Cities, Seas, and Storms

Managing Change in Pacific Island Economies

Volume IV
Adapting to Climate Change

November 30, 2000

PAPUA NEW GUINEA AND PACIFIC ISLANDS COUNTRY UNIT • THE WORLD BANK

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Acronyms and Abbreviations

A$	Australian Dollar
A2	High Climate Sensitivity 4.5^{o} C Greenhouse Gas Emissions Scenario
ADB	Asian Development Bank
B2	Mid Climate Sensitivity 2.5 ^{o} C Greenhouse Gas Emissions Scenario
CDM	Clean Development Mechanism
CICERO	Center for International Climate and Environmental Research
"CIMSIN"	Container Inhabiting Mosquito Simulation Model
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSIRO9M2	9-Layer Global Circulation Model of Australia's Commonwealth Scientific and Industrial Research Organization (Mark 2 Version)
DENSIM	(Mosquito Population) Density Simulation Model
DHF	Dengue Hemorrhagic Fever
DKRZ	Deutsche Klimarechenzentrum (German Climate Monitoring Center)
DSS	Dengue Shock Syndrome
EACNI	East Asia and Pacific Country Management Unit for Papua New Guinea and Pacific Islands (World Bank)
EASRD	East Asia and Pacific Regional Development and Natural Resources Unit (World Bank)
EAPVP	East Asia and Pacific Vice Presidency (World Bank)
ENB	Earth Negotiations Bulletin
ENSO	El Niño Southern Oscillation
ESCAP	Economic and Social Commission for Asia and the Pacific
FAO	Food and Agriculture Organization of the United Nations
F$	Fijian Dollar
FFD	Fiji Fisheries Division
GEF	Global Environmental Facility
GCM	Global Circulation Model
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IGCI	International Global Change Institute
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency

M^3	Cubic Meter
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
MHWS	Mean High Water Spring (Level)
MSL	Mean Sea Level
MT	Metric Ton
NGOs	Nongovernmental Organizations
PACCLIM	Pacific Climate Change Impacts Model
PICCAP	Pacific Islands Climate Change Assistance Programme
PLANTGRO	Plant Growth Model from the Commonwealth Scientific and Industrial Research Organization
PNG	Papua New Guinea
SEPODYM	Spatial Environmental Population Dynamics Model
SLR	Sea Level Rise
SOPAC	South Pacific Applied Geoscience Commission
SPC	Secretariat of the Pacific Community
SPCZ	South Pacific Convergence Zone
SPECTRUM	Population Growth Model from Spectrum Human Resources Systems Corporation
SPREP	South Pacific Regional Environmental Programme
SRES	Special Report on Emission Scenarios
STM	Shoreline Translation Model
SUTRA	Saturated and Unsaturated Transport Model
UNDAC	United Nations Disaster Assessment and Coordination
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar
US	United States
WHO	World Health Organization
WPWP	Western Pacific Warm Pool
WRI	World Resources Institute

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Executive Summary

As the 21st century begins, the Pacific Island people confront a future that will differ drastically from the past. Their physical climate, access to resources, ways of life, external relations and economic structures are undergoing simultaneous and interactive change. Pacific Island countries can actively engage in foreseeing and managing the process of adaptation to these changes, or they can have unplanned adaptation imposed on them by forces outside their control.

Managing these forces will be particularly critical in the area of climate change, a subject that is very difficult for communities and governments to grasp, but of immense and immediate impact on Pacific Island countries. Choosing a development path that decreases the islands' vulnerability to climate events and maintains the quality of the social and physical environment will not only be central to the future well being of the Pacific Island people, but will also be a key factor in the countries' ability to attract foreign investment in an increasingly competitive global economy.

This volume examines the possible impacts of changes in climate on high and low islands of the Pacific, and discusses key adaptation and financing strategies available to Pacific Island countries. The short-term outcome of the report is intended to be an improved understanding of the need and scope for adaptation policies in face of the challenges posed by climate change. Over the long term, it is hoped that the report can assist Pacific Island governments, businesses and communities to better adapt to change by building on the strengths unique to their countries and their people. It is also hoped that the findings of the report can contribute to the on-going international dialogue on adaptation financing.

This volume is divided into seven chapters. Chapter 1 outlines the nature of the challenges posed by climate change. Chapter 2 describes climate change scenarios for the Pacific Island region. Chapter 3 examines the physical and economic impact of these scenarios on a high island of the Pacific – Viti Levu, in Fiji. The potential impacts of climate change on coastal areas, water resources, agriculture, and health are discussed in turn. Chapter 4 examines the potential effect of climate change on a group of low islands – the Tarawa atoll in Kiribati – focusing primarily on coastal and water resource impacts. Chapter 5 discusses the potential impact of climate change on the tuna fisheries of the Central and Western Pacific. Chapter 6 proposes a general adaptation strategy for Pacific Island countries. Key findings and recommendations are summarized on Chapter 7. Annex A describes the methodology and assumptions used to assess climate change impacts. Detailed background studies to this report are included in *References.*

This volume is the last of a four-volume report entitled *"Cities, Seas and Storms: Managing Change in Pacific Island Economies"* produced by the World Bank as the Year 2000 Regional Economic Report for the Pacific Islands. In addition to this specialized volume, the series includes a summary report (Volume I), a volume dedicated to the management of Pacific towns (Volume II), and a volume dedicated to the management of the ocean (Volume III).

Impacts from Climate Change

The warming of the earth's atmosphere is likely to have substantial and widespread impacts on Pacific Island economies, affecting sectors as varied as health, coastal infrastructure, water resources, agriculture, forestry and fisheries.

Some policymakers dismiss the impacts of climate change as a problem of the future. But there is evidence that similar impacts are already being felt: the Pacific Islands are becoming increasingly vulnerable to extreme weather events as growing urbanization and squatter settlements, degradation of coastal ecosystems, and rapidly developing infrastructure on coastal areas intensify the islands' natural exposure to climate events.

According to climate change models, the sea level may rise by 23─43 centimeters and the average temperature by 0.9^0–1.3^0C by 2050. Among the most substantial impacts of climate change would be losses of coastal infrastructure and land resulting from inundation, storm surge, and shoreline erosion. Climate change could also cause more intense cyclones and droughts, the failure of subsistence crops and coastal fisheries, losses in coral reefs, and the spread of malaria and dengue fever.

In the absence of adaptation, a high island such as Viti Levu could experience average annual economic losses (in 1998 dollars) of US$23─$52 million by 2050, equivalent to 2─4 percent of Fiji's GDP. A low group of islands such as the Tarawa atoll in Kiribati could face average annual damages of US$8─$16 million by 2050, as compared to a current GDP of US$47 million. These costs could be considerably higher in years of extreme weather events such as cyclones, droughts and large storm surges.

How certain is climate change? A soon to be released review by the Intergovernmental Panel on Climate Change (IPCC) concludes that mankind has contributed substantially to observed warming over the last 50 years. While there is growing consensus that climate change is occurring, uncertainties remain on the timing and magnitude of the changes. Most studies, however, consider the Pacific Islands to be at high risk from climate change and sea level rise.

A Strategy for Adaptation

How should Pacific Island countries adapt to climate change? One possibility is to do nothing, and by implication hope that climate change does not happen. This is the *de facto* present position of many governments, including those of several Pacific Island countries.

Another possibility might be to assume the worst and embark upon major investments in coastal protection – such as seawalls – and relocation of vulnerable infrastructure. The first approach is unwise in light of the increasing evidence of climate change. The second is impractical and unaffordable.

This report recommends that Pacific Island countries follow a strategy of precautionary adaptation. Since it is difficult to predict far in advance how climate change will affect a particular site, Pacific Island countries should avoid adaptation measures that could fail or have unanticipated social or economic consequences if climate change impacts turned out to be different than anticipated (IPCC 1998). As a first step, it is recommended that Pacific Islands countries adopt 'no regrets' adaptation measures that would be justified even in the absence of climate change. These include better management of natural resources—particularly of coastal habitats, land, and water—and measures such as disease vector control and improved spatial planning.

Acting now to reduce vulnerability to extreme weather events would go a long way toward preparing Pacific countries for the future, and reducing the magnitude of the damage. Taking early action may require adjustments of development paths and the sacrifice of some short-term economic gains. But it would vastly decrease the downsize costs should climate change scenarios materialize. The challenge will be to find an acceptable level of risk─an intermediate solution between a policy of inaction and investing in high cost solutions─and start adapting long before the expected impacts occur.

Under a 'no regrets' adaptation policy, Pacific Island governments would take adaptation goals into account in future expenditure planning, would support community-based adaptation, and would require major infrastructure investments to meet adaptation criteria. Adaptation would be viewed as a key feature in national policy in its own right, and would be taken into account in the development of policies in a wide range of sectors and activities.

The question of who will fund adaptation is a difficult and sensitive issue. Insofar as 'no regrets' measures help reduce the islands' vulnerability to current climate events (independently of climate change) Pacific Island governments would be justified in funding adaptation from reallocations in public expenditures and development aid. Donors could support this process directly, or as part of natural resources and environmental management assistance.

The analysis of this report, however, clearly shows that the Pacific Islands are likely to experience significant incremental costs associated with climate change. It is urgent that the international community develop financing mechanisms to help countries in the receiving end of climate change to fund 'no regrets' adaptation. Countries that have taken early action using their own resources should not be penalized with lower future allocations. These and other disincentives against 'no regrets' policies need to be urgently discussed in international forums. Of paramount importance, however, will be for the international community to move rapidly to develop a financing mechanism to assist countries such as the Pacific Islands in taking early adaptive action. The urgency of this action for small island states cannot be over-emphasized.

Although uncertainties remain, it now seems certain that climate change will affect many facets of Pacific Island people's lives in ways that are only now beginning to be understood. As such, climate change must be considered one of the most important challenges of the twenty-first century and a priority for immediate action.

Chapter 1
Key Challenges

Across the Pacific, atoll dwellers speak of having to move their houses away from the ocean because of coastal erosion; of having to change cropping patterns because of saltwater intrusion; of changes in wind, rainfall, and ocean currents. While these events may simply reflect climate variability, they illustrate the types of impacts likely to be felt under climate change.

Many policymakers dismiss climate change as a problem of the future. But impacts similar to those resulting from climate change are already being felt, as the Pacific Islands become increasingly vulnerable to extreme weather events and to climate variability. Cyclones Ofa and Val, which hit Samoa in 1990–91, caused losses of US$440 million—in excess of the country's annual gross domestic product (GDP). Fiji was hit by four cyclones, two droughts, and severe flooding in the past eight years. In the 1990s alone, the cost of extreme events in the Pacific Island region exceeded US$1 billion (table 1).

Rising Vulnerability to Extreme Weather Events

The impacts of extreme weather events are becoming stronger as the islands' vulnerability rises. Growing urbanization and squatter settlements, degradation of coastal ecosystems, and rapidly developing infrastructure on coastal areas are intensifying the islands' exposure to extreme weather events. At the same time, traditional practices promoting adaptation, such as multicrop agriculture, are gradually weakening (box 2).

Box 1. Climate Change and Climate Variability

Climate change is the gradual warming of the earth's atmosphere caused by emissions of heat-absorbing "greenhouse gases," such as carbon dioxide and methane. The term is generally used to reflect longer-term changes, such as higher air and sea temperatures and a rising sea level.

Climate variability reflects shorter-term extreme weather events, such as tropical cyclones and the El Niño Southern Oscillation (ENSO). While there is some evidence that climate variability will increase as a result of climate change, many uncertainties remain.

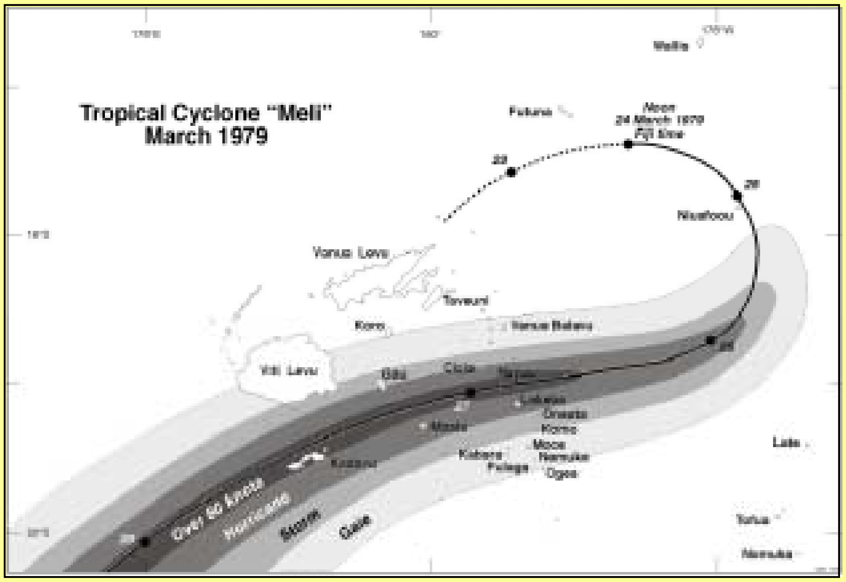
Mitigation and *adaptation* also have distinct meanings among climate change experts. Mitigation refers to efforts to reduce greenhouse gas emissions. Adaptation refers to efforts to protect against climate change impacts.

Table 1. Estimated Costs of Extreme Weather Events in the Pacific Island Region during the 1990s (millions of US$)

Event	*Year*	*Country*	*Estimated losses*
Cyclone Ofa	1990	Samoa	140
Cyclone Val	1991	Samoa	300
Typhoon Omar	1992	Guam	300
Cyclone Nina	1993	Solomon Islands	–
Cyclone Prema	1993	Vanuatu	–
Cyclone Kina	1993	Fiji	140
Cyclone Martin	1997	Cook Island	7.5
Cyclone Hina	1997	Tonga	14.5
Drought	1997	Regional	> 175[a]
Cyclone Cora	1998	Tonga	56
Cyclone Alan	1998	French Polynesia	–
Cyclone Dani	1999	Fiji	3.5

– Not available.
a. Includes losses of US$160 million in Fiji.
Note: Minor events and disasters in Papua New Guinea not included. Costs are not adjusted for inflation.
Source: Campbell 1999, and background studies to this report.

Box 2. Rising Vulnerability to Extreme Weather Events



Tropical cyclones are regular occurrences in many Pacific Islands. Traditional societies adapted to these events by using a range of resilient food crops and food preservation techniques. Many communities used famine foods during times of scarcity and followed traditional obligations to provide for victims of disasters.

This resilience is diminishing, however, leaving many Pacific Islands increasingly vulnerable to extreme weather events. An example is the increasing use of nontraditional crops, such as cassava.

Cyclone Meli devastated much of the Southern Lau Island Group in Fiji in 1979 (see figure). Islands such as Nayau were subject to winds of more than 80 knots; other islands, such as Ogea, experienced only gale force winds.

Island	Distance from storm (kilometers)	Percentage of root crops destroyed			Percentage of tree crops destroyed		
		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 (1995)

The effect of Cyclone Melia on crops depended on the distance from the storm (see table on left). While at the storm center crop damage was nearly 100 percent, at distances of 30-100 kilometers from the storm, traditional crops – such as taro and yam – suffered much less damage than nontraditional crops such as cassava.

Cassava is becoming increasingly prevalent in the Pacific as a subsistence crop because of its ability to grow on poor soils and the low labor inputs required. But its low resilience to cyclones increases the likelihood that food rations will be required during the cyclone season. In most cases, the best strategy for food security in cyclone-prone areas is crop diversity and the maintenance of traditional crops.

If tropical cyclone intensity increases under climate change, it is likely that the trend toward cultivation of cassava will result in greater food crop losses than would be the case if traditional root crops were maintained. From this perspective, promoting traditional multicrop agriculture may also be the best adaptation to climate change.

Compounding Impacts of Climate Change

Arriving on top of this increased vulnerability, climate change is only likely to exacerbate the current impacts, whether or not climate variability increases in the future—and there is some evidence that it may. In low islands, the most substantial damage would come from losses to coastal infrastructure as a result of inundation, storm surge, or shoreline erosion. But climate change could also cause more intense cyclones and droughts, the failure of subsistence crops and coastal fisheries, losses in coral reefs, and the spread of malaria and dengue fever. These impacts could be felt soon: if climate change models are correct, the average sea level could rise 11–21 centimeters and average temperatures could rise 0.5^0–0.6^0C by 2025.

The economic impact could be substantial. Estimates from this study indicate that if climate change scenarios materialize, a high island such as Viti Levu in Fiji could suffer economic damages of more than US$23–$52 million a year by 2050 (in 1998 dollars), equivalent to 2–4 percent of Fiji's gross domestic product (GDP). The Tarawa atoll in Kiribati could face average annual economic damages of US$8–$16 million by 2050 (as compared with a GDP of about US$47 million). In years of strong storm surge, up to 54 percent of South Tarawa could be inundated, with capital losses of up to US$430 million.

Climate change would have the greatest impact on the poorest and most vulnerable segments of the population—those most likely to live in squatter settlements exposed to storm surges and disease (where safety nets have weakened), and those most dependent on subsistence fisheries and crops destroyed by cyclones and droughts. Nevertheless, the impacts of climate change are likely to be pervasive and affect the lives of most Pacific Islanders.

Chapter 2
Climate Change Scenarios in the Pacific

In 1999–2000 the World Bank helped sponsor a study of vulnerability, adaptation, and economic impact of climate change in the Pacific Island region.[1] The analysis used an integrated model of climate change developed for the region, the Pacific Climate Change Impacts Model (PACCLIM), complemented by sectoral impact models, population projections, and baseline data such as historical climate records. Based on the best scientific information available for the region, the following scenarios were used by the study (table 2):

- ***Rise in sea level.*** Sea level could rise 0.2 meters (in the best-guess scenario) to 0.4 meters (in the worst-case scenario) by 2050. By 2100, the sea could rise by 0.5-1.0 meters relative to present levels. The impact would be critical for low-lying atolls in the Pacific, which rarely rise 5 meters above sea level. It could also have widespread implications for the estimated 90 percent of Pacific Islanders who live on or near the coast (Kaluwin and Smith 1997).

- ***Increase in surface air temperature***. Air temperature could increase 0.9^0-1.3^0 C by 2050 and 1.6^0-3.4^0C by 2100.[2]

- ***Changes in rainfall.*** Rainfall could either rise or fall—most models predict an increase—by 8-10 percent in 2050 and by about 20 percent in 2100, leading to more intense floods or droughts.

Table 2. Climate Change and Variability Scenarios in the Pacific Island Region

Impact	*2025*	*2050*	*2100*	*Level of Certainty*
Sea level rise (centimeters)	11—21	23—43	50—103	Moderate
Air temperature increase (degrees Centigrade)				
Fiji	0.5—0.6	0.9—1.3	1.6—3.3	High
Kiribati	0.5—0.6	0.9—1.3	1.6—3.4	High
Change in rainfall (percent)				
Fiji	-3.7—+3.7	-8.2—+8.2	-20.3—+20.3	Low
Kiribati	-4.8—+3.2	-10.7—+7.1	-26.9—+17.7	Low
Cyclones				
Frequency		Models produce conflicting results		Very Low
Intensity (percentage increase in wind speed)		0—20		Moderate
Region of formation		No change		Low
Region of occurrence		No change or increase to north and south		Low
El Niño Southern Oscillation (ENSO)		A more El Niño–like mean state		Moderate

Note: Ranges given reflect a best-guess scenario (lower value) and a worst-case scenario (higher value). Sea level rise is derived from global projections, as regional models have not yet been developed. Temperature and rainfall projections are based on the CSIRO9M2 and the DKRZ Global Circulation Models. ENSO and cyclone scenarios are based on a comprehensive review of climate variability in the South Pacific (Jones and others 1999). For details, see Annex A.

[1] See *Acknowledgments* for a list of the experts and organizations that participated in the study. Background studies to this report are cited in *References*. The assumptions used by the study are detailed in Annex A.

[2] A new report by the Intergovernmental Panel on Climate Change, scheduled to be finalized in early 2001, raises the worst case scenario for surface air temperature to 6^o C by 2100. This means that if the worst case scenario materializes, the impacts may be considerably higher than estimated here.

- ***Increased frequency of El Niño-like conditions***. The balance of evidence indicates that El Niño conditions may occur more frequently, leading to higher average rainfall in the central Pacific and northern Polynesia. The impact of El Niño Southern Oscillation (ENSO) on rainfall in Melanesia, Micronesia, and South Polynesia is less well understood (Jones and others 1999).

- ***Increased intensity of cyclones***. Cyclones may become more intense in the future (with wind speeds rising by as much as 20 percent); it is unknown, however, whether they will become more frequent. A rise in sea surface temperature and a shift to El Niño conditions could expand the cyclone path poleward, and expand cyclone occurrence east of the dateline. The combination of more intense cyclones and a higher sea level may also lead to higher storm surges (Jones and others 1999).

How certain is climate change? The Intergovernmental Panel on Climate Change (IPCC) stated in 1995 that "the balance of evidence suggests a discernible human influence on global climate change" (IPCC 1995). In a report scheduled to be finalized in early 2001, however, IPCC concluded that human influence had contributed substantially to observed warming over the past 50 years.

While there is growing consensus among experts that climate change is occurring, uncertainties remain about the magnitude and timing of the changes. For small island states, these uncertainties are magnified because the area of the countries usually falls below the levels of resolution of the general circulation models used.

Some changes are more certain than others: there is emerging consensus that global average temperature and sea levels will increase. Rainfall changes remain highly uncertain, however, as does the relationship between long-term climate change and extreme events. Uncertainties also increase with spatial resolution: there is greater confidence in model projections of global average changes than in projections of regional or local level changes. Impacts on coastal areas and water resources are generally more certain than impacts on agriculture and health. And uncertainty increases with time: projections for 2100 are less certain than projections for 2050. Despite these uncertainties, most studies consider the Pacific Islands to be at high risk from climate change and sea level rise (Kench and Cowell 1999).

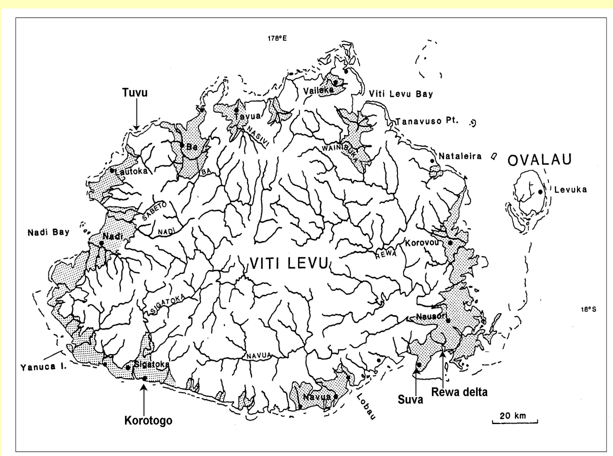
Based on the results of the study, the physical and economic impacts of climate change in the Pacific Island region are illustrated here by the example of a high island—Viti Levu in Fiji—and a group of low islands—the Tarawa atoll in Kiribati. To give perspective to the analysis, all economic damages were estimated for 2050 as if the impacts had occurred under today's socio-economic conditions. Ranges provided represent a "best guess" scenario (the lower bound) and a "worst case" scenario (the upper bound). All economic costs reflect 1998 US dollars, and assume no adaptation.

Chapter 3
Impact of Climate Change on a High Island
Viti Levu, Fiji

With an area of 10,389 square kilometers, Viti Levu is the largest island in Fiji. Seventy-seven percent of Fiji's population—595,000 people in 1996—reside there. It is also in Viti Levu that Fiji's major cities, industries, and tourism facilities are located (box 3).

By 2050, under the climate change scenarios used by the study, Viti Levu could experience annual economic losses of US$23–$52 million (table 3). Because the losses are annual averages, they dampen the potential impact of extreme weather events, which could be

Box 3. Viti Levu (Fiji) at a Glance



Climate: Oceanic tropical
- Average temperature: 23° –27° C.
- Average rainfall: East Viti Levu 3,000–5,000 milimeters.
West V. Levu 2,000–3,000 milimeters.

Major Influences
- Southeast trade winds.
- El Niño Southern Oscillation (ENSO).
- South Pacific Convergence Zone.

Extreme Events
- Tropical cyclones.
- Droughts (often associated with ENSO).

Population
- Population: 772,655 in 1996 (595,000 or 77% in Viti Levu).
- Average annual growth rate: 0.8%.
- 60% rural, but growing urbanization.

Economy
- GDP (1998): US$1,383 million.
- Narrow base, with sugar and tourism dominating.
- Average annual growth: 2.7% (1993–96).
- Growth affected by tropical cyclones and drought.
- Main exports: sugar, gold, garments.

Future Population Trends
- Increasing population density, especially in urban areas, coastal areas, flood plains, and marginal hill lands.

Implications:
- Denser urban structures.
- Spread of urban areas to coastal margins and inland.
- Increase in proportion of squatter housing.
- Increase in coastal infrastructure (related to tourism).

Future Economic Trends
- Continued dependence on natural resources.
- Tourism sector likely to grow.
- Agriculture will continue to be important in subsistence production and as export earner. Role of sugar uncertain due to future removal of subsidies and land tenure. Possible increase in traditional crops, such as kava.
- Growing importance of cash economy.
- Continued dependence on foreign aid.

Future Environmental Trends
- Environmental degradation in densely populated areas (especially coastal and lowland) and in marginal farmland.
- Increase in deforestation.
- Increase in problems of waste disposal (sewage, solid waste, and chemical pollution).

Future Sociocultural Trends
- Reduction in importance of traditional kinship systems.
- Increase in preference for imported foods.
- Increase in noncommunicable diseases associated with nutritional and lifestyle changes.
- Increase in poverty and social problems in urban areas.

Table 3. Estimated Annual Economic Impact of Climate Change on Viti Levu, Fiji, 2050 (millions of 1998 US$)

Impact	*Annual damage*[a]	*Level of Certainty*	*Likely cost of an extreme event*[b]	*Extreme event*
Impact on coastal areas				
Loss of coastal land and infrastructure to erosion	3-6	Moderate	—	—
Loss of coastal land and infrastructure to inundation and storm surge	0.3-0.5	Moderate	75-90	Large Storm Surge
Loss of coral reefs and related services	5-14	Very low	—	—
Loss of nonmonetized services from coral reefs, mangroves and seagrasses	+	Very low	—	—
Impact on water resources				
Increase in cyclone severity	0–11	Moderate	40	Cyclone
Increase in intensity of droughts (related to El Niño)	+	Moderate	50-70	Drought
Changes in annual rainfall (other than impacts on agriculture)	+	Low	—	—
Impact on agriculture				
Loss of sugarcane, yams, taro, and cassava due to temperature or rainfall changes and ENSO	14	Moderate	70	Drought
Loss of other crops	+	Very Low	—	—
Impact on public health				
Increased incidence of dengue fever	1-6	Moderate	30	Large epidemic
Increase in fatal dengue fever cases	+	Very Low	—	—
Increased incidence of diarrhea	0-1	Low	—	—
Infant mortality due to diarrhea	+	Very Low	—	—
Impact of cyclones and droughts on public safety	+	Very Low	—	—
Total estimated damages	**>23-52+**			

+ Likely to have economic costs, but impact not quantified. — Not available.
[a] Reflects the incremental average annual costs of climate change. [b] Reflects the absolute (non-incremental) cost of a future extreme event.
Numbers are rounded.
Note: For assumptions, see annex A.
Source: Background studies to this report.

substantially higher in a particular year: an average cyclone could cause damages of more than US$40 million, while a drought comparable to the 1997/98 event could cost Viti Levu some US$70 million in lost crops.

Among the most significant incremental impacts of climate change would be damages to infrastructure and ecosystems of coastal areas (averaging about US$8–$20 million a year by 2050). But a higher intensity of cyclones could also result in substantial damages, up to US$11 million a year. Changes in rainfall could lead to agricultural losses of US$14 million per year, and the combined effect of higher temperatures and stronger climate variability could result in public health costs of more than US$1–$6 million a year. These estimates assume no adaptation and are subject to large margins of uncertainty. But they probably underestimate the costs of actual damages, as many impacts (such as nutrition and loss of lives) could only be assessed qualitatively.

A. Impact on Coastal Areas

Viti Levu's coastal areas are naturally exposed to weather events. About 86 percent of the 750-kilometer coast lies at elevations that are less than 5 meters from sea level. Intensive urban development, growing poverty, deforestation of watersheds, pollution, and increased exploitation of coastal resources have exposed large areas of the coast to erosion and inundation. Some villages have reported shoreline retreats of 15–

20 meters over the past few decades due to loss of mangroves (Mimura and Nunn 1994).

Climate change is expected to affect the coast of Viti Levu through a rise in sea level (23—43 centimeters by 2050), higher temperatures (0.9—1.3° C by 2050), and more intense cyclones, resulting in further coastal erosion and inundation as well as a decline in coral reefs (figure 4.1). The resulting economic losses are conservatively estimated at US$8—$20 million a year by 2050.

To assess the potential impact of sea level rise on coastal erosion and inundation, four sections of Viti Levu were surveyed (see map, box 3):

- *Suva Peninsula*, representing major towns or about 5 percent of Viti Levu's coast.
- *Korotogo* on the southern coast, representing areas with major tourism settlements and coastal villages (28 percent of the coast).
- *Tuvu*, on the northwest coast, with intensive sugarcane fields and mangroves (about 47 percent of the coast).
- *Western Rewa River Delta*, representing low-lying mangrove and delta areas (10 percent of the coast).

The erosion analysis did not include Suva because the city is already heavily protected by seawalls.

Coastal Erosion. The first-order estimates of potential erosion indicate that, by 2050, Viti Levu's shoreline could retreat by 1—3 meters at Korotogo, 9—12 meters at Tuvu, and 112—251 meters at the Rewa river delta (table 4). Extrapolating these results to other areas of Viti Levu is difficult due to the variations in topography. Nevertheless, using estimates from the three sites surveyed, 1,150—2,300 hectares of coastline (2 to 4 percent of the land below 10 meters altitude) could be lost by 2050. By 2100, the proportion of

Figure 1. Likely Impact of Climate Change on Coastal Areas in Viti Levu, Fiji

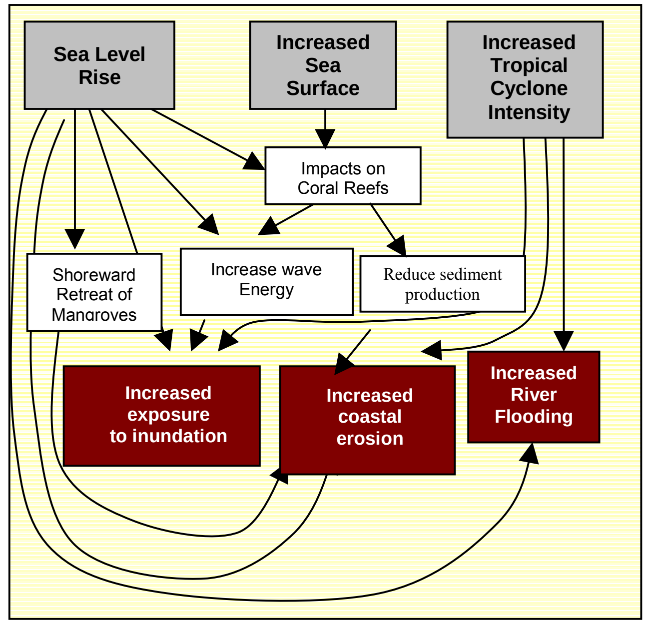


Table 4. Potential Shoreline Retreat in Viti Levu, Fiji Resulting from Sea Level Rise, 2025, 2050, and 2100

Impact	*2025*	*2050*	*2100*
Potential shoreline retreat (in meters)			
Korotogo (South coast)	1	1-3	4-9
Tuvu (Northwest coast)	7-9	9-12	13-29
Western Rewa river delta	50-112	112-251	319-646
Total land eroded (in hectares)			
Tourism areas (like Korotogo)	10-22	22-53	63-145
Sugarcane areas (like Tuvu)	188-253	253-323	362-818
Low-lying mangrove and delta (like Rewa)	390-875	875-1,955	2,485-5,036
Percentage coastal strip eroded (< 10 meters)	1-2	2-4	5-10
Total land eroded (in hectares)	588-1,150	1,150-2,331	2,910-6,000
Value of land lost to erosion (US$ million)			
Tourism areas (like Korotogo)	0.2-0.4	0.4-1.0	1.2-2.8
Sugarcane areas (like Tuvu)	4.3-5.8	5.8-7.3	8.2-18.6
Low-lying mangrove and delta (like Rewa)	8.9-19.9	19.9-44.5	56.5-114.5
Total capital value of land lost	**13.3-26.1**	**26.1-52.8**	**66.0-136.0**
Annualized losses[a]	**1.5-2.9**	**2.9-5.8**	**7.3-15.0**

Notes: Ranges reflect best guess (lower value) and worst case scenarios (higher value). Land eroded and value of land lost are extrapolated from the sites surveyed, and cover about 85 percent of the Viti Levu coast.
a. Reflects the annual value of the losses, or the capital recovery factor.
Source: Background studies to this report. For assumptions, see annex A.

Table 5. Potential Inundation of the Coast of Viti Levu, Fiji, as a Result of Sea Level Rise

		Potential Inundation			
		Physical Impact		*Inundation costs (in US$ million)*	
Sea Level Rise (m)	*Scenario equivalent to*	*Land inundated (ha)*	*Percentage of total land below 10 meters altitude*	*Annualized losses[a]*	*Incremental capital value of lost assets during an extreme event [b]*
0.2	2025 worst-case 2050 best-guess	370	0.6	0.3	14.6
0.4–0.5	2050 worst-case 2100 best-guess	3,530	5.9	0.5	30.1

[a] - Reflects the incremental annual value of the losses due to climate change, or the capital recovery factor. The costs take into consideration the impact of a 1 in 50 year storm event.

[b] - Reflects the incremental cost of capital losses during a 1 in 50 year storm event.

Note: For assumptions, see annex A.

Source: Background studies to this report

land eroded could be as high as 10 percent. Based on current values of land, the annualized economic damages due to climate change would be in the order of US$2.9 to US$5.8 million a year by 2050 (table 4). This is likely to be an underestimate, as the sites surveyed were representative of just about 85 percent of Viti Levu's coast, and the Tuvu site under-represents low-lying sugarcane fields on the north shore.

Coastal Inundation. The analysis conducted in Viti Levu indicates that sea level rise would result in relatively modest levels of inundation ─ affecting about 0.6 to 5.9 percent of coastal land below 10 meters altitude by 2050. However, in years of strong storm surge ─ such as the 1 in 50 year event shown on table 5 ─ Viti Levu could experience losses in capital assets of US$75-$90 million, some US$15-$30 million higher than what is experienced today (table 5).

Past research also suggests the following likely impacts of climate change (Solomon and Kruger 1996):

- Overtopping of shore protection in downtown Suva during extreme wave impacts (if sea level rises 25 centimeters).
- Serious flooding in large parts of Suva Point and downtown Suva even during moderate tropical cyclones (if sea level rises 100 centimeters).
- Raised water tables in low-lying areas.
- Reduced efficacy of in-ground septic and sewer pumping systems.
- Increased sedimentation of channels, shoreward retreat of mangroves, and increased susceptibility to floods in the Rewa Delta.

Mangroves and Coral Reefs. Viti Levu is estimated to have 23,500 hectares of mangroves (Watling 1995) and about 150,000 hectares of coral reefs.[3] Mangroves play key roles in trapping sediments and protecting coastal areas against erosion. They are also vital nursery grounds for coastal fisheries. The impact of sea level rise and storm surges on mangroves is expected to be mixed: some expansion might be observed due to the increased sedimentation of the coastal zone; the net impact of erosion, however, is expected to be negative.

Coral reefs are likely to be particularly affected by climate change. A rise in sea surface temperature of more than 1°C could lead to extensive coral bleaching and, if conditions persist, to coral mortality. Such bleaching events were observed during the 1997–98 El Niño episode (Wilkinson and others 1999) and more recently in Fiji, Tonga and the Solomon Islands

[3] This estimate is derived based on the total area of coral reefs in Fiji (an estimated 1 million hectares, according to WRI 1999), and Viti Levu's share of the total coastal area of Fiji (15 percent).

in April 2000. The deeper water resulting from an increase in sea level could stimulate the vertical growth of corals, but reef response is likely to lag the rise in the sea level by at least 40 years (Hopley and Kinsey 1988; Harmelin-Vivien 1994). As a result, many coral species may not be able to adapt sufficiently rapidly to a succession of bleaching events triggered by higher sea surface temperatures.

The climate change impact on coral reefs in Viti Levu is projected to cost an estimated US$5–$14 million a year by 2050 in lost fisheries, habitat and tourism value (see annex A for detailed assumptions).

B. Impact on Water Resources

Average rainfall could either increase or decrease by 2050 (see table 2). The impact will depend to a large extent on the South Pacific Convergence Zone (SPCZ). If the SPCZ moves away from Fiji and the region shifts to a more El Niño–like state, Viti Levu could experience more pronounced droughts. If the SPCZ intensifies near Fiji, average rainfall could increase.

It is also possible that Viti Levu would experience greater climate variability, with alternating floods and droughts brought on by more intense cyclones and ENSO fluctuations. The sequence of four cyclones and two droughts experienced in 1992–99 could reflect the future pattern of climate variability.

Cyclones. With an average of 1.1 cyclones a year (Pahalad and Gawander 1999), Fiji has the highest incidence of cyclones in the South Pacific. The four tropical cyclones that hit Fiji between 1992 and 1999 killed 26 people and caused damages estimated at US$115 million (Fiji Meteorological Services undated). Most of the damage occurred on Viti Levu.

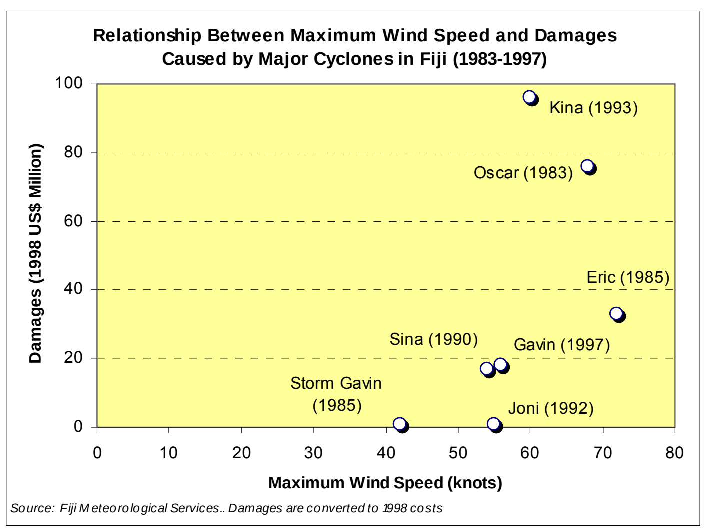
Regional studies indicate that cyclone intensity may increase by 0–20 percent in the Pacific Island region as a result of climate change (Jones and others 1999). Based on historical records of cyclone damage in Fiji and scientific theory, a 20 percent increase in maximum wind speed could result in a 44–100 percent increase in cyclone damage (figure 2).[4] Taking Fiji's average annual cyclone damage for the 1992–99 period (US$14.4 million) as a baseline and adjusting the figure to reflect the relative share

Table 6. Summary of Estimated Annual Economic Impact of Climate Change on the Coast of Viti Levu, Fiji, 2050 (millions of 1998 US$)

Category	*Annual damages*
Impact on coastal assets:	
Loss of land to erosion	2.9–5.8
Inundation of land and infrastructure	0.3–0.5
Impact on coral reefs – Loss of:	
Subsistence fisheries	0.1–2.0
Commercial coastal fisheries	0.0.5–0.8
Tourism	4.8–10.8
Habitat	0.2–0.5
Biodiversity	+
Nonuse values	+
Impact on mangroves[a]	
Impact on seagrasses	+
Total estimated damages	**>8.4–20.4**

+ Likely to have economic costs, but impact not quantified.
[a] Accounted for in the erosion analysis.
Note: For detailed assumptions, see annex A.
Source: Background reports to this study.

