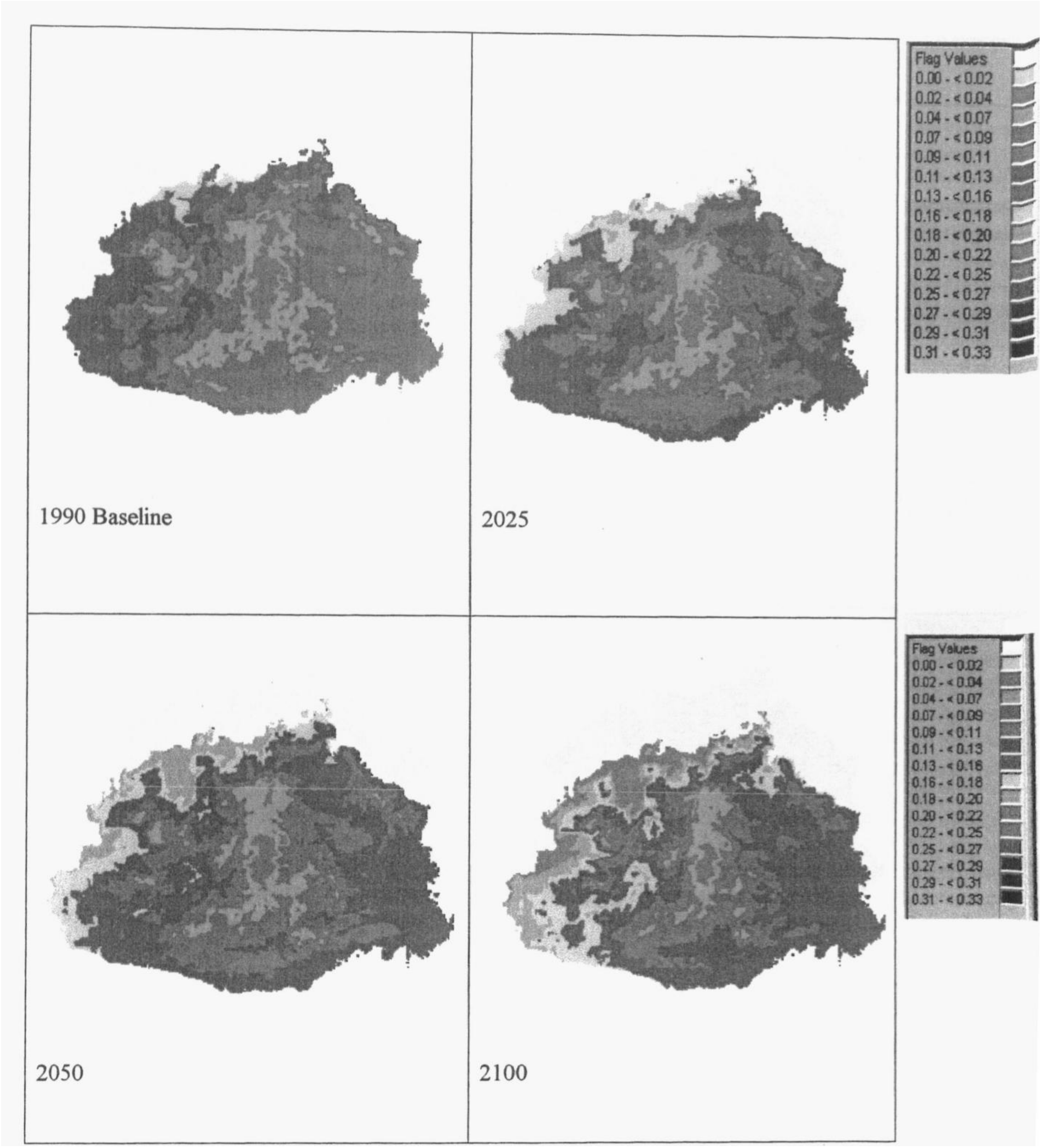

Figure 7.3. Climate change related changes in dengue fever epidemic potential for Viti Levu (Scenario B2 Mid)

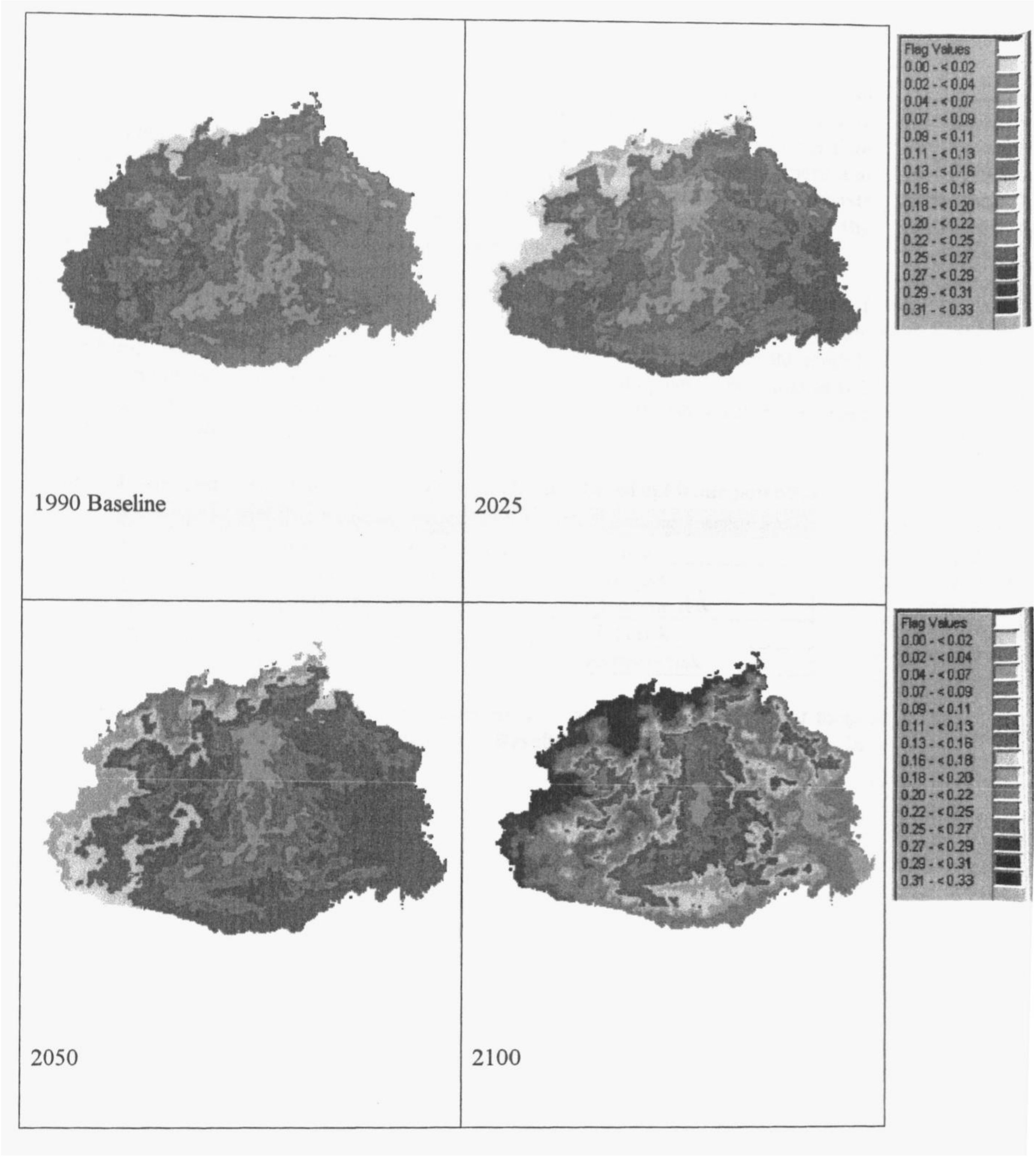

Figure 7.4. Climate change related changes in dengue fever epidemic potential for Viti Levu (Scenario A2 High)

Under present conditions (1990 baseline) dengue fever epidemic potentials are highest in the coastal areas and decrease towards the higher inland areas of Viti Levu. Epidemic potentials in the western division, especially in coastal and hill land areas, are higher than those of similar elevation in the central division. Of the coastal areas the northern and western coasts show the highest epidemic potentials while the southern and eastern coasts are lower. The coastal and hill-land areas near Nadi, Lautoka and western part of the Coral coast show relatively higher epidemic potentials.

In order to further analyse these changes, areas were classified according to categories of epidemic potential. For the purposes of analysis and guided by the current seasonal trends in epidemic risk, the assumption is made that the epidemic risk is low where the model-predicted epidemic potential is less than 0.1, while a predicted epidemic potential of 0.1 to 0.2 represents a higher category of epidemic risk. Two further risk categories were defined and described in the table below.

Table 7.4. **Assigned risk categories based on model-predicted epidemic potential**

Category	**Epidemic Potential**	**Category description**
0	less than 0.01 (or not a land area)	No risk
1	0.01 to just less than 0.1	Low risk
2	0.1 to just less than 0.2	Moderate risk
3	0.2 to just less than 0.3	High risk
4	0.3 to 1.0	Extreme risk

Area calculations of risk categories were undertaken to analyse the magnitude of these changes in risk category of epidemic potential. Results of these analyses are shown in Figures 7.5, 7.6 and 7.7.

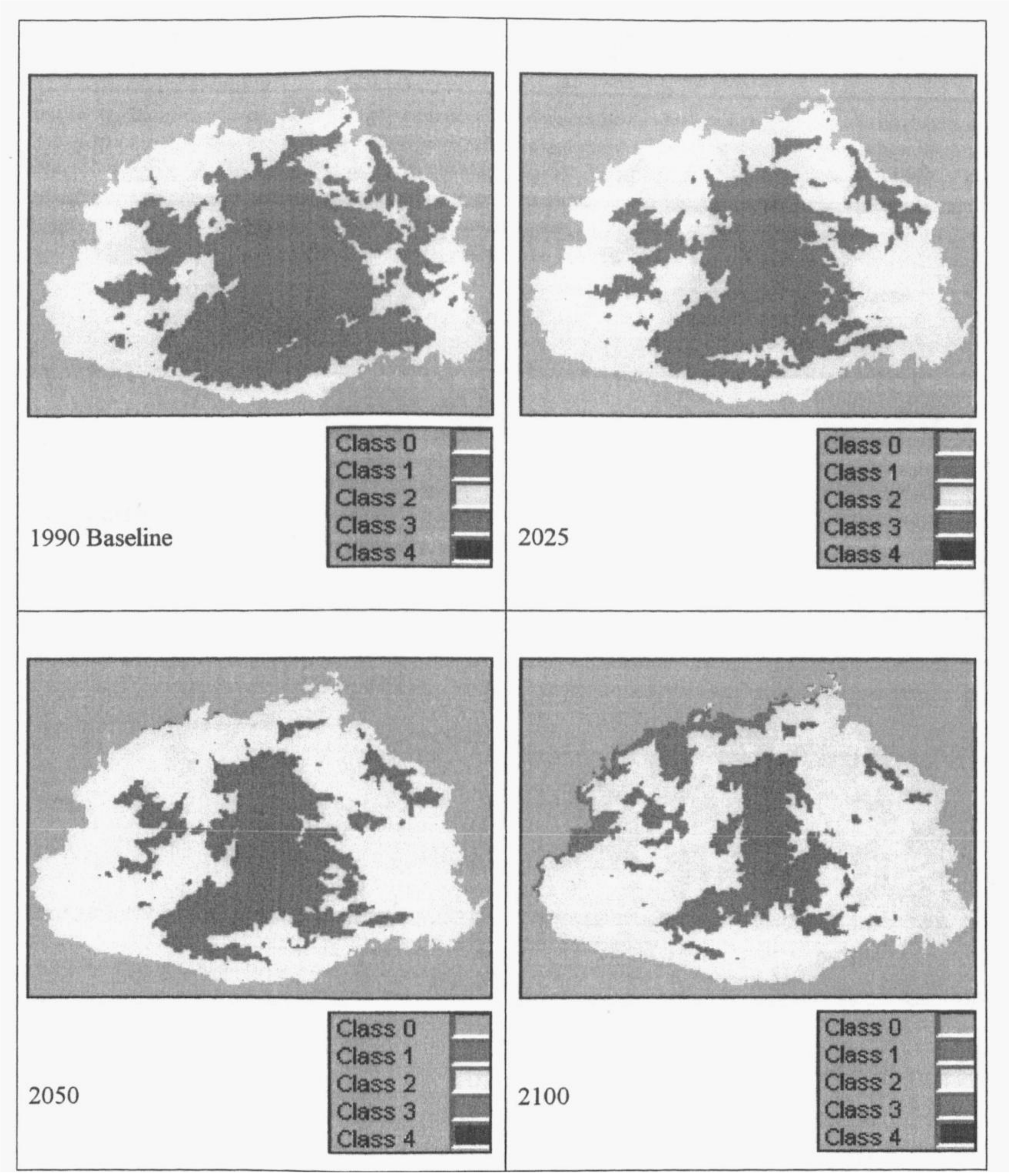

Figure 7.5. Risk classes for dengue fever in Viti Levu based on epidemic potential under present conditions and for future climate change (Scenario B2 Mid)

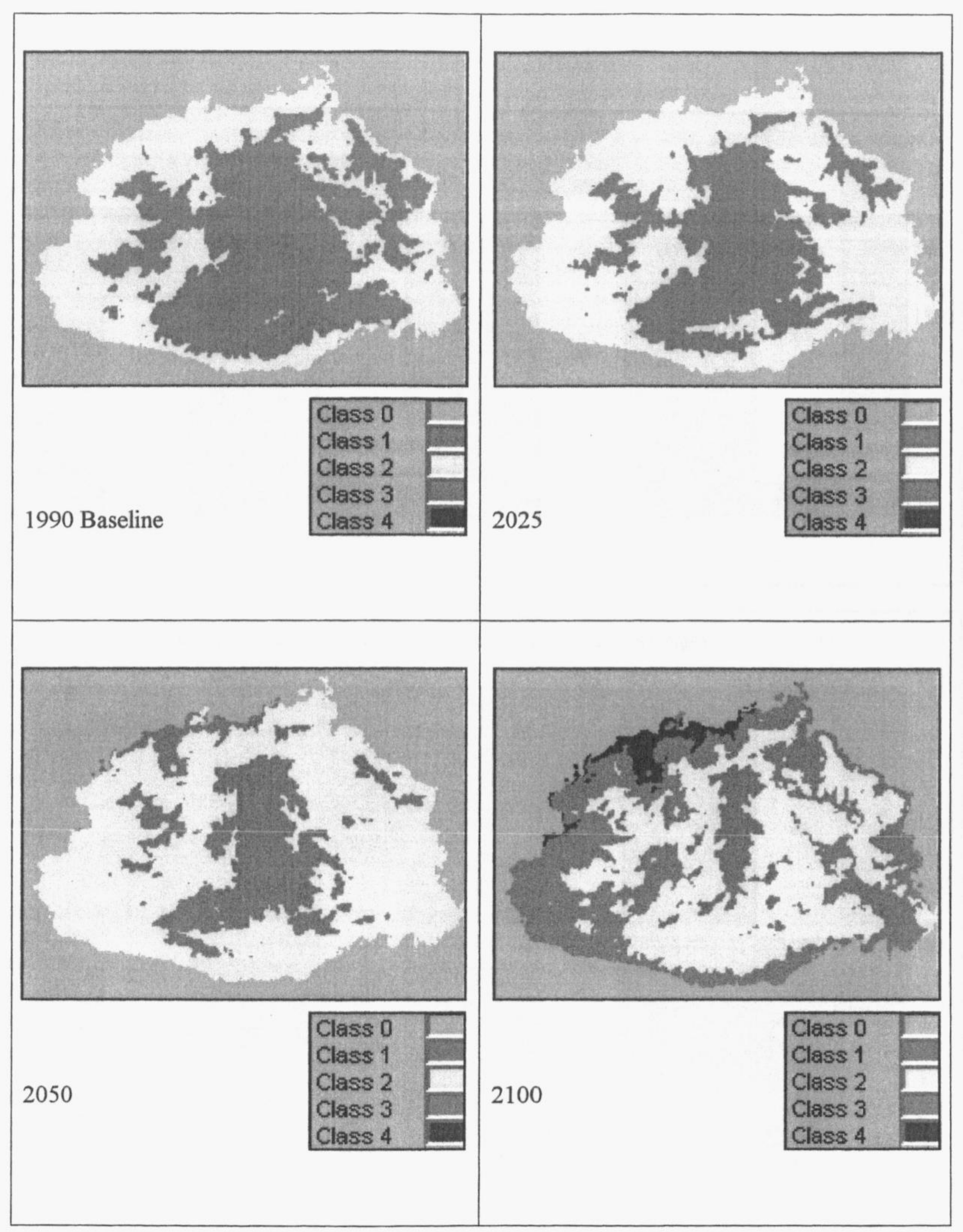

Figure 7.6. Risk classes for dengue fever in Viti Levu based on epidemic potential under present conditions and for future climate change (Scenario A2 High)

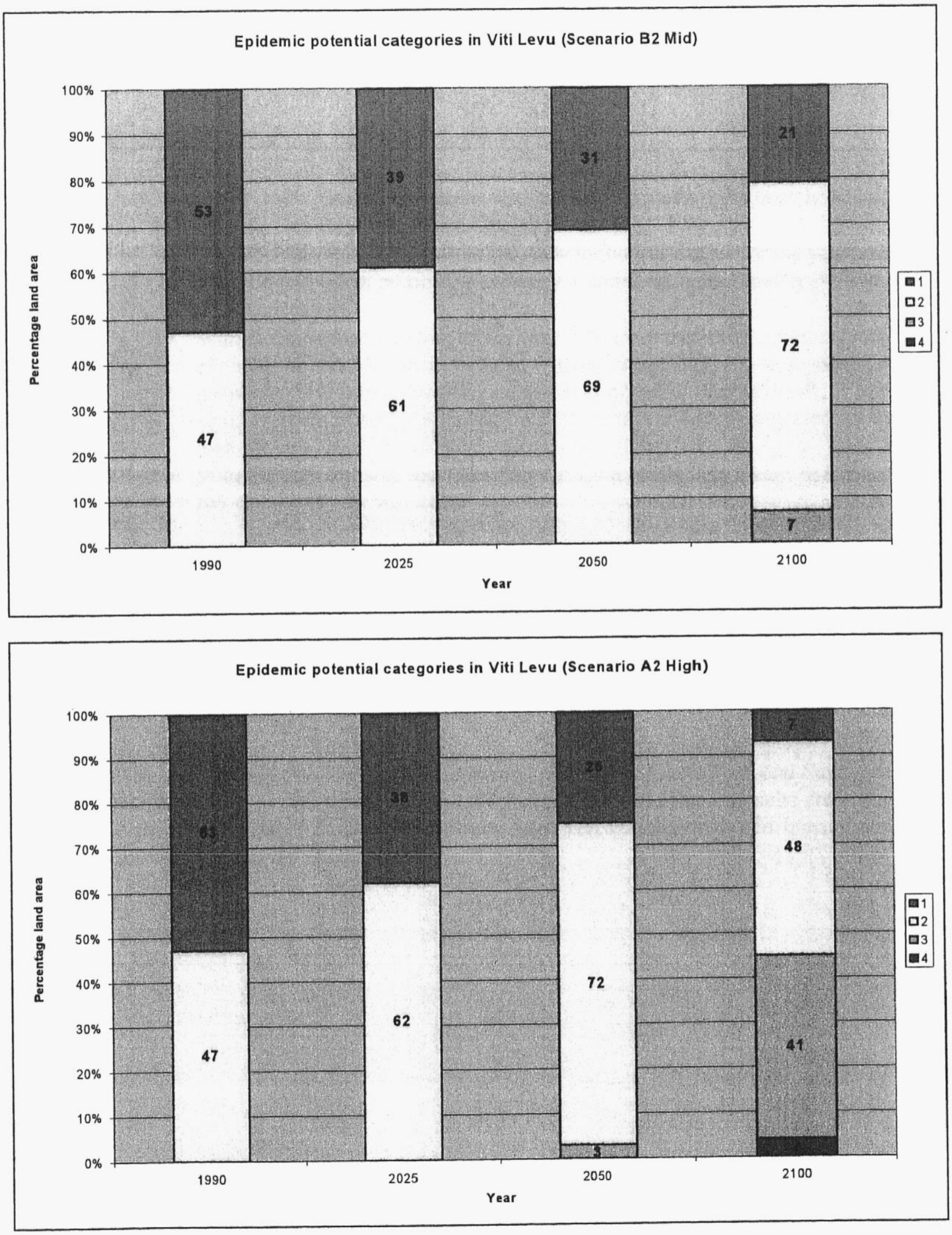

Figure 7.7. Area calculations of epidemic risk categories in Viti Levu (based on model-predicted epidemic potential) under present conditions and for future climate change

Several observations from these results are worth noting:

- Under 1990 baseline conditions Viti Levu is divided approximately equally between Category 1 (53%) and Category 2 (47%).
- The moderate risk area increases similarly for both scenarios for the year 2025 with the proportion ascribed to category 1 and 2, at approximately 40% and 60% respectively.
- With the mid-range scenario, by the year 2100 more than three-quarters (79%) of the land area of Viti Levu is in a moderate or high-risk category. The remaining 21% in the low risk category is confined to the highlands. A very similar pattern of risk is achieved by 2050 under conditions projected by the high scenario.
- With the high scenario, nearly half of Viti Levu (45%) is in a high or extreme risk category by the year 2100.

Percentage change

While the above analyses provide some indication of the seasonality and spatial distribution of epidemic risk both now and in the future, they do not provide a basis for quantification of change for vulnerable populations. As most of the population are located in the coastal areas and particularly in Nadi and Suva, it would be important to attempt to quantify the change in risk for these two areas.

In the final analysis, predicted monthly epidemic potentials for both Nadi and Suva were averaged and the change relative to the 1990 baseline was calculated. Results describing the percentage change in epidemic potential — or percentage increase in transmission efficiency - are shown in Figure 7.8.

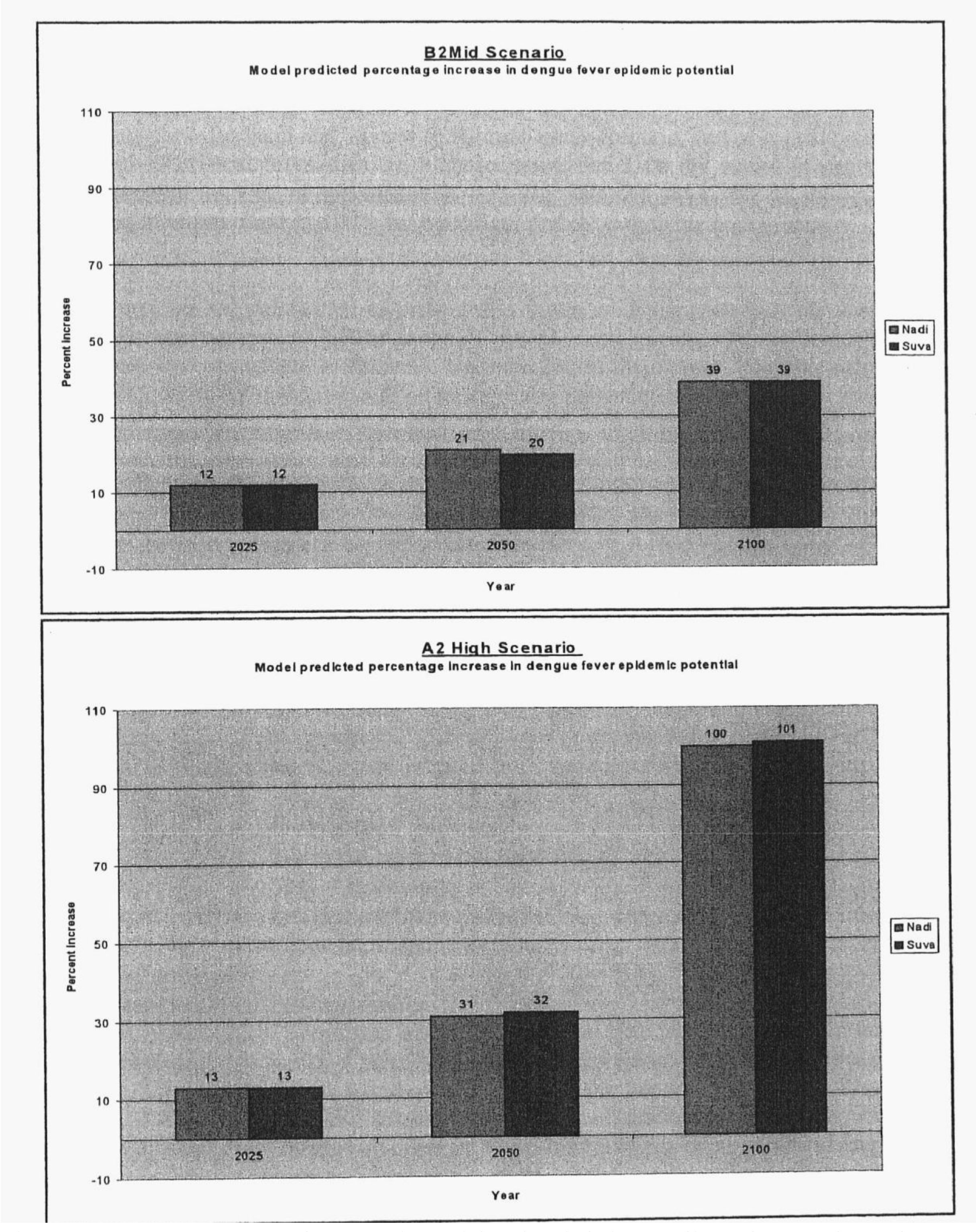

Figure 7.8. Percentage changes in epidemic risk in Nadi and Suva based on model-predicted changes in epidemic potential under present and future climate conditions

Results describe similar changes of slightly more than 10% for 2025 for both scenarios for both centres. For 2050 the model predicts an epidemic potential increase of approximately 20% for Nadi and Suva with the mid-range scenario, and of approximately 30% for both Nadi and Suva with the high scenario. For 2100 the model predicts an epidemic potential increase of approximately 40% for Nadi and Suva with the mid-range scenario, and of approximately 100% for both Nadi and Suva with the high scenario.

Discussion

The model enables the calculation of present and future epidemic potentials for dengue fever. This is one component of the range of social, demographic, environmental and climatic factor that contribute to epidemic transmission of the disease. Higher epidemic potentials indicate that the disease will be more easily transmitted from human to human via the vector population. (See **Annex H4).** This means that with all other factors being equal and specific for a given community and environmental context, higher epidemic potentials will allow an epidemic to grow faster and produce more cases than under conditions of lower epidemic potential. Similarly, higher epidemic potentials allow epidemics of similar size and magnitude to be supported by a smaller vector population than would be required under conditions of low epidemic potential. Thus while analyses of changes in epidemic potentials do not translate directly into a change in number of cases or number of epidemics, changes in epidemic potential are indicative of changes in epidemic risk.

The results obtained above describing changes in epidemic potential, are indicative of possible climate related changes in the epidemiology of dengue fever in Viti Levu. The epidemiological changes which may be inferred from these results include changes in:

- Frequency of epidemics;
- Timing of epidemics (seasonality);
- Size of epidemics;
- Endemicity; and,
- DHF / DSS incidence rates.

Frequency and seasonality of epidemics

With an established vector population in close association with humans, Viti Levu has a high susceptibility to epidemics. Current conditions favour epidemics during the warmer months only. However, analysis has shown that one of the important effects of climate change would be to lengthen and increase this period of susceptibility in both urban centres but with early and marked changes in Nadi. Introductions of virus would trigger epidemics more easily during an extended part of, if not for the whole of the year. Presently epidemics are relatively infrequent (every 10 years). Assuming wide scale exposure in an epidemic, immunity precludes the development of an epidemic caused by the same virus until a new cohort of susceptibles emerges – perhaps over 10 years. With four types of Dengue virus and no cross-over immunity between serotypes, there is scope for the potential increase in the frequency of epidemics. Other factors such as increased urbanisation, increased international travel, and the increased regional prevalence are likely to increase the risks of introduction. Even the larger epidemics in Fiji do not affect more than 5 –10% of the population indicating that a susceptible cohort would not depend on the population growth alone - another factor which may facilitate the increase in possible frequency of epidemics.

Size of epidemics

The trend of increasing epidemic potentials related to climate change in Viti Levu and especially as noted for Nadi and Suva, provide a sound basis for arguing that future epidemics in Fiji may be relatively larger than previously experienced. Given the same number of vectors, the increased epidemic potentials indicate that epidemics would not only be triggered more easily, but also escalate more rapidly and involve a greater number of people. Several factors may exacerbate this trend. Higher human population densities facilitate the more rapid transmission of disease favouring the increase in cases above that than may be attributed to population growth alone. Urbanisation and the changing nature of the urban and peri-urban environment would further increase the potential size of epidemics. Lastly, climate changes may have direct effects on the abundance of vectors further increasing the potential number of dengue cases.

Endemicity

Small islands typically experience dengue fever epidemics rather than all year round endemic transmission. The analysis above clearly indicates that climate change may be associated with a shift from seasonal patterns of epidemics to a year-round risk of epidemic outbreak of dengue. Such changes may also favour ongoing year–round endemic transmission characterised by fewer large-scale epidemics but a higher rate of exposure as cases are distributed more evenly throughout the year.

DHF/DSS incidence rates

The changes noted above, viz increases in frequency and size of epidemics and increased likelihood of endemicity all increase the risks of the more severe forms of dengue fever. It is possible that climate change in Viti Levu will be associated with a disproportionate increase in the DHF and DSS, and consequently a disproportionate increase in fatalities attributable to dengue fever.