Figure 2. Cyclone Wind Speed and Impact in Fiji



[4] See Annex A, pages 32-34 for detailed assumptions.

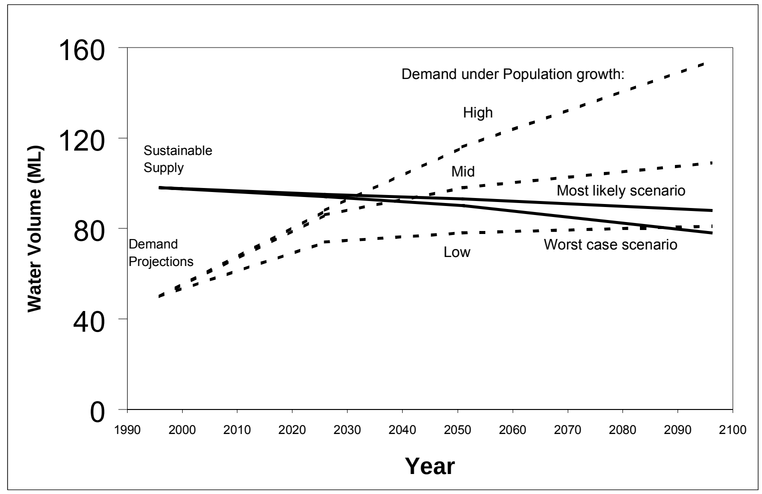
of Viti Levu in Fiji's population, the likely change in cyclone intensity could cost Viti Levu as much as US$11 million a year by 2050.

Droughts. Fiji experienced four El Niño–related droughts between 1983 and 1998. The 1997/98 event—one of the worst on record—caused damages of US$140–$165 million, equivalent to about 10 percent of Fiji's GDP. The drought affected food supplies, commercial crops, livestock, and the water supply of schools and communities. Droughts of this severity could well become the norm in the future. However, due to the scarcity of economic data on past droughts in Fiji, it is not possible to separate the effects of climate variability from those of climate change. The incremental impact of climate change on drought intensity could only be computed for crop losses (see section C). Non-agricultural impacts related to water shortages and nutrition are believed to be substantial, but could not be quantified.

Water Supply. Among the most important effects of climate change are the impacts of changes in rainfall on water supply. Models of two streams in Viti Levu—the Teidamu and Nakauvadra creeks—indicate that rainfall variations could cause a 10 percent change in water flow by 2050 and a 20 percent change by 2100. The direction of the change would depend on whether rainfall increases or decreases. For larger rivers, an increase in rainfall could lead to extensive flood damage.

Figure 3 shows the projected supply and demand for water in Nadi-Lautoka, a prime tourism and urban area of Viti Levu which serves 123,000 people. Provided the distribution system is fully efficient, the impact of a decreasing rainfall scenario would not become substantial until the second part of the century. Under a worst-case scenario and moderate population growth, demand would exceed supply by 38 percent by 2100—as compared to an 18 percent shortfall in the absence of climate change. The deficit caused by climate change is smaller than the amount currently lost to leakage and water losses (29 percent), suggesting that more aggressive leak repair would be a logical adaptation strategy.

Figure 3. Estimated Supply and Demand of Water in Western Viti Levu, under a Decreasing Rainfall Scenario



Note: Assumes future demand to be 300 l/capita/day, 25% loss, yield 98 million l/day.
Sources: JICA 1998 and background studies to this report.

Table 7. Estimated Annual Economic Impact of Climate Change on Water Resources in Viti Levu, Fiji, 2050

Category	*Annual damage (millions of 1998 US$)*
Changes in average rainfall	+
Increased cyclone intensity	0–11.1
Increased severity or frequency of El Niño related drought	++
Total	**0–11.1**

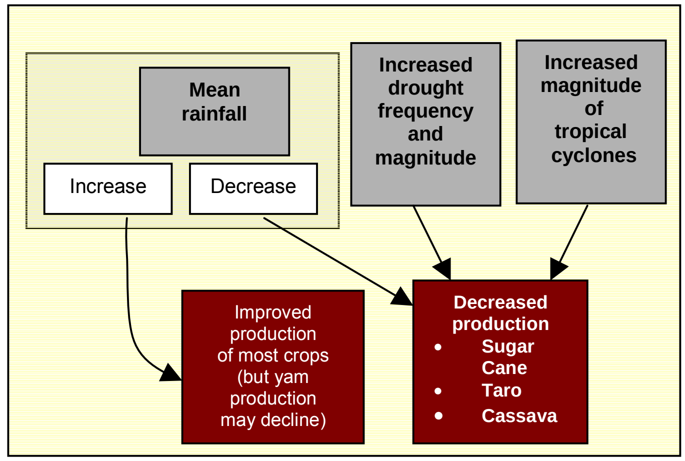
+ Likely to have significant economic costs, but impact could not be quantified.
Source: Background studies to this report.

Table 7 summarizes the quantifiable economic impacts of climate change on the water resources of Viti Levu. The estimate of US$0-$11 million reflects only the average incremental annual costs of more intense cyclones; absolute costs in disaster years could be much higher, up to US$44 million for an average cyclone. Given the uncertainties surrounding extreme events—and the difficulty associated with quantifying certain types of damages—these estimates should be viewed primarily as illustrations of what may happen.

C. Impact on Agriculture

Changes in rainfall, temperature, and climate variability will affect agricultural production in Viti Levu. An 8 percent increase in rainfall (as expected in 2050) would benefit most crops except yams, while a drier climate (an 8 percent decrease in rainfall) would hurt most crops, particularly sugarcane (figure 4).

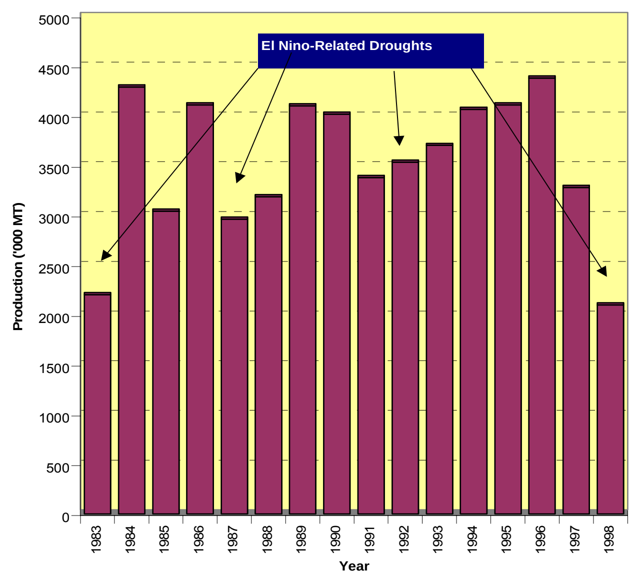
Figure 4. Likely Impacts of Climate Change on Agriculture in Viti Levu, Fiji



The impact of climate change on agriculture in Viti Levu is estimated to cost about US$14 million a year by 2050 (table 8). This estimate reflects annual average costs; damages in an El Niño year could be much greater as indicated by the 1997/98 drought, which cost Viti Levu some US$70 million in lost crops (UNDAC 1998).

The most significant economic damage would be on sugarcane, which accounts for 45 percent of Fiji's exports and is cultivated primarily in Viti Levu. But losses of traditional crops, such as yams and taro, could have a substantial effect on subsistence economies in Viti Levu.

Figure 5. Sugarcane Production in Fiji, 1983–1998



Source: Official Fiii Statistics.

Sugarcane. Sugarcane is particularly sensitive to droughts: the 1983 and 1997/98 events, for example, resulted in a 50 percent loss in production (figure 5).[5] In the future, increases in rainfall during good years may offset the impacts of warmer temperatures, with little change in sugarcane production. However, a warmer—and possibly drier—climate could lead to more intense droughts during El Niño years. Using the impact of the 1997/98 drought as representative of the intensity of future events and assuming a drought frequency similar to that observed in 1983–98 (one drought every four years), the following projections can be made for the next 25–50 years:

- Sugarcane production is likely to total 2 million metric tons—just half of output in a normal year—every four years, or 25 percent of the time (4 out of 16 years).
- Sugarcane production is likely to total 3 million metric tons—three-quarters of output in a normal year—31 percent of the time (5 out of 16 years) as a result of the residual effects of cyclones and droughts.
- Sugarcane production might total 4 million metric tons—the normal level of output—44 percent of the time (7 out of 16 years).

Under this scenario, the future production of sugarcane could average 3.2 million metric tons a year, a drop of 9 percent from the 1983–98 average level of 3.5 million metric tons. The resulting economic losses would be about US$14 million a year by 2025–50, assuming constant sugar prices.

[5] The agricultural climate change model used by the study (Plantgro) did not provide reliable scenarios for sugarcane. The impacts were thus estimated based on historical data.

Table 8. Estimated Economic Impact of Climate on Change on Agriculture in Viti Levu, Fiji, 2050

		Impact of change in average rainfall and temperature		*Impact of change in rainfall, temperature, and climate variability (ENSO)*	
Crop	*Current production (US$ thousands)*	*Economic Impact (US$ thousands)*	*Change in average yield (percent)*	*Economic Impact (US$ thousands)*	*Change in average yield (percent)*
Sugarcane	147,200	—	—	-13,700	-9
Dalo (Taro)	800	-40 – +9	-5 – +1	-111 – +6	-15 – +1
Yam	1,600	-76 – +63	-5 – +4	-164 – +54	-11 – +4
Cassava	2,100	-189 – -105	-9 – -5	-242 – -128	-12 – -6
Total				**-13,800─14,200**	

— Not available. Minus signs indicate an economic cost. Plus signs indicate an economic benefit (from rainfall increases).
Note: Ranges reflect best-guess and worst–case scenarios under two different climate change models. See annex A for assumptions used.
Source: Background studies to this report.

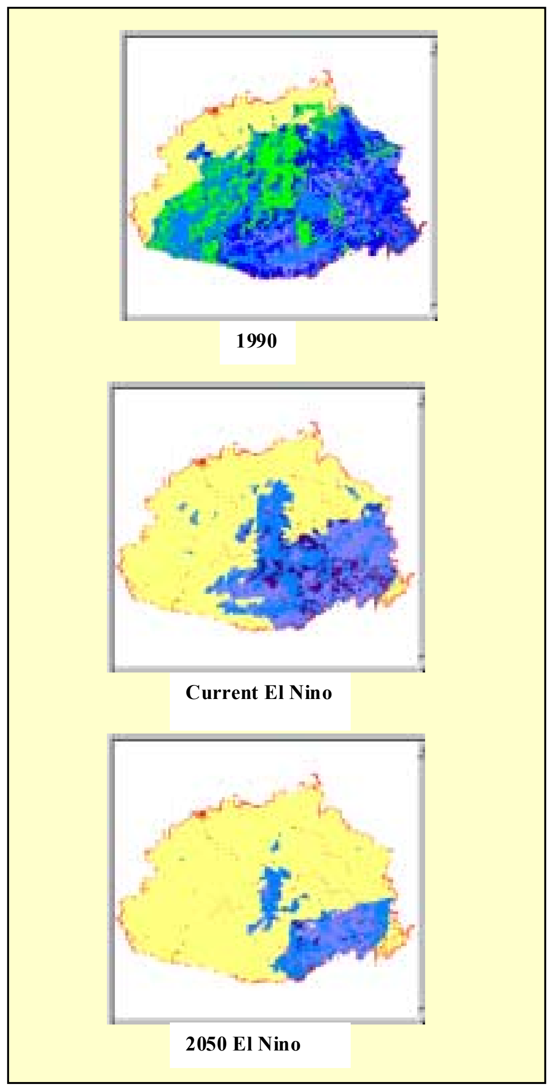
The impact on the Fijian economy is expected to be substantial, but localized. In 1997/98, for example, a 26 percent decline in sugarcane production value led to a decline in GDP of at least 1.3 percent (Ministry of Finance 1999). More importantly, Viti Levu could suffer a 50 percent drop in sugarcane production every fourth year due to stronger El Niños. These periodic droughts could well prove to be the most disruptive to the Fijian economy once preferential trade agreements are phased out.

Food Crops. By 2050 climate change may cost Viti Levu some US$70─520,000 in lost food crop production (table 8). Projected changes in average climate conditions (temperature and rainfall) would have little effect on dalo production. In El Niño years, however, the dalo yield could be reduced by 30–40 percent of current levels (figure 6).

Yam production would also remain relatively unaffected by changes in average conditions. The response to climate variability is the opposite of dalo. During El Niño events, production might be expected to remain the same or even increase. Production could decline by nearly 50 percent, however, as a result of wetter or La Niña–type conditions. This response is consistent with the traditional use of yam and *dalo* as dry and wet season crops.

Cassava output is expected to decline as a result of changes in average climate conditions, with yields falling 5─9 percent by 2050 (table 8). Productivity could also worsen with future

Figure 6. Effect of El Niño─induced Droughts on Taro Cultivation Area and Yields in Viti Levu



Note: Shaded areas show land suitable for cultivation.
Source: Background studies to this report.

climate variability, particularly under an intensified La Niña.

Yaqona (kava) showed little response to climate change or El Niño/La Niña anomalies. *Yaqona* harvests were affected by the 1997/98 drought, however. The crop is best suited to upland areas in central and southwestern Viti Levu, which are least affected by drought. This suggests that if production expands into nontraditional areas, *yaqona* could become increasingly susceptible to climate variation.

D. Impact on Public Health

Climate change could have significant impacts on public health as a result of higher temperatures (0.9–1.3° C by 2050), changes in water supply, and decline in agriculture production. The impacts could include:

- *Direct impacts on public safety*, including injuries, illness, and loss of lives due to cyclones or droughts.
- *Indirect effects*, such as increased incidence of vectorborne diseases (dengue fever and malaria), waterborne diseases (diarrhea), and toxic algae (ciguatera).
- *Nutrition-related diseases*, particularly malnutrition and food shortages during extreme events.

Public health impacts are likely to be particularly severe for the 12-20 percent of households in Fiji that live below the poverty line (UNDP and Government of Fiji 1997). Poor households are more vulnerable to the impacts of climate change because of their greater propensity for infectious diseases, limited access to medical services, substandard housing, and exposure to poor environmental conditions. Many of the poor are also landless and (particularly in urban areas) may lack access to traditional safety nets that assisted them in times of disaster. Poverty is thus both a contributor to vulnerability as well as an outcome of climate-related events.

Quantifying these impacts is difficult, yet it is also vital for the development of appropriate public health policies. Based solely on the likely increase in dengue fever and diarrheal disease, the public health impacts of climate change in Viti Levu are estimated at US$1–$6 million a year by 2050. This figure is almost certainly an underestimate, as it does not take into account the costs of fatalities, injuries, or illnesses from cyclones or droughts; the costs of nutrition-related diseases; or the indirect impact of climate change on the poor and the most vulnerable, including infants.

Public Safety. Fiji has lost more than 77 people to cyclones over the past 20 years (table 9). Injuries and illnesses caused by extreme events are also believed to be significant. Cyclone Kina alone caused 23 deaths in 1992/93, in addition to US$96 million in damages (Fiji Meteorological Services undated). An increase in cyclone intensity, as envisaged, could increase the impact on public safety by as much as 100 percent relative to what is observed today. An average cyclone in the future might come to resemble the impacts of cyclone Oscar (1983) or Eric (1985).

Dengue Fever. Dengue fever is a growing public health problem in Fiji. The most recent epidemic—which coincided with the 1997/98 drought—affected 24,000 people and left 13

Table 9. Loss of Lives and Damages from Recent Cyclones in Fiji, 1983–97

Cyclone	*Number of lives lost*	*Number of people missing*	*Damages (1998 US$ million)*
Oscar	9	—	76
Eric	25	—	33
Storm Gavin	7	3	1
Sina	—	—	17
Joni	1	—	1
Kina	23	—	96
Gavin	12	6	18
Total	**77**	**9**	**242**

Source: Fiji Meteorological Services.

dead, at a cost of US$3–$6 million (Koroivueta, personal communication; Basu and others 1999).

Climate change is expected to cause significant increases in the frequency, severity and spatial distribution of dengue fever epidemics. Higher temperatures would increase the biting rate of mosquitoes and decrease the incubation period of the dengue virus.

In 1990, 53 percent of Viti Levu was at low risk of a dengue epidemic. By 2100 less than 21 percent of the island, all in the interior highlands, may remain at low risk. Under the worst-case scenario, up to 45 percent of the island could be at high or extreme risk of a dengue fever epidemic (table 10). The economic impact would average about US$1-$6 million a year by 2050 (table 11).

Climate change could also result in:

- A 20–30 percent increase in the number of cases of dengue fever by 2050 and as much as a 100 percent increase by 2100 (under a worst-case scenario).
- Dengue fever becoming endemic (that is, occurring all the time rather than in epidemics).
- A change in seasonality, so that dengue fever outbreaks could occur in any month.
- The emergence of more severe forms of the disease, such as dengue hemorrhagic fever and dengue shock syndrome, resulting in higher fatality rates.

Diarrheal Disease. Diarrheal disease is likely to become more common in a warmer and wetter world. More intense droughts and cyclones could also increase the incidence of diarrhea by disrupting water supplies and sanitation systems.

Quantitative analysis indicates that a 1^{o}C increase in temperature could result in at least 100 additional reports of infant diarrhea a month. Since the actual incidence of diarrhea is at least 10 times the incidence of reported cases, a 1^{o}C rise in temperature, as expected by 2050, could lead to 1,000 additional cases of infant diarrhea a month. These results can be used, with lower levels of confidence, to estimate the potential impacts of diarrhea in children and adults. The economic costs of climate change on diarrheal disease are estimated to average US$300,000–$600,000 a year by 2050 (table

Table 10. Potential Impact of Climate Change on Dengue Fever in Viti Levu, Fiji

Likely changes	*Baseline (1990)*	*2025*	*2050*	*2100*
Estimated change in number of cases (percentage change)	0%	10%	20–30%	40–100%
Epidemic potential in Viti Levu (in percentage of land area) [a]				
Low risk	53%	38–39%	25–31%	7–21%
Medium risk	47%	61–62%	69–72%	48–72%
High risk	—	—	0–3%	7–41%
Extreme risk	—	—	—	0–4%
Seasonality				
Nadi	Seasonal	Seasonal	Seasonal to all year	All year
Suva	Seasonal	Seasonal	Seasonal to extended season	Prolonged season to all year
Frequency of epidemics	1 in 10 years	———	Likely increase	———
Severity of strains	———	———	Likely increase	———

[a] - Epidemic potential is an index that reflects the efficiency of transmission in a particular area.
Note: Ranges represent the most likely and worst-case scenarios in the CSIRO9M2 General Circulation Model.
Source: Background studies to this report. For assumptions, see annex A.

11).

Other Public Health Impacts. Fiji is presently malaria-free: the strict border controls and quarantine requirements have so far been successful in keeping the malaria vector *(Anopheles)* away. Climate change could increase the risk of malaria, though modeling results indicate that the epidemic risks in Fiji due to climate change are small.

Climate change could also increase the risk of filariasis. However, Fiji has started an intensive program to control filariasis and is expected to eradicate the disease in 5–10 years (Koroivueta, personal communication).

Nutrition-Related Diseases. More intense cyclones and droughts are likely to increase the incidence of nutrition-related diseases, as subsistence crops and fisheries are affected. The impacts may be similar to those experienced during the 1987 and 1997/98 droughts, when milk production fell 50 percent and some US$18 million in food and water rations had to be distributed (UNDAC 1998). Up to 90 percent of the population in western Viti Levu required emergency food and water rations. Loss of agriculture income and failure of household gardens also caused protein, vitamin, and micro-nutrient deficiency, particularly among young children and the poor.

Table 11. Estimated Annual Economic Impact of Climate Change on Public Health in Viti Levu, Fiji, 2025–2100 (millions of 1998 US$)

Event	*2025*	*2050*	*2100*
Cyclones and droughts[a]	—Likely to be substantial—		
Dengue fever	0.3–2.3	0.5–5.5	0.7–15.9
Diarrheal diseases	0.2	0.3–0.6	0.6–2.2
Nutriton-related illnesses	+	+	+
Total estimated costs	**0.5–2.5**	**0.8–6.1**	**1.3–18.1**

— Not available.
\+ No quantifiable data available, but damages are likely to be substantial.
a. The effect of cyclones and droughts on health could not be calculated, though the overall impact of cyclones was taken into account in section B.
Note: For assumptions, see annex A.
Source: Background studies to this report.

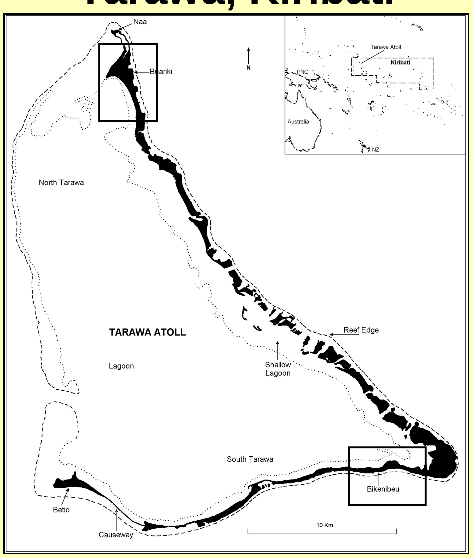
Chapter 4
Impact of Climate Change on Low Islands
The Tarawa Atoll, Kiribati

Like most atolls, Tarawa (30 km^2) is very vulnerable to sea level rise. Most of the land is less than 3 meters above sea level, with an average width of only 430–450 meters (Lands and Survey Division undated). While Tarawa lies outside the main cyclone belt, it is susceptible to storm surges and to droughts, particularly during La Niña events.

The population density of the atoll is unevenly distributed, with South Tarawa (the capital) approaching 5,500 people per square kilometer, while North Tarawa remains sparsely populated, with less than 50 people per square kilometer. As available land in South Tarawa becomes scarcer, development in North Tarawa is expected to accelerate.

Box 4. Tarawa at a Glance

Tarawa, Kiribati



Climate
- Temperature: 26–32°C (average 31°C).
- Average rainfall in central Tarawa: 2,749 milimeters.

Major influences:
- Intertropical Convergence Zone.
- South Pacific Convergence Zone.
- El Niño Southern Oscillation (ENSO).

Extreme events:
- Droughts (often associated with ENSO).
- Tropical cyclones rarely affect Kiribati (but storm surges do).

Population:
- Population of Kiribati: 77,658 in 1995 (35,000, or 45% in Tarawa)
- Average annual growth rate: 1.4% (3% in South Tarawa).
- Population Density: 250/km^2 (Gilbert Islands); 1,800/km^2 (South Tarawa).
- Growing urbanization.

Economy (Kiribati):
- GDP (1998): US$47 million.
- Average annual growth: 4.7% (1990–96).
- Dominated by public sector.
- Significant exports: copra, fish.
- Subsistence agriculture (coconut, taro, breafruit, pandanus) and fisheries vital.

Future Population Trends

Increasing population density:
- Very high population density on South Tarawa.
- Accelerated population growth in North Tarawa.

Implications:
- Denser urban structures.
- Industrial and commercial development.
- Change from traditional housing styles and materials.
- Increase in proportion of squatter housing.
- Increase in coastal infrastructure.

Future Economic Trends
- Continued dependence on natural resources.
- Agriculture will continue to be important in subsistence production, and will remain a small export earner.
- Cash economy will become increasingly important, but subsistence economy will remain significant.
- Continued dependence on foreign aid.

Future Environmental Trends
- Environmental degradation in densely populated areas.
- Continued degradation and irreversible damage to mangroves and coral reefs.
- Increased problems of waste disposal (sewage, chemical, and solid waste pollution).

Future Sociocultural Trends
- Increasing role of cash economy.
- Changes in food preferences toward imported foods.
- Increased noncommunicable diseases associated with nutritional and lifestyle changes.
- Increased poverty and social problems in urban areas.

Tarawa is already becoming increasingly vulnerable to climate change due to high population growth rates and in-migration from outer islands, accelerated development, shoreline erosion, and rising environmental degradation. In such a fragile and crowded environment, even small changes can have a large impact. Socioeconomic trends point to a continuing rise in the atoll's vulnerability in the future (box 4).

By 2050, under the climate change scenarios shown in table 2, Tarawa could experience annual damages of about US$8—$16 million (table 12). This estimate takes into account only the potential impacts of climate change on coastal areas (US$7–$13 million a year) and water resources (US$1–$3 million a year). The cost of several other important impacts—such as loss of agriculture crops and effects on public health—could not be estimated because of insufficient data. Indications suggest that these damages may be substantial.

Table 12. Estimated Annual Economic Impacts of Climate Change on Tarawa, Kiribati, 2050 (millions of 1998 US$)

Impact	*Annual damages*[a]	*Level of Certainty*	*Likely cost of an extreme event*[b]
Impact on coastal areas			
Loss of land to erosion	0.1—0.3	Low	—
Loss of land and infrastructure to inundation	7—12	Low	210-430
Loss of coral reefs and related services	0.2—0.5	Very Low	(storm surge)
Impact on water resources			
Replacement of potable water supply due to change in precipitation, sea level rise, and inundation	1—3	Low	—
Impact on agriculture			
Agriculture Output Loss	+	Low	—
Impact on public health			
Increased incidence of diarrheal disease	++	Low	—
Increased incidence of dengue fever	+	Low	—
Increased incidence of ciguatera		Low	—
Impact of climate change on public safety and on the poor	+	Very Low	—
Potential increase in fatalities due to inundation, and water-borne or vector-borne diseases	+	Low	—
Total estimated damages	**>8—16+**		—

+ Likely to have economic costs, but impact not quantified. — Not available.
[a] Reflects incremental average annual costs of climate change, equivalent here to the capital recovery cost factor of land and infrastructure damaged by inundation, using a discount rate of 10 percent and a 10— year period.
[b] Reflects financial damages to land and infrastructure caused by sea level rise and storm surge during a 1 in 14— year storm event. For detailed assumptions, see annex A.
Source: Background reports to this study.

These costs reflect annual average losses due to climate change. In years of strong storm surge, Tarawa could face capital losses of up to US$430 million in land and infrastructure assets destroyed by inundation. Relocation of communities might be needed if the loss of land and freshwater supplies become critical.

Climate change is thus likely to place a substantial burden on the people and economy of Kiribati. The projected losses could be catastrophic for a country with a 1998 GDP of only US$47 million. These losses, however, assume no adaptation. Communities would likely adapt to sea level rise by elevating their houses or moving further inland, particularly if the changes were gradual. Nevertheless, sea level rise could profoundly affect the economy of Kiribati by inundating the causeways that now link the islets of Tarawa, thus disrupting socio-economic links. Much of the impact of climate change will ultimately depend on the extent to which proactive adaptation measures are adopted.

A. Impact on Coastal Areas

Climate change is likely to affect Tarawa's coast through shoreline displacement resulting from the rise in sea level (by 0.2–0.4 meters by 2050), through inundation and storm surge, and through coastal erosion due to the effect of increases in sea surface temperature and sea level on coral reefs.

To model the impact of coastal erosion and inundation, two representative sections of the Tarawa coast were selected: the islands of Buariki and Naa in North Tarawa and Bikenibeu in South Tarawa (see map in box 4). These areas represent about 20 percent of the area of North Tarawa and about 7 percent of the area of South Tarawa.

Coastal Erosion. Models of shoreline displacement indicate that while all of the atoll's islands are undergoing coastal erosion, the loss of land due to sea level rise is likely to be relatively small—a maximum of 3.2 percent of land by 2100 for Buariki and 3.9 percent for Bikenibeu, leading to economic damages averaging US$0.1-$0.3 million a year by 2050. Higher rates of erosion could arise if sediment supply decreases, which may happen if coral reefs are weakened by climate change. Even these small changes, however, could cause significant impacts given the atoll's narrow width and population concentration.

The islands are expected to become narrower and higher, with Buariki facing a shoreline displacement of 30 percent of the island width. The frequent overwash would result in a build-up of sediments in the center of the islands. These sediments would have to be removed, or infrastructure would have to be displaced.

Coastal Inundation. As a result of ENSO events, Tarawa already experiences significant natural fluctuations of about 0.5 meters in sea level. These fluctuations will affect the inundation potential of the atoll, particularly when combined with storm surges and the projected increase in sea level.

The coastal inundation impacts were modeled by raising the mean high water spring level (the maximum water level reached during spring

Table 13. Likely Impact on Buariki and Bikenibeu, Tarawa, Kiribati of Inundation Caused by Sea Level Rise, 2025, 2050 and 2100

		Buariki			*Bikenibeu*		
			Projected losses			*Projected losses*	
Projected rise in sea level (meters)	*Scenario equivalent to*	*Percentage of land area affected*	*Structures (number)*	*Roads (kilometers)*	*Percentage of land area affected*	*Structures (number)*	*Roads (kilometers)*
0.2	2025 worst-case 2050 best-guess	18%	196 (59%)	6.55 (77%)	0%	0	0
0.4-0.5	2000 baseline + storm surge 2025 best-guess + storm surge 2050 worst-case 2100 best-guess	30%	213 (64%)	6.55 (77%)	2%	34 (2%)	0
	2050 best-guess + storm surge	55%	229(69%)	7.5 (89%)	25%	423(27%)	1.3(29%)
1.0	2050 worst-case +storm surge 2100 best-guess + storm surge 2100 worst-case	80%	245 (74%)	8.5 (100%)	54%	986 (63%)	2.83(66%)
1.5	2100 worst-case + storm surge	85%	316 (95%)	8.5 (100%)	80%	1302 (84%)	4.36 (100%)

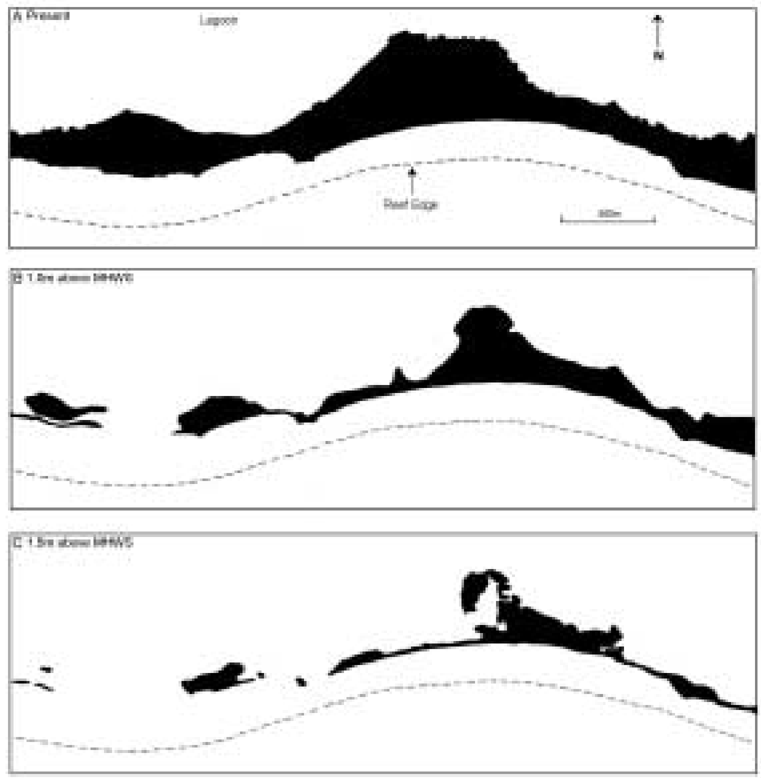
Notes: Storm surges are based on 1 in 14-year event (Solomon 1997).
Source: Background studies to this report.

tides) by the projected increase in sea level. The sea level rise scenarios were also combined with the effects of storm surges likely to occur once every 14 years (Solomon 1997).

The results indicate that under a best-guess scenario, 18 percent of Buariki could be inundated by 2050 (table 13). By 2100 up to 30 percent of Buariki could be inundated. The impact on Bikenibeu would be relatively minor (2 percent inundation). Storm surges, however, could increase damages significantly, with up to 80 percent of Buariki and 54 percent of Bikenibeu inundated by 2050.

Projected losses in infrastructure and roads could be substantial. Under a worst-case scenario, the village of Buariki could be inundated by 2050, as could 59 percent of the structures and 77 percent of the roads. In Bikenibeu, significant impact on infrastructure is not be expected to occur until 2100 under a worst-case scenario, but it could then become substantial, with 66–100 percent of all roads lost under the combined effects of storm surge and sea level rise (figure 7).

Figure 7. Projected Inundation of Bikenibeu Island Tarawa, Kiribati under Worst-Case Scenario



A: Present status
B: Residual island under a worst case scenario, 2100;
C: Residual island under worst case scenario and storm surge, 2100
Source: Background studies to this report.

The projected loss of land and structures is based on existing infrastructure. Actual losses in 2025 and 2050 could be substantially higher, particularly if Tarawa were affected by larger storm surges (such as one in 50-100 year events). The damage could be moderated if population growth was contained and redistributed to less urbanized areas.

Extrapolating the losses for Buairiki and Bikenibeu to the rest of North and South Tarawa, the projected financial losses of land and structure assets in Tarawa could average US$7–$12 million a year by 2050 (table 14). During years of actual storm surges, Tarawa could experience losses of capital assets approaching US$210 to $430 million.

The analysis assumes the loss of all land and structures affected by inundation and storm surge, which may overly pessimistic. However, the rise in sea level will amount to a condition of "permanent inundation" which, combined with the existing standard of housing in Tarawa, is likely to result in the loss of structures unless adaptive action is undertaken. Other factors in the analysis—such as more severe storms and increases in their frequency—are likely to have been underestimated.

Mangroves and Coral Reefs. Tarawa has lost some 70 percent of its mangroves since the 1940s, and only 57 hectares remain (Metz 1996). Hence the impact of sea level rise is expected to be relatively minor.

Healthy coral reefs may respond to increases in sea level by growing vertically. In fact, the historical accretion rate of the Tarawa reef flat (8 milimeters a year) exceeds the rate of

Table 14. Estimated Economic Impact of Inundation Caused by Sea Level Rise in Tarawa, Kiribati, 2050 and 2100 (millions of 1998 US$)

Scenario equivalent to	*Potential Inundation Costs (in US$ million)*	
	Annualized losses[a]	*Capital value of lost assets during a storm surge event*[b]
2050 best-guess	6.6	158.0
2050 worst-case 2100 best-guess	12.4	374.6
2100 worst-case	69.7	497.3

[a] - Reflects the annual value of the losses, or the capital recovery factor. The costs take into consideration the incremental impact of a 1 in 14 year storm event.
[b] - Reflects the incremental cost of capital losses during a 1 in 14 year storm event.
Note: For assumptions, see annex A.
Source: Background studies to this report

projected sea level rise (Marshall and Jacobsen 1985). However, many corals may not be able to adapt to warmer sea surface temperatures and increased concentration of carbon dioxide in the atmosphere, both of which inhibit coral growth. As stated previously, vertical coral growth is likely to lag the increase in the sea level by at least 40 years. This could create a high-energy window, allowing waves of increasing strength to reach the shore. In addition, while the reef is growing vertically the amount of sediment for island building could decline.

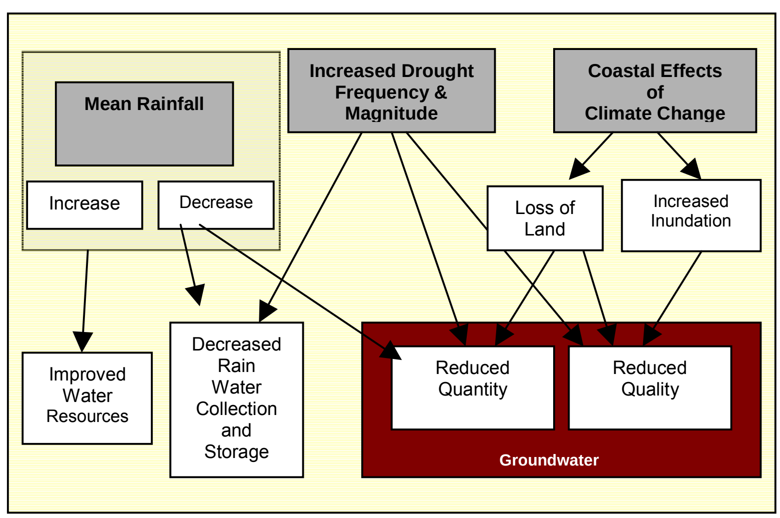
For heavily damaged reefs affected by increased bleaching events a number of consequences are likely. These include further depletion of reef fisheries, failure of the reef to act as an effective buffer of wave energy, and increased island instability as sediment resources decline.

The economic losses of coral reef degradation attributed to climate change would be in the order of US$200,000–$500,000 a year primarily as a result of lost fish production (table 12). This estimate does not include loss of coastal protection, which was reflected in the inundation analysis, or other important reef functions that could not be quantified.

B. Impact on Water Resources

Climate change is likely to affect the water resources of Tarawa through variations in rainfall, evapo-transpiration (caused by a rise in temperatures), increases in the sea level, and extreme events (figure 8). Average rainfall is expected to either decrease by 8–11 percent, or increase by 5–7 percent by 2050 (most models predict an increase). The economic losses resulting from these changes are estimated at about US$1–3 million a year (in 1998 dollars) by 2050.

Figure 8. Likely Impact of Climate Change on Water Resources in Tarawa, Kiribati



Tarawa receives less rainfall than surrounding atolls. The population relies primarily on groundwater resources, complemented by rainfall collected from roofs and desalinated water (a desalination plant has been operational since 1999). Population growth and economic development are likely to place considerable pressure on these resources over the next century.

Water Supply. Models of climate change impact on Tarawa's main groundwater supply (Bonriki) indicate the following:

- *Changes in rainfall.* By 2050 a 10 percent decline in rainfall could cause a 14 percent reduction in groundwater recharge. If, by contrast, average rainfall increased by 7 percent, the groundwater recharge would increase 5.5 percent.

- *Changes in evapo-transpiration.* Evapo-transpiration would increase if the climate warmed, but its effects on groundwater recharge would be much milder than the effect of changes in rainfall. A 10 percent increase in annual evapo-transpiration could result in a 6 percent decline in groundwater recharge.