Spatial distribution

Model-predicted changes in epidemic potential indicate the areas of greatest risk in Viti Levu will be the coastal areas of the western division, followed closely by other coastal areas. This is significant as several non-climate related factors also contribute to the potential dengue fever risk in these areas. Such factors include the relatively high population numbers and densities, high level of international traffic, and the locality of the international airport in Nadi.

Estimation of increase in case numbers

In order to derive an economic evaluation of the effect of climate change on human health as it relates to dengue fever, it is necessary to provide an indication of the possible increase in the number of dengue fever cases that may be attributable to the change in climate. For several reasons, this is an extremely difficult, if not impossible, objective:

- The evolution of a dengue fever epidemic relies on extremely complex interactions of a multitude of factors. Such factors may relate to mosquito biology (breeding sites, ecology, predators, micro-climate, climate, competition between species etc), human behaviour and biology (immunity, birth rate, age structure of population), social factors (living environment, medical services, urbanisation rates and nature), economic factors (housing, use of manufactured container items and packaging etc).
- Changes in epidemic potential may not necessarily correlate with changes in the number of cases or changes in the likelihood of an epidemic.
- The effect of regional climate or non-climate related changes in dengue prevalence cannot be accounted for.
- Possible improvements in medical services, treatment and the possibility of vaccine development cannot be predicted.

Nevertheless, the foregoing analyses suggest a high degree of certainty that climate change (and consequent changes in epidemic potential as predicted by the model) will certainly impact the nature of dengue fever epidemiology in Viti Levu. It can be said with a high degree of certainty that the direction and nature of this change in risk will result in more frequent epidemics, larger epidemics, a higher effort required to attain effective vector control, possible endemicity, possible increase in severe forms of dengue, and an overall increase in the number of cases.

Therefore, for the purposes, of economic assessment, the considered assumption is made that the percentage changes in dengue fever epidemic potential will be indicative of the possible changes in the number of cases averaged out over, for example, a ten or twenty year period cases. With this assumption, results of analysis shown in Figure 7.8, describing the percentage change in epidemic potentials for Nadi and Suva may be used as a basis for assessment. Hence, under the B2Mid Scenario, Viti Levu is estimated to have a 10%, 20% and 40% increase in the number of cases (as compared to the present) for the years 2025, 2050 and 2100, respectively. For the A2High scenario, a 10%, 30% and 100% increase is estimated for the respective time horizons.

It must be stressed that such quantification is indicative only. It is possible that the role of epidemic potential as a contributor to epidemic risk has been over-estimated. However, the assumption is considered a conservative estimate as several factors may contribute to an actual average increase in number of cases attributable to climate change which is at a rate higher than indicated by the rate of increase in epidemic potential. These factors are noted below:

- The possibility of the existence of threshold values in epidemic potential could result in a disproportionately higher number of cases as climate change results in thresholds being exceeded.
- Increased human population densities would allow a disproportionately higher number of people to be exposed and hence

the relationship between increase in epidemic potential and increase in number of cases may be non-linear.

- Climate change may result in the increase in numbers, densities and distribution of dengue vectors and this would compound the increase in risk attributable to climate change related increases in epidemic potential.
- Climate change related increased regional prevalence of all dengue virus serotypes, could result in more frequent introduction and consequently a disproportionately higher case incidence.

In summary, therefore, given the present state of knowledge, the percentage changes in epidemic potential attributable to projected climate change can be used, with reasonable confidence, as a conservative indicative estimate of probable average changes in the case numbers of dengue fever attributable to climate change in Viti Levu.

7.4.2 Potential effects of climate change on diarrhoeal disease

Diarrhoeal diseases are caused by a range of pathogens and predisposed by a range of factors. Relationships between climate and diarrhoeal disease incidence in Fiji are suggested by the marked seasonality of diarrhoea reports and the association of diarrhoeal diseases with extremes of rainfall. The potential mechanisms involved include bacteriological contamination of water supplies, disruption of sanitation systems increased growth of bacterial pathogens under warmer climate conditions and behavioural changes (for example, in times of low rainfall it may be more difficult for families to wash effectively).

Responses to changes in climate will vary depending on the pathogens, causal mechanisms and predisposing factors involved. Nevertheless, several key disease agents and mechanisms may be linked to climate related phenomena and provide a basis for analysis of climate related impacts on diarrhoeal diseases.

Changes in average climate conditions projected by the scenarios presented in Chapter 3 suggest divergent changes in seasonality. Fiji presently has a warm and wet season (October to March) and a cooler and drier season (April to September). The first three months of the year are typically the warmest and wettest, and it is in this period that diarrhoeal diseases are typically the most common. The reasons for this are unclear and may relate to higher temperatures, higher rainfall, or both, (or possibly to confounding factors such as the occurrence of cyclones).

The first scenario based on the CSIRO GCM pattern projects an increase in precipitation and a gradual warming which is attributable to climate change. If the assumption is made that the increased incidence of diarrhoeal disease in the first three months of the year is related to the warmer and wetter conditions typical of these months, this scenario of climate change would suggest a lengthening of the warmer wetter season with an increase in the number of months with higher incidences of diarrhoeal disease.

The climate change scenario presented in Chapter 3 characterised by an increase in climate variability and extremes, is also relevant. An increased frequency and severity of droughts and floods in Viti Levu is likely to be associated with an increased incidence of diarrhoeal disease.

Analysis of monthly reports of diarrhoea in infants between 1978 and 1989 (for which period reasonably complete data are available) suggests that the effect of climate cannot be distinguished statistically from the seasonal pattern. Other influences on diarrhoeal disease rates that may be related to season include food supply (and hence nutritional status), family incomes, major festivals and travel. However, if one assumes that the seasonal pattern is mainly attributable to changes in monthly average temperature and rainfall, then it is possible to estimate the independent effects of these variables on diarrhoea incidence.

Using national data on reports of diarrhoea in infants for 1978-1989, regression modelling indicated that an increase in temperature of 1°C was associated with 100 additional reports per month ($p<0.05$). Extremes of rainfall are independently associated with increased reports. Data for 1990-1991 are missing, but the model was a good predictor of 1992-1998 diarrhoea reports (the correlation coefficient between model predictions and true values was 0.47, $p<0.001$). Further details of the model are given in **Annex H5.**

Since the true incidence of diarrhoea is likely to be at least 10 times the number of reported cases, on the basis of the regression results, an increase of 1°C is estimated to be associated with at least 1000 additional cases per month (based on the current population in Fiji). This result could also be used, with lower confidence, to estimate potential impacts on diarrhoea in children (age 1-5) and adults.

Vulnerability

The western region of Viti Levu is likely to be the most affected by a drought related increase in diarrhoeal disease. Flood related increase in diarrhoeal diseases, are likely to be more diffuse throughout Viti Levu and affect coastal and hill land communities.

Individuals and sectors of society most likely to be affected by an increase in diarrhoea! disease are likely to be similar for both drought and flood events. The most vulnerable individuals and sectors will be the young (especially children under 5 years of age), the poor, the landless, and those in informal and squatter settlements. Contributing factors which are likely to increase as Fiji follows its present development trajectory would include overcrowding, environmental pollution, degradation, and poor living conditions.

7.4.3 Possible effects of climate change on nutrition related illnesses

The most important effects of climate change on nutritional related disorders are likely to be caused by the projected increase in the frequency and severity of droughts, and therefore may be similar to the impacts experienced during 1987 and 1997/1998. Because available data are very limited, it is not possible to make quantitative forecasts of these impacts. However, this may be one of the most important mechanisms by which climate change affects human health.

7.4.4 Climate change, environmental quality, poverty and human well-being

Trends in inequality, resource consumption and depletion, environmental degradation, population growth and ill-health are closely inter-related (Dasgupta, 1995; McMichael, 1995) and will strongly interact with potential climate change impacts. These large scale global trends are driven, at least in part, by international political and economic systems. At present, economic and political incentives to reduce levels of consumption and population growth, pollution and depletion of renewable resources are generally weak. There is a high possibility that climate change will tend to widen social inequalities, increase poverty and worsen environmental quality. These complex, inter-related processes will have major (although largely unquantifiable) human health impacts.

7.5 Adaptation

The analysis of the effects of climate change on human health is limited by data scarcity, confounding variables, incomplete knowledge of causal mechanisms and uncertainties in climate projections, and consequently quantitative estimates of climate impacts on human health necessitate a range of assumptions and are no more than indicative. However, the over-riding value of such an analysis is not in the quantification of impacts, but **in** the determination of indicative impacts and the identification of measures which would constitute appropriate adaptation. While the exact magnitude of impacts may not be clearly stated, analysis of the impacts clearly highlights obvious measures for adaptation which would be of benefit even in the absence of climate change. In essence addressing the public health, environmental and social issues which are important today, provide the strategy for decreasing the possible climate change impacts on human health which may occur in the long term in Fiji.

This section first discusses specific sectoral measures for adaptation, and proceeds to propose adaptation options which are of relevance at the policy and planning level.

7.5.1 Dengue fever

Adaptation to the climate change related increased risk of dengue fever epidemics and increased case incidence rates will include the range of measures currently employed or planned to reduce dengue fever risk. However if the possible effects of climate change on human health are to be avoided, a greater level of effectiveness of vector control and other dengue fever risk reduction measures will need to be achieved. Thus, in order to adapt to climate change, it is not the nature of the effort that should change, but rather the magnitude of the effort.

The scope of adaptation measures can be discussed under the following headings:

- Vector control;
- Preventing exposure;
- Quarantine measures;
- Epidemic preparedness and response;
- Development trends and policies.

Vector control

The most important component to the vector control programme in Fiji is source reduction of breeding sites (Prakash, pers. comm.).

While current vector control aims to maintain the Breteau Index below 35, the projected increase in epidemic potential which may occur as a result of climate change, would suggest that this target for vector control would need to be stricter as transmission efficiency increases.

To achieve a higher level of vector control, there would need to be significant enhancement of the current effort especially in the following areas:

- Support and enhancement of Fiji's innovative vector control programme based on community responsibility and participation which is seen as the key to effective vector control. This involves in a wide range of actions including removal or modification of potential domestic mosquito breeding sites such as used tyres, container-type rubbish, water storage drums, flowerpots and vases etc. Such a programme is supported by a wide range of public education and mobilisation initiatives.
- Support for, research in, and implementation of, complementary vector control measures such as biological control.
- Support and enhancement of vector surveillance and monitoring methods, expertise and technology.

Preventing exposure

Avoiding being bitten by vector mosquitoes is one method of reducing risk. Such measures may include the choice of clothing, use of mosquito nets, applying netting to windows and doors etc. Unfortunately in Fiji's hot climate and considering the fact that *Aedes aegypti* is a day-biting domestic mosquito such measures are likely to be less appropriate or effective.

Quarantine measures

Quarantine measures play a role in preventing the introduction of capable vectors. Unfortunately four capable vector species are already established in Fiji. Quarantine measures which prevent introduction of the virus are not practicably possible as it is carried by humans. The prevention of introduction of infected mosquitoes, however, would contribute to risk reduction. Overall then, and in terms of dengue fever risk alone, quarantine measures are important but have limited value. (The escalation of quarantine measures is more strongly justified from the point of view of the malaria risk.)

Epidemic preparedness and response

With the additional threats of climate change, current measures orientated towards pre-empting, preparing for, and responding to a dengue fever epidemic should be enhanced. This would include measures such as:

- Vector monitoring and mapping;
- Clinical and laboratory surveillance to achieve early warning of a dengue fever epidemic;
- Preparedness of both primary and referral health care systems to respond to and treat dengue fever cases and DHF/DSS cases. This would include enhancement of services, equipment, and clinical expertise and supplies as well as improved access to services;
- Enhanced ability to organise community mobilisation to respond to an epidemic by reducing breeding sites, recognising clinical symptoms, and taking other preventative measures.

Development trends and policies

Development and urbanisation trends in Fiji, point towards increase of the dengue fever risk through such factors as population density increase, urbanisation, increase in informal housing, increase in the prevalence of container items in the domestic environment and poor refuse management. It is clear that addressing these problems and addressing the issues related to water supply and sanitation will be vitally important in reducing dengue fever risk.

7.5.2 Diarrhoeal disease

The preceding analysis of climate associations and climate change related impacts on the incidence of diarrhoea disease highlight the central role of adequate and safe water supplies, sanitation and hygiene. With sanitation and water supply as the central focus of adaptation, a range of measures can be proposed which will be of value even in the absence of climate change or if the nature and magnitude of climate change is different from that projected in this study.

Key options which would reduce the impact of climate change on communities in terms of changed incidence of diarrhoeal disease would include:

- Improved reliability and safety of water supplies;
- Improved sanitation;
- Improved refrigeration and storage of perishable foods;
- The preparation of emergency strategies to cope with the effects of floods and droughts;
- Improved provision of, and access to, primary health care.

7.5.3 Nutrition related diseases

The most important specific adaptation options are discussed in the section on agriculture. Other adaptation options may include a range of measures from disaster management planning to increasing importation of foodstuffs.

7.5.4 Integrated adaptation policies and development planning

It is evident form the preceding discussion, that the most appropriate and effective adaptation to the effects of climate change on human health will not necessitate new or extraordinary measures, but rather take the form of an enhancement of existing measures and initiatives which contribute towards decreasing existing disease rates and ameliorating the worst effects of climate change. While specific measures to achieve this will be required, it is clear that such effective adaptation will be highly dependent on the development and implementation of policies which are of benefit even in the absence of climate change. Such policies need to support pro-active improvement of public health in Fiji and will need to be considered in, and inform, all aspects of development planning. The most important issues which such a policy approach must support include:

- The protection and enhancement of ecological and land productivity;
- Provision of an adequate and healthy standard of housing for all;
- Provision of safe and adequate water supply and improved sanitation especially for those in rural areas and in peri-urban areas;
- Improved management of both liquid and solid waste;
- Employment and the alleviation of poverty;
- Improved access to quality primary health care - especially in rural areas and peri-urban areas.

Prioritising these policy goals will enable Fiji to follow a development trajectory which allow its people to be less vulnerable to the worst effects of climate, change.