- *Changes in sea level.* A rise in sea level of 0.4 meters (the worst-case scenario in 2050) would have little effect on the groundwater supply and could even raise its volume, as the groundwater table (the top of the freshwater lens) would tend to rise while its base remained relatively unaffected. However, if the width of the islands were reduced by inundation—which is likely—the thickness of the groundwater could decline 29 percent.

The combined effect of these impacts is shown in table 15. By 2050 if rainfall declines by 10 percent, the sea level rises by 0.4 meters, and the islands' width is reduced by inundation, the thickness of the groundwater could decline as much as 38 percent. The resulting economic impacts, extrapolating for the Tarawa atoll, would be on the order of US$1.4–$2.7 million a year. If, by contrast, average rainfall increased in the future, the annual economic costs would amount to US$0.7–$1.3 million.

The value of the groundwater was estimated based on what it would cost to replace it by alternative sources, either through expansion into alternative groundwater sources or through desalination. A third alternative source—

Table 15. Estimated Annual Economic Costs of Climate Change on Water Resources in Tarawa, Kiribati, 2050 (millions of 1998 US$)

Climate change scenario	*Percentage change in groundwater thickness*[a]	*Economic costs of substitution by alternative sources*	
		Expansion into new groundwater sources	*Desalination*
Current sea level, 7% increase in rainfall	+5.5	+0.2	+0.4
Current sea level, 10% reduction in rainfall	-14.0	-0.5	-1.0
0.2 meter sea level rise, current rainfall	-0.9	-0.0	-0.1
0.4 meter sea level rise, current rainfall	+2.0	+0.1	+0.1
0.4 meter sea level rise, 10% reduction in rainfall	-12.0	-0.4	-0.8
0.4 meter sea level rise, current rainfall, reduced island width	-29.0	-1.0	-2.0
0.4 meter sea level rise, 7% increase in rainfall, reduced island width	-19.0	-0.7	-1.3
0.4 meter sea level rise, 10% reduction in rainfall, reduced island width	-38.0	-1.4	-2.7
Total costs (under a reduced rainfall scenario)		-1.4 to -2.7	
Total costs (under an increased rainfall scenario)		-0.7 to -1.3	
Total costs		**-0.7 to -2.7**	

a. Reduction in thickness was modeled for the Bonriki freshwater lens in Tarawa and may not apply to other groundwater sources.
Note: Shaded areas indicate the most relevant scenarios of those shown in the table. See annex A for detailed assumptions.
Source: ADB 1996 and background studies to this report.

rainfall collectors—could be less costly but may not be able to compensate for the shortages.

Extreme Events. The effects of extreme events on the water supply of Tarawa could be significant. Currently, high sea levels during El Niño years can lead to seawater contamination of freshwater lenses. Recovery is generally rapid due to the accompanying high rainfall.[6] The higher overtopping and inundation that may occur in the future, however, could considerably increase the risks of saline contamination.

The impacts of droughts could also be substantial, though difficult to quantify. The 1998–99 drought, for example, dried rainwater tanks in South Tarawa and caused shallow groundwater reserves to become brackish (White and others 1999). When rain arrived in March and April 1999, it contaminated groundwater wells, causing a high incidence of diarrhea.

C. Impact on Agriculture

Many of the crops grown in Kiribati are affected by changes in climate. Production of copra—the main cash crop for about 55 percent of Kiribati's population—is sensitive to rainfall, as coconuts require annual rainfall of at least 1,000–1,500 millimeters. *Te babai* (giant taro) is extremely sensitive to reductions in groundwater. *Te babai* pits are also prone to saltwater intrusion as a result of storm surges and overwash.

Climate change is most likely to affect agricultural crops through changes in rainfall. If wetter conditions prevail, production of water-sensitive crops—coconut, breadfruit, and *te babai*—is likely to increase. If rainfall decreases, coconut and *te babai* production will likely decline.

Climate variability may also affect agricultural production, especially during La Niña years, when droughts are most likely to occur.

[6] El Niño increases rainfall in Kiribati. La Niña events are generally accompanied by droughts.

Sea level rise could affect agriculture crops in two major ways: first, through saltwater intrusion, which would affect *te babai* production in particular. Second, through loss of coastal land due to inundation, which could reduce production of copra, breadfruit, and pandanus. Estimates of the cost of damage could not be made due to data and time constraints.

D. Impact on Public Health

Climate change could exacerbate public health problems in Tarawa. The incidence of ciguatera poisoning, diarrheal disease, malnutrition, and vectorborne diseases, such as dengue fever, is likely to rise as a result of increased temperatures and changes in rainfall.

Dengue Fever. There have been four known outbreaks of dengue fever in Kiribati, two during the 1970s and two during the 1980s. South Tarawa is at a relatively high risk of dengue fever epidemics due to a combination of crowded urban areas, ideal climate conditions for the vector (average temperatures of 31°C and rainfall of 500 millimeters a month), the presence of an international airport, and the proliferation of discarded empty bottles and used tires.

A simple model suggests that the risk of dengue fever will increase in the future as a result of climate change, with the epidemic potential—an index measuring the efficiency of disease transmission—expected to increase 22–33 percent by 2050 (table 16). Most of South Tarawa's population would be exposed in the event of an epidemic. However, while future epidemics could expand faster, the number of cases would probably not increase from current levels. The increased prevalence of all dengue-virus serotypes worldwide could also lead to a higher incidence of severe forms of dengue fever—in particular dengue hemorrhagic fever and dengue shock syndrome, which can be fatal.

Ciguatera Poisoning. Kiribati has one of the highest rates of ciguatera poisoning in the Pacific (Lewis and Ruff 1993). The disease is contracted by consuming reef fish that have been contaminated by ciguatoxins.

A recent study found a statistically significant relation between sea surface temperatures and the reported incidence of ciguatera fish poisoning in Kiribati (Hales and others 1999). This relation was used to model the projected increases in ciguatera poisoning (table 16). The model shows that a rise in temperatures is expected to increase the incidence of ciguatera poisoning from 35–70 per thousand people in 1990 to about 160–430 per thousand by 2050.

These results should be interpreted cautiously, as the model is based on many uncertainties and limited data. The overall impact of climate change on ciguatera should perhaps be measured not in terms of incidence rates but in terms of how people respond to the increased risk (Ruff and Lewis 1997). This may include changes in diets, decreased protein intake, increased household expenditures to obtain substitute proteins, and loss of revenue from reef fisheries. In addition, reef disturbance has been linked to ciguatera outbreaks (Ruff, 1989; Lewis 1992), suggesting that improved management of coastal areas would be an important adaptation strategy.

Diarrheal Disease. Increased rainfall would likely result in a reduction in the overall rate of diarrhea due to improved water quality and availability (though flooding may also lead to groundwater contamination). Decreased rainfall—particularly if it resulted in an increase in droughts—would increase the incidence of diarrhea, as water shortages exacerbate sanitation problems. The projected rise in temperature may increase the incidence of diarrhea, primarily by increasing the likelihood of spoiled or contaminated food. Sea level rise could also increase the incidence of diarrhea by decreasing the size of the freshwater lens, exacerbating overcrowding conditions, and disrupting sanitation and water supply.

Tarawa has experienced cholera outbreaks in the past. It is possible that increased temperatures may enhance the pathway of cholera transmission through the high level sewage contamination in Tarawa's coastal waters.

Indirect Public Health Effects. The indirect public health effects of climate change could be far-reaching. They could include increases in malnutrition due to losses of subsistence agriculture and fisheries; deterioration in standards of living due to impacts on primary sectors; loss of land and infrastructure, leading to increased crowding and land shortages; and the immense economic, social, and cultural impacts associated with population relocation if it was required as a result of inundation or water shortages. These diffuse effects could well prove to be the most important impacts of climate change on the public health of the atoll.

Table 16. Estimated Increases in Dengue Fever Epidemic Potential and Incidence of Ciguatera Poisoning in Kiribati as a Result of Climate Change, 2025, 2050, 2100

Impact	*Baseline 1990*	*2025*	*2050*	*2100*
Dengue fever				
Projected epidemic potential[a]	0.18	0.20	0.22–0.24	0.25–0.36
Percentage change from 1990	n.a.	11	22–33	39–100
Ciguatera poisoning incidence				
(per thousand population)	35–70	105–240	160–430	245–1,010

[a] - The epidemic potential index measures the efficiency of disease transmission. A value of 0.2 or above indicates a high epidemic potential.

n.a. – Not applicable.

Note: Ranges indicate best-guess and worst-case scenarios. Changes in atmospheric temperatures were used as a surrogate for sea surface temperature in forecasting the incidence of ciguatera. The model assumed a reporting case rate of 10–20 percent.

Source: Background studies to this report; Hales and others (1999).

Chapter 5
Impact of Climate Change on Regional Tuna Fisheries

Climate change is likely to affect regional tuna fisheries in two major ways: by raising average ocean surface temperatures to levels currently experienced during medium-intensity El Niños (Timmermann and others 1999) and by increasing year-to-year climate variability. Such change may not have an equivalent today. The impacts are likely to be pervasive, affecting the distribution, abundance, and catchability of tuna fisheries (box 5):

- *Decline in primary productivity.* Primary productivity in the central and eastern Pacific would decline due to the increased stratification between warmer surface waters and colder deeper water (and consequent reduction in upwelling). Productivity in the western Pacific could rise.

- *Decline in tuna abundance*. The decrease in upwelling would lead to a decline in the bigeye and adult yellowfin population (the species targeted by the longline fleet). The abundance of purse seine–caught skipjack and juvenile yellowfin is not expected to be affected.

- *Increased pressure on longline fishing*. Given the continued high demand for sashimi and the possibility that prices may rise with a decline in catches, it is likely that longline fishing pressure on adult yellowfin tuna will increase to compensate for

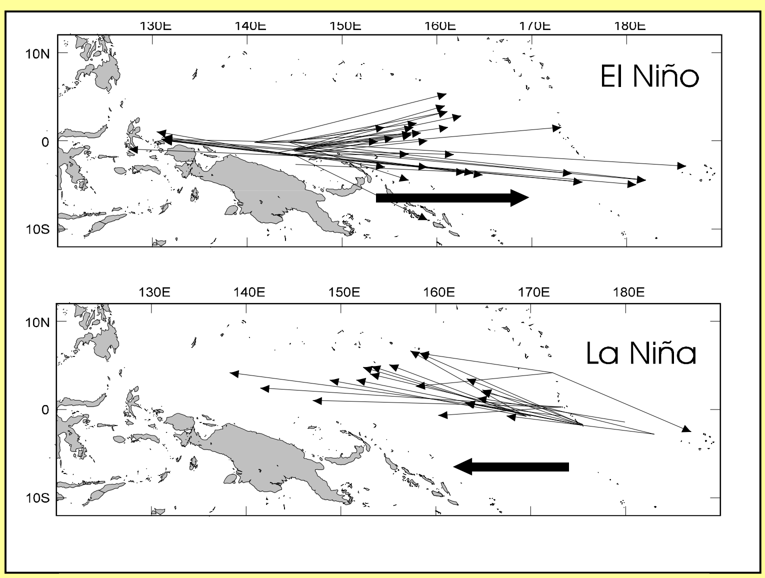
Box 5. Tuna Fisheries and Climate Variability

The distribution of tuna fisheries is affected by the location of the Western Pacific Warm Pool (WPWP), an area of warm surface waters (more than 28°C) that produces virtually all of the tuna caught by purse seine (a fishing method used to collect surface tuna for canning), while catch of tuna by longline (a method used to collect deep water tuna for the *sashimi* market) is more widely distributed over the whole tropical and sub-tropical Ocean. By itself the WPWP is nutrient poor. By contrast, the colder waters of the central equatorial Pacific generate an upwelling of colder, nutrient-rich waters. These two ocean areas meet in a zonal band called the "cold tongue," the primary productivity of which is strongly affected by ENSO variability. During El Niño years the WPWP can extend eastward into the central Pacific by nearly 4,000 kilometers.

Tuna fisheries, particularly skipjack fisheries, move with the WPWP. During El Niño years, countries in the Central Pacific, such as Kiribati and Samoa, experience higher purse seine catches. Countries in the Western Pacific, such as the Solomon Islands and Marshall Islands, enjoy higher catches during La Niña years.

In addition to this geographical displacement, El Niño also influences the abundance of tuna. El Niño years tend to result in higher than average abundance of skipjack a few months later, while La Niña years generally result in higher abundance of adult albacore in the subsequent years. Yellowfin and bigeye abundance are also likely influenced by the ENSO variability. However, as these species are more widely distributed and have extended spawning grounds in both east and west tropical Pacific, the relationship with ENSO is more complex.

Movement of Tagged Skipjack Tuna in the Central and Western Pacific



Source: Lehodey et al. (1997); Lehodey (in preparation) the decline in adult bigeye abundance, leading to unsustainable exploitation if the fishery is not well managed.

- *Spatial redistribution of tuna resources*. The warming of surface waters and the decline in primary productivity in the central and eastern Pacific would result in a redistribution of tuna resources to higher latitudes (such as Japan) and toward the western equatorial Pacific.

- *Increase in climate variability*. Climate change could increase the intensity and frequency of annual climate variability (Jones and others 1999). The likely impact would be an increase in the annual fluctuations of the spatial distribution and abundance of tuna. It is possible that more frequent cold events (such as strong La Niña episodes) could compensate for the decrease in productivity under an El Niño mean state. In addition, even though it is difficult to know what a strong El Niño would mean in the future (box 6), it is likely that such an extreme event could lead to a dramatic decline in productivity in the eastern Pacific.

Box 6. The Likely Future Climate

Likely future climate	***Correspondence with present climate***
Mean state	Moderate El Niño
Moderate El Niño event	Strong El Niño event
Strong El Niño event	Unknown, extremely warm event
Moderate La Niña	Current mean state
Strong La Niña	Moderate La Niña

- *Higher impact on domestic fleets.* Distant water fishing fleets should be able to adapt to changes in the spatial distribution and abundance in tuna stocks. But domestic fleets would be vulnerable to fluctuations of tuna fisheries in their Exclusive Economic Zones. Countries in the central Pacific, such as Kiribati, are likely to be more adversely affected than those in the west. Kiribati's high dependence on tuna fisheries renders it the more vulnerable to these changes, and points to the need to closely collaborate with other coastal states in minimizing the impact of year-to-year fluctuations.

Chapter 6
Toward Adaptation: Moderating the Impact of Climate Change

The economic costs of climate change estimated in chapters 3 and 4 assume no adaptation. In practice, Pacific Island governments and communities could help offset these costs by undertaking adaptation measures. The question is determining which adaptation measures are best in the face of uncertain future impacts.

There is little Pacific Islands can do to prevent climate change (box 7). At the same time, Pacific Island governments cannot afford to ignore the problem. Adapting to climate change may soon become an economic and political imperative.

Box 7. Can Climate Change Be Stopped?

Carbon dioxide in the earth's atmosphere is expected to double by 2050-2100, leading to changes in temperature, rainfall, and sea level rise.

Could the climate then stabilize? It does not appear so. Even if all the major countries signed the Kyoto Protocol and succeeded in stabilizing emissions by 2010, the doubling of carbon dioxide concentration in the atmosphere may only be delayed by a decade or so. Stabilizing emissions does not yet mean stabilizing the concentration of greenhouse gases in the atmosphere. Furthermore, after the concentrations stabilize, the rise in sea level could continue for several centuries (Church and Gregory 2000). Adapting to these changes will therefore be of paramount importance to countries on the receiving end of climate change.

A. The Need for Immediate Action

The development choices made by Pacific Island governments today will have a profound impact on the future vulnerability of the islands and on the magnitude of climate change impacts.

One of the most compelling arguments for acting now is the rising impact of extreme weather events in the Pacific. Even those who argue that climate change may never happen cannot dispute the urgency of reducing the islands' vulnerability against severe climate events. The recent drought and the sequence of cyclones which affected many Pacific Islands during the 1990s attest to an increasing exposure that will, sooner or later, put mounting public pressure on governments and politicians to act. No less compelling is the fact that under an increasing globalized economy, those countries which invest early on adaptation—and, in the process improve the quality of life and reduce investment risks—are likely to hold a competitive advantage for foreign investment. As measures to reduce vulnerability are also among the most effective in adapting to climate change, acting now to reduce current vulnerability will also prepare the Pacific Islands for the long-term effects of climate change.

Another reason for acting now is that failure to do so may result in a loss of opportunities that may not exist in the future. Coral reefs, for example, may not be able to recover from bleaching events if they are weakened by threats such as pollution and mining.

Finally, adaptation strategies may require several decades to be discussed and implemented. Communities living in low-lying areas, for example, may need to relocate further inland into other communities' customary land. This will require extensive public debates on how to place the common good of all above the good of the clan or immediate family, a process that cannot—and should not—be rushed.

Since it is difficult to predict far in advance how climate change will affect a particular site, Pacific Island countries should avoid adaptation measures that could fail or have unanticipated social or economic consequences if climate change impacts turn out to be different than anticipated (IPCC 1998). More appropriate will be 'no regrets' adaptation measures that would be justified even in the absence of climate change. These include, for example, sound management of coastal areas and water supplies, control of pollution, and investment in preventive health.

As it will be shown, a 'no-regrets' adaptation strategy need not involve large investments of public resources — but it will require strong political will, as adaptation measures may face stiff competition from other development activities for scarce funds. Yet it is important to understand that the short-term economic gains of a 'do nothing' strategy could be easily dissipated by the impact of future climate events.

A development path that takes adaptation into account might sacrifice some potential short-term gains in favor of more diversification and a reduction in vulnerability. But it would vastly decrease the downside costs should climate change scenarios materialize. The challenge will be to find an acceptable level of risk — an intermediate solution between investing in high cost solutions and doing nothing — and start adapting long before the expected impacts occur.

B. Guidelines for Selecting Adaptation Measures

Pacific Island countries have a vast array of adaptation measures at their disposal. The following criteria may help guide their selection:

1. ***No regrets.*** Give priority to 'no regrets' measures, such as water resource management, which would be beneficial even in the absence of climate change. Structural measures—such as sea walls and groynes, which provide few benefits other than protection—require a high degree of certainty about the impact at a particular site. If climate change impacts turn out to be different than expected, investments in these measures could have been wasted.

2. ***Level of implementation.*** Adopt general rather than site-specific measures, at least until there is more certainty about localized impacts.

3. ***Bottom up or top-down.*** Use community-based (bottom-up) rather than top-down interventions. Many traditional adaptation measures have been tested and adjusted over the years in response to extreme events. These measures are likely to be more effective than top-down solutions. At the same time, communities will need external help to handle threats—such as pollution—that are beyond their control. A collaborative partnership between the government and communities may prove to be the most effective (see volume III of this report).

4. ***Environmental impacts.*** Select adaptation measures based on their impact on the overall vulnerability of the islands, not only on their impact at a particular site (de Wet 1999). A sea wall, for example, may solve the problems of a particular site but increase erosion downstream.

5. ***Cultural acceptability.*** Ensure that measures are compatible with the socio-cultural traditions of local communities and do not cause social disruption.

6. ***Timing.*** Time measures appropriately. Some adaptation measures—such as expansion of rainwater collectors in Tarawa—may need to be implemented immediately. Others could wait while appropriate responses are developed. As a general rule, the most urgent measures are those needed to protect against current climate events and those on which it may no longer be possible to act in the future.

7. ***Cost-benefit.*** The potential benefits of adaptation measures should clearly exceed their costs.

Two key principles should be kept in mind when selecting adaptation options. First, adaptation is not necessarily limited to interventions that reduce climate change impacts. Measures that increase the resilience of natural systems—by controlling pollution's effects on coral reefs, for example—should also be considered, as should policies that facilitate action on adaptation, such as a legislation empowering communities to manage their own coastal resources.

Figure 9. A Seawall in Qoma, Fiji

Sea walls are built throughout the Pacific to protect settlements against coastal erosion and storms. However, sea walls do not solve the underlying cause of erosion and may cause further problems downstream. In Qoma, Fiji (photo above) the community reported experiencing frequent inundation, which might have been exacerbated by their sea wall. Strategic replanting of mangroves might well have been a more efficient solution to guard against periodic inundation.

Second, it is vital to consider the sociocultural conditions of the Pacific Islands. To an external observer, it may seem appropriate to reinforce traditional Samoan houses to protect against cyclones. From the local communities' point of view, however, a 'do nothing' strategy may well be justified, because labor and materials might be readily available from within the extended family and the houses might be easily rebuilt following cyclones. The adaptation process thus needs to be highly participatory and allow for adjustments as new knowledge about climate change impacts is obtained.

C. Adaptation Options

Table 17 lists possible adaptation options for Pacific Island countries in accordance with the guidelines outlined above. The options include the following:

Adaptation Options for Coastal Areas

A coastal zone management framework that is tailored to the sociocultural conditions of each island should be used for adaptation planning. This framework should have three major goals: preventing loss of lives and property, avoiding development in inundation-prone areas, and ensuring that critical coastal ecosystems, such as coral reefs, are protected and remain functional. Specific adaptation options could include:

- *Management of coral reefs and mangroves.* Adaptation strategies should involve community leaders in enforcing penalties for reef and mangrove destruction, controlling pollutants, promoting sources of construction materials other than coral, and replanting mangroves. Structural adaptation measures— such as groynes or seawalls— should be screened for their compatibility with coral reef management.

- *Protection of towns.* Construction of seawalls is likely to be the measure of choice to prevent erosion in densely populated coastal areas. However, seawalls do not resolve the underlying cause of erosion, and they can promote offshore movement of beach sediments (figure 9). They are also costly to build and maintain, and they will need to be extended as the sea level rises. Seawalls should be used only to protect valuable property and buildings that cannot be relocated. For new infrastructure, the use of setbacks and relocation could be considered.

- *Land use policies.* Land use policies should encourage settlements away from low-lying and high-risk coastal areas through, for example, the use of coastal hazard mapping (as currently developed in Samoa).

- *Prevention of erosion.* Depending on the infrastructure and population density, adaptation options to prevent coastal erosion may include (i) no response, where there is little habitation or infrastructure; (ii) accommodation, where property is replaced as it is damaged; and (iii) shoreline protection, in areas with large populations and significant infrastructure. In low islands or atolls, where it is essential to retain overwash sediments, options might include replantation of mangroves, pandanus, and other coastal vegetation to promote shoreline accretion, closing or narrowing selected passages between the lagoon and the ocean, and the strategic use of groynes to help minimize the transfer of sediments from the ocean side to the lagoons. Groynes, however, should be used only in key locations—such as the passage edges of islands—as they tend to cause downstream erosion and require continuing maintenance. In less developed areas the use of setbacks to control future development, beach nourishment and relocation of infrastructure might be preferable.

- *Protection against inundation.* On islands with little infrastructure, the costs of protection are likely to be prohibitive, and relocation or modification of structures to accommodate surface flooding could be considered. On the more populated atoll islands—such as South Tarawa in Kiribati, Majuro and Ebeye in the Marshall Islands, and Funafuti in Tuvalu—strategies to allow overwash sediment to naturally increase the elevation of the island may help offset the impacts of inundation. Where land ownership disputes are not an issue, new structures should be set back from the shoreline and elevated to allow for periodic flooding.

- *Population relocation.* If all other measures fail, population relocation may need to be considered. While some communities may opt to move on their own, population relocation would pose immense social and political risks for Pacific Island governments, as nearly all inhabitable land is under some form of customary ownership.

Adaptation Options for Water Resources

The uncertain impacts of climate change on rainfall call for adaptation measures that take into account both drought and flood control. In arid islands in particular, it will be vital to improve the management of existing water resources and to develop supplementary sources of supply. Interventions could include:

- *Leakage control.* Current rates of water leakage—29 percent in Western Viti Levu and 50 percent in Tarawa—could be considerably reduced through improved plumbing. Spring-loaded taps and communal tanks and stand pipes may also help reduce wastage.

- *Water conservation incentives.* The introduction of water fees and metered consumption—as done in Tonga—could help discourage high levels of water use. Licenses issued to large water users should require that water be conserved during droughts and should impose strict penalties for unauthorized connections.

- *Watershed management.* In high islands such as Viti Levu, management of water resources should be combined with land management in the form of reforestation, protection of wetlands, and soil conservation. This could be facilitated by consolidating water and catchment management responsibilities under a single authority.

- *Development of alternative sources of water.* On arid islands, particularly on atolls, alternative water sources may need to be developed. Rainwater collection could be promoted by fitting new buildings with underground cisterns and encouraging all new houses to be fitted with rainwater storage. Desalination should be considered only when rainwater or groundwater sources are insufficient, as the cost—about US$4 per cubic meter—remains high. Future technological breakthroughs may help make desalination more affordable. Water importation is not considered a viable alternative due to the high costs—about US$19 per cubic meter—and shipping risks (ADB 1996; Shalev 1992).

- *Flood control.* In islands with extensive rivers (such as Viti Levu) flood control measures might include widening and diverting channels, retarding basins, and building weirs (JICA 1998). The risk of flood damage could also be reduced by regulating development on flood plains and promoting flood-proof housing.

Adaptation Options for Agriculture

Adaptation strategies for the agricultural sector should focus on 'no regrets' measures that also help reduce the adverse impacts of extreme weather events. These include the following:

- *Climate-proofing farming systems.* These could be promoted through research, enhancement, and promotion of traditional land management practices, including dry/wet season crop rotations and breeding for drought tolerance.

- *Promotion of sustainable production systems.* Sustainable production systems include agroforestry and cover crops to improve soil fertility, conserve moisture, and prevent soil erosion (FAO 1999). This is especially recommended in high islands such as Viti Levu.

- *Promotion of land use planning.* Wider promotion of land use planning and improved seasonal forecasting, needs to be part of a wider 'adaptation package'. Mapping of soil and climate zones, particularly in high islands, would improve the matching of crops and land use practices.

- *Importation of food* may be increasingly required to handle the effects of droughts and cyclones.

Adaptation Options for Public Health

Adaptation strategies to minimize public health impacts do not require extensive new interventions. Rather, existing initiatives that reduce the vulnerability of the population, and particularly the poor, should be enhanced. Actions should include not only improving public health but also strengthening the resilience of the ecosystems on which the population depends for food and income. Specific measures could include:

- *Integrated adaptation strategies.* Adaptation strategies should include a range of interventions to reduce the vulnerability of the population, such as improved sanitation and water supply, management of solid and liquid waste, protection of groundwater, reduction of poverty (particularly among urban squatter settlements), increased access to primary health care, and protection of subsistence food supplies. Many of these measures would also help control the incidence of diarrheal disease.

- *Control of dengue fever.* Adaptation strategies should include further support to vector control programs that collaborate with communities to reduce mosquito breeding sites. They should also improve epidemic preparedness through vector monitoring, early warning systems, and better preparation of primary health care facilities to treat dengue hemorrhagic fever and dengue shock syndrome.

- *Control of ciguatera.* In countries affected by ciguatera, adaptation measures should include control of non climate-related threats to coral reefs (such as pollution and blast fishing), monitoring of ciguatoxic areas, and public awareness of the risks of consuming the heads, roe and viscera of reef fish.

Adaptation Options for Tuna Fisheries

In the short-term, Pacific island nations need to reduce their vulnerability to fluctuations in the tuna catch of their Exclusive Economic Zones. This could involve:

- *Stronger regional collaboration* in the negotiation of multilateral agreements with distant water fishing nations (see Volume III, Chapter 3).
- *Income smoothing* mechanisms for license fees.
- *Better use of ENSO forecasting,* to help prepare countries for spatial and temporal changes in tuna distribution.
- *Diversification of domestic fleets,* and eventual reduction of the fishing effort to adjust to increased fluctuations in tuna resources.

In the long term it will be essential to strengthen the management of bigeye and yellowfin tuna stocks, which appear most threatened by future climate change. Since declines in tuna fisheries are likely to shift the domestic fleet's fishing pressure to overexploited coastal resources, measures to improve coastal management are also urgently needed.

D. Implementing Adaptation

The previous sections argued for Pacific Island governments to encourage 'no regrets' adaptation. But how should this be implemented in practice?

Governments cannot do it alone. Adaptation measures are and will continue to be implemented primarily by communities, the private sector, and individuals. But the role of Pacific Island governments will be essential in mainstreaming adaptation into policy and development planning, in creating partnerships with communities, nongovernmental organizations (NGOs) and the private sector, and in dealing with problems only the government can handle (such as disaster management).

Mainstreaming Adaptation

Adaptation goals need to be identified as a clear priority in national policies and development plans. Of particular importance will be the role of the Departments of Health, Environment, Agriculture, Public Works, and Fisheries. Conflicts among these agencies' development and adaptation goals—such as the impact of sand mining licensing on coastal management programs—need to be addressed. The objective would be to transform climate change from "something that may happen in the future" to a priority feature of current development planning.

In the short to medium term, all major new development projects—such as coastal mining and dredging—should undergo adaptation screening. This process should assess both the likely impact of climate change on the project, as well as the project's impact on the islands' vulnerability (de Wet 1999). Adaptation screening need not require extensive new legislation but rather a revision of environmental impact assessments to take adaptation into account. The Coastal Hazard Mapping program in Samoa is a step in this direction.

Building Partnerships

In building partnerships with communities, individuals, and the private sector, the government may need to play a pivotal role in the following areas:

- *Creating an Enabling Policy and Legal Framework.* This may include prioritizing adaptation into national planning,

Table 17. Selected Examples of Adaptation Measures

Goal	*Adaptation measure*	*No regrets?*	*Level of implementation*	*Bottom up or top down*	*Negative Environmental impacts?*	*Culturally acceptable?*	*Timing*	*Cost-benefit*
Moderate impacts on coastal areas								
Protection of critical ecosystems	Increase Public awareness		Generic	Both	No	Yes	Immediate	Positive
	Prohibit extraction of reef and sand	Yes	Sector specific	Both	No	May increase building costs	Immediate	Positive
	Prevent mangrove removal	Yes	Sector specific	Both	No	Unknown	Immediate	Positive
	Control pollution	Yes	Generic	Top down	No	Unknown	Immediate	Unknown
	Control overfishing	Yes	Sector specific	Both	No	Loss of food	Immediate	Positive
Protection of towns and property	Engineered structures (such as seawalls)	No	Site specific	Top down	Probably	Unknown	Unknown	Unknown
	Set back development from shoreline	No	Site specific	Both	Unknown	Land tenure?	Can wait	Unknown
	Raise structures	No	Site specific	Both	Unknown	Unknown	Can wait	Unknown
Land use policies	Coastal hazard mapping	Yes	Site specific	Top down	No	Yes	Immediate	Unknown
Control of erosion	Mangrove replantation	Yes	Sector specific?	Both	No	Yes	Immediate	Positive
	Engineering works in passages	No	Site specific	Top down	Probably	Unknown	Can wait	Unknown
	Groynes	No	Site specific	Top down	Probably	Unknown	Immediate	Positive(?)
Moderate impacts on water resources								
Water resource management	Leakage control	Yes	Sector specific	Both	No	Yes	Immediate	Positive
	Pricing policies (fees, levies, surcharges)	Yes (?)	Sector specific	Top down	No	Problematic	Immediate	Positive
	Conservation plumbing	Yes	Sector specific	Both	No	Unknown	Immediate	Positive
	Stricter penalties to prevent waste	Yes (?)	Generic	Top down	No	Resistance?	Immediate	Positive
Catchment management	Reforestation, soil conservation	Yes	Generic and site specific	Both	No	Yes	Immediate	Positive
	Establishment of a Water Authority	Yes	Sector specific	Top down	No	Unknown	Immediate	Positive
Alternative water supply	Expansion of rainwater collection	Yes	Sector and site specific	Both	Unknown	Maybe	Immediate	Unknown
	Alternative groundwater use	Yes	Sector and site specific	Top down	Unknown	Land tenure?	Can wait	Unknown
	Desalination	No (?)	Sector and site specific	Top down	Unknown	High costs	Can wait	Unknown
	Importation	No (?)	Sector specific	Top down	No	High costs	Can wait	Negative
Flood control	Diversion channels, weirs, etc.	No	Site specific	Top down	Probably	Unknown	Immediate	Unknown
	Land use controls, flood proof housing	No (?)	Site specific	Both	No	Land tenure?	Immediate	Unknown
Moderate impacts on agriculture								
Community sustainability programs	Traditional weather-resistant practices	Yes	Sector specific	Bottom up	No	Yes	Immediate	Positive
Sustainable production systems	Agroforestry, water conservation	Yes	Sector specific	Both	No	Unknown	Immediate	Positive
Research	Flexible farming systems	Yes	Sector specific	Top down	No	Unknown	Immediate	Positive(?)
Land use policies	Mapping of suitable cropping areas	Yes	Generic	Top down	No	Unknown	Immediate	Positive
	Avoid cultivation on marginal lands	Yes	Site specific	Top down	No	Disruptive	?	Positive
Moderate impacts on public health								
Integrated adaptation strategies and control of diarrheal disease	Poverty reduction programs	Yes	Generic and site specific	Top down	Unknown	Yes	Immediate	Positive?
	Improved sanitation and water supply	Yes	Sector and site specific	Both	No	Yes	Immediate	Positive
	Waste management	Yes	Sector and site specific	Both	No	Unknown	Immediate	Positive
	Protection of groundwater	Yes	Sector and site specific	Both	No	Unknown	Immediate	Positive
	Squatter settlement management	Yes	Site specific	Both	Unknown	Yes ?	Immediate	Positive
Control of dengue fever	Community-based vector control	Yes	Sector and site specific	Bottom up	No	Unknown	Immediate	Positive
	Improved preparedness (monitoring)	Yes	Sector specific	Top down	No	Yes	Immediate	Positive
	Prevention of exposure	Yes	Sector specific	Bottom up	Unknown	Difficult?	Unknown	Unknown
Control of ciguatera poisoning	Reduce destructive practices to coral reefs	Yes	Sector specific	Both	No	Food, income?	Immediate	Positive
	Monitoring and public awareness	Yes	Sector specific	Both	No	Yes	Immediate	Positive
Moderate impacts on tuna fisheries								
Stronger regional collaboration	Multilateral agreements	Yes	Sector specific	Top down	Unknown	Distrust?	Immediate	Positive
Research	Better ENSO forecasting	Yes	Generic	Top down	No	Yes	Immediate	Positive
	Improved tuna management	Yes	Sector specific	Top down	No	Yes	Immediate	Positive
Fleet management	Diversification of domestic fleets	No	Sector and site specific	Top down	Unknown	Problematic	Can wait	Positive

harmonizing conflicting sectoral policies, and providing the necessary legal and technical support for community-based adaptation measures such as co-management in coastal areas.

- *Strengthening Institutions.* Government planning in Pacific Island countries is often sector-oriented, with little capacity to respond to local level needs and conditions. Where this is the case, there is a need to strengthen the links between local communities and national and regional governments so that the communities increasingly gain a voice in planning and budgetary decisions. Local communities should also be encouraged to work across village boundaries to reach consensus on the adaptive strategies that need to be applied to larger areas—particularly if relocation is likely to be needed.

- *Supporting Collaborative Programs.* Community-based programs such as vector control, water conservation, coastal management, or mangrove replantation will need the support of external partners such as the government or NGOs. At first, external support should focus on galvanizing community action. Later, it should shift to technical advice and assistance in areas communities cannot handle on their own.

- *Mobilizing Public Action.* Public awareness and discussion forums involving community representatives could help convey information about the impacts of climate change and gain consensus on the adaptation options. Of special importance would be awareness efforts aimed at community leaders.

- *Handling Disaster Mitigation and Providing Public Services.* Some adaptation measures will need to rely on government interventions. These include early warning systems and disaster mitigation programs, improvements in primary health care, and coastal protection in town areas.

E. Funding Adaptation

Much of the costs and success of adaptation will depend on the extent to which communities, individuals, and the private sector own and implement the strategies. This requires government support for community-based efforts, and may require working through traditional decision making processes to ensure 'buy-in' at the local level. By asking new development projects to follow adaptation standards, Pacific Island governments could also shift part of the costs of adaptation to private investors.

'No regrets' adaptation measures do not involve significant costs if initiated sufficiently early. Samoa's environmental health program, for example, operates with a budget of US$113,000 a year. The Coastal Zone Management Project in Majuro, financed by UNDP, cost US$367,000 for four years of operation. By contrast, sea walls surrounding the Tarawa atoll would require capital investments of about US$1.5-$1.8 million (table 18).

In this context, it is recommended that Pacific Island countries adopt urgently a 'no regrets' policy aimed at decreasing their present vulnerability to extreme weather events (which may exist independently of climate change). As a first step, Pacific Island governments should assess how public expenditures could be adjusted to support this strategy, and how other partners in the process—in particular communities and the private sector—may help defray the costs. As a second step, Pacific Island governments and donors should study how to reallocate or attract new development aid to fund 'no regrets' activities that cannot be adequately funded by public expenditures. The recently agreed "Pacific Islands Framework for Action on Climate Change, Climate Variability and Sea Level Rise" (SPREP 2000) could be used as a basis to prioritize donor assistance. Many 'no regrets' interventions—such as improved sanitation or coastal management—could be justified as part of regular environmental assistance.

Even though 'no regrets' measures have the double benefit of reducing short-term exposure to climate variability as well as long-term vulnerability to climate change, it is important that the two aspects be kept separate in international negotiations. Adoption of an early 'no regrets' strategy by a country should not diminish its chances of accessing climate change adaptation funds in the future.

Table 18. Indicative Adaptation Costs (US$)

Measure	*Cost*
Annual Operational Costs[a]:	
Land use planning	33,700
Waste management	181,900
Biodiversity protection and natural parks	167,000
Environmental education and information	102,500
National disaster council	30,700
Reforestation	297,800
Watershed projection and management	113,800
Support to community-based fisheries management	81,400
Community disease control	205,800
Environmental health	112,600
Nutrition	83,400
Investment Costs:	
Human waste management (composting toilets)[b]	800,000
Elevating houses [b]	1,700,000-3,200,000
Seawalls [c]	1,540,000-1,830,000
Coastal Zone Management Project for Majuro Atoll[d]	367,300

[a] Costs reflect Samoa 1999-00 public expenditure allocations. GDP Samoa US$205 million.
[b] Covering North Tarawa (population 6,000, area 1,500 ha). GDP Kiribati US$47.9 million
[c] Covering Tarawa atoll (population 35,000, area 3,200 ha). The cost per linear meter is about US$155, excluding maintenance costs.
[d] Costs represent allocation for four years for Majuro (population 86,110).
Source: Legislative Assembly of Samoa 1999; UNDP 1996; background studies to this report.