7.6 References

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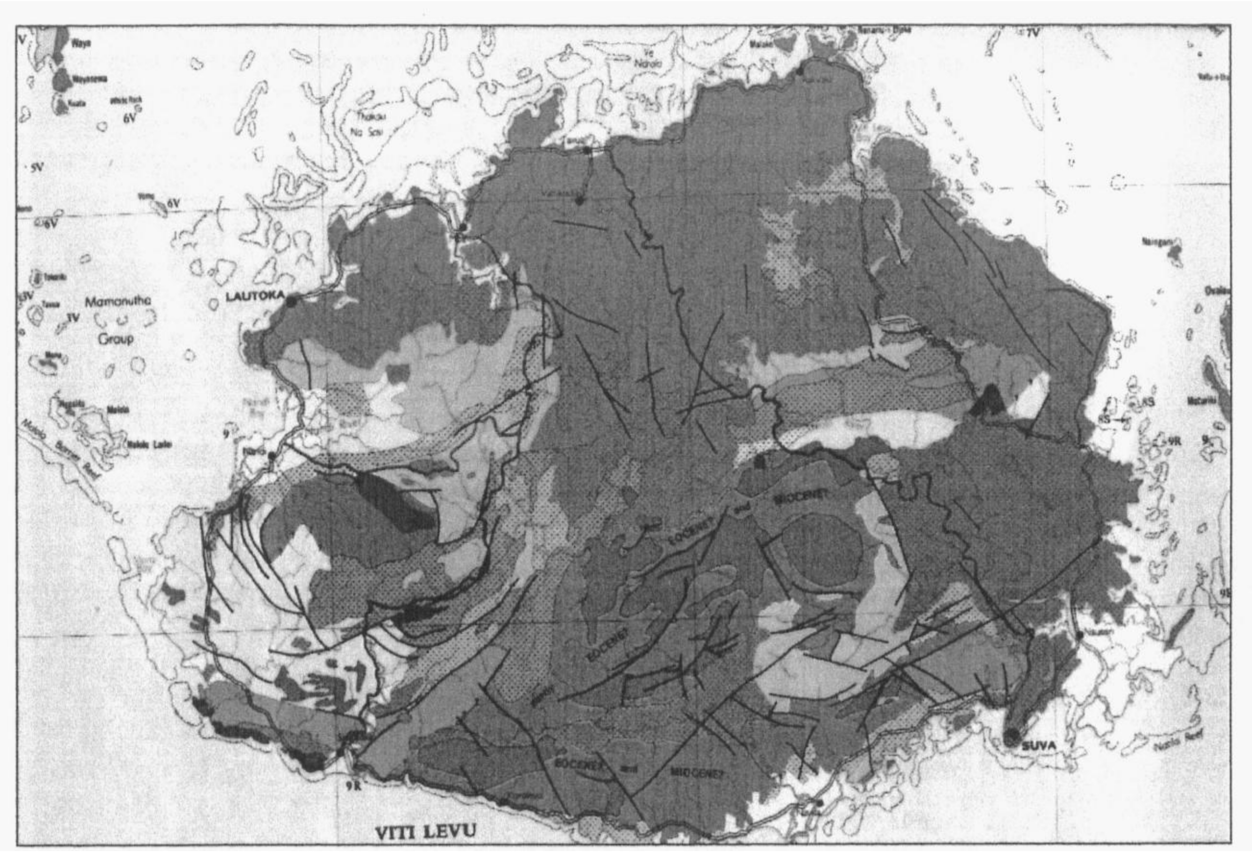
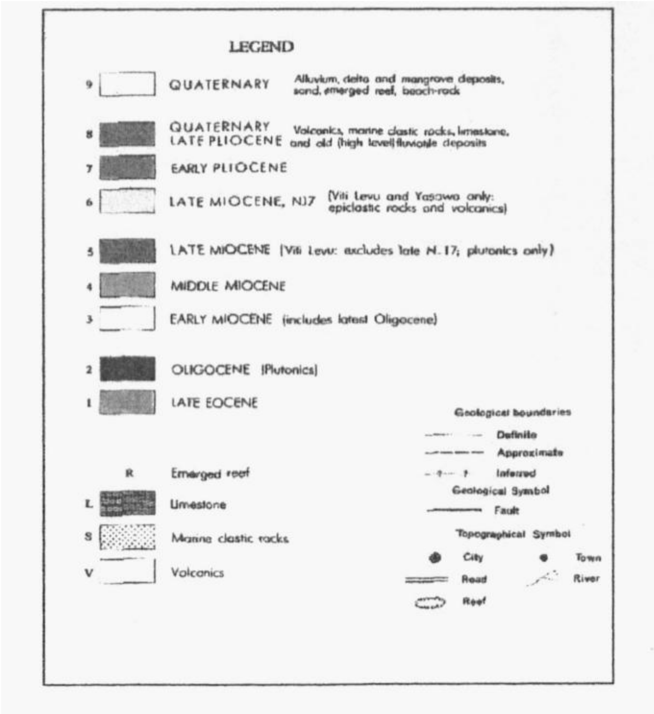
8 Annexes

8.1 Annexes to Coastal chapter

Annex C1: Geological map of Viti Levu





Annex C2: Inundation analysis for Suva

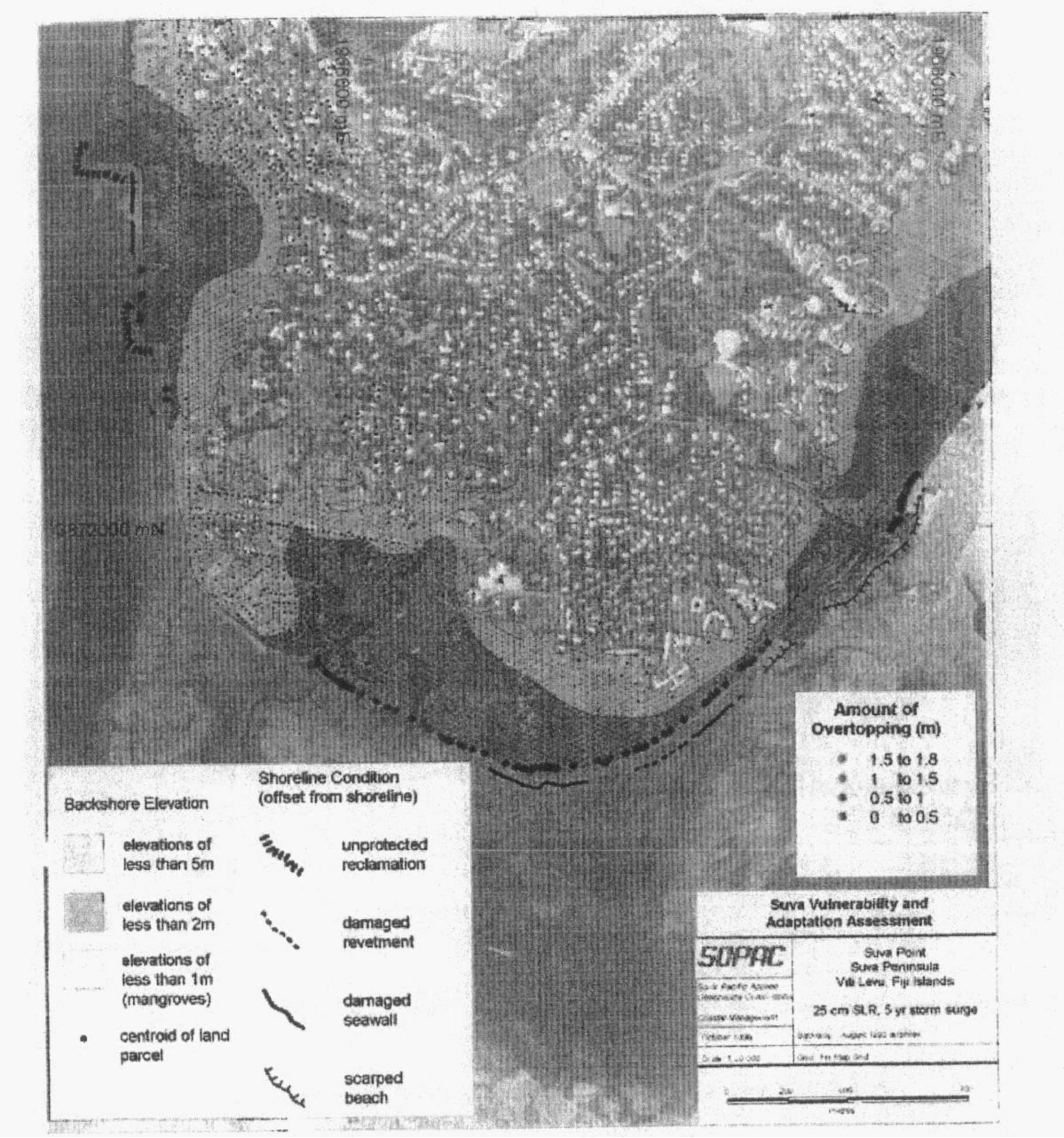


Figure 34. Amount of overtopping at points of known elevation around Suva Point for **a 5** ***year storm event under a 0.25-m*** **sea-level** ***rise***

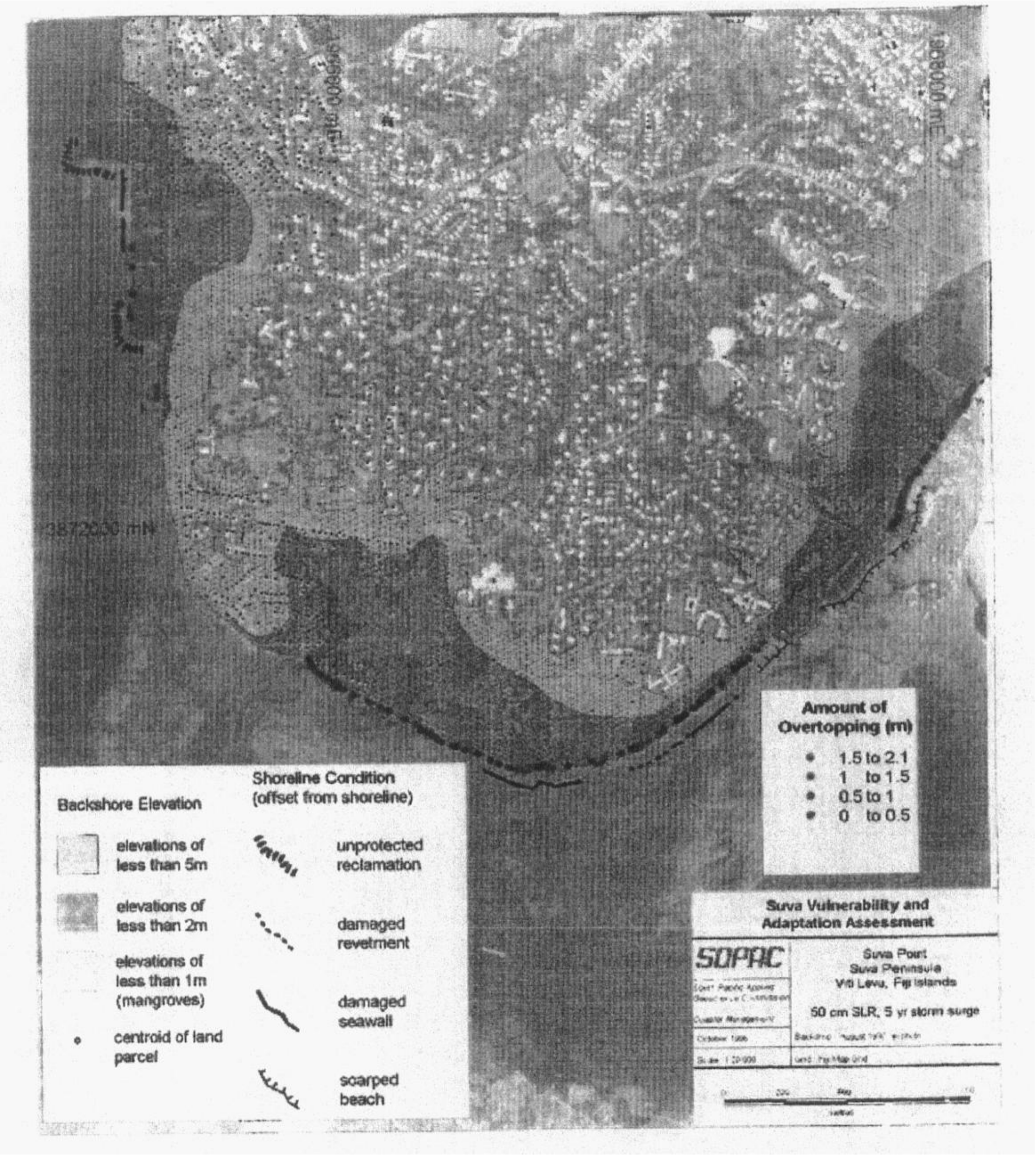
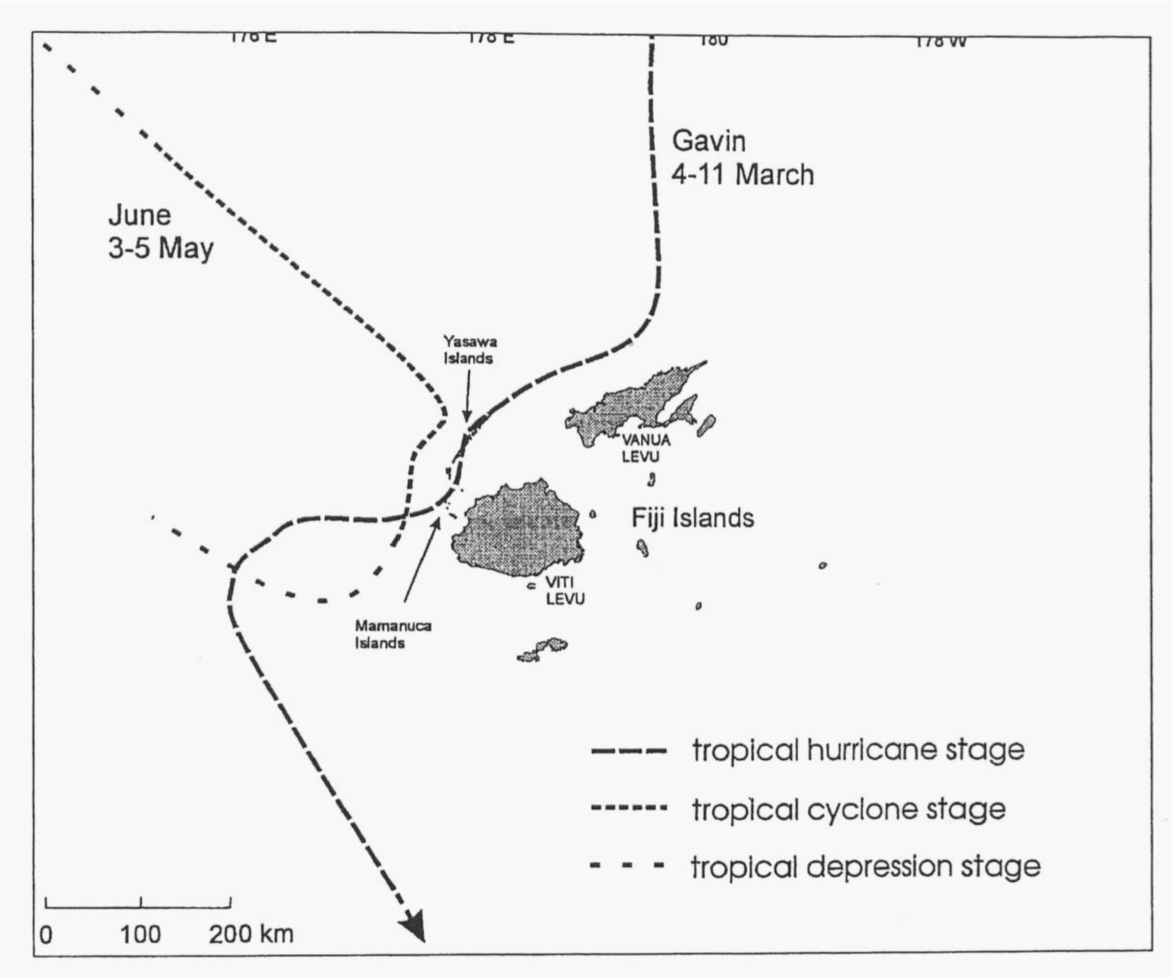


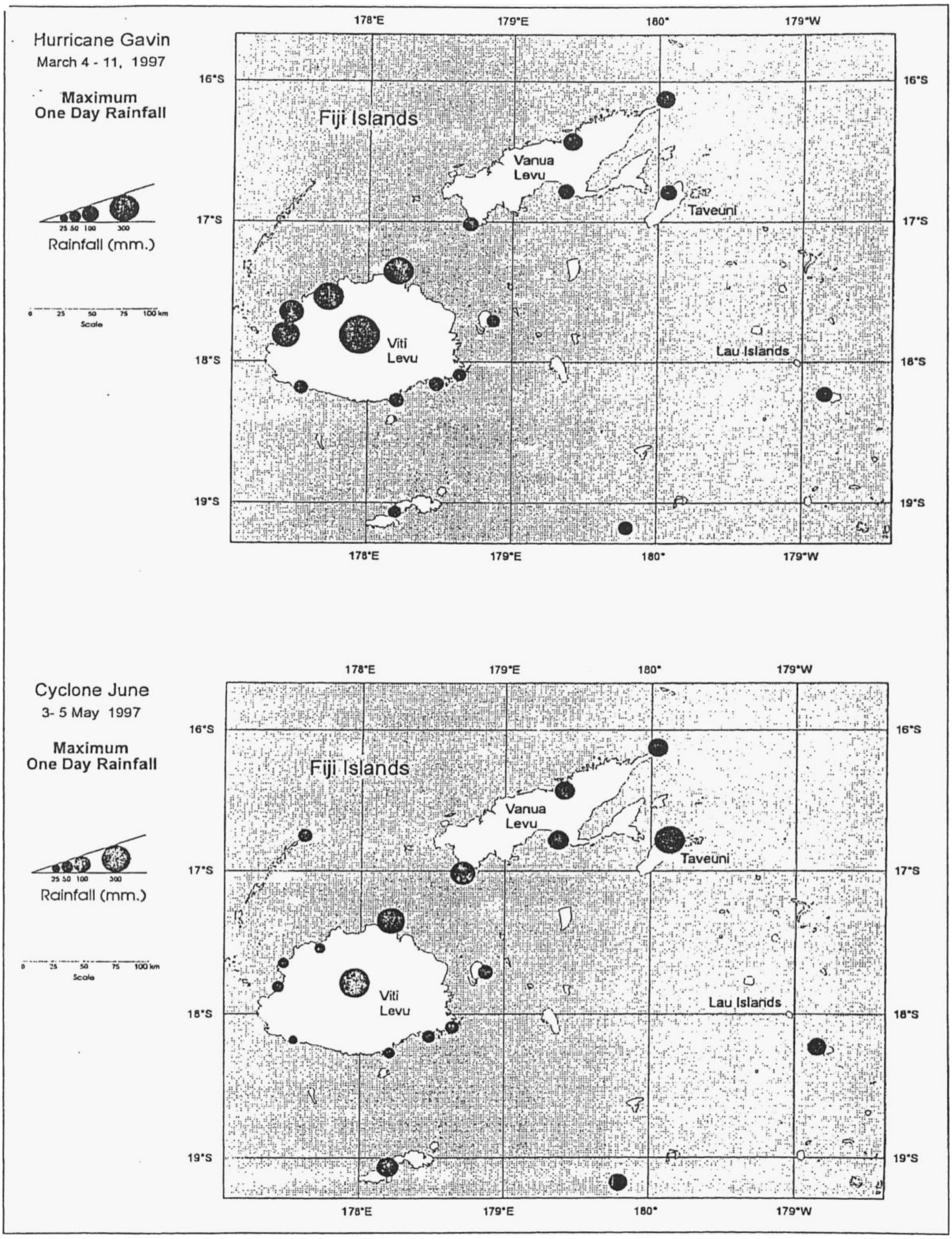
Figure 35 Amount of overtopping at points of known elevation around Suva Point for a 5-year storm event under a 0.50-m sea-level rise.

8.2 Annexes to Water Resources chapter

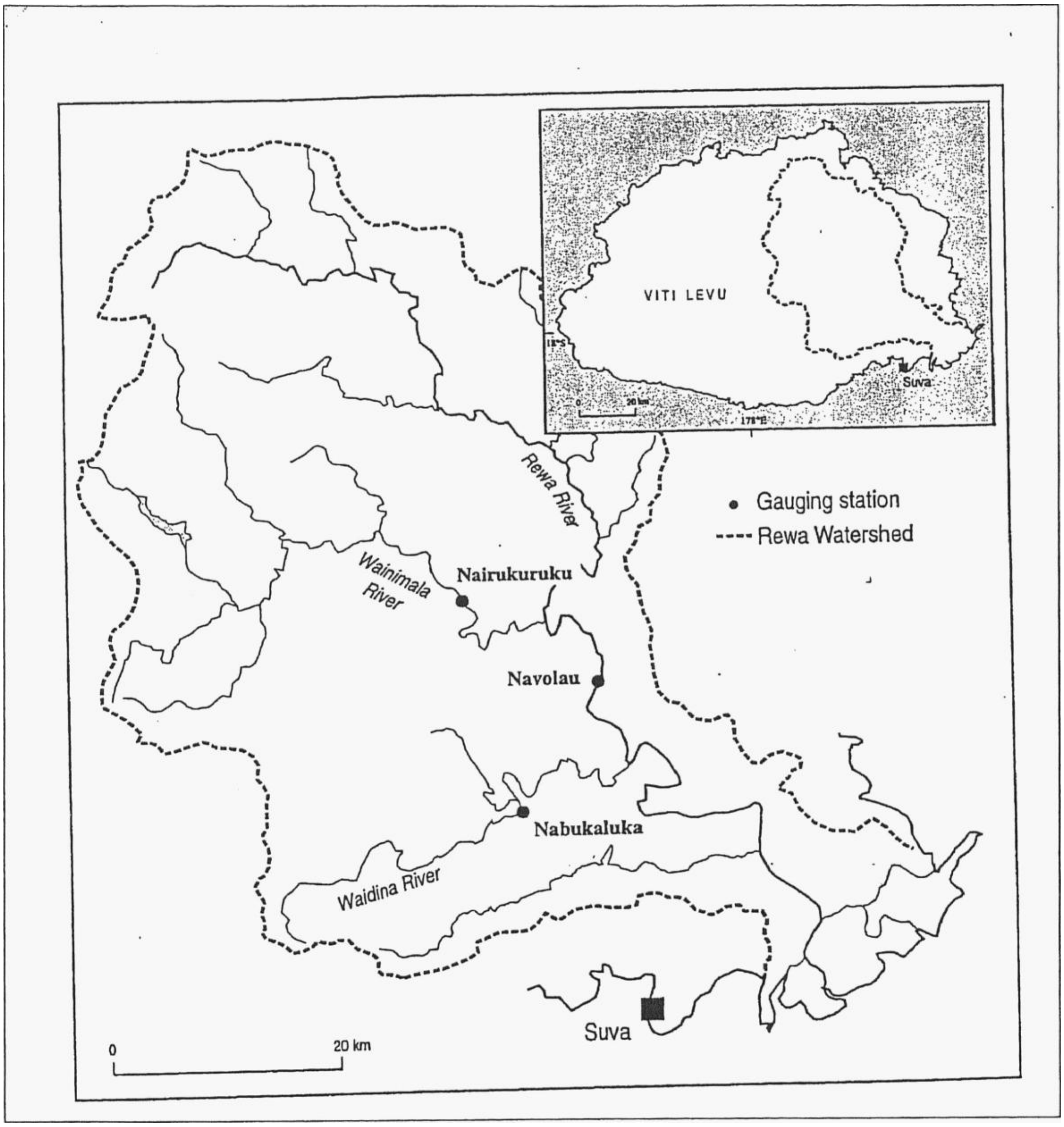
Annex W1: Cyclone tracks



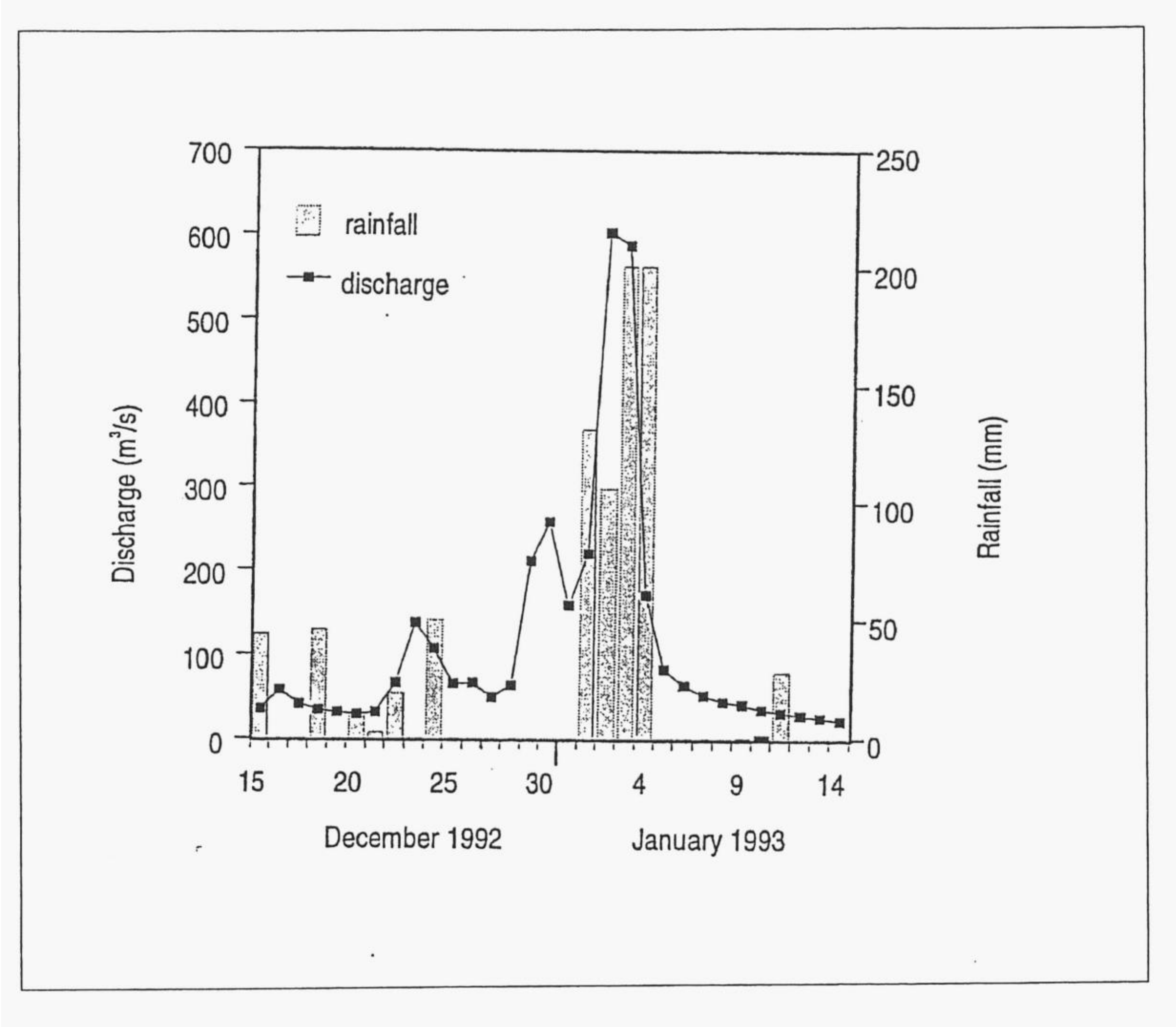
Annex W2: Maximum one-day rainfalls produced by cyclones Gavin and June across the Fiji Islands



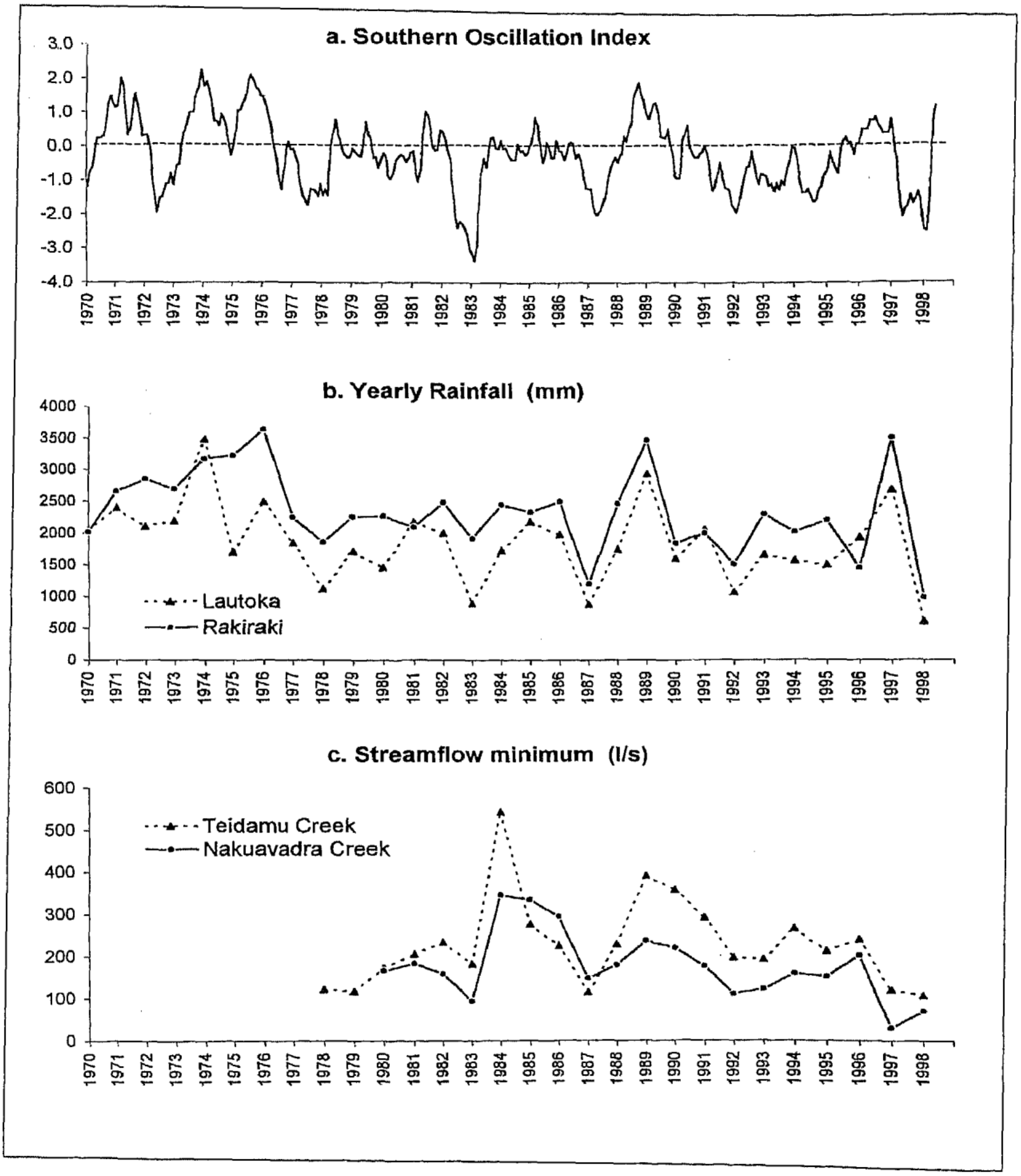
Annex W3: Rewa River drainage basin and major tributaries