Similarly, donors should not be led to believe that because 'no regrets' adaptation benefits the countries independently of climate change, the justification for incremental financing is weak. To do so would be to tip the scale in favor of structural solutions (such as seawalls), which are clearly incremental. One of the reasons communities like sea walls is that they can receive government support for their construction. Pacific Island government officials have often expressed the view that it is easier to obtain international aid for structural measures than for 'no regrets' solutions. These disincentives need to be urgently addressed in future international climate change discussions, in order to maintain 'no regrets' strategies at the forefront of adaptation financing, and benefit— rather than penalize—the countries most willing to take early action

The international debate on financing of adaptation has not progressed far. Globally, the United Nations Framework Convention on Climate Change (UNFCCC) provides the umbrella agreement for mitigation of greenhouse gas emissions. The Convention also includes provisions to begin work on adaptation to climate change. To date, however, progress on adaptation has been slow. Many observers feel that the perceived high costs of adaptation may have curbed enthusiasm to assist those countries most in need of support. As a consequence, funds from the Global Environmental Facility (GEF), the main financing mechanism for climate change, have been available only for mitigation of greenhouse gas emissions and for studies and capacity building done in the context of national communications.[7] International negotiations under the Conference of Parties of the UNFCCC have not yet agreed to the financing of actual adaptation (Stage III) measures.

Pacific Island countries are understandably concerned about the slow pace of these negotiations. Since they contribute only a negligible amount to the world's greenhouse gas emissions, they view the stalling of Phase III as a way for emission-producing countries to avoid recognizing their responsibilities toward

[7] National assessments of vulnerability and adaptation. National communication strategies have been supported by the Pacific Islands Climate Change Programme (PICCAP), funded by UNDP through the South Pacific Regional Environmental Programme (SPREP).

countries on the receiving end of climate change.

Other funding mechanisms may be available sooner. One of the most promising sources is the Clean Development Mechanism (CDM) under the Kyoto Protocol.[8] A share of the CDM proceeds is envisaged to help vulnerable countries meet the costs of adaptation. The timing of this 'CDM tax' will depend to a large extent on the entering into force of the Kyoto Protocol, however, and it is unlikely to be available in the short term.

The findings of this report clearly show that the Pacific Island countries are likely to experience significant incremental costs associated with global climate change in the future. The responsibility is now on the international community to move urgently with a financing mechanism to help coastal states defray these costs. The urgency of this action for small island states such as the Pacific Islands cannot be over-emphasized.

At the same time, Pacific Island countries should continue to speak with one voice at international climate change forums. Much has been accomplished already under the support of the Pacific Island Climate Change Programme (PICCAP). A strengthened focus on optimal adaptation strategies and economic analysis—particularly on the costs and benefits of adaptation measures—could strengthen their case in international negotiations, broaden the climate change constituency, and mainstream climate change into the economic and development planning of the Pacific Islands.

[8] The Kyoto Protocol, launched in 1997, is a commitment to decrease world emissions of major greenhouse gases by at least 5 percent below 1990 levels by 2008–12. The Clean Development Mechanism is a process to promote joint reduction of greenhouse emissions by developing and industrial countries (ENB 1999).

Chapter 7
Summary of Key Findings and Recommendations

The following conclusions can be derived from the analysis:

- ❑ The Pacific Islands are already experiencing severe impacts from climate events. This is evidenced by cyclone damage of more than US$1 billion during the 1990s and by the impact of recent droughts in Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, and Palau (SPREP 2000).

- ❑ The islands' vulnerability to climate events is growing, independently of climate change. Current trends point to a continuing rise in vulnerability in the future which will be exacerbated by climate change.

- ❑ Climate change is likely to impose major incremental social and economic costs on Pacific Island countries. In disaster years the impact could be particularly high, causing significant economic and social problems.

- ❑ Climate change may affect all Pacific Islanders, particularly the poor and most vulnerable. Climate change may also exacerbate poverty by reducing coastal settlement areas and affecting the crops and fisheries on which many communities depend.

- ❑ Failure to adapt now could not only lead to major damages, but also result in a loss of opportunities to act in the future. Some coral reef areas, for example, may no longer be able to recover in the future if degradation continues at the present rates.

- ❑ By acting now to reduce their present-day vulnerability to extreme weather events, Pacific Island countries could go a long way toward diminishing the effects of climate change in the future.

Based on these conclusions, a number of key recommendations can be derived.

Pacific Island Governments

- *Adopt a 'No Regrets' Adaptation Policy.* Pacific Island governments should put in place an urgent policy of 'no regrets' adaptation, aimed at increasing the natural resilience of the islands and reducing their vulnerability to present-day weather events. 'No regrets' measures could include, for example, the management of critical coastal ecosystems (such as coral reefs), control of urban pollution, water conservation, culture of weather-resistant crops and disease vector control. Under such a policy, Pacific Island governments would take adaptation goals into account in future expenditure and development planning. Insofar as these measures helped reduce existing vulnerability (independently of climate change), Pacific Island governments would be justified in using reallocations of public expenditures and development aid to fund these activities.

- *Develop a Broad Consultative Process for Implementing Adaptation.* Pacific Island governments should start a process of consultation with community representatives, the private sector, and other civil society institutions (such as churches and NGOs), on a national strategy for adaptation. The strategies should build upon the National Communications developed by the PICCAP country teams. The objective would be mainstream adaptation into national policies and development plans, to gain consensus on priority adaptation measures, and to build partnerships for their implementation.

- *Require Adaptation Screening for Major Development Projects.* To help defray future costs, Pacific Island governments should require all major infrastructure projects to undergo adaptation screening as part of an expanded environmental impact assessment.

- *Strengthen Socio-Economic Analysis of Adaptation Options.* Further work on the specific socio-economic impacts of climate change and adaptation—such as done under this study—could help strengthen the Pacific Island countries' position in international discussions on adaptation financing. A better understanding of the physical and economic impacts would also help mainstream climate change into broader development planning.

Donors

- *Support 'No Regrets' Adaptation.* Donors have an important role to play in discussing with Pacific Island countries how to best orient development assistance in support of national adaptation strategies. This could be done either through stand alone interventions or as part of natural resources and environmental management programs.

- *Support Adaptation Screening.* To the extent possible, donors should adopt adaptation screening as part of their policy requirements on environmental impact assessments.

International Community

- *Operationalize Adaptation Financing.* Given the importance of taking early action on adaptation, the international community needs to urgently agree on the mechanism and size of adaptation financing—be it in the form of the Global Environmental Facility, a tax on the Clean Development Mechanism as currently discussed, or others. The findings from this study support the argument that Pacific Island countries will likely experience significant incremental costs from climate change, and will need access to global adaptation funding.

- *Remove Incentives against Immediate Action on 'No Regrets' Adaptation.* Countries that have taken early action on adaptation using their own public expenditures or development aid should not be penalized with a lower allocation of global adaptation funds, once these become available. Similarly, the justification for international financing of 'no regrets' adaptation needs to be recognized and promoted in its own right. Failure to do so could tilt the balance towards a 'wait and see' attitude, in favor of more expensive, but clearly incremental, structural solutions (such as seawalls).

Although many uncertainties remain, it now seems clear that climate change will affect many facets of Pacific Island people's lives and economies in ways that are just now beginning to be understood. Climate change therefore must be considered one of the most important challenges of the twenty-first century and a priority for immediate action.

References

Background Studies to this Volume

Aaheim, H. A., L. Sygna (2000). *An Economic Assessment of Impacts of Climate Chang on Fisheries in the Pacific.* Report Prepared for the World Bank by the Center for International Climate and Environmental Research , University of Oslo, Norway.

Campbell, J. (2000). *Climate Change Vulnerability and Adaptation Assessment for Fiji. Technical Summary and Synthesis.* Report Prepared for the World Bank by the Center for International Global Change Institute, Waikato University, Hamilton, New Zealand.

Campbell, J. (2000). *Climate Change Vulnerability and Adaptation Assessment for Kiribati. Technical Summary and Synthesis.* Report Prepared for the World Bank by International Global Change Institute, Waikato University, Hamilton, New Zealand.

Falkland, T. (2000). *Additional Groundwater Modelling of the Bonriki Freshwater Lens, Tarawa, Kiribati, using the SULTRA Groundwater Model.* Prepared for the World Bank and International Climate Change Institute by Ecowise, Australia. International Global Change Institute, Waikato University, Hamilton, New Zealand, and the World Bank. Washington. D.C.

Feresi, J., G. Kenny, N. De Wet, L. Limalevu, J. Bhusan and I. Ratukalou, editors (2000), with contributions from S. Hales, R. Maharaj, R. Ogoshi, and J. Terry. *Climate Change Vulnerability and Adaptation Assessment for Fiji.* Prepared and published by Fiji Pacific Island Climate Change Assistance Programme (PICCAP). Copyright: 2000 Government of Fiji and IGCI, University of Waikato, Hamilton, New Zealand.

International Global Change Institute (IGCI) and South Pacific Regional Environment Programme (SPREP) (1999). PACCLIM WORKSHOP - *Modelling Climate and Sea-level Change Effects in Pacific Island Countries*, August 23-27, 1999. International Global Change Institute. Hamilton, New Zealand.

International Global Change Institute (IGCI) in collaboration with the Pacific Islands Climate Change Assistance Programme (PICCAP) Fiji Country Team (2000). *Climate Change Vulnerability and Adaptation Assessment for Fiji. Supplemental Fiji Coastal Impacts Study.* Report Prepared for the World Bank. University of Waikato, New Zealand.

King, Wayne (2000). *Climate Change Overview and Background Related to Adaptation Options and Evaluation*. Contribution for the World Bank Regional Economic Report for Pacific Island. South Pacific Regional Environmental Programme. Apia, Samoa.

Lehodey, P. (2000). *Impacts of Climate Change on Tuna Fisheries in the Tropical Pacific Ocean*. Prepared by the Secretariat of the Pacific Community as edited by IGCI in partnership with South Pacific Regional Environment Programme (SPREP) and Pacific Islands Climate Change Assistance Programmed (PICCAP). Noumea, New Caledonia.

Lehodey, P. and P. Williams (2000). Data on Tuna Catch in Central and Western Pacific. Electronic files, Secretariat of Pacific Community, Noumea, New Caledonia.

Stratus Consulting (2000). *Economic Implications of Climate Change in Two Pacific Island Country Locations. Case Illustration of Tarawa, Kiribati and Viti Levu.* Prepared under sub-contract to CICERO (Oslo, Norway). Boulder, Colorado.

Taeuea, T., I. Ubaitoi, N. de Wet and G. Kenny, editors (2000), with contributions from N. Teuatabo, P. Kench, T. Falkland, and S. Hales. *Climate Change, Vulnerability and Adaptation Assessment for Kiribati.* Prepared and published by Kiribati Pacific Island Climate Change Assistance Programme (PICCAP). Copyright: 2000, Government of Kiribati and IGCI, University of Waikato, New Zealand.

Van Aalst, Maarten. Contribution to the Climate Change Chapter of the Regional Economic Report. Washington, D.C.

References[9]

ADB (1996). *Findings and Recommendations, Sanitation and Public Health Project. Final Report.* Prepared for the Asian Development Bank by Royds Consulting Party Ltd. in association with KPMG and Kab Beriki and Associates. December. Manila, Philippines.

Alam, K. and A. C. Falkland (1997). *Vulnerability to Climate Change of the Bonriki Freshwater Lens , Tarawa.* Report No. HWR97/11, ECOWISE Environmental, ACTEW Corporation, prepared for the Ministry of Environment and Social Development, Republic of Kiribati, April 1997.

Basu and Others (1999). *Rising to the Challenge!* A resource document for the Dengue Action Planning Forum at the Forum Secretariat. Suva, May 1999. Fiji Ministry of Health, Suva.

Beagley, (1998).

Bertignac, M. P. Lehodey, J. Hampton (1998). A Spatial Population Dynamics Simulation Model of Tropical Tunas Using a Habitat Index Based on Environmental Parameters. Fisheries Oceanography, 7(3/4): 326-335.

Campbell (1995*). Dealing with Disaster*. Government of Fiji, Suva; East-West Center, Honolulu, Hawaii.

Campbell, J. (1999). *Vulnerability and Social Impacts of Extreme Events*. Presented during the PACCLIM Workshop, August 23-27, 1999. In International Global Change Institute (IGCI) and South Pacific Regional Environment Programme (SPREP) (1999). PACCLIM WORKSHOP - *Modelling Climate and Sea-level Change Effects in Pacific Island Countries*, August 23-27, 1999. International Global Change Institute. Hamilton, New Zealand.

Cesar, H. (1996). *Economic Analysis of Indonesian Coral Reefs.* Environmental Department. The World Bank, Washington, D.C.

Christensen, L. (1982). *Management and Utilization of Mangroves in Asia and the Pacific*. FAO Government Paper # 3. Food and Agriculture Organization of the United Nations. Rome, Italy.

[9] Many of the references were consulted by the contributing authors to this volume, and are included in the bibliography of their background studies. Only references that were directly quoted in this volume are included here.

Clark, K. M. (1997). *Current and Potential Impact of Hurricane Variability on the Insurance Industry*. In H. F. Diaz and R.S. Pulwarty (editors). "Hurricanes, Climate and Socioeconomics." Springer.

Constanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt (1997). *The Value of the World's Ecosystem Services and Natural Capital*. Nature, 387:253-260.

Cubash, U., K. Hasselmann, H. Hock, E. Maier-Reimer, U. Mikolajewicz, B. Santer and R. Sausen (1992*). Time Dependent Greenhouse Warming Computations with a Coupled Ocean-Atmosphere Model.* Climate Dynamics, 8:55-69.

De Groot, R. S. (1992). *Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision Making.* Wolters-Noordhoff, Groningen. 315 pp.

De Wet, Neil (1999). *A Conceptual Framework for Adaptation to Climate and Sea-Level Change in Pacific Island Countries.* In International Global Change Institute (IGCI) and South Pacific Regional Environment Programme (SPREP) (1999). PACCLIM WORKSHOP - *Modelling Climate and Sea-level Change Effects in Pacific Island Countries*, August 23-27, 1999. International Global Change Institute. Hamilton, New Zealand.

Earth Negotiations Bulletin (ENB) (1999). Summary of the Fifth Conference of the Parties to the Framework Convention on Climate Change. Earth Negotiations Bulletin. Published by the International Institute for Sustainable Development (IISD). Http:// www.iisda.ca accessed November (1999).

Eastman, J. R. (1995). *IDRISI for Windows — User's Guide Version 1.0.* Clark Labs for Cartographic Technology and Geographical Analysis, Clark University, Worcester.

Environmental Protection Agency (EPA). 1999. *Health Risk Reduction and Cost Analysis for Radon in Drinking Water.* United States Environmental Protection Agency, EPA-815-2-99-002. Washington, D.C.

Food and Agriculture Organization of the United Nations (FAO). 1996. FAOSTAT Database. http://apps.fao.org/cgi-bin/nph-db.pl?subset = agriculture. Accessed January 19, 2000.

Feresi, J., G. Keeny, N. De Wet, L. Limalevu, J. Bhusan and I. Ratukalou, editors (2000), with contributions from S. Hales, R. Maharaj, R. Ogoshi, and J. Terry. *Climate Change Vulnerability and Adaptation Assessment for Fiji.* Prepared and published by Fiji Pacific Island Climate Change Assistance Programme (PICCAP). Copyright: 2000 Government of Fiji and IGCI, University of Waikato, Hamilton, New Zealand.

Fiji Fisheries Division (FFD) 1999. *Annual Report 1998.* Prepared by the Ministry of Agriculture, Fisheries and Forests. Suva, Fiji.

Fiji Real Estate (2000). http://www.fijirealestate.com/waidroka/property-map.html. Consulted May 2000.

Food and Agriculture Organizations of the United Nations (FAO) (1999). *Environment and Natural Resources in Small Island Developing States*. Rome, 12 March, 1999.

Gittinger, J.P. (1982). *Economic Analysis of Agricultural Projects.* EDI Series in Economic Development. Economic Development Institute, the World Bank. Washington, D.C.

Gordon, H.B. and S.P.O. O'Farrell (1997). *Transient Climate Change in the CSIRO Coupled Model with Dynamic Sea Ice.* Monthly Weather Review, 125(5): 875-907.

Graham, T., N. Idechong, and K. Sherwood (2000). *The Value of Diving and the Impacts of Coral Bleaching in Palau.* Presented at the 9th International Coral Reef Symposium, October 23-27, Bali, Indonesia.

Hackett, C. (1988). *Matching Plants and Land: Development of a General Broadscale System from a Crop Project for Papua New Guinea.* Natural Resources Series No. 11, CSIRO Division of Water and Land Resources. Commonwealth Scientific and Industrial Research Organization, Australia.

Hackett, C. (1991). PLANTGRO: A Software Package for Coarse Prediction of Plant Growth. Australia Commonwealth Scientific and Industrial Research Organization. Clayton, Australia.

Hales, S., P. Weinstein, Y. Souares, A. Wood (1999). *El Nino and the Dynamic of Vector Borne Disease Transmission.* Environmental Helth Perspectives 107: 99-102.

Harmelin-Vvien, M.L. (1994). *The Effects of Storms and Cyclones on Coral Reefs: A Review.* Journal of Coastal Research. Special Issues 12, 211-232.

Holland, G. J. (1997). *The Maximum Potential Intensity of Tropical Cyclones.* Journal of Atmospheric Science, 54 : 2519-2541.

Hopley, D. and D.W. Kinsey (1988*). The Effects of a Rapid Short-term Sea-Level Rise on the Great Barrier Reef in Taueva, Tianuare, Ioane Ubaitoi*. In I.G. Pearman (ed.). "Greenhouse: Planning for Climate Change". Commonwealth Scientific and Industrial Research Organization (CSIRO), Melbourne, Australia, p. 189-201.

International Global Change Institute (IGCI) and South Pacific Regional Environment Programme (SPREP) (1999). PACCLIM WORKSHOP - *Modelling Climate and Sea-level Change Effects in Pacific Island Countries*, August 23-27, 1999. International Global Change Institute. Hamilton, New Zealand.

Intergovernmental Panel on Climate Change (IPCC)(1996). *Climate Change 1995: The IPPC Second Assessment Report.* Watson, Rt., M.C. Zinyowera and R.H. Moss (eds). Cambridge University Press, Cambridge and New York.

Intergrovernmental Panel on Climate Change (IPPC) (1998). *Summary Report: IPCC Workshop on Adaptation to Climate Variability and Change.* March 29-April 1, 1998. San Jose, Costa Rica.

JICA (1998). *The Study on Watershed Management and Flood Control for the Four Major Viti Levu River in the Republic of Fiji*. Draft Final Report, Main Report prepared by the Yachiyo Engineering Co., Ltd. for the Japan International Cooperation Agency, Ministry of Agriculture, Fisheries and Forests, Fiji. July.

Jones, R.N., P.H. Whetton, K.J.E. Walsh, R. Suppiah and K.J. Hennessy (1999). *Scenarios of Climate Variability for the South Pacific.* In International Global Change Institute (IGCI) and South

Pacific Regional Environment Programme (SPREP) (1999). PACCLIM WORKSHOP - *Modelling Climate and Sea-level Change Effects in Pacific Island Countries*, August 23-27, 1999. International Global Change Institute. Hamilton, New Zealand.

Kench, P. and P. Cowell (1999). *Impacts of Sea Level Rise and Climate Change on Pacific Coasts.* In International Global Change Institute (IGCI) and South Pacific Regional Environment Programme (SPREP) (1999). PACCLIM WORKSHOP - *Modelling Climate and Sea-level Change Effects in Pacific Island Countries*, August 23-27, 1999. International Global Change Institute. Hamilton, New Zealand.

Koroivueta, personal communications (1999). As quoted In Feresi, J., G. Keeny, N. De Wet, L. Limalevu, J. Bhusan and I. Ratukalou, editors (2000), with contributions from S. Hales, R. Maharaj, R. Ogoshi, and J. Terry. *Climate Change Vulnerability and Adaptation Assessment for Fiji.* Prepared and published by Fiji Pacific Island Climate Change Assistance Programme (PICCAP). Copyright: 2000 Government of Fiji and IGCI, University of Waikato, Hamilton, New Zealand.

Legislative Assembly of Samoa (1999). *Approved Estimates of Receipts and Payment of the Government for the Financial Year Ending 30th June 2000.* Parliamentary Paper 1999, No. 9. Apia, Samoa.

Lehodey, P. (Submitted). The Pelagic Ecosystem of the Tropical Pacific Ocean: Dynamic Spatial Modelling and Biological Consequences of ENSO. Submitted to Progress in Oceanography, Special Issue of the "Beyond El Niño" Conference, March 23-26, 2000. La Jolla, California, USA.

Lehodey, P. (2000). *Impacts of Climate Change on Tuna Fisheries in the Tropical Pacific Ocean*. Prepared by the Secretariat of the Pacific Community as edited by IGCI in partnership with South Pacific Regional Environment Programme (SPREP) and Pacific Islands Climate Change Assistance Programmed (PICCAP). Noumea, New Caledonia.

Lehodey, P., J. M. Andre, M. Bertignac, J. Hampton, A. Stoens, C. Menkes, L. Memery, N. Grima (1998). *Predicting Skipjack Tuna Forage Distributions in the Equatorial Pacific Using a Coupled Dynamical Bio-Geochemical Model.* Fisheries Oceanography, 7(3/4): 317-325.

Lehodey, P., M. Bertignac, J. Hampton, A. Lewis and J. Picaut (1997). *El Nino Southern Oscillation and Tuna Western Pacific.* Nature. 389: 715-718.

Lewis, R. (1992). *Ciguatera in the Pacific.* Bulletin Societe Pathologie Exotique 85: 427-434.

Lewis, R. J. and T. A. Ruff (1993). *Ciguatera: Ecological, Clinical, and Socio-Economic Perspectives.* Critical Reviews in Environmental Science and Technology 23: 137-156.

McLean, R. F. (1989). *Kiribati and Sea Level Rise.* Report to the Commonwealth Secretariat.

Marshall, J.F. and G. Jacobsen (1985). *Holocene Growth of a mid-Pacific Atoll*: Tarawa, Kiribati: Coral Reefs, 4:11-17.

Metz, (1996).

Mimura, N., and Nunn, P.D. (1998). *Journal of Coastal Research, 14, 37-46.*

Ministry of Finance of Fiji (MNP). 1999. *Economic and Fiscal Update. Supplement to the 2000 Budget Address*. Ministry of Finance and National Planning. November 5, 1999. Suva, Fiji.

Pahalal, Janita and Jai Shree Gawander (1999). *The Impact of Climate Change on Sugar Cane in Fiji.* Fiji Meteorological Service and Sugarcane Research Center and Fiji Sugar Corporation, Suva and Lautoka, Fiji.

Patz, J.A., W.J. M. Martens, D.A. Focks, and T.H. Jetten (1998). *Dengue Fever Epidemic Potential as Projected by General Circulation Models of Climate Change.* Environmental Health Perspectives, 106:3:147-153.

PNG Consultants (1996).

Ruff, T. A. (1989). *Ciguatera in the Pacific: A Link with Military Activities.* Lancet 1L 201-205.

Ruff, T.A. and R.J. Lewis (1997). *Clinical Aspects of Ciguatera: An Overview*. Pacific Health Dialog Vol. 4. No.2, pp. 119-127.

Shalev, Z. (1992*). Draft 10 Year National Water Master Plan.* United Nations Department of Technical Cooperation for Development. Project KIR/87/006.

Sistro, N. (1997). *The Economic Value of Fiji's Ecosystems.* Technical Group 5 Report for Fiji Biodiversity Strategy and Action Plan. Government of Fiji, Suva.

Solomon, S. (1997). *Assessment of the Vulnerability of Betio (South Tarawa, Kiribati) to Accelerated Sea-level Rise*. SOPAC Technical Report 251. South Pacific Geoscience Commission, Suva, Fiji.

Solomon, S. and J. Kruger (1996). *Vulnerability and Adaptation Assessment: Coastal Impact of Sea Level Change, Viti Levu, Fiji.* SOPAC Technical Report No. 242. South Pacific Geoscience Commission, Suva, Fiji

South Pacific Applied Geoscience Commission (SOPAC), 1998. *Demand Management and Conservation Project, Field Investigation in South Tarawa, Kiribati.* Prepared by Ed Burke, Project Manager, Water Resources Unit, SOPAC. Miscellaneous Report 302. Suva, Fiji.

South Pacific Regional Environment (SPREP) 2000. *Draft Pacific Island's Framework for Action on Climate Change, Climate Variability and Sea Level Rise*. Apia, Samoa.

SPECTRUM (1999). *Spectrum Population Software*. Human Resource Systems Corporation. http://www.spectrumhr.com.

South Pacific Regional Environmental Programme (SPREP), 2000. *Draft Pacific Island's Framework for Action on Climate Change, Climate Variability and Sea Level Rise.* Apia, Samoa.

Stratus Consulting (2000). *Economic Implications of Climate Change in Two Pacific Island Country Locations. Case Illustration of Tarawa, Kiribati and Viti Levu.* Prepared under sub-contract to CICERO (Oslo, Norway). Boulder, Colorado.

Taeuea, T., I. Ubaitoi, N. de Wet and G. Kenny, editors (2000), with contributions from N. Teuatabo, P. Kench, T. Falkland, and S. Hales. *Climate Change, Vulnerability and Adaptation Assessment for Kiribati.* Prepared and published by Kiribati Pacific Island Climate Change Assistance Programme (PICCAP). Copyright: 2000, Government of Kiribati and IGCI, University of Waikato, New Zealand.

Timmermann, A., Oberhuber, J., Bacher, A., esch, M., Latif, M., Roeckner, E. (1999). Increased El Niño Frequency in a Climate Model Forced by Future Greenhouse Warming. *Nature* **398**, 694-697.

United Nations Development Programme (UNDP) and Government of Fiji (1997). *Fiji Poverty Report.* United Nations Development Program. Quality Press, Suva, Fiji.

United Nations Development Programme (UNDP) (1996). Establishing a Coastal Management Program for Majuro Atoll. Proposal of the Government of the Marshall Islands. United Nations Development Programme, Suva, Fiji.

United Nations Disaster Assessment and Coordination (UNDAC) 1998. UNDAC Mission Reports on Fiji Drought. http://www.reliefweb.int/w/rwb.nsf/S/A3238C8D6E14D385C12566C9004C0D9C. Accessed September 1999. In Stratus Consulting (2000). *Economic Implications of Climate Change in Two Pacific Island Country Locations. Case Illustration of Tarawa, Kiribati and Viti Levu.* Prepared under sub-contract to CICERO (Oslo, Norway). Boulder, Colorado.

United Nations Educational, Scientific and Cultural Organization (UNESCO). 1991. *Hydrology and Water Resources of Small Islands. A Practical Guide. Studies and Reports on Hydrology No. 49.* Prepared by A. Falkland (ed.) and E. Custodio with contributions from A. Diaz Arenas and L. Simler and case studies submitted by others. Paris, France, 435 pp.

Voss, C. I. (1984). SUTRA: A Finite Element Simulation Model for Saturated, Unsaturated, Fluid-Density Dependent, Groundwater Flow with Energy Transport or Chemically-Reactive Single-Species Solute Transport. US Geological Survey, Water Resources Investigation Report, 84-4389, 409 pp.

Watling, D. (1985). *A Mangrove Management Place for Fiji (Phase 1).* South Pacific Commission and Fiji Government. Suva, Fiji.

Westmacott, S., H. Cesar and L. Pet-Soede (2000). *Socio-Economic Assessment of the Impacts of the 1998 Coral Reef Bleaching in the Indian Ocean.* In Westmacott, S. , H. Cesar, L. Pet-Soede, J. De Schutter. "Assessing the Socio-Economic Impacts of Coral Reef Bleaching in the Indian Ocean. CORDIO Report Submitted to the World Bank African Environment Department. The World Bank, Washington, D.C.

White, I, A. Falkland, B. Etuati, E. Merdi, and T. Metuatera. (1999). Recharge of Fresh Groundwater Lenses: Field Study, Tarawa Atoll, Kiribati. Second International Colloquium on Hydrology and Water Management i n the Humid Tropic, Panama City, 21-26 Larch.

Wigley, T.M.L. (1994). *MAGGIC: Model for the Assessment of Greenhouse-gas Induced Climate Change.* Users Guide and Scientific Reference Manual, University Corporation for Atmospheric Research, Boulder, Colorado.

Wilkinson, Clive, Olof Linden, Herman Cesar, Gregor Hodgson, Jason Rubens and Alan E. Strong (1999). *Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change?* Ambio Vol 28 ,No. 2, March: 188-196.

World Bank (2000a). *Cities, Seas, and Storms: Managing Change in Pacific Island Economies.* Volume I: Summary Report (draft). Papua New Guinea and Pacific Islands Country Unit. The World Bank. Washington, D.C. November 13, 2000.

World Bank (2000b). *Cities, Seas, and Storms: Managing Change in Pacific Island Economies.* Volume II: Managing Pacific Towns (draft). Papua New Guinea and Pacific Islands Country Unit. The World Bank. Washington, D.C. November 30, 2000.

World Bank (2000c). *Cities, Seas, and Storms: Managing Change in Pacific Island Economies.* Volume III: Managing the Use of the Ocean (draft). Papua New Guinea and Pacific Islands Country Unit. The World Bank. Washington, D.C. November 30, 2000.

World Health Organization (WHO), 1996. *Climate change and Human Health.* [McMichael, A.J., Haines, A., Sloof, R., and Kovats, S. (eds.)]. World Health Organization, Geneva.

World Health Organization (WHO). 1998. *Weekly Epidemiological Record,* No. 36, 4. September 1998. Published by the World Health Organization, Geneva.

World Resources Institute (1999). *Status of Coral Reefs Classified by Potential Threat from Human Activities. Status of the World's Coral Reefs: Pacific Ocean Page.* World Resources Institute. http://www.wri.org/wri/indictrs/reefocea.htm. Accessed January 2000.

Annex A
Assumptions Used in the Assessment of Climate Change Impacts

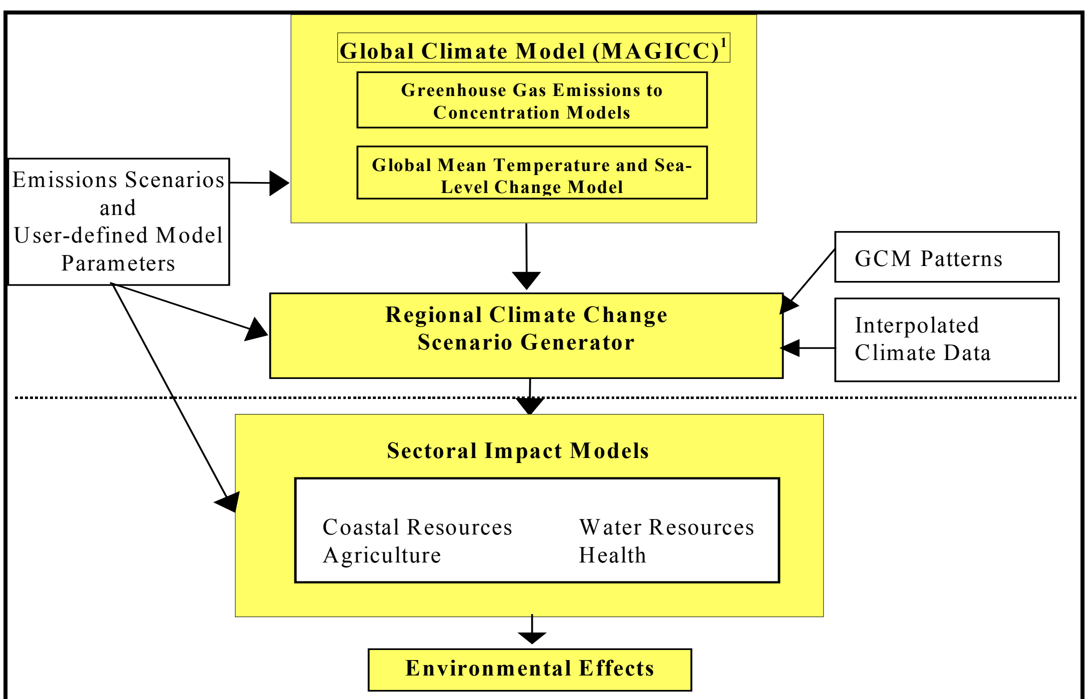
The analysis of climate impacts was conducted by a multi-disciplinary team from more than 20 different institutions (see *Acknowledgments*). To allow for a more in-depth assessment of climate change impacts on key economic sectors, the study team focused on Viti Levu (Fiji) as an example of a high island, and on the Tarawa atoll (Kiribati) as an example of low islands in the Pacific. The two study sites were also selected based on the availability of data.

The assessment of climate change impacts relied on an integrated assessment model, the Pacific Climate Change Impacts Model (PACCLIM), which was developed for the Pacific Island region by the International Global Change Institute (IGCI). PACCLIM was originally developed as a regional scenario generator under the Pacific Islands Climate Change Assessment Program (PICCAP). For the purposes of this study, PACCLIM was enhanced to provide projections of the effects of climate change and sea-level rise on four major sectors (figure A.1):

- Coastal areas
- Water resources
- Agriculture
- Health

Where possible, historical data, qualitative observations, expert judgments and existing literature were also used to verify or reject projected impacts, or to provide further information on possible effects.

Figure A.1 . The PACCLIM Model System and Main Components



1- Model for the Assessment of Greenhouse Gas Induced Climate Change

The impact of climate change on regional tuna fisheries was assessed separately using present knowledge on tuna biology and fisheries, as well as the recent findings on the environmental impacts of ENSO on tuna stocks in the western central Pacific Ocean (Lehodey and others, 1997; Lehodey 2000). The analysis was also based on simulation results from the Spatial Environmental Population Dynamics Model (SEPODYM) developed at the Secretariat of Pacific Community Oceanic Fishery Programme (Lehodey and others 1998; Bertignac and others 1998; Lehodey, submitted). This model takes into consideration the movement of tuna and the effects of environmental variability. Sea surface temperature, oceanic currents, and primary production are used in the model to delineate tuna spawning areas, the transport of larvae and juveniles, and simulations of tuna forage distribution.

A. General Scenarios

Rainfall and Temperature Changes

The scenarios developed for Viti Levu and Tarawa were based on general circulation models (GCMs). While GCMs do not have the resolution to yield accurate results at the scale of the Pacific Island region or individual countries, there tends to be an agreement among the various models on changes in temperature. However, the models show inconsistencies in projections of rainfall, and capture poorly the effects of ENSO phenomena. These shortcomings were handled as described below.

Temperature and rainfall scenarios for Viti Levu and and Tarawa were projected for the years 2025, 2050 and 2100 using the PACCLIM Scenario Generator. Two greenhouse gas (GHG) emission scenarios were used: the Special Report on Emission Scenarios (SRES) B2 mid (climate sensitivity of 2.5^{o} C), and the SRES A2 high (climate sensitivity of 4.5^{o} C) scenario. These correspond to the "best-guess" and "worst-case" scenarios described in this report.

The study adopted the results from two different GCMs. The first of these is known as the 9 Layer Global Circulation Model of Australia's Commonwealth Scientific and Industrial Research Organization, or CSIROM2 (Gordon and O'Farrell 1997) which has been scrutinized and validated for the South Pacific region. The second GCM chosen was the Deutsche Klimarechenzentrum (German Climate Monitoring Center) DKRZ, developed by Cubasch and others (1992). PACCLIM also included two other models, the Canadian Climate Centre and the Hadley Center GCMs. However, these models agree with CSIROM2 in projecting rainfall increases. The DKRZ model, by contrast, projects a decrease in rainfall. Given the importance of droughts for Pacific Island countries, the DKRZ model was chosen along with the CSIROM2 to represent the range of possible impacts resulting from rainfall changes. The resulting scenarios of temperature and rainfall change for Fiji and Kiribati are shown on tables A.1 and A.2.

Table A.1. Summary of Temperature and Rainfall Change Scenarios for Fiji

General Circulation Model	*Emissions Scenario*	*2025*		*2050*		*2100*	
		Temp (°C)	*Rainfall (%)*	*Temp (°C)*	*Rainfall (%)*	*Temp (°C)*	*Rainfall (%)*
CSIROM2	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

Table A.2. Summary of Temperature and Rainfall Change Scenarios for Kiribati

General Circulation Model	*Emissions Scenario*	*2025*		*2050*		*2100*	
		Temp (°C)	*Rainfall (%)*	*Temp (°C)*	*Rainfall (%)*	*Temp (°C)*	*Rainfall (%)*
CSIROM2	B2 (mid)	0.5	2.8	0.9	5.0	1.6	8.4
	A2 (high)	0.6	3.2	1.3	7.1	3.4	17.7
DKRZ	B2 (mid)	0.5	-4.3	0.9	-7.5	1.6	-12.8
	A2 (high)	0.6	-4.8	1.3	-10.7	3.3	-26.9

Sea Level Rise

Confidence in GCM projections of sea level rise at the regional level remains low. There is also limited long-term historical data at the country level. Accordingly, global mean projections of sea level rise were used as first order estimates for the analysis (table A.3). This was carried out by using a global climate model, the Model for the Assessment of Greenhouse Gas Induced Climate Change, or MAGICC (Wigley 1994) in the linked model system of PACCLIM.

Table A.3. Summary of Global Sea Level Rise Projections

Scenario	*2025*	*2050*	*2100*
B2 (mid-range, best guess)	11 cm	23 cm	50 cm
A2 (high-range, worst case)	21 cm	43 cm	103 cm

Climate Variability: Changes in Cyclones and ENSO

Because the GCMs do not yet account for ENSO variability or changes in the frequency or magnitude of extreme climate events, analogues based on recent patterns of occurrence were used to analyze the potential impact of future events in Fiji. Kiribati lies outside the cyclone path, and there was insufficient information to quantify the impact of ENSO-related droughts or floods beyond qualitative statements.

Cyclones. A recent review of climate variability in the South Pacific area (Jones and others 1999) projects an increase in cyclone intensity of 0 to 20 percent by mid-century. This increase in cyclone intensity was applied to baseline conditions derived from the sequence of actual cyclone events in Fiji from 1992 to 1999. No changes were assumed in cyclone frequency.

ENSO. Existing regional research (Jones and others 1999) predicts that average conditions in the future will increasingly resemble a present-day El Niño. For Fiji, the frequency of El Niño-induced droughts in 1983-98[1] —one drought every four years—and an intensity comparable to that of the 1997/98 drought were used to represent future climate conditions.

Socio-Economic Scenarios

Given the high level of uncertainty associated with future socio-economic conditions, the economic costs of climate change were estimated based on the likely economic impacts of 2050 scenarios *as applied to today's (1998) conditions*. While this approach is likely to underestimate the magnitude of future

[1] The use of the 1983-98 period was largely based on the availability of sugarcane data for the period.

impacts, it provides policy makers with an estimate that is closer to the present-day reality that surrounds them. An exception to this principle was made for health impacts, which are closely related to population size. The economic impacts on health were computed by taking into account population projections for 2050 (tables A.4 and A.5).

Table A.4. Population Projections for Fiji

Growth Rate Projection	*2026*	*2051*	*2096*
Low	1,110,000	1,260,000	1,280,000
Medium	1,180,000	1,480,000	1,720,000
High	1,210,000	1,620,000	2,300,000

Note: Assumes an on-going reduction in total fertility rate, gradual increases in life expectancy and decreasing infant mortality rates. Migration patterns have not been included in the projections. Projections are based on the 1996 census and were developed using SPECTRUM Policy Modeling System (Version 1.33) demographic software (Futures Group International, USA). Numbers are rounded to the nearest 1000.