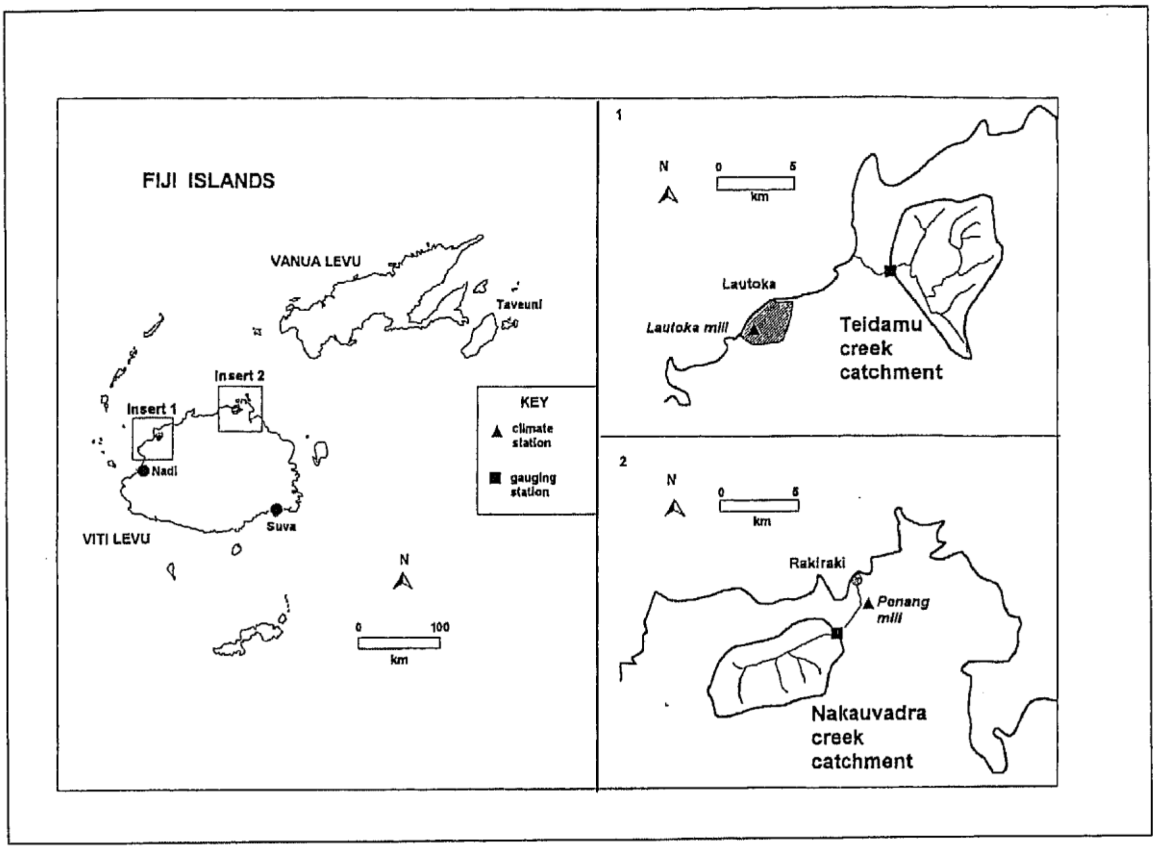
Annex W4: Rainfall and discharge associated with Cyclone Kina at the Nabukaluka gauging station, Waidina river



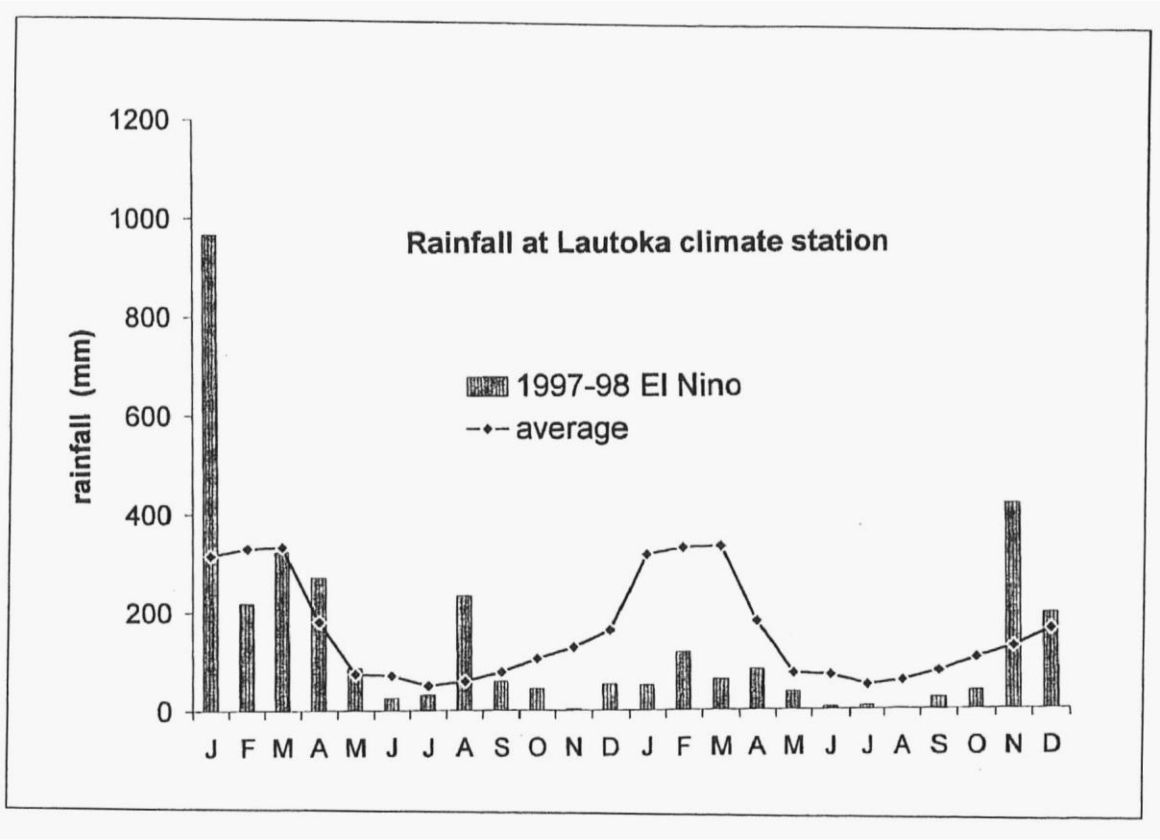
Annex W5: Relationship between the Southern Oscillation Index, yearly rainfall and stream baseflows in the drought-prone north and west of Viti Levu



Annex W6: Location of Lautoka and Rakiraki climate stations and the Teidamu and Nakauvadra creeks



Annex W7: Rainfall at Lautoka climate station



8.3 Annexes to Health chapter

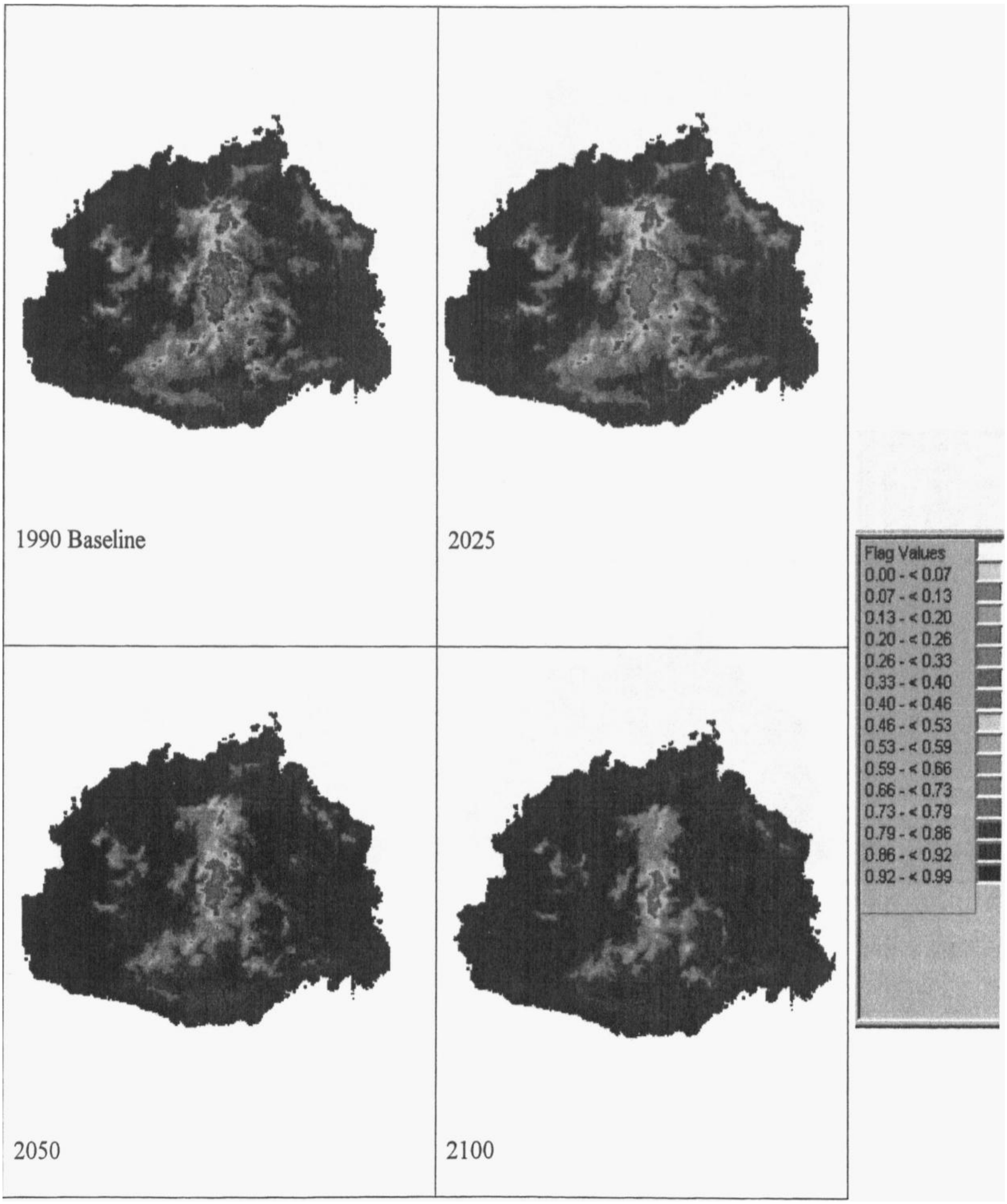
Annex Hl: Temperature and malaria epidemiology

Critical temperature in malaria epidemiology (◦C)	
Minimum temperature for mosquito development	**8 to 10**
Minimum temperature for parasite development	**14 to 19**
Optimum temperature for mosquitoes	**25 to 27**
Maximum temperature for parasite and mosquito	**40**

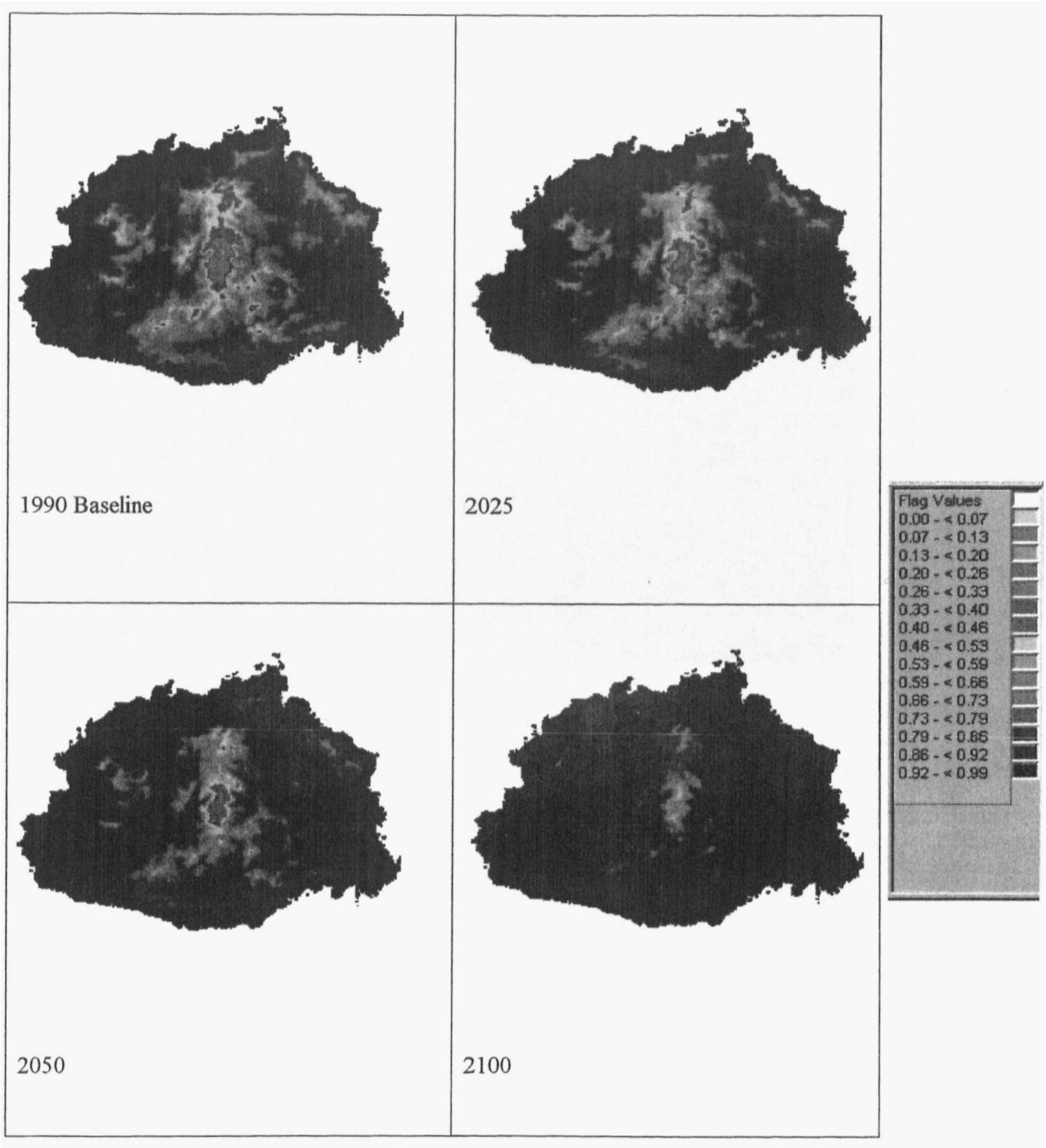
(source: WHO, 1996)

Annex 1-12: Malaria epidemic potentials for present and projected future climate in Fiji

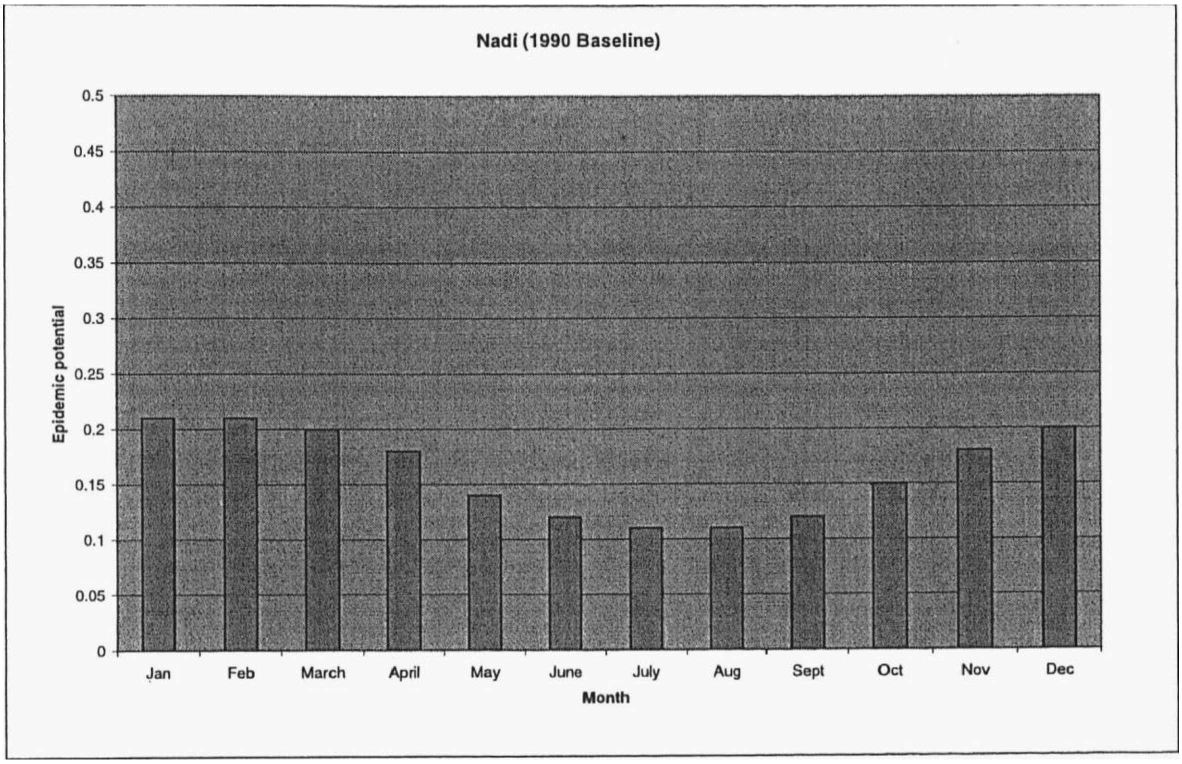
Malaria: Scenario B2 Mid

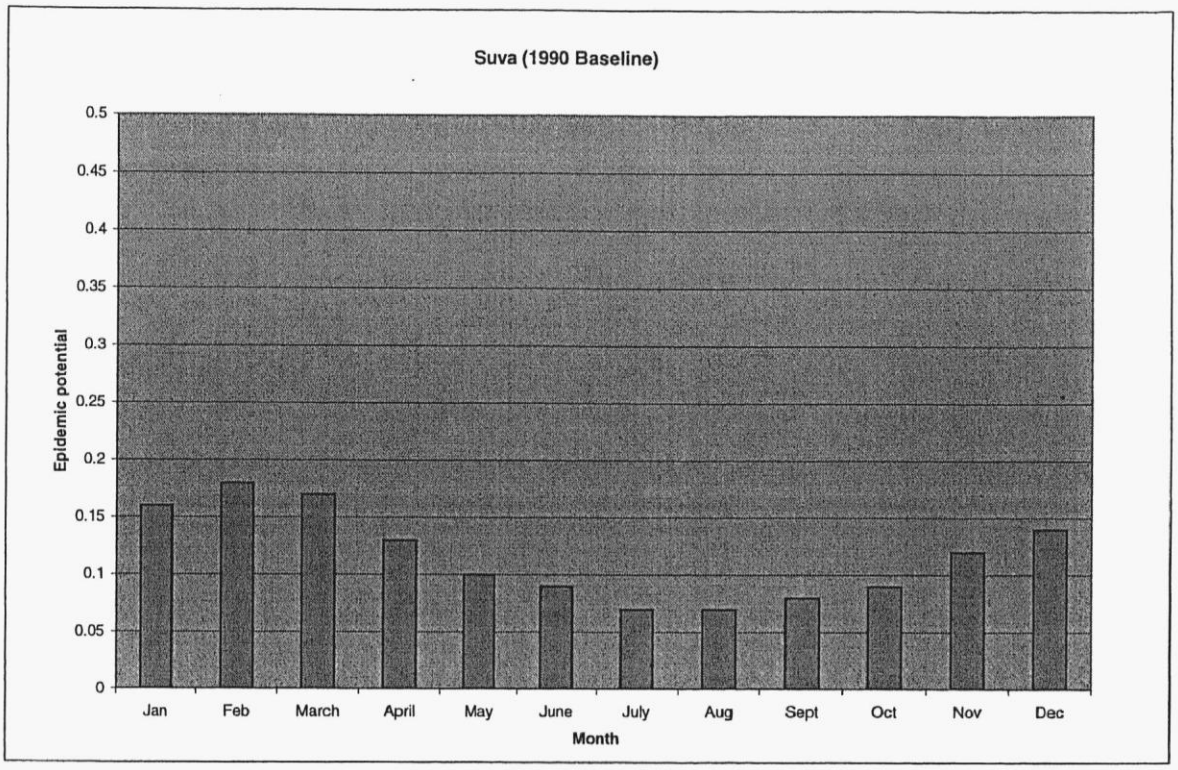


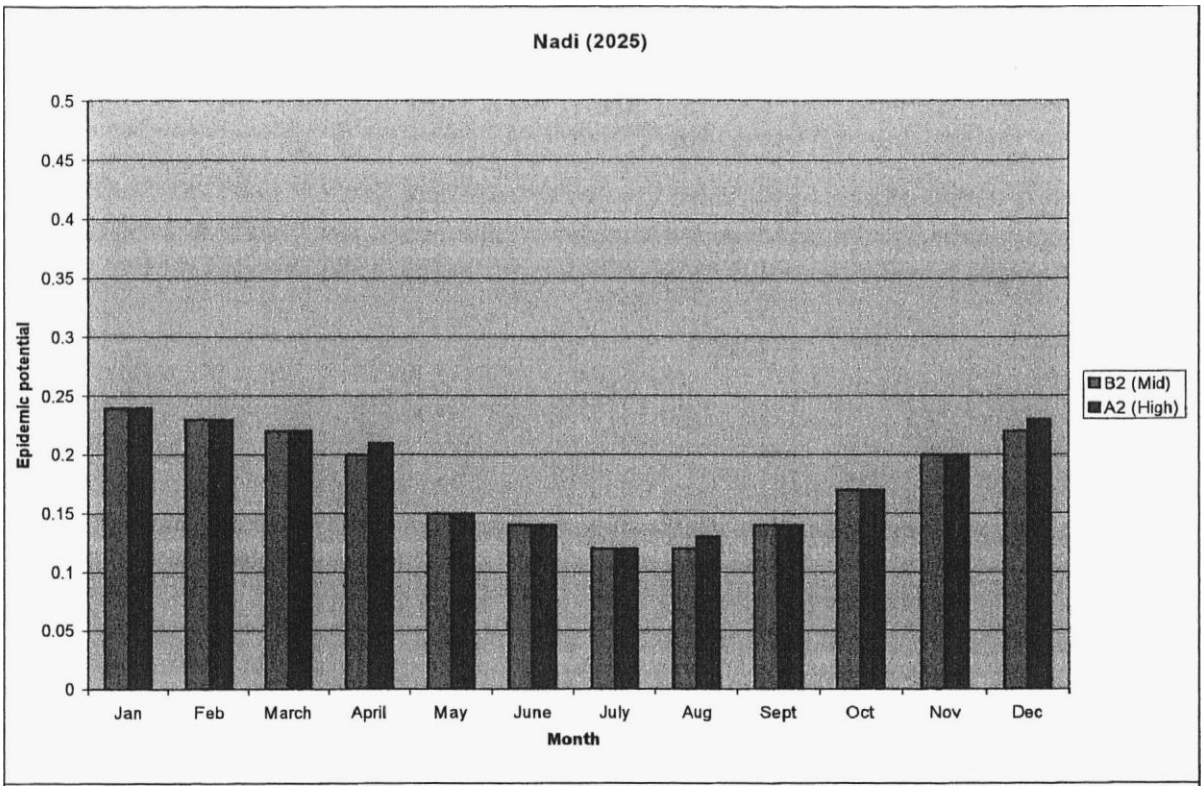
Malaria: Scenario A2 High

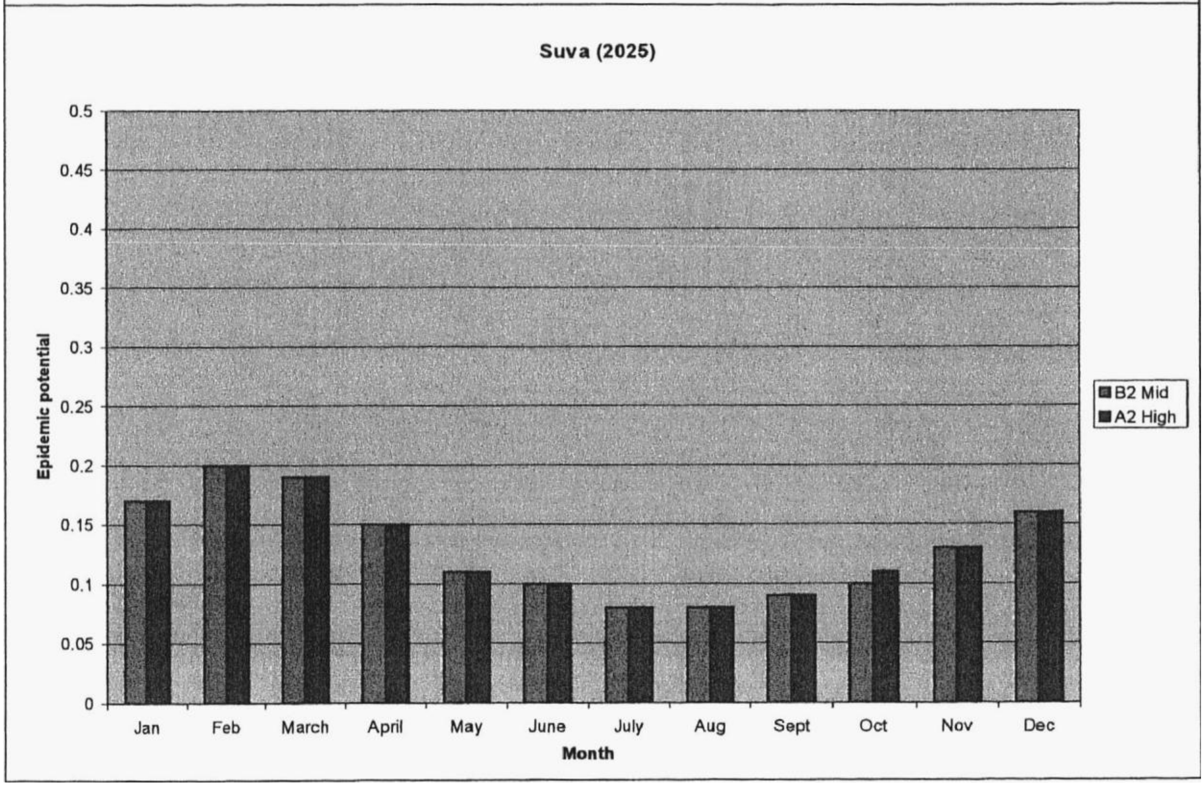


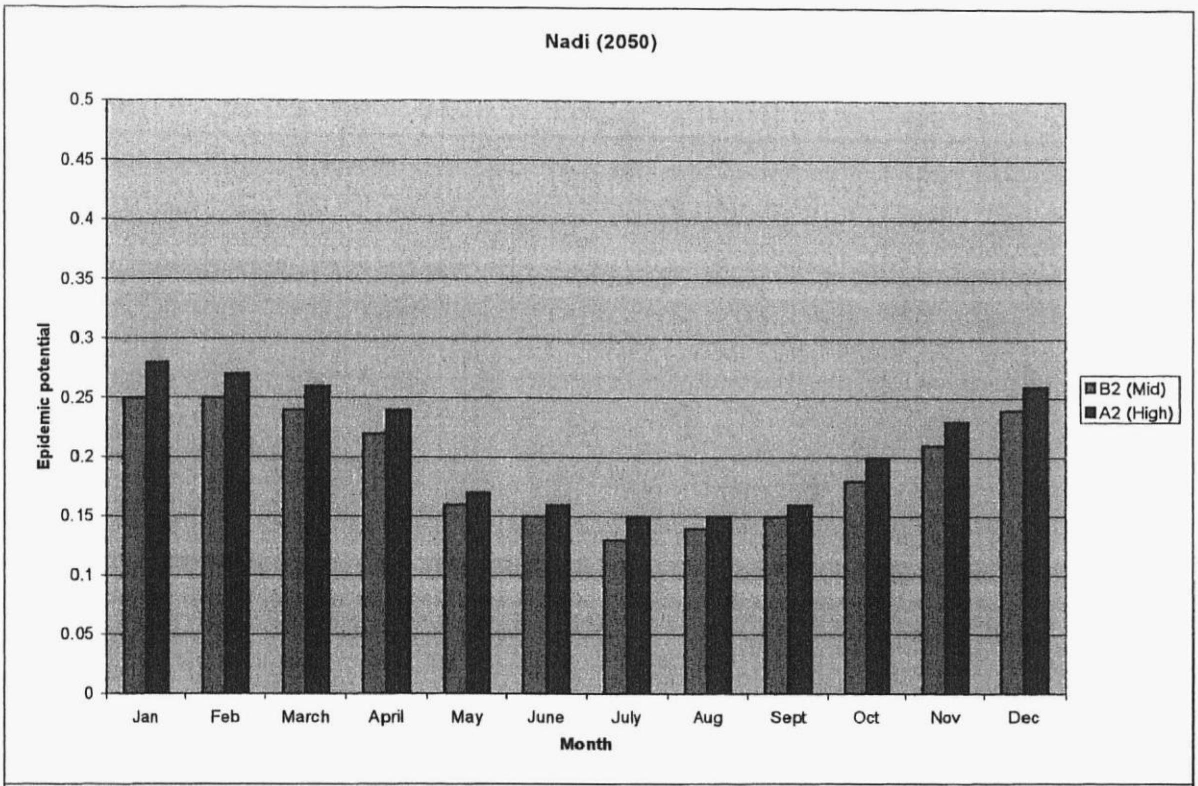
Annex H3: Model-predicted monthly epidemic potentials (dengue fever) for Nadi and Suva under present climate conditions and for the study scenarios of climate change