Table A.5. Population Projections for Kiribati

Growth Rate Projection	*2025*	*2050*	*2100*
Low	128,000	154,000	165,000
Mid-range	139,000	187,000	246,000
High	146,000	215,000	351,000

Note: Projections are based on the 1995 census data and have been developed using SPECTRUM demographic software.

All costs were reported in 1998 US dollar values. Data for different years were converted into 1998 values by appropriate price indeces (such as producer or consumer price indeces). The costs represent annual average losses due to climate change and/or future climate variability. When ranges are given, they reflect a best-guess (the lowest value) and a worst-case scenario (the highest value).

The economic costs assume no adaptation. In practice, communities are likely to undertake adaptation measures to protect against climate change impacts. Hence, the costs presented in this analysis should be interpreted as what could happen under a policy of inaction. The economic estimates are also partial and do not take into account secondary interactions. For example, climate change is not only likely to affect water resources, but could also decrease economic production. This could in turn lead to a lower water demand than what would be expected in the absence of climate change. The nature of these interactions, however, is too complex and uncertain to be included in the analysis.

The use of annual average costs mask the actual impact of climate events in a given year. For example, if droughts of severity A happened every four years, the annual average cost would be one-fourth of the costs of A. But for a disaster year, the impact would be A , or four time as high as the annual average. In order to illustrate this, the summary tables for Viti Levu and Tarawa include both the average annual damages as well as the likely costs of an extreme event.

For periodic events affecting major infrastructure—such as the impacts of sea level rise on coastal areas—the annualized value of the losses was estimated using the capital recovery factor of infrastructure and land. This factor is estimated as follows (Gittinger 1982):

$$\frac{[i(1+i)^n]}{[(1+i)^n - 1]}$$

where i = rate of interest (assumed to be 10 percent) and n = number of years when losses can accrue.

Uncertainties

The development of climate change scenarios is fraught with uncertainties. The uncertainties become even greater as one seeks to identify impacts resulting from the projected climate and sea-level changes. For small island states the uncertainties are further magnified as the areas of the countries usually fall below the levels of resolution of global circulation models.

As one moves from the general to the more specific, the level of certainty decreases. A major problem with climate impact assessment is that many impacts are site specific, depending on the shape of a beach, the conditions of a watershed, the level of existing environmental degradation, the crops a farmer plants or the socio-economic conditions of a given locality. Accordingly, adaptive action, when implemented, will need to be carried out with the specific impacts in mind. For this reason, choosing specific adaptive actions is problematic until greater certainty in impact assessment is achieved. Nevertheless, one can point to some generic sets of impacts and a range of broad adaptive approaches to them. This was the approach taken in this report.

The levels of predictive certainty also recede as attention is focused further into the future. It is perhaps no exaggeration to state that developing scenarios of social and economic conditions one century into the future is even more difficult than projecting climate and sea-level conditions.

It is not possible to place clear statistical boundaries to the uncertainties inherent in the vulnerability and adaptation studies. The accompanying box, however, summarizes the uncertainties in the study. Uncertainties associated with the economic analysis are included in the summary tables of Viti Levu (table 3, Chapter 3) and Tarawa (table 12, Chapter 4). The assumptions used are clearly delineated in this Annex to enable replication of the results, application to other studies, and corrections in the original analysis should improved assumptions become available in the future.

Box A.1. Summary of Uncertainties

Relative Level of Certainty

Base scenarios

- Temperature
- Rainfall
- Extreme events
  - drought
  - tropical cyclones
  - ENSO events
  - Sea level
  - Socio-economic

Impact scenarios

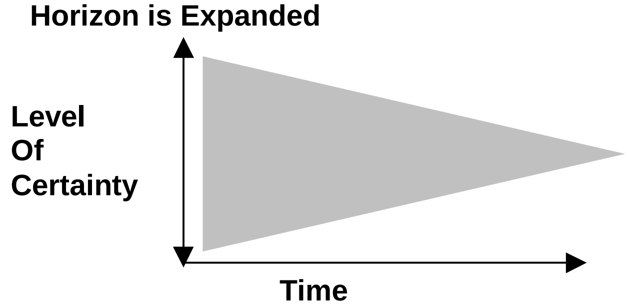
- Coastal
- Water Resources
- Agriculture
- Health

- **Adaptive Responses**
  - Generic
  - Sector specific
  - Site specific

Key: Level of Certainty

High **Medium** **Low**

Reduced Certainty As Predictive Horizon is Expanded



B. Impacts on Coastal Areas

General

The analysis of impacts on the Viti Levu and Tarawa coasts involved the following:

- *Selection of case study sites,* representative of the coastal types found in the islands.
- *Transect surveys* on each study site.
- *Assessment of Island Shoreline Displacement (Erosion analysis)* using the Shoreface Translation Model.
- *Assessment of Island Inundation,* using topographic maps.
- *Assessment of Land and Infrastructure* impacted by inundation.
- *Extrapolation of case study sites* to the remainder of the islands.
- *Economic analysis of land and infrastructure losses***,** comparing 2050 conditions with the baseline.

Selection of Case Study Sites

In both Viti Levu and Tarawa, case study sites were selected to represent the broad physical and socio-economic conditions found in the islands. The case study sites─two in Tarawa, and four in Viti Levu─were selected based on morphology, biological characteristics, population density, and land-use. The selection involved the PICCAP country teams of Fiji and Kiribati, as well as specialists from IGCI.

Transect Surveys

In each site, 2-3 representative transects were surveyed for the erosion analysis, from the reef edge and across the islands (in Tarawa) and across the coastal margin (in Viti Levu).

Assessment of Island Shoreline Displacement (Erosion Analysis)

The analysis of island shoreline displacement (erosion analysis) was based on the Shoreface Translation Model (STM), adapted to the conditions of Tarawa and Viti Levu under rising sea levels (Cowell et al. 1995, Kench and Cowell 1999). This model incorporates elements of both the Standard and Generalized Brunn Rules,[2] as well as hybrids of the two, but goes further in allowing for time-varying morphological dimensions (such as shoreface) and sediment gains and losses (such as those due to littoral sand transport).

Simulations of shoreline recession and changes to the coastal morphology were undertaken for 0.1 meter increments of sea level rise (figure A.2). The simulations assumed the following:

- A balanced sediment budget (no additional gains or losses) under present conditions and conditions of sea level rise. This assumption is unlikely to hold for the Rewa river delta site in Viti Levu or for significant rises in sea level (0.5 meters or more). However, no data were available on sediment discharge rates or possible changes in sediment transport with sea level rise.

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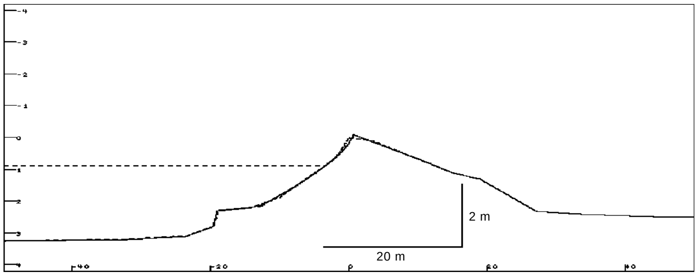
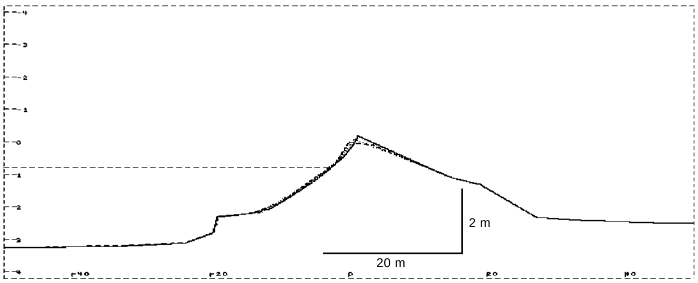
[2] The Standard Brunn Rule is the most common method for assessing shoreline change (Solomon 1997). However, this rule applies to steep substrates and is not appropriate to low-lying atolls. The Generalized Brunn Rule, by contrast, allows for sub-aerial beach dune and lagoon to move upward as an equilibrium response to sea level rise, and is more appropriate to atoll conditions.

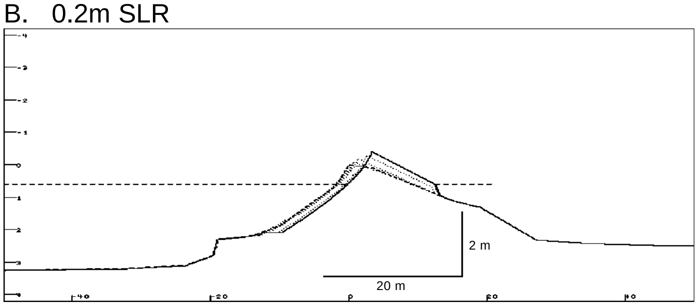
Figure A.2. Simulation of Shoreline Retreat After Varying Rates of Sea Level Rise in a transect of Buariki, North Tarawa, Kiribati



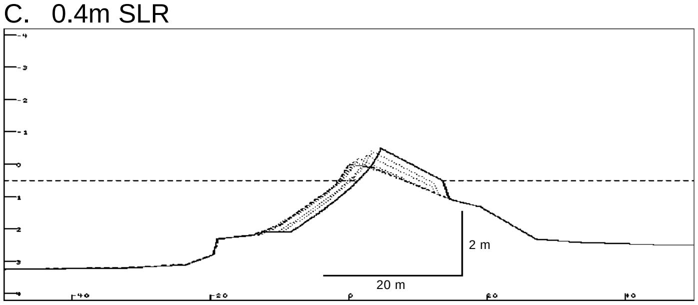
A. 0.1m SLR



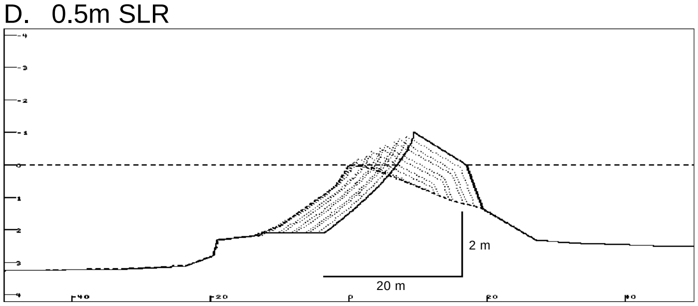
B. 0.2m SLR



C. 0.4m SLR



D. 0.5m SLR



E. 1.0m SLR

Sea-Level Rise	*Shoreline Recession (m)*
0.1	0.6
0.2	1.2
0.3	2.6
0.4	3.2
0.5	4.5
0.6	5.2
0.7	6.5
0.8	7.2
0.9	8.4
1.0	9.5

- For Tarawa, hard surfaces (either reef flat or conglomerate platform) were assumed to extend horizontally under sand island and truncate the shoreline profile.
- For Tarawa, the uppermost hard substrate (conglomerate platform or reef surface) was assumed to extend horizontally beneath the sand island from the point at which it is buried by the beach-sediment lens.
- For Viti Levu, based on anecdotal evidence of storm inundation, washover of the coastal margin was allowed in the model (up to 50 meters), allowing for deposition of sediment on the island surface.

Assessment of Island Inundation (Inundation Analysis)

The inundation analysis was done using a simple drowning concept. For Viti Levu, topographic maps had too coarse a scale (20 meter intervals) to be used. Therefore, field surveys of elevation and aerial photographs were used to construct maps with 1 meter contours along sections of the coast at each case study site. For Tarawa, the survey team used topographic maps supplied by the Land Management Division, which contained 1 meter contours with all surveyed structures and road systems clearly marked.

To determine baseline conditions, the Mean High Water Spring tide level (MHWS) was determined using data from the Suva tide gauge in Viti Levu (MHWS=0.64 meters), and from the National Tidal Facility in Tarawa (MHWS=2.53 meters). A second baseline was constructed by adding the impact of periodic storm surges to the MHWS, based on historical records of water levels and the frequency of these storms. For Viti Levu, a 1 in 50 year storm surge level causing a surge of 0.98 meters (Solomon and Kruger 1996) was added to the MHWS, producing a baseline — with storm surge — of 1.62 meters. For Tarawa, a 1 in 14 year storm surge causing a surge of 0.88 meters (Solomon 1997) was used, producing a baseline — with storm surge — of 3.41 meters.

The inundation analysis was performed by raising the MHWS level by different sea level rise increments, corresponding to the scenarios of sea level rise (table A.9), and sea level rise with storm surge. The analysis assumes no change in the level of MHWS. It was also assumed that the frequency of storms would not increase under sea level rise. This is a very conservative assumption, as an increase in cyclone intensity could lead to more storms surpassing the baseline storm surge conditions. However, the effects of more intense cyclones are already accounted for in the water resources analysis of Viti Levu. The estimate of climate change impact also does not take into account other potential major events, such as a 1 in 100 year storms. Finally, the analysis assumes that the islands' surface remains static, such as what would happen in Tarawa if sediment redistribution on top of the islands was prevented.

Assessment of Land and Infrastructure Impacted by Erosion and Inundation

In Viti Levu, the land types and infrastructure likely to be impacted by erosion and inundation at the survey sites were estimated from aerial photography and field surveys. In Tarawa, the land and infrastructure likely to be inundated was calculated from the maps provided by the Land Management Division. Due to the quality of the maps the type of structure could not be determined.

Extrapolation of Case Study Sites to Viti Levu and Tarawa Atoll

In order to determine the impact on the whole islands, the results of the case study sites had to be extrapolated. In Viti Levu, the extrapolation was based on the length of coast sampled relative to the total length of coast for that land type. Given the morphology of Viti Levu — a high island — an extrapolation by area (rather than length of shoreline) would have require a judgment of which altitude is considered "coastal". For Tarawa, an extrapolation by area was possible due to the low altitude of the atoll (where most of the land is coastal).

Economic Analysis of Land and Infrastructure Losses

The analysis of land and infrastructure structures lost to erosion and inundation was based on the extrapolated values (above), and the difference between sea level rise conditions and the baseline. Thus, a sea level rise of 0.4 meters (the worst case scenario for 2050) was compared to current conditions of MHWS. A sea level rise of 0.4 meters with storm surge was compared to current conditions with storm surge. These two results were then weighted by the frequency of storm surge. For Kiribati, for example, the impact of sea level rise without storm surge was assumed to occur in 13 out of 14 years. The impact of sea level rise with storm surge was assumed to occur once every 14 years (reflecting the present frequency of storms).

The economic value of land and infrastructure should reflect the value of their potential future use. Under perfect market conditions, the economic value of land should resemble its market price. This may not hold in Kiribati, however, as most land is not freely traded. For lack of economic estimates, the market value of structures and land — as provided by Government agencies — was used in the Tarawa analysis. For Viti Levu, where more economic data were available, the cost of land lost reflects its economic value.

In the Tarawa analysis, it was assumed that all land and infrastructure affected by inundation would be lost. This may be overly pessimistic. However, it should be remembered that the analysis assumes that in 13 out of 14 years, inundation is caused solely by sea level rise (and not by storm surge). This progressive rise in sea level is a form of permanent inundation which is likely to destroy the existing structures in the absence of adaptation. In Viti Levu, only land was considered to be lost in its entirety, while structures were considered to be only partially lost due to construction standards that already account for periodic inundation.

The economic value of land and infrastructure reflects the capital value of a stock. In order to compute the annualized losses, the capital value needs to be adjusted by a capital recovery factor that reflects losses to depreciation and the way the population values present-day assets. An interest rate of 10 percent was used for both Viti Levu and Tarawa. Viti Levu structures were assumed to last 25 years, while Tarawa structures were assumed to last 10 years based on current construction standards.

Viti Levu

Impact of Erosion Caused by Climate Change on Viti Levu's Coast

A. Physical Impact of Coastal Erosion due to Sea Level Rise

The coast of Viti Levu is approximately 750 km long. Using a 1:50,000 topographic map, the coast was divided into four broad categories of land types representing about 90 percent of the total coast (table A.6). The remaining area (not sampled) consists primarily of sand spits and small deltas.

Table A.6. Division of Viti Levu Coast into Land Types

Coastal Type	*Length of Coast (in km)*	*% of Total Coast Represented*	*Case Study Site*	*Length of Coast of Case Study Site (in km)*
Southern coast: Narrow coastal plain, high tourism area, overlying fringing reef	170	28	Korotogo	0.44
Northern coast: Mangrove fringed coast bordered by barrier reef. High density sugarcane plantations.	281	47	Tuvu	1.0
Urban areas: Suva, Lautoka, Lami, Nadi	37	5	Suva Peninsula	5.575
Rewa river delta: Southeast Viti Levu. Low-lying delta with mangrove systems	78	10	Western Rewa river delta	1.0
Total	**566**	**90**		

The erosion analysis used three of the case study sites: Korotogo, Tuvu, and Rewa river delta. The urban center of Suva was not chosen for this analysis as the center is almost entirely protected by seawalls and the shoreline would not respond naturally to erosion processes. The analysis involved three key steps:

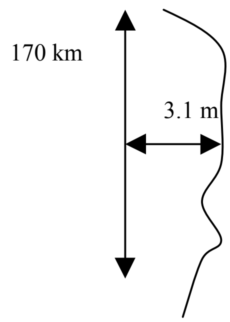
Step 1. Estimate Potential Shoreline Retreat for Case Study Sites. The estimated potential erosion for all three case study sites is shown on table A.7, as obtained through the Shoreline Translation Model.

Step 2. Extrapolate Erosion to the Rest of the Coast. To estimate the impact of sea level rise on whole coast of Viti Levu, the potential shoreline retreat at the case study sites was multiplied by the length of coast that each study site represented.

Table A.7. Potential Shoreline Retreat in Viti

Sea Level Rise (meters)	*Potential Shoreline Retreat (in meters)*		
	Korotogo	*Tuvu*	*Rewa*
0.1	0.6	6.7	50.0
0.2	1.3	9.0	112.2
0.3	1.9	10.6	181.7
0.4	3.1	11.5	250.7
0.5	3.7	12.9	318.6
0.6	4.9	15.9	385.6
0.7	5.5	18.2	451.8
0.8	6.7	21.4	517.1
0.9	7.3	25.5	581.9
1.0	8.5	29.1	645.6

Example: For a sea level rise of 0.4 meters, the extrapolated shoreline retreat for the southern coast (represented by Korotongo) is:



3.1 meters x 170 kilometers (or 170,000 meters) = ***527,000 square meters or 53 hectares.***

The extrapolated land lost to erosion for other rises in sea level and land types is as shown on table A.8 (the shaded cell corresponds to the example above). Adding all three coastal land types, the total land lost to erosion is estimated at 590-1,150 hectares in 2025, 1,150-2,330 hectares in 2050, and 2,910-6,000 hectares in 2100 (numbers are rounded).

Step 3. Estimate Proportion of Coastal Land that is Lost to Erosion. The total area of coastal land in Viti Levu that is below 10 meters is 600 square kilometers, or 60,000 hectares. Dividing the area lost to erosion by this figure, the percentage of coastal land below 10 meters lost to erosion is 1-2 percent in 2025, 2-4 percent in 2050, and 5-10 percent in 2100 (see last shaded row on table A.8).

Table A.8. Estimated Coastal Retreat, Land Eroded and Value of Eroded Land for Viti Levu

Sites	*Estimate*	*2025*		*2050*		*2100*	
		Best guess	*Worst case*	*Best guess*	*Worst case*	*Best guess*	*Worst case*
	Sea level rise	*0.1*	*0.2*	*0.2*	*0.4*	*0.5*	*1.0*
Southern Coast	Potential retreat (in meters) at Korotogo	0.6	1.3	1.3	3.1	3.7	8.5
	Extrapolated land eroded (in hectares)	10	22	22	53	63	145
	Value of eroded land (in US$ million)	0.2	0.4	0.4	1.0	1.2	2.8
Northern Coast	Potential retreat (in meters) at Tuvu	6.7	9.0	9.0	11.5	12.9	29.1
	Extrapolated land eroded (in hectares)	188	253	253	323	362	818
	Value of eroded land (in US$ million)	4.3	5.8	5.8	7.3	8.2	18.6
Rewa Delta	Potential retreat (in meters) at Rewa	50.0	112.2	112.2	250.7	318.6	645.6
	Extrapolated land eroded (in hectares)	390	875	875	1,955	2,485	5,036
	Value of eroded land (in US$ million)	8.9	19.9	19.9	44.5	56.5	114.5
Total	Extrapolated area eroded (in hectares)	588	1,150	1,150	2,331	2,910	5,999
	Percentage of coastal land (below 10 meters)	1	2	2	4	5	10
	Value of eroded land (in US$ million)	13.3	26.1	26.1	52.8	66.0	136.0

Example: Total area lost to erosion in 2050 (1,150 to 2,331 hectares) / 60,000 hectares = 1.9-3.9 or 2-4%.

B. Economic Impact of Coastal Erosion due to Sea Level Rise

The economic losses due to erosion can be estimated in three key steps:

Step 1: Estimate the Economic Value of a Hectare of Land Lost. This analysis starts by assessing the land types likely to be lost to erosion, and estimating their economic value per hectare. The economic value of land is equal to the expected value of its future use. The two major types of land use found in the study sites are mangroves (Tuvu and Rewa) and tourism and habitation (Korotogo):

Korotogo	high value, tourism and habitation use (southern coast)
Tuvu	mangrove land
Rewa delta	mangrove land

1.1. Economic Value of Mangrove Land: the economic value of mangrove land is the present value of its use and ecological functions (both present and future). In Viti Levu, mangroves are important as a source of subsistence and commercial fisheries, medicinal plants, and raw materials such as firewood. Mangroves are also important habitats for numerous species, and play key roles in coastal protection.

- ***Annual Value of Subsistence Fishing***. There is no official estimate of the value of subsistence fisheries in Fiji, though its volume is estimated at about 18,000 metric tons a year (FFD 1999). Estimates from this report (see Table 3.1, Volume I) indicate a value of F$7.7-$13.3 million a year, but this reflects only its value to food security. By lack of a better estimate, one can multiply the volume of subsistence fisheries by the average value of artisanal fisheries (F$3.0/kg), as reported by the Fisheries Division yearbook (FFD 1999), yielding an estimate of F$53.5 million in 1998.

  From discussions with Fisheries Division experts, mangroves are assumed to account for 35-40 percent of the coastal fisheries production.

  Viti Levu accounts for 58 percent of the land area in Fiji and for 77 percent of its population. It is therefore assumed that Viti Levu accounts for 58 to 77 percent of Fiji's mangrove fisheries. The higher estimate (77 percent) is justified by the fact that mangrove use is affected by population pressure and Viti Levu, as a high island, has a larger proportion of Fiji's mangroves than other islands. Thus:

  F$53.5 million x 35-40 % x 58-77 % (adjustment for Viti Levu) = F$10.9 to F$16.5 million

  The total area of mangroves in Viti Levu is estimated at 23,500 hectares (Watling 1985). Hence, the annual value per hectare of subsistence fisheries associated with mangroves is estimated to be:

  (F$10.9 to F$16.5 million) / 23,500 hectares = ***F$464 to F$702 per hectare per year***

- ***Annual Value of Commercial Fishing.*** The Fisheries Division yearbook lists the value of artisanal fisheries catch in 1998 at F$20.7 million (FFD 1999). Industrial fisheries are not counted here, since they include primarily offshore (tuna) fishing. Using the same assumptions as for subsistence fisheries, the value of mangroves associated with commercial fishing is:

  F$20.7 million x 35-40% x 58-77 % (adjustment for Viti Levu) = F$4.2 to F$6.4 million

  F$4.2 to F$6.4 million / 23,500 hectares = ***F$179 to F$272 per hectare per year***

- ***Annual Value of Medicinal Plants.*** The value of mangroves as a source of medicinal plants is estimated at about US$200 a year per rural household in accordance with a previous worldwide study (Constanza and others 1997). Using a 1998 exchange rate of 1US$=1.96 F$, this yields a value of F$392 per rural household per year.

  The total number of households in Fiji in 1991 was 136,363 according to UNDP (1997). Using the population growth rate for Fiji and assuming no change in average household size, the number of households in 1998 is estimated at about 144,185 in 1998. Assuming that 77 percent of these households are in Viti Levu (in accordance with the total population distribution), and that 60 percent are rural households:

  144,185 x 77 % (for Viti Levu) x 60 % (rural households) = 66,613 rural households in Viti Levu.

  Assuming that 40 to 60 percent of medicinal plants originate from mangroves:

  66,613 x F$392 x 40-60 % = F$10.4 to F$15.4 million

  Converting this value into a per hectare value yields:

  (F$10.4 to F$15.4 million) / 23,500 hectares = ***F$442 to F$655 per hectare per year.***

- ***Annual Value of Raw Materials.*** Mangroves are an important source of fuelwood and construction materials. Based on a worldwide review by Contanza et al. (1997), the annual value of raw materials are estimated at around ***F$349 per hectare per year.***

- ***Annual Value of Habitat Functions.*** Mangroves support important biodiversity. Based on a study for Thailand conducted by Christensen (1982), the annual value of habitat functions are estimated at around ***F$308 per hectare per year***.

- ***Annual Value of Coastal Protection.*** Mangroves help trap sediments, protecting the coast against erosion. The value of coastal protection in Fiji was estimated by Sistro (1997) at ***F$2,896 per hectare per year.***

The total annual value of mangrove land is therefore:

(F$464 to $702) + (F$179 to $272) + (F$442 to $655) + F$349 + F$308 + F$2,896 = F$4,638 to F$5,182 per hectare per year

Converting to US dollars (1 US$ = F$1.96 in 1998) / US$2370-$2,644 per hectare per year

Or an average of ***US$2,505 per hectare per year.***

It is assumed that on eroded land the entire value of mangroves is lost. This assumption seems reasonable from discussions with experts (note, however, that the assumption does not hold for inundated land, where a net gain in mangrove area may be possible as a result of climate change).

The economic value of mangrove land lost to erosion needs to take into account the opportunity value of the land, or the stream of benefits that would occur in the future if the land was not lost to erosion. In general, people value future benefits less than present-day benefits. The value today of a stream of future benefits is called the ***Present Value,*** and the rate at which people discount future benefits is called the ***discount rate***. In perfect markets, the discount rate is equal to the opportunity cost of capital, around 10 percent. Assuming that the stream of annual benefits would continue for 25 years,[3] the present value of mangrove land lost to erosion is as follows:

Present Value (10 % discount rate, 25 years, US$2,505 per hectare per year) = ***US$22,738 per hectare.***

1.2. Economic Value of Land in Southern Coast. The economic value of land in the Southern coast was derived from estimates made by Beagley (1998) for a 150 hectare tourism development site in southern Viti Levu, and checked against the prices of real estate as listed in the web sites of various agents (namely Fiji Real Estate 2000). The estimates are as follows:

F$507,000 per hectare for resort development areas (7 percent of the land)
F$41,825 per hectare for land adjacent to roads (17 percent of the land)
F$5,436 per hectare for agriculture land (76 percent of the land)

The value of resort development land is roughly similar to its residual value taking into account future use and therefore represents its economic value. Weighing the values of land by the area they represent (and rounding off the numbers) gives a weighted average value of:

(F$507,000 x 7 %) + (F$42,000 x 17%) + (F$5,500 x 76%) = F$46,810 per hectare.

These estimates are based on freehold land, which can be sold. Up to 91 percent of the land in Viti Levu, however, is held under customary tenure and can only be leased. Leased land costs generally 20 percent less than freehold land (Robert Gillett, personal communication, May 2000). Thus, an additional adjustment is needed:

(F$46,810 per hectare x 9 %) + [80 % x (F$46,810 per hectare x 91%)] = F$38,300 per hectare
freehold land (9%) *crown or native lease (91%)*

Converting into US dollars (at US$1 = F$1.96 in 1998), gives an estimate of ***US$19,600 per hectare***

The higher value of mangrove land as compared to land in the southern coast reflects economic values that are not taken into account in market transactions, such as the protection, habitat, and subsistence value of mangroves.

Step 2: Estimate the Economic Value of Land lost to Erosion. With the two estimates of economic value, US$22,738 per hectare for mangrove land in Tuvu and Rewa delta, and US$19,600 per hectare for the southern coast, one can easily derive the economic value of eroded land (table A.8).

Example: Table A.8 shows that by 2050, under the worst case scenario, the southern coast will lose 53 hectares of land. At a value of US$19,600 per hectare, the economic losses are estimated at:

53 hectares x US$19,600 per hectare = US$1.0 million

For the northern coast, under the same assumptions of sea level rise, 323 hectares of land could be lost. At a value of US$22,738 per hectare, the economic losses could total:

323 hectares x US$22,738 per hectare = US$7.3 million

By adding the economic impacts on the three land types, the estimated economic losses due to erosion for Viti Levu amount to US$13.3-$26.1 million in 2025, US$26.1-$52.8 million in 2050, and US$66.0-$136.0 million in 2100 (table A.8). The lower range reflects a best guess scenario, the higher range a worst case scenario in 2050.

[3] After 25 years, the value today of future benefits would be so small ─ because of the discount rate ─ as to be negligible.

Step 3: Estimate the Annualized Value of the Losses. The last step in the economic analysis involves calculating the annualized losses. This can be estimated through the capital recovery factor:

$[i(1+i)^n] / [(1+i)^n -1]$ where i = rate of interest (10 percent) and n = number of years when losses can accrue. In the case of Viti Levu, n was assumed to be 25 years.

Hence, $[i(1+i)^n] / [(1+i)^n -1] = [0.1(1.1)^{25}] / [(1.1)^{25} -1] = 0.11$

Applying this factor to the capital losses gives annualized losses of:

0.11 x US$13.3-$26.1 million =	***US$1.5 to $2.9 million (in 2025)***
0.11 x US$26.1-$52.8 million =	***US$2.9 to $5.8 million (in 2050)***
0.11 x US$66.0-$136.0 million =	***US$7.3 to $15.0 million (in 2100)***

While the erosion analysis was based on profiles that represented large sections of the coast, caution is needed in interpreting the extrapolations, as the topography of Viti Levu varies greatly. Nonetheless, the extrapolated values provide an order of magnitude estimate of potential impacts due to climate change.

Impact of Inundation Caused by Climate Change on Viti Levu's Coast

A. Physical Impact of Inundation due to Sea Level Rise

The inundation analysis was carried out in three sites: Tuvu, Korotogo and Suva Peninsula. The Rewa river delta was excluded due to the difficulty of separating natural flooding from sea level rise over very low gradient delta surfaces. The analysis of physical impacts involved six steps:

Step 1: Determine Baseline Conditions. The Mean High Water Spring (MHWS) tide level in Viti Levu is 0.64 meters. A 1 in 50 year storm surge can increase MHWS by 0.98 meters, to a total of ***1.62 meters***.

Table A.9. Water Level under Baseline Conditions and Sea Level Rise in Viti Levu, Fiji

Water Level (in meters)	*Equivalent Scenario*
0.64	1998 Baseline MHWS
0.75	2025 Best Guess
0.87	2025 Worst Case 2050 Best Guess
1.10	2050 Worst Case 2100 Best Guess
1.67	1998 Baseline MHWS + storm surge[a] 2100 Worst Case 2025 Best Guess + storm surge
1.85	2025 Worst Case + storm surge 2050 Best Guess + storm surge
2.12	2050 Worst Case + storm surge 2100 Best Guess + storm surge

Notes: Current (baseline conditions) of sea level are shaded.
[a] The baseline with storm surge is 1.62 meters, but it approximates the conditions under the other scenarios.

Step 2: Estimate Projected Changes in Water Level under Sea Level Rise. The water levels for the different sea level rise scenarios are as given in the first column of table A.9.

Step 3: Estimate the Area of Inundated Land. For each of the three case study sites, the potential inundation was estimated by raising the MHWS by sea level rise increments and estimating the land affected by inundation. The results are shown in table A.10.

Step 4: Estimate the Number of Structures. The number of buildings, extent of roads, mangrove and sugarcane land, and railway affected by potential inundation were counted and estimated for each of the case study sites (see table A.10). These include buildings and roads (in the Suva Peninsula), and mangrove, sugarcane plantations, and railways in Tuvu. In Korotogo, only land is expected to be affected.

Table A.10. Potential Inundation at Case Study Sites, Viti Levu

Water Level (m)	*Scenario*	*Suva Peninsula* Land (m^2)	*Suva Peninsula* Buildings (no.)	*Suva Peninsula* Roads (m)	*Korotogo* Land (m^2)	*Tuvu* Land (m^2)	*Tuvu* Mangrove (m^2)	*Tuvu* Sugarcane (m^2)	*Tuvu* Railway (m)
0.64	1998 Baseline MHWS	–	–	–	–	–	–	–	–
0.75	2025 Best Guess	15,000*	–	–	–	5,000[a]	5,000[a]	–	–
0.87	2025 Worst Case 2050 Best Guess	38,705	–	–	1,570	10,066	10,066	–	–
1.10	2050 Worst Case 2100 Best Guess	60,581	–	–	2,457	120,793	120,793	–	–
1.67	1998 Baseline MHWS + storm surge 2100 Worst Case 2025 Best Guess + storm surge	475,441	87	5,943	4,662	264,568	192,310	–	–
1.85	2025 Worst Case + storm surge 2050 Best Guess + storm surge	572,035	112	6,126	5,397	266,051	192,310	–	–
2.12	2050 Worst Case + storm surge 2100 Best Guess + storm surge	668,628	137	6,310	6,132	267,535	192,310	1,845	1,000

Notes: a. Estimate only. When the difference in water levels of two scenarios were too close to allow for determination of changes in inundation, the scenarios were combined and the highest water level was depicted.

Step 5: Extrapolate for Viti Levu. The linear length of coast for each of the sites surveyed is as follows:

Tuvu - 1,000 meters or 1.0 km
Korotogo - 440 meters or 0.44 km
Suva Peninsula - 5,575 meters or 5.575 km

To extrapolate the case study sites to Viti Levu, the inundation values of table A.10 were first converted into inundation per linear kilometer of coast by dividing them by the length of coast of the study sites.

Example: For a 2050 Best Guess scenario, the inundation per linear kilometer of coast for the Suva Peninsula is:

38,705 m^2 / 5.575 kilometers = 6,942 m^2 inundated per linear kilometer of coast

For Korotogo, under the same scenario:

1,570 m^2 / 0.44 kilometers = 3,569 m^2 inundated per linear kilometer of coast

For Tuvu, under the same scenario:

10,066 m^2 / 1.0 kilometers = 10,066 m^2 inundated per linear kilometer of coast

Second, the inundated areas were extrapolated to the length of coastline that the case study sites represent (table A.6).

Example: For the same scenario above, the extrapolated land inundation in hectares for urban areas of Viti Levu is:

6,942 m^2 per linear kilometer of coast x 37 kilometers = 256,854 m^2 or 25.7 hectares.

For Korotogo:

3,569 m^2 per linear kilometer of coast x 170 kilometers = 606,730 m^2 or 60.7 hectares.

For Tuvu:

10,066 m^2 per linear kilometer of coast x 281 kilometers = 2,828,546 m^2 or 282.9 hectares.

A similar extrapolation can be done for structures. For example, for a 2050 Best Guess scenario with storm surge in Suva:

112 buildings / 5.575 kilometers = 20 buildings per linear kilometer of coast

and extrapolating to all urban areas:

20 buildings per linear kilometer of coast x 37 kilometers = 742 buildings (with rounding).

The final results of this extrapolation can be seen on table A.11. In Tuvu, to allow for an estimate of the value of land not under mangrove or sugarcane use, a new category was created entitled "other land." This is equal to *Total Land - Land under Mangrove - Land under Sugarcane.*

Table A.11. Potential Inundation Extrapolated to Viti Levu

Water Level (m)	*Scenario*	*Urban Areas*			*Southern Coast*	*Northern Coast*			
		Land (ha)	*Buildings (no.)*	*Roads (km)*	*Land (ha)*	*Mangrove (ha)*	*Sugarcane (ha)*	*Other Land (ha)*	*Railway (ha)*
0.64	1998 Baseline MHWS	–	–	–	–	–	–	–	–
0.75	2025 Best Guess	10.0	–	–	–	140.5	–	–	–
0.87	2025 Worst Case 2050 Best Guess	25.6	–	–	60.7	282.9			–
1.10	2050 Worst Case 2100 Best Guess	40.1	–	–	94.9	3,394.3	–	–	–
1.67	1998 Baseline MHWS + storm surge 2100 Worst Case 2025 Best Guess + storm surge	314.9	576	39.4	180.1	5,403.9	–	2,030.4	–
1.85	2025 Worst Case + storm surge 2050 Best Guess + storm surge	378.9	742	40.6	208.5	5,403.9	–	2,072.1	–
2.12	2050 Worst Case + storm surge 2100 Best Guess + storm surge	442.8	907	41.8	236.9	5,403.9	51.8	2,113.8	281.0

Note: Estimates may differ slightly due to rounding.

Step 6: Estimate Proportion of Coastal Land that is Inundated. As seen above, the coastal area of Viti Levu below 10 meters altitude is 60,000 hectares. By comparing the total land inundated with this figure, one can estimate the proportion of coastal land (below 10 meters) likely to be inundated by sea level rise. This is simply computed as the ratio between the total land likely to be inundated (the sum of total land inundated for urban areas, and the south and north shores) and the 60,000 hectares of coast that are found at below 10 meters altitude (table A.12).

Example: The proportion of coastal land likely to be inundated under a 2050 Worst Case scenario is:

(40.1 + 94.9 + 3,394.3) / 60,000 = 5.9 percent.

Table A.12 Proportion of Coastal Land Likely to be Inundated by Sea Level Rise

Water Level (m)	*Scenario*	*Total Land Area Inundated (in hectares)*				
		Urban Areas	*South Coast*	*North Coast*	*Total Viti Levu*	*Proportion of Coastal Area Below 10 m*
0.64	1998 Baseline MHWS	–	–	–	–	
0.75	2025 Best Guess	10.0	–	140.7	**150.7**	**0.3%**
0.87	2025 Worst Case 2050 Best Guess	25.6	60.7	282.9	**369.2**	**0.6%**
1.10	2050 Worst Case 2100 Best Guess	40.1	94.9	3,394.3	**3,529.3**	**5.9%**
1.67	1998 Baseline MHWS + storm surge 2100 Worst Case 2025 Best Guess + storm surge	314.9	180.1	7,434.4	**7,929.4**	**13.2%**
1.85	2025 Worst Case + storm surge 2050 Best Guess + storm surge	378.9	208.5	7,476.0	**8,063.4**	**13.4%**
2.12	2050 Worst Case + storm surge 2100 Best Guess + storm surge	442.8	236.9	7,517.7	**8,197.5**	**13.7%**

Note: Total area inundated in north coast equals total area mangrove + total area sugarcane + total other land on table A.11.

B. Economic Impact of Inundation due to Sea Level Rise

This analysis can be done in four major steps:

Step 1: Estimate the economic value of land and structures lost to inundation. The erosion analysis showed how the economic value of land in the southern coast and land under mangroves could be computed. For the inundation analysis, additional estimates are needed for land, buildings and roads in urban areas, and sugarcane and railway values in the northern coast.

1.1 Economic Value of Land in Southern Coast. As estimated before, the economic value of land in the southern coast of Viti Levu is about ***US$19,600 per hectare.*** Because inundation is likely to recur, inundated land is assumed to lose all of its economic value.

1.2 Economic Value of Mangrove Land in Northern Coast. Contrary to coastal erosion, which may lead to a replacement of mangrove species and a net loss, the impact of inundation on mangrove ecosystems is likely to be neutral or even beneficial. Most mangroves should be able to adapt to slow inundation, and the deeper roots resulting from sea level rise could help trap additional nutrients (Andrew Hooten, personal communication, June 2000). Consequently, no major economic losses resulting from inundation of mangroves are expected, and the inundated mangrove land is costed at ***US$0 per hectare***.

1.3. Economic Value of Urban Land. According to a recent survey conducted by Margaret Chung and consultations with a major real estate firm in Suva, the value of developed freehold land in the city averages about F$40,000 per acre, or F$100,000 per hectare. Assuming that only 9 percent of the land is under freehold status, and that non-freehold land sells for 20 percent less, the weighted average value of land is, at 1998 exchange rates (1 US$ = F$1.96):

(F$100,000 x 9%) + [0.8 x (F$100,000 x 91%)] = F$81,800 per hectare / 1.96 = ***US$41,735 per hectare***

It is assumed that the market price of urban land reflects its economic value.

1.4. Economic Value of Urban Buildings. The coastal survey in Fiji was conducted just prior to the coup of May 2000. Subsequently, it has been difficult to obtain accurate estimates of real estate values. Nonetheless, an estimate made by Robert Gillett (Gillett, personal communication, May 2000), indicates the following values for shorefront houses in Suva:

About 1/3 of the houses are of original boxy Indian-style costing approximately F$150,000
About 1/3 of the houses have been rebuild, at values of approximately F$250,000
About 1/3 of the houses are luxurious dwellings worth about F$400,000 each

For the purpose of the analysis, it is assumed that inundation would destroy about 50 percent of the boxy houses, 15 percent of the rebuilt houses, and only about 5 percent of the luxury houses (as these are generally built to withstand storms). Hence:

(F$150,000 x 50%) + (F$250,000 x 15%) + (F$400,000 x 5 %) = F$132,500 or ***US$67,600 per building***.

This estimate is conservative, since it does not take into account the higher value of commercial buildings that could be affected by inundation.

1.5. Economic Value of Urban Roads. According to a JICA proposal (1998), the cost of building a 1.1 kilometer of roadway in a residential area in Nadi was F$330,000 in mid-1997. Road construction and improvements elsewhere were estimated at F$530,000 for 1.5 kilometers of road. These estimates suggest an average cost of road construction of about F$300-$353,000 per kilometer. Adjusting to 1998 values by the housing consumer price index (from IMF reports), yields an estimate of F$314-$361,800 per kilometer or US$160-$184,600 per kilometer.

The impact of inundation on roads is difficult to assess. However, discussions with infrastructure experts suggest that it is not unreasonable to assume a loss of 25 percent of the value of the road, due to the need for higher maintenance and reconstruction. Hence, the economic value of roads lost to inundation is estimated at:

Average of US$160-$184,600 is US$172,300 x 25 % = ***US$43,000 per kilometer of road.***

1.6. Economic Value of Sugarcane Land in Northern Coast. The economic value of sugarcane land depends on the opportunity cost of the land use, in this case sugarcane plantations. It is assumed that inundated land would lose all of its sugarcane production value.

The average production of sugarcane — accounting for possible reductions in yield due to climate change — is 52.7 metric tons per hectare per year (FAO 1996 and study estimates). The price of sugarcane adjusted to 1998 values, was F$75.7 per metric ton. Hence, the value of sugarcane land is:

F$75.7 per metric ton x 52.7 metric tons/ha/year = F$3,987 or ***US$2,034 per hectare per year.***

Similarly to the value of mangrove land in the erosion analysis, it is necessary to compute the future benefit stream of sugarcane production lost as a result of inundation. Using a 10 percent discount rate and a benefit stream of 25 years, the present value of sugarcane land is as follows:

Present Value (US$2,034 per year, 25 years, 10% discount rate) = ***US$18,463 per hectare***.

1.7. Economic Value of Other Land. A significant amount of land in the northern coast does not fit the description of mangrove or sugarcane areas. Unfortunately, no estimates were available of the value of this land. Until better estimates are available, the assumption was made that this land was worth 80 percent of the agricultural land value in the southern coast (F$5,500 per hectare). Hence, the value of the "other land" lost to erosion is:

F$5,500 per hectare x 80 % = F$4,400 or ***US$2,200 per hectare***

1.8. Economic Value of Railways. No data were available to compute the potential impact of inundation on railways. The railways found in the northern shore are most likely used for sugarcane transport, and are only affected under a 2050 worst case scenario or 2100 best guess scenario with storm surge.

Step 2: Estimate the Economic Value of Land and Structures Lost to Inundation. From the calculation above, the value of land and structures lost to inundation is as follows:

Unit values of Land and Structures Lost to Inundation:

Urban land	US$41,735 per hectare
Urban buildings	US$67,610 per structure
Urban roads	US$43,000 per kilometer
Land in southern coast	US$19,600 per hectare
Mangrove land in northern coast	US$0 per hectare
Sugarcane land in northern coast	US$18,463 per hectare
Other land	US$2,200 per hectare
Railway	not computed

These estimates were used to compute the total economic losses due to inundation, by multiplying the unit values by the estimates of land and structures lost on table A.11.

Example:

The urban land lost to inundation under the Best Guess scenario for 2050 is 25.6 hectares. At a value of US$41,735 per hectare, the total loss is 25.6 hectares x US$41,735 per hectare = US$1,068,416 or US$1.1 million.

Step 3: Estimate the Total Economic Loss Caused by Climate Change. The next step in the analysis is to estimate the losses that can be attributed to climate change. For this, it is necessary to compare future conditions with the present baseline. Future conditions with storm surge (SS) need to be compared to the appropriate baseline with storm surge (the second shaded area on table A.13).

Hence, for *a 2050 Best Guess (BG) scenario*, the economic losses due to climate change are as follows:

Without storm surge: 2050 BG - 1998 Baseline MHWS = US$2.3 million
With storm surge: 2050 BG with SS - 1998 Baseline with SS = US$76.4-61.8 million = US$14.6 million

The storm surge conditions reflect a 1 in 50 year storm. Assuming conservatively that there is no increase in storm frequency, conditions without storm surge are likely to occur in 49 out of 50 years. Storm surge conditions would continue to occur in 1 out of 50 years. Hence, the weighted average is:

(US$2.3 million x 49/50) + (US$14.6 million x 1/50) = ***US$2.5 million***

Table A.13. Economic Value of Land and Structures Lost to Inundation in Viti Levu (millions of 1998 US$)

Water Level (m)	*Scenario*	*Urban Areas*			*Southern Coast*	*Northern Coast*			*Total Losses*
		Land	*Buildings*	*Roads*	*Land*	*Mangrove Land*	*Sugarcane Land*	*Other Land*	
0.64	1998 Baseline MHWS	–	–	–	–	–	–	–	–
0.75	2025 Best Guess	0.4	–	–	–	0.0	–	–	**0.4**
0.87	2025 Worst Case 2050 Best Guess	1.1	–	–	1.2	0.0			**2.3**
1.10	2050 Worst Case 2100 Best Guess	1.7	–	–	1.9	0.0	–	–	**3.6**
1.67	1998 Baseline MHWS + storm surge 2100 Worst Case 2025 Best Guess + storm surge	13.1	39.0	1.7	3.5	0.0	–	4.5	**61.8**
1.85	2025 Worst Case + storm surge 2050 Best Guess + storm surge	15.8	50.2	1.7	4.1	0.0	–	4.6	**76.4**
2.12	2050 Worst Case + storm surge 2100 Best Guess + storm surge	18.5	61.3	1.8	4.6	0.0	1.0	4.7	**91.9**

Note: Shaded areas indicates baseline values.

For a 2050 Worst Case scenario, the economic losses due to climate change are as follows:

Without storm surge: 2050 Worst Case (WC) - 1998 Baseline MHWS = US$3.6 million
With storm surge: 2050 WC with SS - 1998 Baseline with SS= US$91.9-61.8 million=US$30.1 million

Weighing the above estimates by the frequency of the storm surge:

(US$3.6 million x 49/50) + (US$30.1 million x 1/50) = ***US$4.1 million***

Step 4: Estimate Annualized Losses Caused by Climate Change. Similarly than for the erosion analysis, the above costs reflect capital losses. In order for the losses to be expressed in annualized terms, it is necessary to multiply the capital losses by the capital recovery factor of 0.11:

0.11 x US$2.5 million = ***US$0.28 million***

0.11 x US$4.1 million = ***US$0.45 million***

Though the annualized losses (***US$0.3-$0.5 million***) appear small, it should be remembered that in years of strong storm surge, Viti Levu could experience incremental losses in the order of ***US$14.6-30.1 million***. If no account is made of current storm impacts, the absolute value of these losses could amount to US$76 to US$92 million by 2050.

Impacts of Climate Change on Coral Reefs of Viti Levu

Climate change is expected to affect coral reefs primarily through increases in sea surface temperature (resulting in coral bleaching), sea level rise, and the impact of stronger cyclones and storm surges, which lead to extensive destruction of the reef system. These impacts need to be computed separately from those of land erosion and inundation.

Step 1: Estimate the Total Area of Coral Reefs in Viti Levu. The area of coral reefs surrounding Viti Levu is unknown, though Fiji has about 1 million hectares of reef (WRI 1999). Several approaches are possible to estimate Viti Levu's reef area: the first is to assume that Viti Levu's share of Fiji's land area also applies to its coral reefs. Under this approach, Viti Levu would have 58 percent of Fiji's reefs, or 580,000 hectares. This estimate is clearly exaggerated, however. While Viti Levu is a large island, many other small islands in Fiji are surrounded by coral reefs, with a ratio of coral reef to land area much greater than Viti Levu.

The more correct approach ─ albeit subject to future confirmation ─ is to assume that the area of coral reef is broadly proportioned to the length of the coast line. The total coastal area of Fiji is 5,010 kilometers (Robert Gillett, personal communication) while the coastal area of Viti Levu is 750 kilometers, or 15 percent of the total for Fiji. This suggests that the area of coral reefs in Viti Levu is 15 percent of that of Fiji, or 150,000 hectares. This estimate was used for the analysis.

Step 2: Determine the Products or Functions Lost as a Result of Climate Change. Climate change is likely to affect the following uses and functions of coral reefs: productivity of subsistence and commercial fisheries, tourism, biodiversity or habitat values, and coastal protection. The value of these functions is examined in turn below.

As a result to overexploitation and habitat degradation, some 19 percent of Fiji's coral reefs are presently considered to be at high risk, with an additional 48 percent are at moderate risk (WRI 1999). As a low bound estimate, it is assumed that all of the high risk reefs ─ which are already under severe stress ─ would die as a result of climate change. As a high end estimate, it is assumed that all of the high risk reefs plus half of the reefs at moderate risk (24 percent) might also die in the future. Thus, the analysis assumes a mortality of 19 to 43 percent of the total area of coral reef. This is a reasonable estimate given the latest scientific knowledge and the extent of the bleaching that affected 50-100 percent of the corals above 30 meters deep in southern Viti Levu in early 2000 (South and Skelton 2000).

Step 3: Estimate the Economic Losses Resulting from Climate Change

3.1. Annual Losses in Subsistence Fishing. Dead or bleached reefs do not necessarily lose their fisheries value, as they tend to be quickly covered by algae and lead to a proliferation of herbivorous fish. In the long term, however, dead reefs will tend to break away, and more substantial losses of productivity can be expected (Clive Wilkinson, Tom Goreau, and Herman Cesar, personal communication, May 2000). It is assumed conservatively that the 19-43 percent of reefs that would die would lose 50 percent of their fisheries value.

Though Viti Levu may have only 15 percent of the Fiji reefs, the majority of the artisanal and subsistence catch originates from the island, where 77 percent of the Fiji population live. Hence, it is reasonable to assume that the subsistence fisheries of Viti Levu account for 15 to 77 percent of Fiji's total.

As seen in the estimation of mangrove values, subsistence fishing in Fiji was valued at approximately F$53.5 million in 1998, taking into account 1998 official estimates of subsistence catch and the average market price for artisanal fisheries (FFD 1999). Coral reefs are assumed to account for between 35 and 45 percent of the coastal fisheries production (Esaroma Ledua, personal communication, March 2000).

The value of subsistence fishing in Viti Levu is therefore:

F$53.5 million	x	15 to 77 %	x	35 to 45 %	= F$2.8 to F$18.5 million
(total value of subsistence fisheries)		*(Viti Levu's share of (total catch)*		*(Share of subsistence (fisheries dependent on coral reefs)*	

Assuming a 19 to 43 percent loss in reefs due to climate change, and a loss of 50 percent in reef fisheries productivity, the impacts of climate change on Viti Levu's subsistence fisheries are as follows:

F$2.8 to F$18.5 million	x	19 to 43%	x	50%	= ***F$0.3 to F$4.0 million per year***
(Value of subsistence fishing in Viti Levu)		*(Estimated reef mortality due to climate change)*		*(loss of fisheries from dead reefs)*	

3.2. Annual Losses in Commercial Fishing. As per the estimation of mangrove values, artisanal fishing in Fiji was valued at F$20.7 million in 1998 (FFD 1999). Using the same assumptions as for subsistence fishing:

F$20.7 million	x	15 to 77 %	x	35 to 45 %	= F$1.1 to F$7.2 million
(total value of artisanal fisheries)		*(Viti Levu's share of (total catch)*		*(Share of artisanal (fisheries dependent on coral reefs)*	

F$1.1 to F$7.2 million	x	19 to 43%	x	50%	= ***F$0.1 to F$1.5 million per year***
(Value of artisanal fishing in Viti Levu)		*(Estimated reef mortality due to climate change)*		*(loss of fisheries from dead reefs)*	

3.3. Annual Losses in Tourism. While tourism is a F$568 million a year industry in Fiji, only a relatively minor proportion of tourists is likely to cease visitation due to coral reef mortality. A similar phenomena was reported in Maldives after the massive reef mortality in 1997-98. Most tourists were said to visit the Maldives for its beaches and leisure, rather than its reefs. The strange coloration of bleached reefs, and the growth of soft coral and herbivorous fish can in some cases provide additional attractions for snorkelers and divers.

The most likely tourist category to be affected by coral reef mortality are dive tourists. Numerous attempts were made to obtain statistics on dive tourism in Fiji, but these data does not appear to be available. Pending further information, it is assumed that extensive coral reef mortality would result in a 15 percent drop in tourism revenues. This is in line with recent estimates from Palau that indicate a 9 percent drop in divers' willingness to pay following the 1997-98 bleaching event (Graham, Idechong and Sherwood 2000). Similar surveys in East Africa indicate that 19 percent of the tourists visiting Zanzibar (and 39 percent of those visiting Monbasa) would likely reroute their travel if they knew coral reefs were bleached (Westmacott, Cesar and Pet Soede 2000).

It was similarly difficult to ascertain the share of tourism revenues that is spent on Viti Levu. A conservative assumption is to use Viti Levu's share of Fiji's land mass (58 percent). The impact of climate change on tourism linked to the health of coral reefs is therefore:

F$568 million	x	58%	x	15%	= F$49.4 million
(annual tourism revenues)		*(% of tourists to Viti Levu)*		*(proportion of tourism likely to be affected by coral mortality)*	

F$49.4 million	x	19 to 43% of the reefs	=	***F$9.4 to F$21.2 million per year***
(tourism revenues in Viti Levu likely to be affected by coral mortality)		*(estimated coral mortality from climate change)*		

3.4. Annual Losses in Habitat Value. In addition to their fisheries, recreational and protection values, coral reefs play important roles in biodiversity as habitats for marine life. No estimate is available for this function in Fiji. However, a parallel study for the Galapagos indicates a value (expressed in 1998 F$) of about F$16 per hectare (de Groot 1992). This estimate is used as here as a fist order approximation only.

As discussed above, Viti Levu is assumed to have 15 percent of Fiji's reefs. Hence, the habitat value likely to be lost to climate change would be as follows:

F$16 per hectare per year	x	150,000 hectares	x	19 to 43 %	=	***F$0.5 to F$1.0 million per year***
(annual habitat value)		*(estimated area of Viti Levu's reefs)*		*(estimated coral mortality from climate change)*		

3.5. Annual Losses in Coastal Protection Value. Coral reefs play a vital role in the protection of the coast. Following bleaching or mortality events due to elevations in ocean surface temperature, coral reefs are likely to sustain their production function for some time, but will eventually break and wash away (Clive Wilkinson, personal communication). While the loss of coastal protection caused by bleaching events is technically separate from the impact of sea level rise on coastal areas, it is difficult to isolate the two impacts. Hence, no estimate was done of the loss of coastal protection resulting from coral reef mortality. Estimates from other countries indicate that this value may be substantial, around US$60,000 to US$550,000 per square kilometer of reef (Cesar 1996).

Step 4: Add up the Impacts. Since the estimates of the various impacts are already annualized, no further adjustment is required, as done for the erosion and inundation analyses. Hence, the impacts can be simply added to give an estimate of the impacts of climate change on the coral reefs of Viti Levu (table A.14).

Table A.14. Total Estimated Annual Economic Impact of Climate Change on the Coral Reefs of Viti Levu, Fiji (millions of 1998 US$)

Losses in:	*Annual Damages*	
	Millions of 1998 F$	*Millions of 1998 US$*
Subsistence fisheries	0.3 to 0.4	0.1 to 2.0
Commercial (coastal) fisheries	0.1 to 1.5	0.05 to 0.8
Tourism	9.4 to 21.2	4.8 to 10.8
Habitat	0.5 to 1.0	0.2 to 0.5
Coastal Protection	—	—
Others (nonuse values, etc.)	+	+
Total estimated damages	10.3 to 27.7	***5.2 to 14.1***

Notes: — Not available; + Not available, but believed to be substantial.

Tarawa Atoll

Impact of Erosion Caused by Climate Change on Tarawa's Coast

A. Physical Impact of Coastal Erosion due to Sea Level Rise

The Tarawa atoll has a land area of 30 square kilometers (about 3,000 hectares). All land in Tarawa can be classified as "coastal" since it rarely rises more than 5.0 meters above sea level, with much of the land at less than 3 meters altitude (McLean 1989).

To model the impact of erosion and inundation, two case study sites were selected: Bikenibeu island, representing the type of conditions found in South Tarawa, and Buariki, representing the conditions found in North Tarawa. Two transects were surveyed in Bikenibeu and three transects were surveyed in Buariki (table A.15).

Table A. 15. Case Study Sites for Tarawa

Coastal Type	*Area (hectares)*	*Proportion of Tarawa atoll*	*Case Study Sites*	*Area of Case Study Sites (hectares)*
South Tarawa; *densely populated, some coastal protection, location of major infrastructure and government*	1,577	50%	Bikenibeu	104
North Tarawa: *sparsely populated, less developed infrastructure, traditional dwellings, subsistence living*	1,526	50%	Buariki	293

Notes: Area of South Tarawa and North Tarawa said to be 3,896 and 3,771 acres, respectively, in the study's economic analysis report. Area of Bikenibeu and Buariki derived from table 3.10 of the original Kiribati Vulnerability and Adaptation report.

The estimate of physical impact involved three major steps:

Step 1. Estimate Potential Shoreline Erosion. The level of shoreline displacement was estimated using the Shoreline Translation Model (STM) described earlier in this Annex, and is shown on table A.16.

Table A. 16. Protential Shoreline Retreat in Case Study Sites, Tarawa

Sea Level Rise (meters)	*Projected Area of Buariki Eroded*						*Projected Area of Bikenibeu Eroded*			
	North Transect		*Central Transect*		*South Transect*		*West Transect*		*East Transect*	
	Shore Retreat (meters)	*Area Eroded (hectares)*	*Shore Retreat (meters)*	*Area Eroded (hectares)*	*Shore Retreat (meters)*	*Area Eroded (hectares)*	*Shore Retreat (meters)*	*Area Eroded (hectares)*	*Shore Retreat (meters)*	*Area Eroded (hectares)*
0.1	0.6	0.1	0.9	0.2	0.5	0.1	0.5	0.2	0.4	0.2
0.2	1.2	0.2	2.3	0.5	1.0	0.2	1.0	0.4	0.6	0.2
0.3	2.6	0.4	3.0	0.7	2.3	0.4	2.0	0.8	0.8	0.3
0.4	3.2	0.5	4.4	1.0	2.9	0.5	2.5	1.0	1.0	0.4
0.5	4.5	0.7	5.0	1.1	3.6	0.6	3.5	1.4	1.2	0.5
0.6	5.2	0.8	6.5	1.4	4.2	0.7	4.0	1.6	1.5	0.6
0.7	6.5	1.0	7.3	1.6	4.8	0.8	5.0	2.0	1.8	0.7
0.8	7.2	1.2	9.1	2.0	5.5	0.9	5.5	2.2	2.2	0.9
0.9	8.4	1.3	14.2	3.1	6.1	1.0	6.5	2.6	2.7	1.1
1.0	9.5	1.5	30.5	6.7	6.7	1.1	7.0	2.8	3.2	1.3

Notes: Shaded areas indicate the scenarios of sea level rise considered in the study

Step 2. Estimate the Proportion of the Study Sites Land that is Lost to Erosion. To compute the proportion of the study sites' land that is likely to be lost to erosion, the projected area eroded in each of the transects was first added up to provide a total area eroded for Buariki and Bikernibeu.

> *Example:* For a 0.5 meters sea level rise, the area eroded in Buariki is as follows:
>
> 0.7 hectares + 1.1 hectares + 0.6 hectares = 2.4 hectares
> *(north transect) (central transect) (south transect)*
>
> For a 0.4 meters sea level rise, the area eroded in Bikenibeu is:
>
> 1.0 hectares + 0.4 hectares = 1.4 hectares
> *(west transect) (east transect)*

These totals can then be compared with the area of the study sites (table A.15) to determine the proportion of land lost to erosion.

> *Example:* For a 0.5 meters sea level ride in Buariki:
>
> 2.4 hectares / 293 hectares = 0.0082 or 0.8 percent.
>
> For a 0.4 meters sea level rise in Bikenibeu:
>
> 1.4 hectares / 104 hectares = 0.013 or 1.3 percent.

The proportion of land eroded for all major sea level rise scenarios is shown on table A.17.

Table A.17. Estimated Potential Land Erosion as a Result of Climate Change in Tarawa

Areas		*2025*		*2050*		*2100*	
	Estimate	*Best guess*	*Worst case*	*Best guess*	*Worst case*	*Best guess*	*Worst case*
	Sea level rise	*0.1*	*0.2*	*0.2*	*0.4*	*0.5*	*1.0*
North Tarawa	Potential land eroded in Buariki (in hectares)	0.4	0.9	0.9	2.0	2.4	9.4
	Percentage of total land (%)	0.1	0.3	0.3	0.7	0.8	3.2
	Extrapolated land eroded in North Tarawa (in hectares)	2.0	4.6	4.6	10.2	12.7	48.8
	Value of eroded land (in US$ million)	0.1	0.2	0.2	0.4	0.6	2.1
South Tarawa	Potential land eroded in Bikenibeu (in hectares)	0.4	0.6	0.6	1.4	1.9	4.1
	Percentage of total land (%)	0.4	0.6	0.6	1.3	1.8	3.9
	Extrapolated land eroded in South Tarawa (in hectares)	5.7	9.8	9.6	21.1	28.5	61.8
	Value of eroded land (in US$ million)	0.3	0.6	0.6	1.3	1.7	3.7
	Total Tarawa	***0.4***	***0.8***	***0.8***	***1.7***	***2.3***	***5.8***

Shaded areas refer to the example given above. Numbers may not add up due to rounding.

Step 3. Extrapolate Erosion to the Rest of Tarawa. If it can be assumed that Buariki and Bikenibeu are broadly representative of the conditions found in North and South Tarawa, then the proportions of land lost to erosion can also be applied to the total area of North and South Tarawa to determine the total potential land eroded in the atoll.

Example:

For 0.5 meters sea level rise in North Tarawa:

0.83 percent x 1,526 hectares = 12.7 hectares

(proportion of land lost to erosion in Buariki) (area of North Tarawa)

For 0.4 meters sea level rise in South Tarawa:

1.34 percent x 1,577 hectares = 21.1 hectares

These estimates are shown on table A.17 above.

B. Economic Impact of Coastal Erosion due to Sea Level Rise

The analysis of economic impacts involved two key steps:

Step 1: Estimate the Economic Value of Land Lost to Erosion. To compute the economic impact of coastal erosion, it is necessary to know the value of land per hectare. The Land Management Division in Kiribati quotes the following values for land in Tarawa:

For North Tarawa:	Unimproved residential land	A$18,000 per acre
	Commercial land:	A$100,000 per acre
For South Tarawa:	Unimproved residential land:	A$20,000 per acre
	Commercial land:	A$100,000 per acre

For the purposes of the estimation, and by lack of other data, it was assumed that these values reflect the economic value of land in Tarawa.

In North Tarawa, it was assumed that 10 percent of the land was used for commercial purposes, while 90 percent was assumed to be unimproved residential land. In South Tarawa, 20 percent of the land was assumed to be for commercial purposes, while 80 percent was unimproved residential land. Hence, the weighted average value of land is:

For North Tarawa: (A$18,000 x 90%) + (A$100,000 x 10%) = A$26,200 per acre

For South Tarawa: (A$20,000 x 80%) + (A$100,000 x 20%) = A$36,000 per acre

Converting into hectares (1 hectare = 2.5 acres) and US$ (1US$ = A$1.5 in 1998):

For North Tarawa: A$26,200 x 2.5 / 1.5 = US$43,670 per hectare
For South Tarawa: A$36,000 x 2.5 / 1.5 = US$60,000 per hectare

These unit costs can then be applied to the extrapolated land eroded in North and South Tarawa (table A.17) to determine the potential losses due to erosion.

Example:

For the worst case scenario of 2100, the estimated land eroded in North Tarawa is 49.3 hectares. The eroded land in South Tarawa is 60.6 hectares. Applying the unit costs above:

For North Tarawa: 48,8 hectares x US$43,670 per hectare = US$2,131,096 or US$2.1 million
For South Tarawa: 61.8 hectares x US$60,000 per hectare = US$3,708,000 or US$3.7 million

The total value of land eroded in Tarawa for this scenario is US$5.8 million.

The economic costs of erosion are therefore ***US$0.4-$0.8 million in 2025, US$0.8-$1.7 million in 2050, and US$2.3-$5.8 in 2100.***

Step 2: Estimate the Annualized Value of the Losses. The values above represent the loss of capital due to inundation. To calculate the annualized losses, it was assumed, in discussions with an expert, that the duration of most structures in Tarawa averaged about 10 years. Using a discount rate of 10 percent, and applying it to the capital recovery factor formula gives the following capital recovery factor:

$[i(1+i)^n] / [(1+i)^n - 1]$ where i = rate of interest (10 percent) and n = number of years when losses can accrue (10 years).

Hence, $[i(1+i)^n] / [(1+i)^n - 1] = [0.1(1.1)^{10}] / [(1.1)^{10} - 1] = 0.16$

Applying this factor to the capital losses due to erosion, yields the following annualized losses:

0.16 x US$0.4 to $0.8 million = ***US$0.1-$0.13 million in 2025***
0.16 x US$0.8 to $1.7 million = ***US$0.1-$0.3 million in 2050***
0.16 x US$2.3 to $5.8 million = ***US$0.4-$0.9 million in 2100***

Impact of Inundation Caused by Climate Change on Tarawa's Coast

A. Physical Impact of Inundation due to Sea Level Rise

The analysis of physical impacts involved four key steps:

Step 1: Determine Baseline Conditions. The Mean High Water Spring (MHWS) tide level for Tarawa is 2.53 meters. A 1 in 14 year storm — the baseline with storm surge — raises the sea level to approximately 3.0 meters under baseline conditions.

Step 2: Estimate Projected Changes in Water Level under Sea Level Rise. The water levels for the different sea level rise scenarios are displayed on the first column of table A.18. These are derived by simply adding sea level rise scenarios onto the MHWS baseline.

Step 3: Estimate the Area of Inundated Land and Infrastructure. Based on the simulations of the area inundated at various water levels, the land area, number of structures, and length of road inundated were calculated from maps provided by the Kiribati Land Management Division. The results are presented on table A.18.

Table A.18. Potential Inundation at Case Study Sites, Tarawa

Water Level (m)	Scenario:	Buariki Land area affected (hectares)	Buariki Structures (number)	Buariki Roads (kilometer)	Bikenibeu Land area affected (hectares)	Bikenibeu Structures (number)	Bikenibeu Roads (kilometer)
2.53	1998 Baseline MHWS	--	--	--	--	--	--
2.75	2025 Worst Case 2025 Best Guess	53 (18%)	196 (59%)	6.55 (77%)	0 (0%)	0	0
3.00	1998 Baseline with storm surge 2050 Worst Case 2100 Best Guess	89 (30%)	213 (64%)	6.55 (77%)	1.9 (2%)	34 (2%)	0
3.2	2050 Best Guess + storm surge	161(55%)	229 (69%)	7.5 (89%)	(25%)	423 (27%)	1.26 (29%)
3.56	2050 Worst Case +storm surge 2100 Best Guess+storm surge 2100 Worst Case	233 (80%)	245 (74%)	8.5 (100%)	56 (54%)	986 (63%)	2.83 (66%)
4.0	2100 Worst Case+ storm surge	248 (85%)	316 (95%)	8.5 (100%)	83 (80%)	1302 (84%)	4.36 (100%)

Note: Projected losses in structures and roads derived from topographic maps (Land Management Division of Kiribati). Storm surge is based on a 1 in 14 year event (Solomon 1997). Figures in parenthesis indicate percentage of the land, infrastructure and/or roads inundated (relative to the total for the study sites).

Step 4: Extrapolate to all Tarawa. Assuming that Buariki and Bikenibeu are broadly representative of the conditions of North and South Tarawa, respectively, a simple extrapolation can be used to derive the physical impact on the entire atoll. For land, the percentage of land that is projected to be inundated in Buariki and Bikenibeu was applied directoy to the area of North and South Tarawa. For example, for the 2025 Worst Case scenario, 18 percent of the land of Buariki is expected to be inundated. This percentage can be then applied to the total area of North Tarawa, 1,526 hectares (table A.15), yielding a total area of land inundated of approximately 275 hectares (table A.19).

Similarly for structures, a simple extrapolation can be used. To calculate the number of structures for North Tarawa under a 2025 Worst Case scenario:

No. of structures affected in Buariki (196) x Area of North Tarawa (1,526)/Area of Buariki (293) = ***1,021 structures.***

The results are summarized on table A.19, which also contains the results of the economic analysis explained below.

B. Economic Impact of Inundation due to Sea Level Rise

The economic impact analysis involved three key steps:

Step 1: Estimate the economic value of land and structures lost to inundation. From the economic analysis of erosion impacts, the average unit value of land in South Tarawa was estimated at US$60,000 per hectare, while the value of land in North Tarawa averaged US$43,670 per hectare.

Table A.19. Estimated Economic Value of Land and Structures Lost to Inundation

Water Level (m)	*Scenario*	*North Tarawa*				*South Tarawa*				*Total Tarawa*
		Land Lost		*Structures Lost*		*Land Lost*		*Structures Lost*		
		hectares	*Costs (US$M)*	*No.*	*Costs (US$M)*	*Hectares*	*Costs (US$M)*	*No.*	*Costs (US$M)*	*Costs (US$M)*
2.53	1998 Baseline MHWS	—	—	—	—	—	—	—	—	—
2.75	2025 Worst Case 2050 Best Guess	274.7	12.0	1,021	20.4	0.0	0.0	0.0	0.0	**32.4**
3.00	1998 Baseline + storm surge 2050 Worst Case 2100 Best Guess	457.8	20.0	1,109	22.2	31.5	1.9	516	10.3	**54.4**
3.2	2050 Best Guess + storm surge	839.3	36.7	1,193	23.9	394.3	23.7	6,414	128.3	**212.4**
3.56	2050 Worst Case + storm surge 2100 Best Guess + storm surge 2100 Worst Case	1,220.8	53.3	1,276	25.5	851.6	51.1	14,951	299.0	**429.0**
4.0	2100 Worst Case + storm surge	1,297.1	56.6	1,646	32.9	1,261.6	75.7	19,743	394.9	**560.1**

Shaded area indicates baseline conditions.

The cost of structures was estimated at A$30,000 each (US$20,000), from data from the Kiribati Land Management Division. Table A.19 shows the estimate of economic value of land and structures lost to inundation. The interpretation of the topographic maps did not allow for a differentiation of the type of structure affected. Data were also not available to estimate the economic costs of road losses to erosion.

Example: In the 2050 Best Guess Scenario, about 1,021 structures are estimated to be affected by inundation. The value of these losses is therefore:

1,021 x US$20,000 or US$20.4 million.

Step 3: Estimate the Net Economic Losses Caused by Climate Change. Similarly to the Viti Levu analysis, the future conditions need to be compared with the correct baseline: for example, if one is estimating conditions under 2050 Best Guess with storm surge, the correct comparator would be a scenario of 1998 Baseline conditions with storm surge.

Hence, for a 2050 Best Guess (BG) scenario, the economic losses are as follows:

Without storm surge: 2050 BG - 1998 Baseline MHWS = US$32.4 million
With storm surge: 2050 BG with SS - 1998 Baseline with SS = US$212.4 - US$54.4 = US$158.0 million

The storm conditions reflect a 1 in 14 year storm. Assuming no change in the frequency of storms, storm surge conditions are likely to occur once every 14 years, while no storm surge conditions are likely to occur in 13 out of 14 years. The weighted average loss is therefore:

(US$32.4 million x 13/14) + (US$158.0 million x 1/14) = ***US$41.4 million***

For a 2050 Worst Case Scenario (WC), the economic losses would be:

Without storm surge: 2050 WC - 1998 Baseline MHWS= US$54.4 million
With storm surge: 2050 WC with SS - 1998 Baseline with SS = US$429.0 - US$54.4 = US$374.6 million

(US$54.4 million x 13/14) + (US$374.6 million x 1/14) = ***US$77.3 million***

Step 4: Estimate the Annualized Losses Caused by Climate Change. Similarly than for the erosion analysis, the costs above reflect capital losses. For the losses to be expressed in annualized terms, it is necessary to multiply them by the capital recovery factor, which is 0.16 (see erosion analysis).

The annualized costs are therefore:

0.16 x US$ 41.4 million = ***US$6.6 million*** for a best guess scenario in 2050

0.16 x US$ 77.3 million = ***US$12.4 million*** for a worst-case scenario in 2050.

In years of strong storm surge, Tarawa could experience incremental losses in the order of ***US$158-$375 million*** by mid-century. If no account is made of current storm impacts, the absolute value of these losses could amount to ***US$212-$429 million*** by 2050.

Impacts on Coral Reefs and Mangroves

Tarawa has lost some 70 percent of its mangroves since 1940, and only 57 hectares remain (Metz 1996). The impact of sea level rise is therefore considered to be negligible, and could be even positive as higher water levels may lead to denser root systems and expansion of mangroves shoreward.

Climate change is likely to have a significant impact on coral reefs, however. Bleaching caused by warmer sea surface temperatures and the impact of sea level rise could impact subsistence and commercial fisheries, habitat functions, and the coastal protection role of coral reefs. Losses in tourism value are considered negligible as Tarawa does not have a developed dive or snorkel tourism industry.

The physical and economic impact analysis involved three major steps:

Step 1: Estimate the Area of Coral Reefs: The reef area of Tarawa is 129 km^2 or 12,900 hectares (Stratus 2000).

Step 2: Determine the Products or Functions Lost as a Result of Climate Change. No estimate is known of the present status of coral reefs in Tarawa. However, in-country discussions indicate that it is not unreasonable to assume a loss of 10 to 40 percent of the reefs by 2050 under climate change conditions. Similarly to Viti Levu, it is assumed — conservatively —that dead reefs would retain about 50 percent of their fisheries productivity.

Step 3: Estimate the Economic Losses Resulting from Climate Change

3.1. Annual Value of Subsistence Fishing. Government statistics put the value of subsistence fishing in Kiribati at A$6.3 million in 1998. This figure needs to be adjusted for Tarawa. A population proportion (45 percent of the I-Kiribati population lives in Tarawa) rather than an area adjustment was used because several of the islands of Kiribati — particularly on the Phoenix group — are uninhabited.

Hence, A$6.3 x 45 % = A$2.8 million (for 12,900 hectares of reefs)

Assuming a 10 to 40 percent reef loss, and a 50 percent loss in fisheries productivity, the value of subsistence fisheries lost is:

0.10 to 0.40 x 0.5 x A$2.8 = A$0.14 to $0.57 million, or (at an exchange rate of 1 US$ = A$1.5)

US$0.14 to $0.38 million per year

3.2. Annual Value of Commercial Fishing. Commercial fishing in Kiribati is targeted primarily at offshore tuna resources which are not directly related to coral reefs. The value of commercial reef fisheries, which are commonly designated as "artisanal fisheries", is unknown in Kiribati. However, exports of ornamental fish and seaweed were valued at A$0.7 million each in 1998, in accordance with IMF statistics. This almost certainly underestimates commercial fish production, but it is difficult to separate offshore tuna from reef-related fisheries in the fish export category found in official statistics. Hence, only ornamental fish and seaweed value were taken into account in the analysis:

A$0.7 million (for seaweed) + A$0.7 million (for ornamental fish) = A$1.4 million

Adjusting for Tarawa and for reef loss gives the following economic value of commercial reef fisheries lost to climate change:

0.10 to 0.40 x 0.5 x 45% x A$1.4 million = A$0.032 to A$0.126 or ***US$0.02- $0.08 million per year***

3.3 Annual Habitat Value. A study in the Galapagos (de Groot 1992) estimates the annual habitat value of coral reefs at approximately US$8 per hectare of reef. However, the conditions in the Galapagos are too distinct from those in Kiribati for this estimate to be of relevance. The habitat value of coral reefs in Tarawa is probably substantial, but it was not quantified by the study.

3.4. Coastal Protection Value. Given the difficulties of separating the impacts of coral reef loss from those of inundation and erosion resulting from sea level rise, the coastal protection value of coral reefs was assumed to be largely accounted for in the erosion and inundation analysis, and was therefore not quantified here.

Hence, the annual value of coral reefs lost due to climate change in the Tarawa atoll is estimated at ***US$0.16 to $0.46 million per year.***

C. Impacts on Water Resources

For the estimation of the impacts of climate change on water resources in Viti Levu and Tarawa, the study team followed slightly different methodologies. In Viti Levu, where cyclones are of paramount importance, historical records of these extreme events were used to derive an estimate of the future impact. The impact on climate change on surface hydrology was based on the water resources model developed by PACCLIM.   The Tarawa water resources analysis, however, used a SUTRA groundwater model (Voss 1984) which took into account the mixing between freshwater and underlying seawater. This is considered superior and of greater reliability than the "sharp interface" model incorporated into PACCLIM, which assumes a sharp boundary between freshwater and seawater. The specific methods followed in the two case studies are outlined in further detail below.