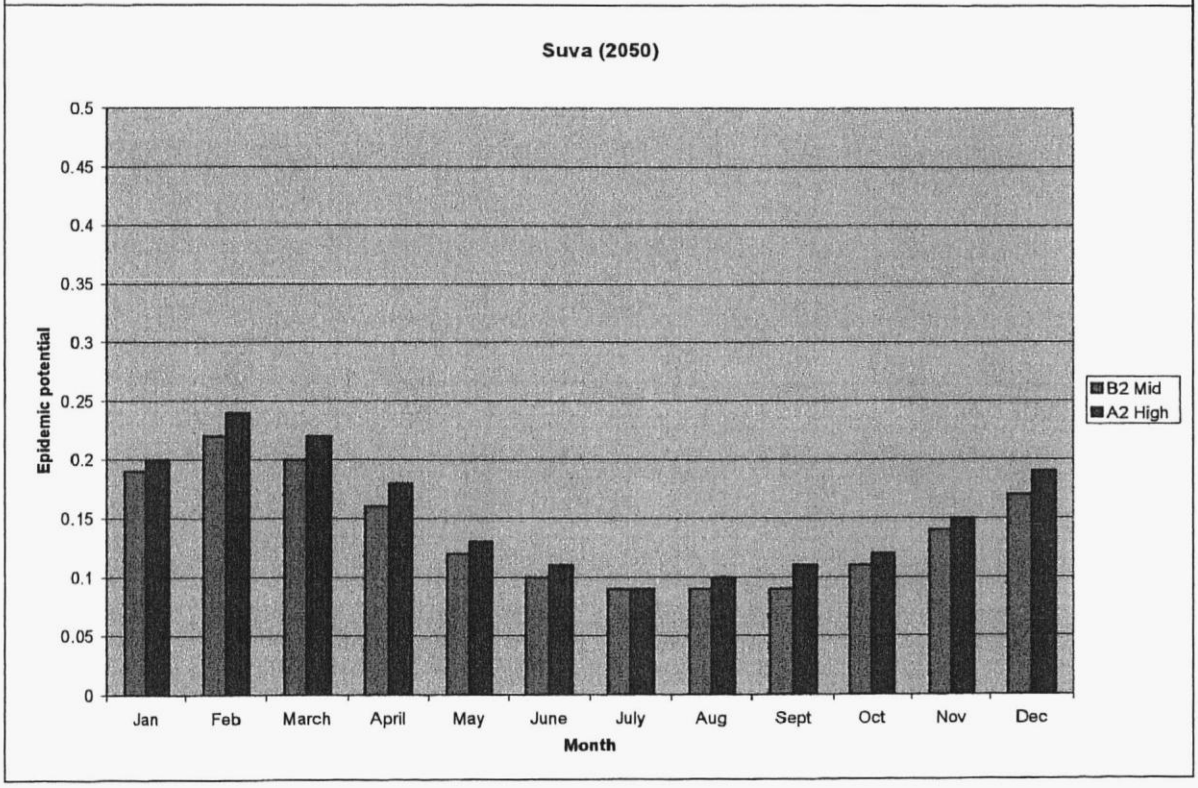


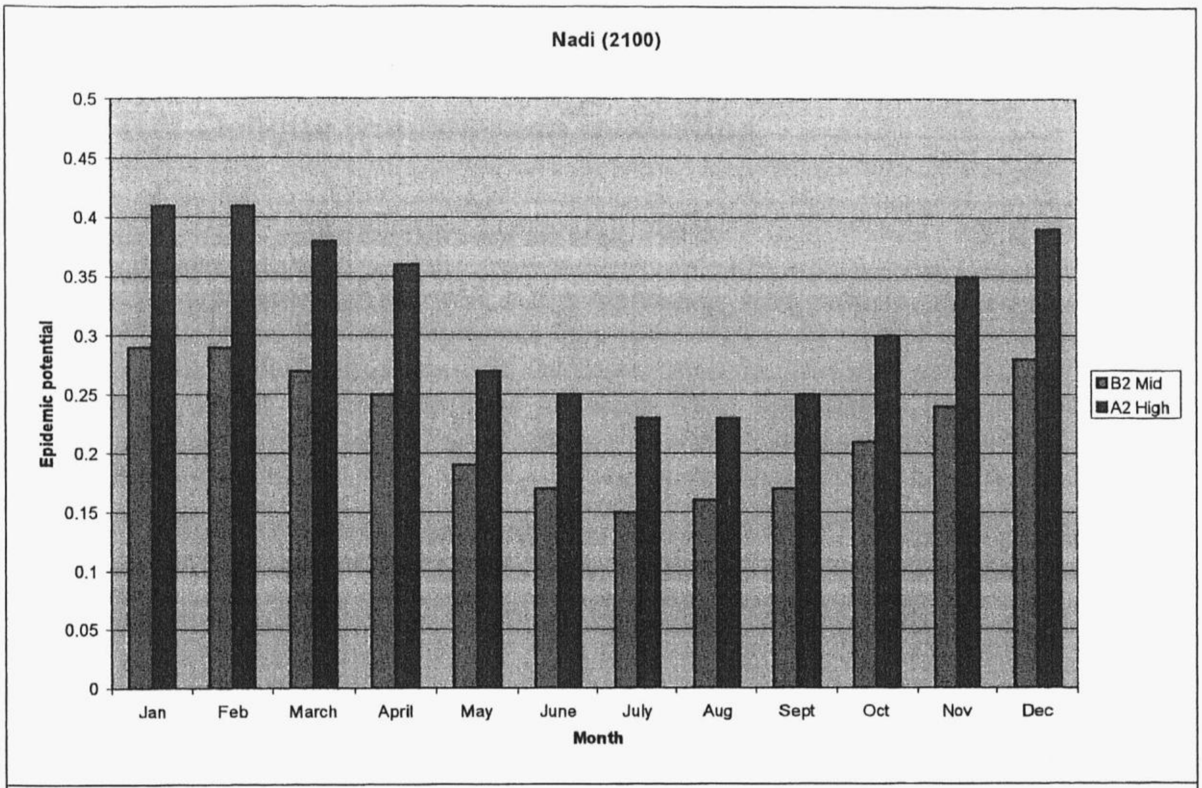

Suva (1990 Baseline)
Epidemic potential
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month

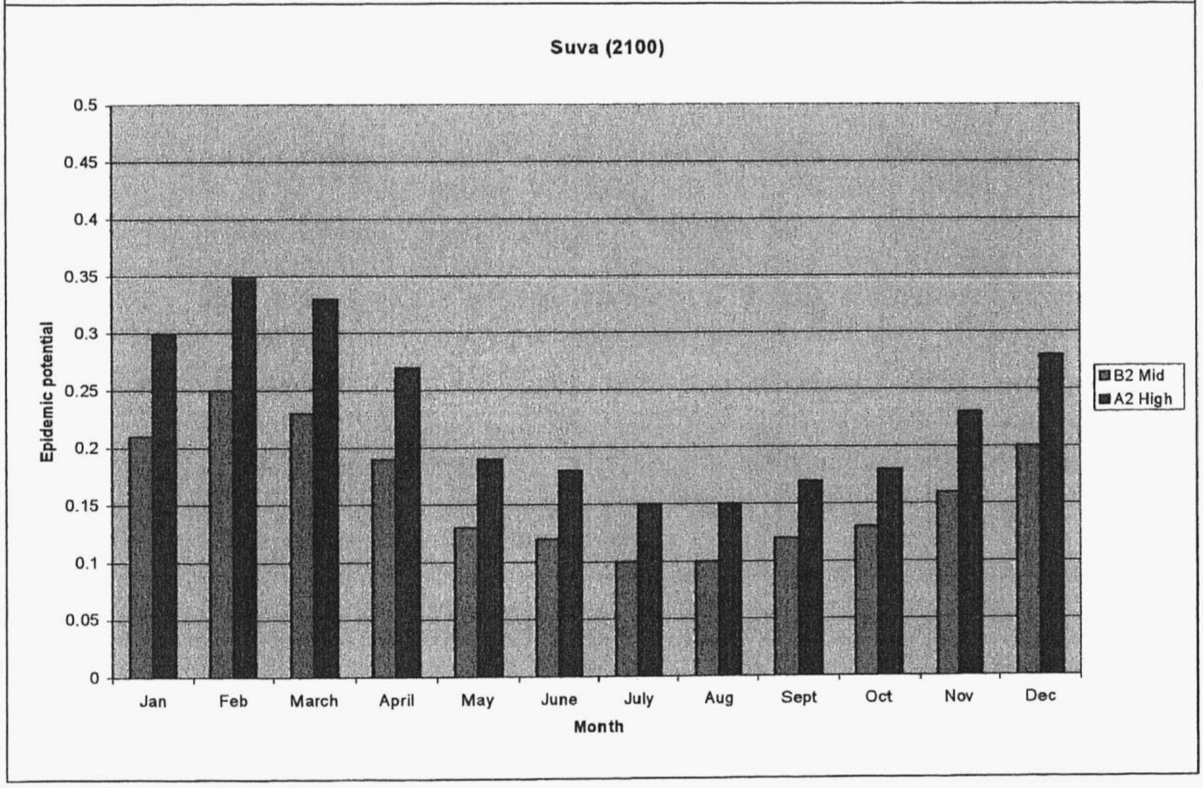

Nadi (2025)
Epidemic potential
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
B2 (Mid)
A2 (High)


Suva (2025)
Epidemic potential
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
B2 Mid
A2 High


Nadi (2050)
Epidemic potential
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
B2 (Mid)
A2 (High)


Suva (2050)
Epidemic potential
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
B2 Mid
A2 High


Nadi (2100)
Epidemic potential
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
B2 Mid
A2 High


Suva (2100)
Epidemic potential
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
B2 Mid
A2 High

Annex H4: Dengue transmission modelling

Dengue transmission modelling: (from Patz et al, 1998):

The basic reproduction rate *Rho* (R_0), a commonly used term to predict epidemic dynamics of infectious diseases, represents the vectorial capacity multiplied by the length of time that a person remains viremic, in the case of dengue. This term yields the average number of secondary human infections produced from one infected person among a susceptible human population. If ***R*** **=** 1, disease is likely to persist; if its value is <1, the disease will tend to die out.

We focus on the VC equation that contains all parameters of R except for duration of viremia, which is relatively constant. The equation defines the mean number of potential contacts infected by a mosquito population per infectious person per unit time:

$$VC = mbca^2 p^n / -\mathrm{Ln}\,(p)$$

where m is the number of female mosquitoes per person , b is the probability that an infectious mosquito transmits dengue while biting a susceptible human, c is the probability that a mosquito acquires a dengue infection while biting a viremic human, a is the number of bites per person per day, n is the duration of the extrinsic incubation period (EIP) , and p is the survival rate of the mosquito.

Vector density (m) is strongly related to environmental conditions. Rearranging the VC equation in terms of **m ,** while setting VC to 1, allows calculation of the number of mosquitoes per person necessary to maintain viral transmission and thus determination of the critical density threshold of a vector population necessary to maintain viral transmission . This represents the average number of female mosquitoes per person necessary for an infectious human case to give rise to one new case of dengue in a susceptible population.

Epidemic potential. Our outcome measure, epidemic potential (EP), is simply the reciprocal of the critical density threshold. Increases in epidemic potential indicate that conditions are suitable for fewer vectors to effectively potentiate epidemic spread in a given area where *A.aegypti* and the virus are present.

Annex H5: Data analysis — Diarrhoeal disease in Fiji

National reports of diarrhoea in infants were available from the Secretariat of the Pacific Community for 1978-1989. About 5% missing values were estimated by imputation based on seasonal patterns. A further series (reports from 1993-1996) was not used in the initial modelling to allow the predictive ability of the model to be tested.

Because smoothed scatterplots of diarrhoea reports vs rainfall indicated a "U-shaped" exposure-response relationship, two dummy variables were constructed indicating departure of rainfall rate above ("rainH") and below ("rainL") the monthly mean value (5x10E-5 kg/m2/minute in these data).

```
regression results:

Model 1: diarrhoea ("D") regressed date and temperature ("temp")

  Source |       SS       df       MS                  Number of obs =     144
---------+------------------------------               F(  2,   141) =    4.08
   Model |  1017459.17     2  508729.587               Prob > F      =  0.0189
Residual |  17570752.8   141  124615.268               R-squared     =  0.0547
---------+------------------------------               Adj R-squared =  0.0413
   Total |  18588211.9   143  129987.496               Root MSE      =  353.01

------------------------------------------------------------------------------
       D |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    date |  -.0152886   .0232669     -0.657   0.512      -.0612857    .0307085
    temp |   69.30295   25.16908      2.753   0.007       19.54541    119.0605
   _cons |   -915.055    723.556     -1.265   0.208      -2345.476    515.3657
```

```
------------------------------------------------------------------------------

Model 2: diarrhoea regressed on date, temperature ("temp"), rainL and rainH

  Source |       SS       df       MS                  Number of obs =     144
---------+------------------------------               F(  4,   139) =    4.30
   Model |  2048434.52     4  512108.63                Prob > F      =  0.0026
Residual |  16539777.4   139  118991.204               R-squared     =  0.1102
---------+------------------------------               Adj R-squared =  0.0846
   Total |  18588211.9   143  129987.496               Root MSE      =  344.95

------------------------------------------------------------------------------
       D |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    date |  -.0232551   .0229811     -1.012   0.313      -.0686928    .0221826
    temp |   97.40192   46.00771      2.117   0.036       6.436509    188.3673
   rainL |    72.9511   33.63849      2.169   0.032       6.441825    139.4604
   rainH |   41.13071   20.10164      2.046   0.043       1.386189    80.87522
   _cons |  -1749.837   1302.194     -1.344   0.181      -4324.505    824.8312
------------------------------------------------------------------------------
```

As a test of the approach, Model 2 was then used to predict diarrhoea reports ("Dpred") 1992-1996, and the correlation between predicted and actual values calculated.