Viti Levu

The impacts of climate change on the water resources of Viti Levu were estimated for cyclones, surface hydrology and water balance. No estimate of incremental costs could be made for El Niño-related droughts, however, given the absence of data on baseline drought conditions. Nonetheless, the impacts of droughts is partially taken into account by the agriculture impact analysis (Section D).

Impact of More Intense Cyclones

Fiji has the highest incidence of cyclones in the South Pacific, an average of 1.1 cyclones a year (Pahalal and Gawander 1999). To be as representative as possible of present-day conditions, the intensity and frequency of actual cyclones in the 1992-99 period was used as a baseline. Reliance on historical data was necessary since GCM models and PACCLIM do not reflect well the effects of cyclones. The impact analysis involved three key steps.

Step 1: Estimate the Future Impact of Cyclones. Jones and others (1999) estimate that cyclone intensity (maximum wind speed) could increase by 0-20 percent by mid-century as a result of climate change. In order to compute the potential impacts of this increase in intensity, it was necessary to estimate how the increase in wind speed will affect cyclone damage.

Three estimates were used for this purpose:

- The historical records of the Fiji Meteorological Services for seven recent (1983-97) cyclones indicate damages of F$67 million (in 1998 value) for an average cyclone with wind speed of 58 knots. A 20 percent increase in wind speed over this historical average would be equivalent to cyclones Oscar (68 knots, 1983) and Eric (72 knots, 1985), which averaged F$106 million in damages — a ***59 percent increase*** (see figure A.3).

- From the existing theory, an increase in wind speed by 20 percent should result in a ***44 percent increase*** $(1+0.2)^2 = 1.44$ in wind force (J. Terry, personal communication, May 2000).

- A recent study (Clark 1997) indicates that a 15 percent increase in cyclone severity is likely to result in a doubling of the damages, or a ***100 percent increase***.

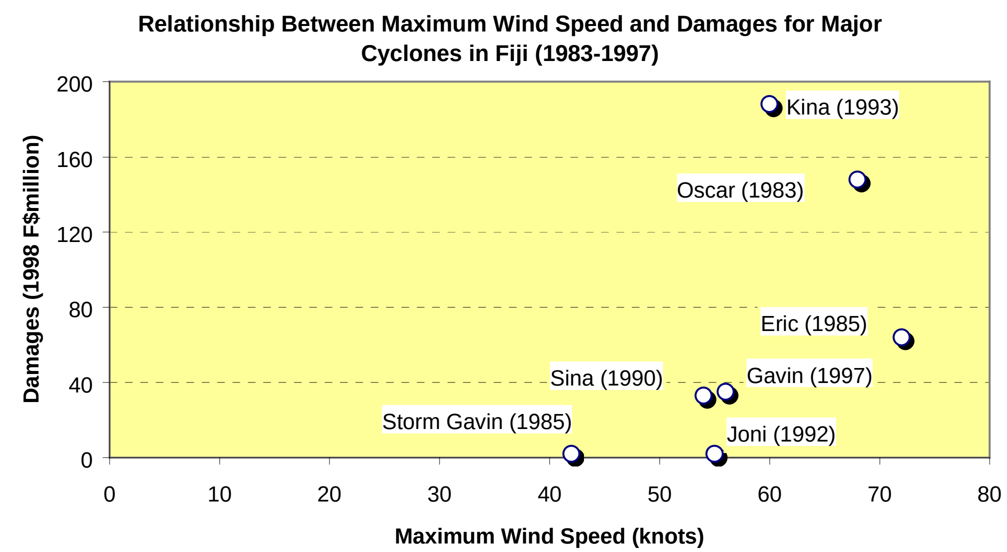
Figure A.3. Cyclone Damage as a Function of Wind Speed, Fiji

Data courtesy from Fiji Meteorological Services.

	Maximum Wind Speed	Cyclone damage (F$ million)
Oscar (1983)	68	148
Eric (1985)	72	64
Gavin (1985)	42	2
Sina (1990)	54	33
Joni (1992)	55	2
Kina (1993)	60	188
Gavin (1997)	56	35

Average cyclone	
Wind Speed	Damages
58	67

Average cyclone + 20%	
Wind Speed	Damages
70	106



Source: Fiji Meteorological Services.. Damages are converted to 1998 costs

Taking these three estimates into consideration, an increase in wind speed of 20 percent could result in a 44 to 100 increase in total damages. This broad estimate recognizes the large variations that can result from cyclone origin, trajectory and characteristics.

Step 2: Estimate the Baseline Conditions. Using the 1992-99 period as an analogue for baseline conditions, the average annual damages due to cyclones amount to F$28.3 million per year in 1998 values (table A.20).

The Fiji Meteorological Services confirmed that the estimated damages pertain to Fiji as a whole, and not just to Viti Levu. Given the correlation between population concentration and infrastructure, adjusting the damages by the proportion of the population that lives in Viti Levu is preferable to adjusting it by area. Hence, the average annual cyclone damages for Viti Levu — the baseline for the analysis — is:

F$28.3 million per year x 77 % = ***F$21.8 million per year***

Table A.20. Damages from Cyclones in Fiji (1992-99)

Cyclone	*Year*	*Damages (millions of 1998 F$)*
Joni	1992	2
Kina	1993	188
Gavin	1997	35
Gale June	1997	1
Average		56.5
Yearly average 1992-99 *(8 years)*		**28.3**

Source: Fiji Meteorological Services, and background studies to this report.

Step 3: Estimate the Future Economic Costs of a Rise in Cyclone Intensity. The impact of a 0 to 20 percent increase in maximum cyclone intensity is as follows:

- If the change is 0 percent, climate change has zero incremental impact;
- If the change is 20 percent, damages could increase by 44 to 100 percent

Thus, for a 20 percent increase in cyclone intensity:

44 % to 100 % of F$21.8 million = F$9.6 to F$21.8 million , or US$4.9-$11.1 million at 1998 exchange rates.

Hence, the average annual incremental impact of climate change on cyclone intensity is ***US$0 to US$11.1 million***.

However, in absolute (non incremental) terms, the likely cost of an extreme event in Viti Levu would be:

F$56.5 million *(Average cyclone Losses in 92-99)*	x	0.77 = *(Correction for Viti Levu)*	F$43.5

F$43.5 million *(Losses in Viti Levu)*	/	1.96 *(US$ conversion)*	x	0-2.0 = *(Projected increase in intensity)*

= ***US$0-$44 million***

Impact of Droughts

With El Niño conditions expected to prevail in the future, Fiji could experience accentuated droughts. The 1997-98 drought which caused damages of F$275 to F$325 million could well become the norm in the future. The drought affected food supplies, commercial crops, livestock, and the water supply of schools and communities (table A. 21). The damages of the 1997/98 drought — a 1 in 100 years event — are considered indicative of the type of droughts that might be expected in the future. Since approximately F$125 million were losses to sugarcane (mostly incurred in Viti Levu) and F$15 million were losses to other crops, one can assume the following indicative (absolute) costs for future droughts in Viti Levu:

Table A.21. Major Drought-Related Damages and Expenditures for the Drought of 1997-1998, Fiji (millions of 1998 F$)

Item	*Cost*
	$125
Sugarcane crop rehabilitation programme	$43.7
Food and water rations	$33[a]
Weaning foods	$3.6 [b]
Food crop losses	$15 [c]
Crop re-establishment needs	$0.41
Welfare payments & lost income	$75[d]
School children funding	$0.625 [e]
School water tanks and gardens	$1.5
Draft animals grass-starved	$2.4 [f]
Milk production decline (50%)	$10.9[g]
Farm drains and creeks	$0.26 [h]
Irrigation to re-establish sugarcane	$0.040
Boreholes for water supply	$0.630 [i]
Commercial forest	$80 [j]
Health and nutrition	$1.8 [k]
Macro impacts	+ [l]
Fire damage (up to 10% of forest areas)	+
Tourism	+
Total	*F$313.9+*

Notes:
a. Ten months at $3.3 million per month.
b. F$360,000 per month times 10 months.
c. Estimate of revenue losses from failed new plantings, by Director of Ag Extension.
d. F$2,000 per family times 15,000 farm families, covering 6 months of recovery, prorated to also include 9 months of zero income. There is some potential double counting with the sugarcane crop loss value on line 1.
e. 10,000 children missed school because of hardship. F$500K was fundraising target to reach 8,000 still in need.
f. Molasses block feeding program to restore work animals to work condition.
g. F$39,600 loss per day, for 275 days (75% of a year).
h. One year of 2 year grant program to clean up drains.
i. 675 families served by boreholes, at F$937 per family.
j. Re-establish dead plants only, only for mahogany plantation.
k. Foreign aid food assistance received.
l. Budget deficit of 2.4% GDP; negative GDP growth of 4.0% rather than anticipated 3.0% positive growth. Cost to government is 30% of budget (or 3 times the revenue loss).

Source: UNDAC (1998) supplemented with original analysis.

The total costs, F$275–$325 million, are equivalent to US$140–$165 million

The agricultural losses, F$125 + F$15 million are equivalent to US$71 million

Thus, the non-croped related losses in Viti Levu are:

(US$140–$165 million) – US$71 million = US$69–$94 million x 0.77 = ***US$50-$70 million (rounded)***

The crop related losses in Viti Levu include all the losses of sugarcane plus 77 percent of the losses in other crops:

US$64 million + (US$7.7 million x 0.77) = ***US$70 million***

From 1983 to 1998, Fiji experienced four El Niño related droughts, or 1 every 4 years. With the exception of the 1997-98 event, these more normal droughts could be considered the baseline variability conditions against which to measure a more severe event (such as the 1997-98 drought). Unfortunately, no information exists on the impact of these earlier droughts apart from agricultural yields, and one cannot rule out the possibility that the 1983-98 period already reflects some incremental impacts of climate change. Given these constraints, the incremental impact of climate change on droughts could not be assessed at this stage. About 40-50 percent of the costs of the 1997-98 drought involve agricultural impacts, and these were assessed separately in Section D.

Impact of Changes in Precipitation and Temperature on River Flow

The impact of rainfall changes on the water resources of Viti Levu was estimated for two water courses, the Nakauvadra Creek and the Teidamu Creek. The Nakauvadra Creek drains 28 km^2 of steeplands in northern Viti Levu. The Teidamu Creek drains a 56 km^2 watershed in the northwestern part of Viti Levu. Both streams have been monitored by the Hydrology Section of the Fiji Public Works Department since the early 1980s.

Projections of rainfall for Fiji under climate change conditions vary according to the two GCM models used by the study, which predict both an increase (with the CSIRO9M2 model) and a decrease in rainfall (DKRZ model). Using the PACCLIM water resources impact model, the results suggest that under the scenarios of climate change considered by the study, there would be a change of ± 10 % in the water flow by 2050 and of ± 20 % by 2100 (table A.22). Given the similar climate, land uses, topography and commercial areas between these creeks and the major Nadi and Ba rivers, similar changes in flow may occur there. A possible increase of 10-20% in flood volume could cause extensive damage to industrial and commercial areas. Conversely, if a lower rainfall scenario materializes, the Nadi, Ba and Sigatoka rivers could experience salt intrusion causing problems for agricultural irrigation.

The economic impact of these scenarios could not be assessed due to lack of data.

Table A.22 Predicted Future 1 in 10 year Low and High Daily Flows for the Teidamu and Nakauvadra Creeks, under Climate Change Scenarios (Viti Levu)

CGM Model		*Temperature Change °C*	*Rainfall Changes (%)*	*2025 Flow conditions (% change from baseline)*		*2050 Flow conditions (% change from baseline)*		*2100 Flow conditions (% change from baseline)*	
				Low flow	*High flow*	*Low flow*	*High flow*	*Low flow*	*High flow*
Teidamu Creek									
CSIRO9M2	B2 mid	0.5	3.3	+3.9	+3.3	+5.9	+5.7	+9.8	+9.6
	A2 high	0.6	3.7	+3.9	+3.7	+8.8	+8.2	+20.6	+20.3
DKRZ	B2 mid	0.5	-3.3	-2.9	-3.9	-3.9	-5.7	-9.8	-9.7
	A2 high	0.6	-3.7	-2.9	-7.8	-7.8	-8.2	-19.6	-20.3
Nakauvadra Creek									
CSIRO9M2	B2 mid	0.5	3.3	+3.4	+3.3	+5.7	+5.7	+9.2	+9.7
	A2 high	0.6	3.7	+3.4	+3.7	+8.0	+8.2	+19.5	+20.3
DKRZ	B2 mid	0.5	-3.3	-3.5	-3.7	-5.7	-5.7	-10.3	-9.7
	A2 high	0.6	-3.7	-3.5	-3.7	-8.0	-8.2	-20.7	-20.3

Impact of Changes in Precipitation and Temperature on Water Supply

A simulation of climate change scenarios impact was made for the Nadi-Lautoka Regional Water Supply Scheme. The scheme is the second largest in Fiji, serving an estimated 123,000 people in western Viti Levu (PNG Consultants 1996). The safe sustainable yield of the water sources (the Vaturu dam and the Lautoka sources) is 98 million liters a day (ML/day). This is based on a water availability of a 1 in 15 year drought event. The Vaturu dam currently supplies 45 ML/day and the other sources 14.5 ML/day. About 29 percent of the water supply is unaccounted for water, due to leakage and illegal connections. In 1996, the per capita demand for water was 330 l/day (JICA 1998). This is assumed to represent the average per capita consumption of both commercial and domestic users.

Future water demand was calculated based on a conservative 300 l/day average per capita, a 25 percent loss rate, and the population growth rates estimated in this study (table A.23). Under the baseline conditions, demand would exceed the sustainable supply in 2051 and 2041 for the mid and high population growth scenarios.

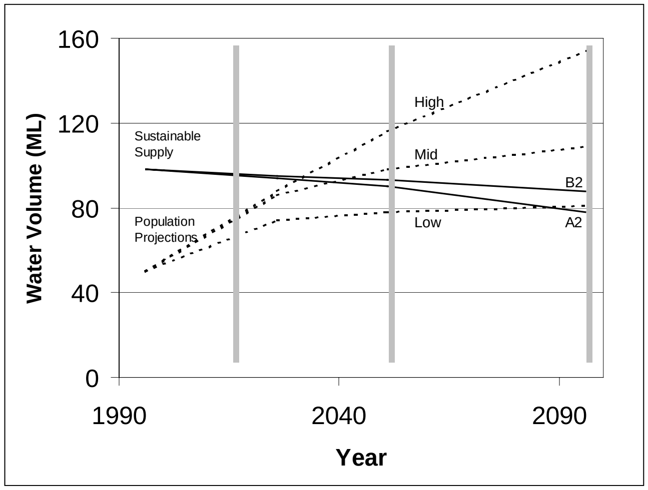
Using PACCLIM to estimate the future water supply under climate change conditions, and the results of the Teidamu creek as a proxy, it can be seen that the effects of climate change only become significant by 2050. With a low population scenario, climate change does not have significant impacts apart from the high scenario for 2100.

Table A.23. Projected Approximations of Potential Water Surplus (+) or Potential Deficit (-) of the Nadi-Lautoka Water Supply Scheme

(presented as deviation from sustainable yield with and without climate change)

	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

Figure A.4. Projections of Future Water Demand and Supply under Climate Change Conditions



As for the water flow analysis, no data were available to permit an estimation of the economic impacts of climate change.

Tarawa

The analysis of climate change impacts on water resources of Tarawa used a water balance model to estimate water recharge and then a groundwater model to analyze the impact of decreased recharge and changes in sea level on the thickness of the freshwater lens (Alam and Falkland 1997). The study did not account for changes in evapotranspiration.

Impact on Water Recharge

In low coral islands with a shallow water table, the water balance equation can be expressed as:

$$\mathbf{R = P - (E_I + E_S + T_L) \pm dV}$$

where

P is rainfall,
E is actual evapotranspiration, composed of:
interception (E_I),
evaporation and transpiration from the soil zone (E_S); and
transpiration of deep rooted vegetation directly from groundwater (T_L).
R is recharge to groundwater, and
dV is the change in soil moisture.

A study by Alam and Falkland (1997) estimated monthly recharge estimates using the water balance model for the Bonriki freshwater lens, the main water source for Tarawa. The water balance model used by this study (originally for 1954-1991) was adjusted to cover the 1954-1996 period, using daily rainfall data and estimates of daily evaporation data collected at the Betio meteorological station in Tarawa (Station No. J61000). The soil moisture zone at Bonriki is typically 500 millimeters thick based on observations from shallow pits and wells. The field capacity was assumed to be 0.15 based on typical values for sand-type soils (UNESCO 1991). The operating range of soil moisture was assumed to be from 25 to 75 millimeters, and the amount of evaporation from the soil moisture zone was assumed to be linearly related to the available soil moisture content.

The predominant vegetation types on the island are coconut trees and a variety of grasses and other shallow rooted vegetation. Crop factors of 1.0 and 0.8 were assumed for, respectively, grasses and shallow rooted vegetation, and coconut trees. The potential evaporation rate for coconut trees was taken to be 80 percent of potential evaporation while that for grasses or other shallow rooted vegetation was assumed to be equal to potential evaporation.

Using the water balance model described above, the impact of changes in rainfall on the water recharge at Bonriki was derived by linearly adjusting all daily rainfall values by the selected percentage change. The results are summarized on table A.24.

Table A.24. Impacts of Changes in Rainfall on Water Recharge in Bonriki, Tarawa

Mean Annual Rainfall (mm)	*% of Current Mean Annual Rainfall*	*Mean Annual Water Recharge (mm)*	*% of Current Mean Annual Water Recharge*
1327	65	415	41
1668*	75	583*	57
1632	80	667	65
1838	90	843	82
2040 (Current)	100	1023	100
2245	110	1207	118
2449	120	1393	136

** - Extrapolated values from table 4.1 in Taueua et al. (2000).*

The climate change scenarios used by this study project up to -11 to + 7 percent change in rainfall by 2050 and up to -27 to +18 percent change by 2100. As table A.24 indicates, a 10 percent change in rainfall could lead to an almost 20 percent change in the water recharge. Under the worst case scenario in 2100, the water recharge could change by up to - 43 percent (for a 25 percent decline in rainfall) to +36 percent (for a 20 percent increase in rainfall).

Analysis of Impacts on Groundwater

A. Physical Impacts of Climate Change on the Groundwater Resources of Tarawa

The water balance of a small island groundwater system can be expressed as follows:

$$\mathbf{R = GF + D + Q \pm \Delta S}$$

where

R is net recharge,
GF is groundwater outflow (to the sea),
D is dispersion at the base of the groundwater,
Q is groundwater extraction (normally by pumping), and
ΔS is change in freshwater zone storage.

The SUTRA groundwater model (Voss 1984) was applied to a selected cross section of the Bonriki freshwater lens to analyze the impact of climate change and sea level rise scenarios on the freshwater thickness. The SUTRA model was calibrated and verified using measured groundwater conditions in the mid to late 1980's. Groundwater data was available from a network of salinity monitoring boreholes at Bonriki installed in the early to mid 1980s.

A baseline scenario was created for current conditions (Alam and Falkland 1997). These included recharge to groundwater based on a 20 percent coverage of deep rooted trees (predominantly coconut trees) and a pumping rate of 1,000 cubic m^3/day, which is equal to the current pumping rate. The critical time selected for comparison was that occurring in November 1985 at the end of a long drought, which produced the thinnest freshwater lens condition.

The impact of eight scenarios of rainfall change, sea level rise, and potential loss of island width on the Bonriki freshwater lens are summarized on table A.25. The scenarios reflect the 2050 conditions forecasted by the models used by the study: they include a best guess (0.2 meters) and worst case (0.4 meters) scenario of sea level rise, and the projected rainfall changes (+ 7 to - 10 percent) under the worst case scenarios[4]. The analysis also took into account a reduced island width due to inundation of 230 meters, or 19 percent of the total width of the island. This corresponds to the likely area inundated at the station sampled.

Table A. 25. Impacts on the Bonriki Freshwater Lens Thickness due to Possible Climate Change Scenarios

Climate Change and Sea Level Rise Scenario	*Average change in freshwater thickness compared with baseline scenario*	
	(meters)	*(%)*
1. Baseline scenario (current mean sea level and rainfall; average freshwater thickness = 12.1 m)	-	-
2. Current MSL, 7% increase in rainfall	+0.66	+5.5
3. Current MSL, 10% reduced rainfall	-1.7	-14
4. 0.2 meters MSL rise, current rainfall	-0.1	-0.9
5. 0.4 meters MSL rise, current rainfall	+0.25	+2.0
6. 0.4 meters MSL rise, 10% reduced rainfall	-1.4	-12
7. 0.4 meters MSL rise, current rainfall, reduced island width	-3.5	-29
8. 0.4 meters MSL rise, 7% increased rainfall, reduced island width	-2.3	-19
9. 0.4 meters MSL rise, 10% reduced rainfall, reduced island width	-4.7	-38

Note: MSL = mean sea level

As expected, the freshwater thickness increases or decreases depending on whether a scenario of increased or decreased rainfall materializes. A rise in mean sea level *per se* could increase the freshwater lens volume, as the groundwater table (the top of the freshwater lens) rises while its base remains relatively unaffected. However, if sea level rise was accompanied by a reduction of island width due to inundation (which is likely), the freshwater thickness would be reduced by 19 to 38 percent, depending on whether scenarios of increased or decreased rainfall materialized (see scenarios 8 and 9 on table A.25). These estimates reflect the combined impacts of a reduced island width, and 'worst case' scenarios of sea level rise and rainfall changes in 2050. A 'best guess' scenario of rainfall change could result in relatively lesser impacts, but this might be offset by the lower rise in groundwater table caused by a smaller (0.2 meters) sea level rise.

[4] Best guess scenarios (+5 to -7.5 percent) fall within these two extremes.

B. Economic Impact of Climate Change on the Groundwater Resources of Tarawa

For the purposes of the economic analysis, it is assumed that the Bonriki freshwater lens is representative of other groundwater systems in Tarawa, and that changes in the thickness of the lens reflect changes in volume. The current yield of the Bonriki and Buota freshwater lenses is 1,300 m^3/day, serving a population of about 26,000. The public water system currently fails to meet demand due to an estimated 50 percent leakage (SOPAC 1998) and the presence of illegal connections.

If in the future all islands of North Tarawa were developed for groundwater use, the estimated additional yield would amount to nearly 3,900 m^3/day, or a total of 5,200 m^3/day with the Bonriki and Buota water supplies. Hence, 5,200 m^3/day is taken as the total groundwater capacity for Tarawa, and the basis for the estimated impact.

The economic cost of climate change can be estimated based on what it would cost to replace the lost groundwater capacity. Two replacement sources were considered: (i) the costs of rehabilitation and expansion into additional groundwater sources; and (ii) desalination. A third possibility ─ rainwater collectors ─ is likely to be less expensive than desalination, but could not be computed at this stage.

The analysis involved three major steps:

Step 1: Estimate the Unit Costs of Substitutes. The costs of rehabilitation and expansion into new groundwater sources in North Tarawa are estimated at A$2.6/$m^3$ in 1995 (ADB 1996). The 1995 costs of desalination are estimated at between A$4.0 to A$6.2/m^3 (ADB 1996). The higher figure appears to be more accurate. Nonetheless, as desalination costs are likely to decrease in the future, an average of the two estimates was used, or A$5.1/$m^3$.

Step 2: Convert into 1998 US dollars. The unit costs above are 1995 estimates. To convert them into 1998 U.S. dollars, an index of inflation such as the Tarawa Retail Price Index needs to be applied:

Year	*Retail Price Index (% change)**
1996	1.5
1997	2.2
1998	4.7

* IMF estimates.

For the costs of groundwater expansion:

A$2.6 x 1.015 = A$2.64
A$2.64 x 1.022 = A$2.70
A$2.70 x 1.047 = A$2.82

Converting into US dollars by the 1998 exchange rate (1US$ = A$1.5):

A$2.82 / 1.5 = US$1.9/ m^3.

For the costs of desalinated water:

A$5.1 x 1.015 = A$5.18
A$5.18 x 1.022 = A$5.29
A$5.29 x 1.047 = A$5.54

Converting into US dollars:

A\$5.54 / 1.5 = ***US\$3.7/ m^3.***

Step 3: Estimate the Costs of Substitution. Assuming that the percentage reductions in groundwater thickness apply to the total groundwater supply of Tarawa (5,200 m^3/day), the economic costs of having to substitute existing supplies by alternative sources as a result of climate change are as shown on table A.26.

Table A.26. Estimated Annual Economic Costs of Climate Change on Water Resources in Tarawa, 2050 (millions of 1998 US\$)

Climate Change and Sea Level Rise Scenario	*% change in groundwater thickness*	*Economic costs of substitution by alternative sources*	
		Expansion into new groundwater sources	*Desalination*
Baseline scenario (current mean sea level and rainfall; average freshwater thickness = 12.1 m)	-		-
Current MSL, 7% increase in rainfall	+5.5	+0.2	+0.4
Current MSL, 10% reduced rainfall	-14	-0.5	-1.0
0.2 meters MSL rise, current rainfall	-0.9	-0.0	-0.1
0.4 meters MSL rise, current rainfall	+2.0	+0.1	+0.1
0.4 meters MSL rise, 10% reduced rainfall	-12	-0.4	-0.8
0.4 meters MSL rise, current rainfall, reduced island width	-29	-1.0	-2.0
0.4 meters MSL rise, 7% increased rainfall, reduced island width	-19	-0.7	-1.3
0.4 meters MSL rise, 10% reduced rainfall, reduced island width	-38	-1.4	-2.7
Total costs (under a reduced rainfall scenario)		-1.4 to -2.7	
Total costs (under an increased rainfall scenario)		-0.7 to -1.3	
Total costs		**-0.7 to -2.7**	

Example:

For a reduction of 38 percent in total supply, the costs of expanding into new groundwater sources are:

5,200 m^3/day x 0.38 = 1976 m^3/day x US\$1.9/m^3 = US\$3,754 x 365 (to account for yearly costs) = US\$1.4 million.

The costs of expanding into desalinated water are:

5,200 m^3/day x 0.38 = 1976 m^3/day x US\$3.7/m^3 = US\$7,311 x 365 (to account for yearly costs) = US\$2.7 million.

Several caveats need to be attached to the analysis. First, the conditions in Bonriki may not apply to other groundwater sources in Tarawa. Second, the costs of alternative rainwater collectors are likely to be lower than those of desalination. Third, if population pressures continue, there may be no additional groundwater sources onto which to expand supply. Background reports to this study, however, estimate that an additional 2,600 m^3/day of groundwater supply might be obtained by reclaiming land in Temaiku Bight, on the southeastern part of the Tarawa atoll. Hence, the assumptions made appear defensible.

D. Impacts on Agriculture

Viti Levu

The impacts of climate change on the agriculture production of Viti Levu were estimated using the PLANTGRO model (Hackett 1988, 1991), which was incorporated into PACCLIM and was linked to the scenario generator and Fiji data. PLANTGRO allows the derivation of notional relationships between plant response (suitability) and different levels of 23 climate and soil factors. The outputs can be in the form of:

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

The PLANTGRO model was used to model the impacts of climate change on the production of yam, taro, and cassava. The study team attempted to use PLANTGRO to assess the suitability and yield of sugarcane under present conditions, but the model under-predicted yields in the western part of Viti Levu, where the industry is centered. Estimates of climate change impact for sugarcane were therefore derived based on historical estimates and future projections of climate variability.

Impact of Climate Change and Variability on Sugarcane Production

Sugarcane production is affected by both rainfall and by climate variability, especially El Niño-induced droughts. The cumulative effects of a sequence of extreme events can be particularly damaging to sugarcane. The 1998 drought, which followed a sequence of natural disasters in Fiji, led to a nearly 50 percent reduction in sugarcane production estimated to cost US$64 million (Figure A.5 and table A.27):

Figure A.5: Impacts of El Niño- induced Droughts on Sugarcane Production in Fiji (Cane Crushed) 1983-98

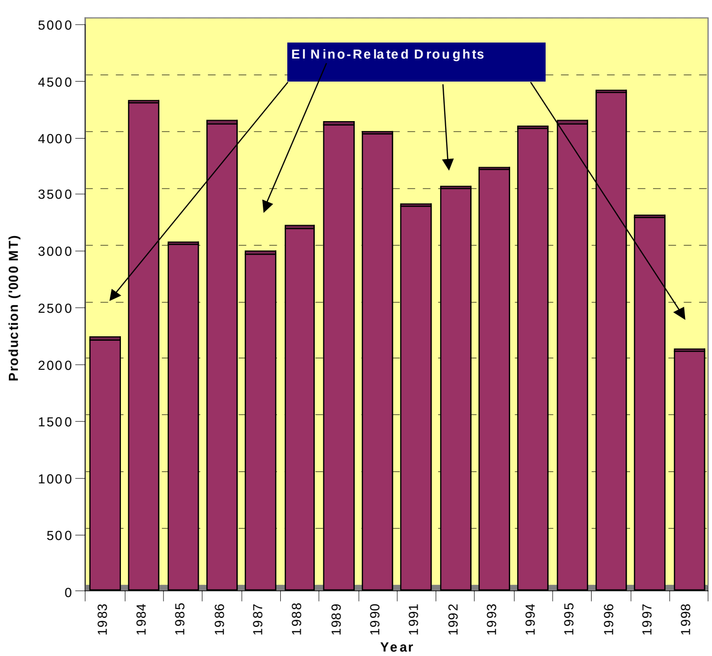


Table A.27. Production of Sugarcane in Fiji, 1983-88 ('000 MT)

Year	*Production ('000 MT)*
1983	2202
1984	4290
1985	3042
1986	4109
1987	2960
1988	3185
1989	4099
1990	4016
1991	3380
1992	3533
1993	3703
1994	4063
1995	4110
1996	4379
1997	3280
1998	2100
Average	3528

The present expectation in Fiji is for an annual sugarcane production in the order of four million tonnes. As can be seen in Figure A.5, this level of production has been attained in only seven of the last 15 years. Of the other eight years, all but one (1985) were associated with El Niño-droughts, which also tend to be associated with a greater frequency of tropical cyclones of hurricane force winds (Pahalad and Gawander 1999). Intermediary production years (such as 1993) reflect a slow recovery from the effects of droughts and cyclones.

The analysis of physical and economic impact involved three major steps:

Step 1: Estimate the Baseline Conditions. The baseline conditions reflect the impact of climate variability (droughts and cyclones) at present times. Hence, future production levels should not be compared to a normal year (such as 1990, with 4 million metric tons), but to an average year over a representative period of time. Taking 1983-1998[5] as a basis for the analysis, the average baseline production during this 16 year period was 3.53 million metric tons (table A.27).

Step 2: Estimate Future Production under Climate Change and Climate Variability. Under future climate change conditions, the adverse effects of warmer temperatures (due to increased evapotranspiration and heat stress) may be offset by the possibility of higher rainfall. However, it is likely that the effects of bad years might be worsened by warmer and possibly drier conditions. The 1997/98 El Niño drought, regarded as a 1 in 100 year event, may become more of the norm during El Niño years. If this were the case, and based on the same frequency of droughts as observed in the 1983-98 period (Figure A.5), the following production might be expected within the next 25 to 50 years:

- 25 percent of the years (4 out of 16 years) would have half the normal production: 2 million MT
- 31 percent of the years (5 out of 16 years) would have three-fourths of the normal production: 3 million MT
- 44 percent of the years (7 out of 16 years) would have normal production: 4 million MT.

The frequency of droughts and 'recovery' years is based on the historical records of Figure A.5.

The weighted average production in a given year in the future is therefore:

(0.25 x 2 million MT) + (0.31 x 3 million MT) x (0.44 x 4 million MT) = ***3.2 million MT***

This represents a 9 percent drop relative to the average for the 1983-98 period (3.5 million MT)

Step 3: Estimate the Economic Impact of Future Climate Change and Climate Variability. The 1998 price paid to sugarcane growers was F$81.79 per metric ton, or US$41.73 at the 1998 exchange rate of 1US$ = F$1.96.

The average annual economic damages to surgarcane caused by future climate change and variability can then be computed as follows:

(3.528 million MT x US$41.73/MT) - (3.2 million MT x US$41.73/MT) = US$147.2 - US$133.5 million
= ***US$13.7 million***

It is assumed that all of the sugar production is harvested in Viti Levu.

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[5] Readers may note that this period differs from that used as the analogue for cyclone impacts (1992-99). The reason is that droughts, occurring less frequently than cyclones, need a longer historical period on which to base the analysis. Also, 1983-98 was the period for which data on sugarcane was available.

Impact of Climate Change and Variability on Other Crops (Taro, Yam and Cassava)

The PLANTGRO model in PACCLIM was used to model the impact of climate change and climate variability on taro, yams and cassava. The model was run for the following conditions:

Baseline Conditions:

Average year (1990)	
Current El Niño:	+0.5°C, -50% rainfall
Current La Niña	-0.5°C, +50% rainfall

2050 Conditions:

CSIRO9M2 Global Circulation Model and Best Guess Scenario	+0.9°C, +5.7% rainfall
CSIRO9M2 Global Circulation Model and Worst Case Scenario	+1.3°C, +8.2% rainfall
DKRZ Global Circulation Model and Best Guess Scenario	+0.9°C, -5.7% rainfall
DKRZ Global Circulation Model and Worst Case Scenario	+1.3°C, -8.2% rainfall
2050 El Niño	+1.5°C, -60% rainfall
2050 La Niña	+0.5°C, +60% rainfall

The 2050 El Niño and La Niña models include both average changes in climatic conditions, as well as in climate variability. Similar models were run for 2025 and 2100, but were not used in the final analysis. For each of the above models, the images produced were imported into an IDRISI Global Information System (Eastman 1985), and the land area in each yield class (0-5 metric tons/ha; 5-10 metric tons/ha; 10-15 metric tons/ha) was calculated. This represents areas of suitability for the different yield classes, rather than actual area in production. However, the changes observed in the suitable land areas as climatic conditions are simulated allow for an estimate of the relative impacts of climate change on production yields (table A.28).

Table A.28. Relative Impact of Climate Change and Climate Variability on Taro Yield

	Baseline (1990)			*2050 Conditions*					
				2050 Normal Year					
	1990 Normal Year	*1990 El Niño Year*	*1990 La Niña Year*	*CSIRO Best Guess*	*CSIRO Worst Case*	*DKRZ Best Guess*	*DKRZ Worst Case*	*2050 El Niño Year*	*2050 La Niña Year*
1.No. of hectares suitable for cultivation with yield of:									
0-5 t/ha	2232.7	6456.3	877.0	2065.5	1992.0	2619.0	2766.5	8789.3	759.5
5-10 t/ha	4935.3	3477.0	5291.0	5127.3	5221.3	4723.3	4688.8	1720.3	5395.8
10-15 t/ha	3397.5	634.3	4397.5	3372.8	3352.3	3223.3	3110.3	56.0	4410.3
2. Percentage of hectares per land class:									
0-5 t/ha	21%	61%	8%	20%	19%	25%	26%	83%	7%
5-10 t/ha	47%	33%	50%	49%	49%	45%	44%	16%	51%
10-15 t/ha	32%	6%	42%	32%	32%	31%	29%	1%	42%
3. Weighted average yield (in tons/hectare)									
	8.1	4.7	9.2	8.1	8.1	7.8	7.7	3.4	9.2
4.Change from baseline (relative to a 1990 normal year, in percentage)									
	0%	-41.4%	+13.8%	+0.8%	+1.1%	-3.3%	-4.8%	-58.2%	+14.6%

Note: Shaded figures relate to the examples on page 45. Numbers may not add up due to rounding.

On the table above, the first set of estimates represents the number of hectares suitable for cultivation in each of the three land classes (0-5 tons/ha; 5-10 tons/ha; 10-15 tons/ha). This figure changes according with each of the 9 simulated scenarios, and is provided through PACCLIM and PLANTGRO.

The second set of estimates represents the percentage of land suitable for cultivation in each of the three land classes.

Example: The 1990 average baseline conditions project 3397.5 hectares of land suitable for cultivation with a yield of 10 to 15 metric tons per hectare.

First, one computes the total number of hectares suitable for cultivation:

2,232.7 + 4,935.3 + 3,397.5 = 10,565.5

Then one computes the proportion of area suitable for cultivation having a yield of 10 to 15 metric tons per hectare:

3,397.5 hectares : 10,565.5 hectares = 32 percent.

Hence, under this scenario, 32 percent of the area suitable for cultivation would have yields of 10-15 tons/ha.

The third set of estimates represents the weighted average yield of each of the scenarios:

Example: The 1990 average baseline conditions are distributed as follows:

0-5 tons/ha land:	2,232.7 hectares or 21% of the total
5-10 tons/ha land:	4,935.3 hectares or 47% of the total
10-15 tons/ha land:	3,397.5 hectares or 32 % of the total

The weighted average yield uses the mid-value of each land type. Thus, for 0-5 tons/ha land, the mid-value would be 2.5 tons/ha; for 5-10 tons/ha land, the mid-value would be 7.5 tons/ha; etc.

The weighted average uses these mid-values, multiplied by the percentage of each land class, is as follows:

(2.5 tons/ha x 0.21) + (7.5 tons/ha x 0.47) + (12.5 tons/ha x 0.32) = 8.1 tons/ha.

Finally, the fourth and last set of estimates computes how the average yield for each scenario differs from the 1990 baseline average:

Example: The 1990 weighted average yield is 8.1 tons/ha. The yield during a 1990 El Niño is only 4.7 tons/ha. Thus:

4.7 / 8.1 = 0.586.

The yield during a 1990 El Niño is only 58.6 percent that of a normal year (on average). This means that the average yield during an El Niño event decreases by 1-0.586 = 0.414 or -41.4 percent.

Tip: To estimate the percent decline or increase relative to the baseline, use [{scenario} / {baseline} - 1] x 100 to determine the percentage reduction or increase.

For the 2050 El Niño and La Niña conditions, the relevant comparison is with the baseline El Niño and La Niña conditions:

Example: The 1990 weighted average yield during an El Niño year is 4.74 tons/ha. The estimated yield during a 2050 El Niño year is 3.36 tons/ha (the numbers are rounded on table A.28). The incremental difference is:

[(3.36 / 4.74) -1)] x 100 = 29.1 percent.

Similarly than for taro, one can also estimate the change in yield of yam and cassava caused by the combined effects of climate change and climate variability (tables A.29 and A.30)

Table A.29. Relative Impact of Climate Change and Climate Variability on Yam Yield

	Baseline (1990)			*2050 Conditions*					
	1990	*1990*	*1990*	*2050 Average Conditions*				*2050*	*2050*
	Average Conditions	*El Niño Year*	*La Niña Year*	*CSIRO Best Guess*	*CSIRO Worst Case*	*DKRZ Best Guess*	*DKRZ Worst Case*	*El Niño Year*	*La Niña Year*
No. of hectares suitable for cultivation with yield of :									
0-5 t/ha	1749.3	779.0	6677.5	2171.8	2389.3	1348.0	1228.0	873.3	7598.8
5-10 t/ha	3694.3	5420.5	1506.5	3458.8	3335.3	3887.8	3969.3	6229.5	1148.3
10-15 t/ha	5122.0	4366.0	2381.5	4935.0	4841.0	5329.8	5369.3	3462.8	1818.5
% hectares per land class:									
0-5 t/ha	17%	7%	63%	21%	23%	13%	12%	8%	72%
5-10 t/ha	35%	51%	14%	33%	32%	37%	38%	59%	11%
10-15 t/ha	48%	41%	23%	47%	46%	50%	51%	33%	17%
Weighted average yield (in tons/hectare)									
	9.1	9.2	5.5	8.8	8.7	9.4	9.5	8.7	4.8
4.Change from baseline (relative to a 1990 normal year, in percentage)									
	0%	+1.1%	-39.9%	-3.2%	-4.8%	+3.2%	+4.0%	-4.1%	-47.6%

Note: Numbers may not add up due to rounding.

Table A.30. Relative Impact of Climate Change and Climate Variability on Cassava Yield

	Baseline (1990)			*2050 Conditions*					
	1990	*1990*	*1990*	*2050 Average Conditions*				*2050*	*2050*
	Average Conditions	*El Niño Year*	*La Niña Year*	*CSIRO Best Guess*	*CSIRO Worst Case*	*DKRZ Best Guess*	*DKRZ Worst Case*	*El Niño Year*	*La Niña Year*
No. of hectares suitable for cultivation with yield of :									
0-5 t/ha	728.0	736.5	2178.3	728.0	735.0	1110.0	1131.5	935.8	3847.5
5-10 t/ha	7400.8	7880.0	5955.3	8208.8	8479.3	7763.0	8051.8	8450.5	5108.3
10-15 t/ha	1929.8	1442.0	1925.0	1121.8	844.3	1185.5	875.3	672.3	1102.8
% hectares per land class:									
0-5 t/ha	7%	7%	22%	7%	7%	11%	11%	9%	38%
5-10 t/ha	74%	78%	59%	82%	84%	77%	80%	84%	51%
10-15 t/ha	19%	14%	19%	11%	8%	12%	9%	7%	11%
Weighted average yield (in tons/hectare)									
	8.1	7.9	7.4	7.7	7.6	7.5	7.4	7.4	6.1
4.Change from baseline (relative to a 1990 normal year, in percentage)									
	0%	-3.0%	-8.9%	-5.0%	-6.7%	-6.9%	-9.0%	-9.0%	-24.2%

Note: Numbers may not add up due to rounding.

In order to estimate the economic impact of climate change and variability on food crops, the following five steps were followed:

Step 1: Compute Baseline Production for Viti Levu. Tables A.28-30 are useful to estimate the percentage change in average yields caused by the different climatic conditions. However, the 'suitability' areas do not reflect actual production. To estimate the baseline production in Viti Levu, one needs to use actual production statistics. FAO (1996) provides the following estimates of production in 1990, an 'average' year in Viti Levu (table A.31).

Table A.31. Production of Major Fijian Food Crops (1990)

Crop	*Land Area (hectares)*	*Yield (tons/ha)*	*Production (thousand tons)*	*Price (F$/ton)*	*Value (millions F$)*
Taro	4,632	1.9	8.8	230	2.0
Yam	1,099	7.1	7.8	500	3.9
Cassava	4,352	5.4	23.5	220	5.2

Source: Statistics on yield, production, and price come from the FAOSTAT database (FAO 1996) for the base year 1990.
Note: Acreage and value are derived from these basic statistics. Tons represent metric tons.

The figures above are for Fiji as a whole. To estimate the production for Viti Levu, the production figures need to be adjusted by the proportion of total land that Viti Levu represents (58 percent), assuming relative uniform yields across Fiji:

Crop	*Production (thousands tons)*	*Adjustment for Viti Levu*	*Total Production Viti Levu (thousand tons)*
Taro	8,800	x 0.58	5,104
Yam	7,800	x 0.58	4,524
Cassava	23,500	x 0.58	13,630

Step 2: Adjust the Value of Production to 1998. To convert the 1990 prices to 1998 values, one can use the consumer price index (CPI) for Fiji (MFNP 1999):

Year	*CPI (% change)*	*Taro (F$/ton)*	*Yam (F$/ton)*	*Cassava (F$/ton)*
1990 baseline	0.0	230.0	500.0	220.0
1991	6.5	245.0	532.5	234.3
1992	4.9	257.0	558.6	245.8
1993	5.2	270.3	587.6	258.6
1994	0.6	271.9	591.2	260.1
1995	2.2	277.9	604.2	265.8
1996	2.4	284.6	618.7	272.2
1997	2.9	292.8	636.6	280.1
1998	8.1	**316.6**	**688.2**	**302.8**

(see page 4 for an explanation of inflation adjustment)

The 1998 baseline production value of the three crops in Viti Levu is therefore:

Crop	*Production* (metric tons)	*Price* (1998 F$/ton)	*Production Value* (1998 F$ thousands)
Taro	5,104	316.6	1,616
Yam	4,524	688.2	3,113
Cassava	13,630	302.8	4,127

Or, converting into 1998 US$ (at an exchange rate of 1 US$ = F$1.96):

Crop	*Production Value (1998 US$ thousands)*
Taro	824
Yam	1,588
Cassava	2,106

Step 3: Compute Baseline Production taking into Account Climate Variability. As for sugar, it would be incorrect to compare future climatic conditions with an average production year, as conditions such as El Niño or La Niña play a strong role in the present-day production of food crops. Hence, it is necessary to compute a baseline that takes present-day climate variability into account. This can be done by observing the sequence of El Niño/La Niña events in Fiji (see Figure A.5). While La Niña does not play a vital role in sugarcane, it is quite important for food crops, in particular for yam and cassava. Hence, the occurrence of La Niña years needs also to be taken into account.

During the 16 year period of 1983-98, there were 7 years that could be considered ‘normal’, 4 El Niño years, 2 La Niña years, and 3 ‘intermediary’ years. Since El Niño years are the most important for taro, while La Niña plays a stronger role in the production of yam and cassava, the intermediary years are taken to involve levels of production between a ‘normal’ and a ‘El Niño’ year for taro, and between a ‘normal’ and a ‘La Niña’ year for yam and cassava.

An occurrence of once every 4 years for El Niño is equivalent to a probability of occurrence of 25 percent in any given year (4 : 16). Similarly, an occurrence of 2 in 16 for La Niña is equivalent to a probability of nearly 15 percent.[6] Normal years occur with a probability of 40 percent, and intermediary years with a probability of 20 percent. Hence, for all three food crops, the probability of occurrence is as follows:

Baseline Conditions

	Taro	*Yam*	*Cassava*
	Probability of occurrence		
El Niño 1990	25%	25%	25%
La Niña 1990	15%	15%	15%
Normal Year 1990	40%	40%	40%
Intermediary Year (El Niño to normal)	20%	–	–
Intermediary Year (La Niña to normal)	–	20%	20%

[6] 15 percent was used, rather than the more technically correct 12.5 percent, because it is debatable whether Fiji experienced 2 or 3 La Niñas during the 1983-98 period.

If it is recalled, the above baseline conditions result in the following changes in average yield from a normal year (see tables A.28 to A.30):

Baseline Conditions

	Taro	*Yam*	*Cassava*
	Changes in yield from the baseline (in percentage)		
El Niño 1990	-41.4%	+1.1%	-3.0%
La Niña 1990	+13.8%	-39.9%	-8.9%
Normal Year 1990	0%	0%	0%
Intermediary year (El Niño to normal)[1]	-20.7%	—	—
Intermediary year (La Niña to normal)[1]	—	-20.0%	-4.5%

[1] - average of a normal year and an El Niño year (or a La Niña year)

It is then relatively simple to compute a weighted average of the two tables above to derive the variability coefficient:

Baseline Conditions

	Probability of Occurrence	*Taro*	*Yam*	*Cassava*
		Change in yield from the baseline (in percentage)		
El Niño 1990	25%	-41.4%	+1.1%	-3.0%
La Niña 1990	15%	+13.8%	-39.9%	-8.9%
Normal Year 1990	40%	0%	0%	0%
Intermediary year (El Niño to normal)	20%	-20.7%	—	—
Intermediary year (La Niña to normal)	20%	—	-20.0%	-4.5%
Variability Coefficient		-12.4%	-9.7%	-3.0%

Example: The variability coefficient for taro is:

(0.25 x -41.4%) + (0.15 x +13.8%) + (0.4 x 0%) + (0.2 x -20.7%) = -10.35 + 2.07 + 0 - 4.14 = -12.4%

One can then derive a baseline production which takes into account climate variability:

Table A. 32. Baseline Production (1990) Taking Into Account Climate Variability

Crop	*Normal Production (metric tons)*	*Variability Coefficient (% change in yield due to climate variability)*	*Baseline Production w/ climate variability (metric tons)*	*Production Value w/ climate variability (thousands of 1998 US$)*
Taro	5,104	-12.4 %	4,524	722
Yam	4,524	-9.7%	4,085	1,434
Cassava	13,630	-3.0%	13,630	2,043

Example: For yam, the baseline production value (taking into account climate variability) is:

4,524 tons *(average production in a normal year in Viti Levu)*	x	(1-0.097) *(variability coefficient)*	=	4,085 tons *(average production) taking into account climate variability)*
4,085 *(average production w/ variability)*	x	F$688.2 *(1998 price per ton)*	=	F$2,811,300 *(total value of production w/ variability)*
F$2,811,300 *(total value of production in Fijian dollars w/ variability)*	/	1.96 *(exchange rate to US$ in 1998)*	=	US$1,44,335 *(total value of production in 1998 US dollars, taking variability into account)*

Step 4: Compute Impact of Climate Change on Average Conditions. The impact of climate change on average conditions is simply the difference in yield and production value of an average year in 2050 relative to an average year in 1990 (table A.23). In order to account for uncertainty, a range of predicted yield changes was constructed by taking into account all four scenarios of tables A.28 to A.30 (CSIRO Best Guess and Worst Case Scenarios, and DKRZ Best Guess and Worst Case Scenarios).

Table A. 33. Impact of Climate Change (Rainfall and Temperature) on Average Climatic Conditions, 2050

Crop	*Average Baseline Conditions (in 1990)*		*Impact of Climate Change on Average Climatic Conditions (2050)*	
	Average Production (metric tons)	*Production Value (in 1998 US$ thousands)*	*Change in Average Yields*	*Costs of Climate Change (in 1998 US$ thousands)*
Talo	5,104	824	-4.8% to +1.1%	-40 to + 9
Yam	4,524	1,580	-4.8% to +4.0%	-76 to + 63
Cassava	13,630	2,101	-9.0% to -5.0%	-189 to -105

Notes: Minus signs denote costs of climate change.
Plus signs denote a benefit if scenarios of higher rainfall (as predicted by the DKRZ model) materialize.

Example: For cassava, the impact of climate change on average climatic conditions is as follows (table A.30):

The predicted change in average yields under the CSIRO Best Guess scenario is -5.0%
The predicted change in average yields under the CSIRO Worst Case scenario is -6.7%
The predicted change in average yields under the DKRZ Best Guess scenario is -6.9%
The predicted change in average yields under the DKRZ Worst Case scenario is -9.0%

Hence, the range of predicted changes is -9.0% to - 5.0%. Applying these changes to the baseline production value:

-0.09 x US$2,101,000 = - US$ 189,090
-0.05 x US$2,101,000 = - US$ 105,050

The cost of changes in average climatic conditions in 2050 ranges from US$189,000 to $105,000.

Step 5: Compute the Impact of Climate Change and Climate Variability. To estimate the impact of climate change and climate variability in 2050, one can use a method similar to that of Step 3, by computing variability coefficients for the conditions likely to prevail in 2050 relative to a normal year in 1990.

Tables A.28 to A. 30 provide the expected changes in yields of 2050 conditions relative to the 1990 baseline:

	Taro	*Yam*	*Cassava*
	Changes in Yield from the 1990 Baseline (in percentage)		
El Niño 2050	-58.2%	-4.1%	-9.0%
La Niña 2050	+14.6%	-47.6%	-24.2%
Normal Year 2050	-4.8% to +1.1%	-4.8% to +4.0%	-9.0% to -5.0%

To compute the variability coefficients, one needs to apply the weights considered in Step 3. This assumes no change in the frequency of El Niño and La Niña events in the future:

		Taro	*Yam*	*Cassava*
	Probability of Occurrence	*Change in yield from the baseline (in percentage)*		
El Niño 2050	25%	-58.2%	-4.1%	-9.0%
La Niña 2050	15%	+14.6%	-47.6%	-24.2%
Normal Year 2050	40%	-4.8% to +1.1%	-4.8% to +4.0%	-9.0% to -5.0%
Intermediary year (El Niño to normal)	20%	-58.2% to +1.1%	—	—
Intermediary year (La Niña to normal)	20%	—	-47.6% to +4.0%	-24.2% to -5.0%

"Intermediary years" are assigned the range of values between a normal and abnormal year. Hence, for taro, the change in yield during an intermediary year could range from -58.2% (the change during an El Niño year) to +1.1% (the change in average climatic conditions).

The variability coefficients for 2050 conditions are therefore:

	Taro	*Yam*	*Cassava*
Variability coefficients	-25.9% to -11.7%	-19.6% to -5.8%	-14.3% to -8.9%

Example: The variability coefficient for yam is:

(0.25 x -4.1%) + (0.15 x -47.6%) + (0.4 x -4.8%) + (0.2 x -47.67%) = -19.6% for the lower bound and
(0.25 x -4.1%) + (0.15 x -47.6%) + (0.4 x +4.0) + (0.2 x +4.0%) = -5.8% for the upper bound

One can then apply these variability coefficients to the normal production in 1990 to derive the expected production in 2050 under both climate change and climate variability (table A.34).

Table A. 34. Expected Production in 2050 with Climate Change and Climate Variability

Crop	*Average Baseline Conditions (in 1990)*		*Variability Coefficient in 2050*	*Expected Conditions in 2050 due to Climate Change and Climate Variability*	
	Production (metric tons)	*Value (in 1998 US$ thousands)*		*Production (metric tons)*	*Value (in 1998 US$ thousands)*
Talo	5,104	824	-25.9% to -11.7%	3,782 to 4,507	611 to 728
Yam	4,524	1,580	-19.6% to -5.8%	3,637 to 4,262	1,270 to 1,488
Cassava	13,630	2,101	-14.3% to -8.9%	11,681 to 12,417	1,800 to 1,914

Example: The expected production of cassava in 2050 is as follows:

The variability coefficient of -14.3% to -8.9% indicates the proportion by which the 1990 normal yield is reduced under the future conditions.

13,630 tons x (1-0.143) = 11,681 (for the lower bound)
13,630 tons x (1-0.089) = 12,417 (for the upper bound)

Table A.34 shows the expected production and value under future conditions of climate change (rainfall and temperature) and variability (El Niño/La Niña conditions). It does not indicate, however, the costs of these changes. To do this, one needs to compute the difference between the 2050 conditions — with climate variability — and the 1990 baseline conditions (also with climate variability). This is shown on table A.35 below.

Table A. 35. Impact of Climate Change (Rainfall and Temperature) and Climate Variability (ENSO) on Food Crops, 2050

Crop	*1990 Baseline Conditions with Climate Variability*		*2050 Conditions with Climate Change and Variability*		*2050 Impacts of Climate Change and Variability (2050)*	
	Production (metric tons)	*Value (in 1998 US$ thousands)*	*Production (metric tons)*	*Value (in 1998 US$ thousands*	*Changes in Yield (in percentage)*	*Economic Costs (in 1998 US$ thousands)*
Taro	4,471	722	3,782 to 4,507	611 to 728	-15.4% to +0.8%	-111 to +6
Yam	4,085	1,434	3,637 to 4,262	1,270 to 1,488	-11.0% to +4.3%	-164 to +54
Cassava	13,221	2,042	11,681 to 12,417	1,800 to 1,914	-11.7% to -6.1%	-242 to -128

Example: For Taro, the production in 2050 is 3,782 to 4,507 metric tons. The production under the 1990 baseline is 4,471 metric tons. Hence, the change in yield is as follows:

[(3,782 / 4,471) -1] x 100 = -15.4 percent (for the lower bound) and
[4,507 / 4,471) - 1] x 100 = +0.8 percent (for the upper bound)

The economic costs of climate change and variability are therefore:

611 - 722 = -US$111,000 (for the lower bound) and
728 - 722 = + US$6,000 (for the upper bound)

The upper bound represents a net economic gain under a scenario of rainfall increase. The lower bound represents a net economic loss under a scenario of rainfall decrease.

The overall impact of climate change on the agriculture sector of Viti Levu is summarized in table A.36.

Table A.36. Estimated Economic Impact of Climate on Change on Agriculture in Viti Levu, Fiji, 2050 (thousands of 1998 US$)

		Impact of change in average rainfall and temperature		*Impact of change in rainfall, temperature, and climate variability (ENSO)*	
Crop	***Current production*** *(US$ thousands)*	*Economic Impact (US$ thousands)*	*Change in average yield (percent)*	*Economic Impact (US$ thousands)*	*Change in average yield (percent)*
Sugarcane	147.2	—	—	-13,700	-9
Dalo (Taro)	800	-40 – +9	-5 – +1	-111 – +6	-15 – +1
Yam	1,600	-76 – +63	-5 – +4	-164 – +54	-11 – +4
Cassava	2,100	-189 – -105	-9 – -5	-242 – -128	-12 – -6
Total				**-13,800 – 14,200**	

— Not available. Minus signs indicate an economic cost. Plus signs indicate an economic benefit (from rainfall increases).
Note: Ranges reflect best-guess and worst–case scenarios under two different climate change models.
Source: Background studies to this report.

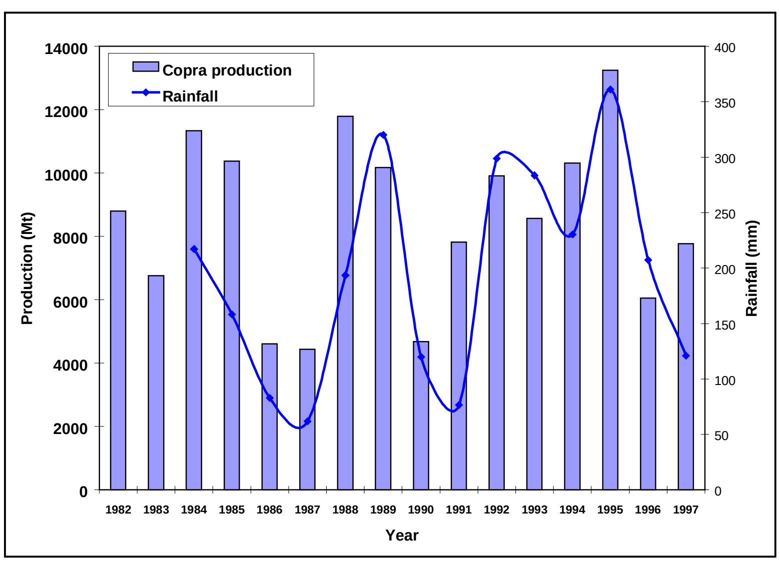
Tarawa

The physical and economic impact of climate change on the agriculture of the Tarawa atoll could not be computed quantitatively due to lack of statistical data. However, some qualitative judgments can be made. Climate change is most likely to impact agricultural crops through changes in rainfall. Coconuts, for example, require an annual rainfall of 1,000-1,500 millimeters or more. Copra production is closely related to rainfall, albeit with a two year lag (Figure A.6). Te babai (the giant taro) is also extremely sensitive to reductions in groundwater, and prone to saltwater intrusion as a result of storm surge and overwash.

If wetter conditions prevail in the future, production of water sensitive crops — coconut, breadfruit and te babai — is likely to increase. If rainfall decreases as a result of climate change, copra and te babai production would be adversely affected. Of equal interest is the likely effect of climate variability on agricultural crops. Droughts are most likely to occur during La Niña years. An intensification and/or increase in frequency of La Niña events, coupled with higher average temperatures, could have significant negative effects on the major crops.

Sea level rise could affect agriculture crops in two ways. The first is through salt-water intrusion, which would affect te babai production in particular. The second is through loss of coastal land due to inundation, which could reduce the production of copra, breadfruit or pandanus.

Figure A.6: Variation in Copra Production with Rainfall in Kiribati



Note: Rainfall is offset by two years relative to copra production

E. Impacts on Health

Viti Levu

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 cumulative mechanisms (as exemplified by the effects of a cyclone or drought on the national economy and living standards).

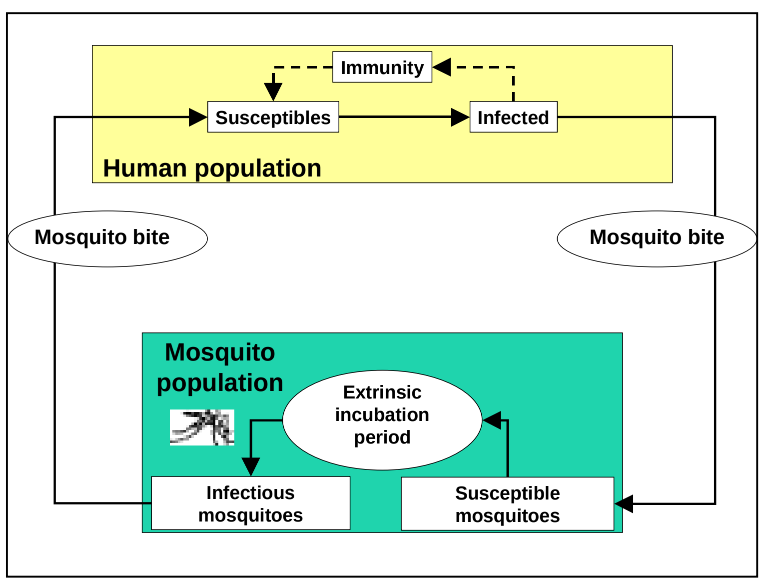
The potential impacts of climate change on human health in Viti Levu were analyzed quantitatively for dengue fever and diarrheal disease. These illnesses have a clear climate linkage and are amenable to quantitative analysis. Other effects such as nutrition deficiencies caused by more intense cyclones were taken into account in the water resources analysis (though the impact of droughts on nutrition could not be quantified). The potential impact of more intense cyclones on human fatalities can be estimated, but it involves controversial estimates of the value of a statistical life. This method of valuation is based on the monetary value individuals place on lowering their mortality risks. With estimates of this type only available in developing countries, extrapolations to the Fiji conditions would require comparing the value of a statistical life in Fiji with that of the United States (for example) a procedure which remains highly controversial. While this method is illustrated here in the economic analysis of dengue fever, it was not applied to cyclone fatalities as this would have required estimating average fatality rates, an estimate which is highly uncertain (as it depends on individual cyclone paths and intensity).

The impact of climate change on malaria, while important, does not appear to be a substantial threat in Fiji due to the absence of the vector. Filiarisis, another vector-borne disease, is expected to be eradicated within 5-10 years. While changes in sea surface temperatures are believed to influence, in some sites, the incidence of ciguatera (an illness caused by ingestion of fish contaminated by ciguatoxins), such relation was not found in Fiji (Hales et al. 1999).

Impacts of Climate Change on Dengue Fever

Dengue fever, a mosquito-borne viral disease, is a significant and potentially increasing public health problem in Fiji. The most recent epidemic — in 1998 — involved an estimated 24,000 cases and resulted 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. Rising temperatures also increase the epidemic risk by increasing the biting rate of the mosquito vector and the replication rate of the dengue virus (Figure A.7).

Figure A.7. Dengue Fever Transmission Cycle



The model used in PACCLIM to assess the impact of climate change on dengue fever was based on the CIMSIN and DENSIM models relating epidemic potential—an index reflecting the efficiency of transmission—to ambient temperature (Patz et al. 1998). This relationship was 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 as projected by the scenarios used in the study. Rainfall was not considered in this model because the main dengue fever vector, *Aedes aegypti*, is adapted to the urban and domestic environment where breeding sites may be created by artificial water containers. These breeding sites may be equally available under low rainfall conditions.

Since both of the general circulation models used by this study project similar changes in temperature (see page A.2) and the health impacts are modeled by temperature alone, only the CSIRO9M2 global circulation model was used for scenario construction. The scenarios took into consideration both a 'best guess' emissions scenario as well as a 'worst case' scenario (as outlined in table A.1). Present monthly patterns of epidemic potential in Nadi and Suva and spatial characteristics of epidemic potential in Viti Levu were entered into the model, and analyzed under future climatic conditions in 2025, 2050, and 2100.

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 could not account for the range of climatic, environmental and ecological factors affecting mosquito abundance, or distribution and effects specific to vector species other than *Aedes aegypti.* Changes in the frequency and severity of extreme events and social aspects of transmission dynamics such as human population density, travel, immunity and housing conditions which may influence disease transmission (Hales et al. 1999) were also not captured under the model. Nonetheless, the dengue fever model in PACCLIM is the best semi-quantitative tool available to assess the possible impacts of climate change on human health in Fiji.

In order to analyze the impact of climate change on epidemic potential, different areas of Viti Levu were classified according to their epidemic risk. Five categories of epidemic risk were constructed (table A.37). The risk was considered to be low where the model-predicted epidemic potential was less than 0.1. An area with an epidemic potential of 0.3 or higher was considered to be at extreme risk of an epidemic. Increases in epidemic risk were then evaluated for different areas of Viti Levu. PACCLIM produces both Geographical Information System simulations as well as quantitative projections of the epidemic distribution risk. Monthly variations in epidemic potential were also included in the model in order to estimate changes in the seasonality of dengue fever. Annual averages employed to estimate geographical and time-based impacts.

Table A. 37. Risk Categories of a Dengue Fever Epidemic Based on Model-predicted Epidemic Potential in Viti Levu, Fiji

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

Note: Epidemic potential is an index that reflects the efficiency of transmission in a particular area.

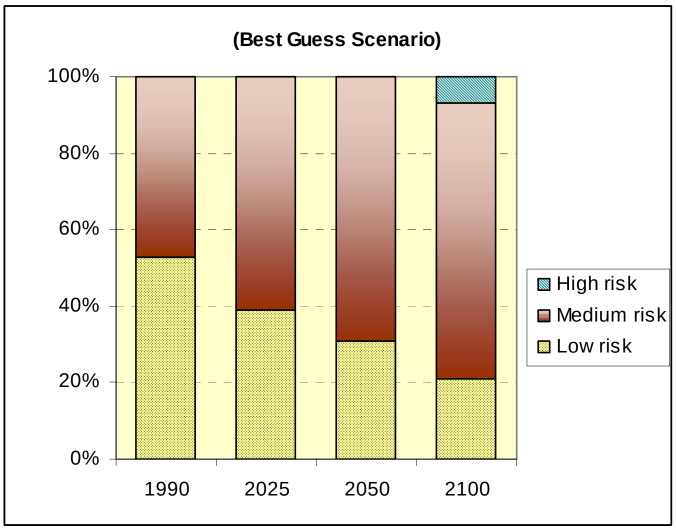
The analysis of climate change impacts on dengue fever involved five major steps:

Step 1. Estimate the Baseline Conditions. Under the present conditions (1990 baseline), 53 percent of the area of Viti Levu is considered to be at a low risk of a dengue fever epidemic. About 47 percent is at a moderate risk of an epidemic. Dengue fever epidemic potential is highest in the coastal areas and decreases towards the highlands. Epidemic potentials in the west, especially in coastal and hill land areas, are higher than in the central area. Also, the coastal areas in the north and west of the island have a higher epidemic potential than the southern and eastern coasts, especially near Nadi, Lautoka and western part of the Coral Coast.

Step 2. Estimate the Impact of Climate Change. Figure A.8 and table A.38 summarize the impacts of climate change predicted by the model:

- ***Changes in Epidemic Potential and Seasonality in Nadi and Suva.*** By 2050, the epidemic potential is projected to increase by 20-30 percent in Nadi and Suva. By 2100, the epidemic potential could increase by 40-100 percent. Dengue fever epidemics, which now occur seasonally from November to April and with a frequency of once every 10 years could become endemic, occurring all year round and with increasing frequency by the end of the century.

Figure A.8. Projected Changes in Epidemic Risk of Dengue Fever in Viti Levu (2025, 2050,



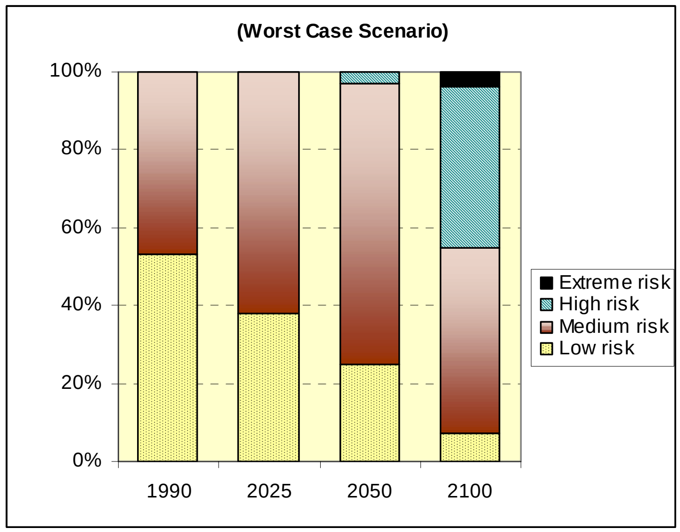


Table A. 38. Potential Impact of Climate Change on Dengue Fever in Viti Levu, Fiji

Likely Changes		*Baseline (1990)*	*2025*	*2050*	*2100*
Estimated Change Epidemic Potential		0%	10%	20-30%	40-100%
Epidemic Potential in Viti Levu:					
	Low	53%	38-39%	25-31%	7-21%
	Medium	47%	61-62%	69-72%	48-72%
	High	—	—	0-3%	7-41%
	Extreme	—	—	—	0-4%
Seasonality	Nadi	Seasonal	Seasonal	Seasonal to All Year	All year
	Suva	Seasonal	Seasonal	Seasonal to Extended Season	Prologued season to all year
Frequency of epidemics		1 in 10 years		Likely Increase	
Severity of strains				Likely Increase	

Note: Ranges represent the best guess and worst case scenarios. Only the CSIRO GCM model was used here.

- ***Spatial Changes.*** Spatial changes in epidemic potential can be analyzed using mapping functions in PACCLIM. The results are summarized in Figure A.8. By 2050, some 69-72 percent of Viti Levu is expected to be at moderate risk of an epidemic (a 50 percent increase over 1990). By 2100, under a high scenario, nearly half of Viti Levu (45 percent) is projected to be at high or extreme risk. At greatest risk will be the coastal areas of the Western Division.

- ***Size of epidemics.*** With an increase in epidemic potential, exacerbated by rising population densities and urbanization, future epidemics are expected to escalate more easily and involve a greater number of people than currently observed. Climate change may also have direct effects on vector abundance.

- ***Likelihood of Severe Strains.*** The increase in the frequency and size of the epidemics and shift to endemicity could inrease the risks of more severe forms of dengue fever, such as dengue shock syndrome (DSS) and dengue haemorrhagic fever (DHF). This could increase the number of fatalities relative to what is observed today.

Step 3: Estimate the Change in Number of Dengue Fever Cases. In order to calculate the economic costs of climate change on dengue fever, it is necessary to estimate the possible increase in the number of cases attributable to climate change. Several factors make this estimate particularly challenging: (a) dengue fever epidemics rely on complex interactions between the mosquito biology (such as breeding sites, predators, competition), and socio-economic factors (such as the living environment of villages and towns); (b) changes in epidemic potential may not necessarily correlate with changes in the number of cases; and (c) it is difficult to predict the improvements in medical services, treatments and possible vaccine development that may occur in the future.

For the purposes of the economic analysis, however, it is assumed that the percentage change in dengue fever epidemic potential is indicative of the possible changes in the number of cases averaged out over a 10-20 year period. The estimated change in the number of cases in Viti Levu is therefore:

Estimated Changes in the Number of Dengue Fever Caused by Climate Change

Baseline (1990)	*2025*	*2050*	*2100*
—	10%	20-30%	40-100%

where the ranges indicate the best guess (lower bound) and worst case scenarios (upper bound).

Step 4: Estimate the Unit Cost of an Epidemic in the Baseline Scenario. The most recent dengue fever epidemic in Fiji, in 1997/98, was the worst in Fiji's history, causing an estimated 24,000 cases of illness, 1,700 hospital admissions and 13 deaths. The epidemic occurred during a severe drought related to the 1997/98 El Niño event, and cost an estimated F$6.5 million (Koroivueta, personal communication, 1999). This estimate accounts only for hospitalization and personnel costs, treatment and medication, intra-venous fluid costs and laboratory services.

Apart from the possible loss of human life, dengue fever epidemics involve many direct and indirect economic costs (Basu et al, 1999):

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

A typical epidemic in the future may involve the following cost breakdown (modified from NZMoH 1996):

Table A.39. Potential Impact of a Dengue Fever Epidemic in the Future

Cost Items	*Potential Impact*
Nature of epidemic	1000 cases of classical dengue 10 cases of Dengue Haemorrhagic Fever 1 death
Medical costs	100 hospitalizations for 1 week 10 intensive care cases for one week (with a further 2 weeks of hospitalization)
Time off work[a]	500 for 1 week 400 for 2 weeks 100 for 3 weeks 9 for 4 weeks (1 death)

Note: [a] Assumes all cases are working adults.

The economic analysis used the cost breakdown of table A.39. However, the *total number of cases* considered in the baseline estimate was based on the historical evidence of the 1989/90 epidemic (3,700 cases) and the 1997/98 epidemic (24,000 cases). This range (3,700-24,000 cases per epidemic) was considered to best represent the baseline conditions of the 1990s.

Based on the available information, four components of epidemic costs were quantified:

- Medical costs
- Loss of productivity due to illness
- Willingness to pay to avoid illness
- Willingness to pay to avoid premature fatality

4.1. Medical Costs: The medical costs of dengue fever epidemics can be computed from historical records. Using the costs of the 1997/98 epidemic as a basis (F$6.5 million), the medical costs per case are as follows:

F$6.5 million : 24,000 *(no. of cases of the 1997/98 epidemic)* = F$271 or US$138 per case

The baseline conditions are assumed to involve 3,700 to 24,000 cases per epidemic. Hence,

US$138 per case x 3,700 cases = US $511,580
US$138 per case x 24,000 cases = US$3,316,300

The medical costs per epidemic (for the baseline conditions) are therefore ***US$0.5-$3.3 million.***

4.2. Loss of Productivity due to Illness. The loss of productivity due to illness was computed based on the 'time off work' estimates of table A.39.

Assuming each week to have 5 working days, the number of working days lost to illness is as follows:

500 cases x 5 working days (1 week)	=	2,500 working days lost
400 cases x 10 working days (2 weeks)	=	4,000 working days lost
100 cases x 15 working days (3 weeks)	=	1,500 working days lost
9 cases x 20 working days (4 weeks)	=	160 working days lost
Total working days lost	=	*8,180*

To determine the average number of working days lost per case of dengue fever, the above number is divided by the number of cases in table A.39 (1,011):

8,180 : 1,011 = 8.09 working days per case

Multiplying this by the number of cases under the baseline conditions (3,700-24,000):

8.09 x 3,700 = 29,937
8.09 x 24,000 = 194,184

or approximately 29,940-194,180 working days lost per epidemic

The economic value of a working day can be approximated by the Gross Domestic Product (GDP) per capita:

Fiji's GDP in 1998 (US$1,383 million) / Population of Fiji (772,655 in 1998) = US$1,790

This value can then be divided by the number of working days a year (5 working days x 52 weeks = 260 working days) to yield the economic value of a working day:

US$1,790 / 260 = US$6.88 per day of lost work

This analysis involves several broad assumptions. Not all Fijians work, for example. If this had been considered in the analysis, the value of a working day—for the proportion of the population that works—would be higher than US$6.88. At the same time, not all Fijians affected by dengue fever are workers. These two factors are assumed to cancel themselves out: in other words, the value of a day of lost work is assumed to be the average of a working day for workers, and a day of inactivity for nonworking Fijians.

The lost productivity due to illness is:

29,940 working days lost x US$6.88 per day of lost work = US$206,000 (for the lower bound)
194,184 working days lost x US$6.88 per day of lost work = US$1,336,000 (for the upper bound)

The lost productivity due to illness for the baseline conditions is therefore valued at ***US$0.2 to US$1.3 million per epidemic.***

4.3. Willingness to Pay to Avoid Illness. The willingness to pay to avoid illness is the welfare that dengue fever sufferers lose due to pain, suffering, and disruption to their normal life routine. Technically, it is the value that individuals would be willing to pay to avoid a day of restricted activity due to dengue fever. This type of estimates of willingness to pay require surveys of 'contingent valuation' that are not available in Fiji. For lack of a better measure, the value of avoiding a restricted activity day was derived from average estimates in the United States (US$50 per person). The applicability of this estimate to Fiji needs to be considered in the context of differentials in per capita income, as well as of differences in how disease is perceived and valued in the local culture.

To make a rough extrapolation to the Fijian context, the value of a restricted activity day in the United States (US$50 per person) was first converted to a percentage of the per capita GDP of the United States (US$22,000).

US$50 / US$22,000 = 0.227 percent of per capita GDP

This was then applied to the per capita GDP for Fiji, US$1,790 to obtain the adjusted value of a restricted activity day in Fiji:

0.227 percent x US$1,790 = US$4.07 per restricted activity day.

The number of restricted activity days can be determined from table A.39. However, since individuals can value a restricted activity day independently to whether it is a working or a weekend day, one week of illness is assumed to correspond to 7 days of restricted activity:

500 x 7 restricted activity days (1 week)	=	3,500
400 x 14 restricted activity days (2 weeks)	=	5,600
100 x 21 restricted activity days (3 weeks)	=	2,100
9 x 28 restricted activity days (4 weeks)	=	252
Total restricted activity days	=	*11,452*

This number can then be divided by the number of cases in table A.39, and adjusted by the number of cases of the 1989/90 and 1987/98 epidemics:

11,452 / 1,011 = 11.33

11.33 x 3,700 = 41,911
11.33 x 24,000 = 271,858

or 41,910 to 271,860 days of restricted activity

Multiplying this by the estimated value of a restricted activity day yields the following results:

US$4.07 x 41,910 = US$170,600
US$4.07 x 271,860 = US$1,106,500

The willingness to pay to avoid illness for the baseline conditions is therefore valued at ***US$0.17 to US$1.1 million per epidemic.***

4.4. Willingness to Pay to Avoid Premature Fatality. The willingness to pay to avoid premature fatality can be assessed through what is commonly called the value of a statistical life. As stated before, the extrapolation of this value across different countries and cultures remains highly controversial and should be interpreted with extreme caution.

Based predominantly on premature fatality valuation studies in the United States, the generally accepted range for a value of a statistical life ranges from US$2 million to US$16 million, with US$5.8 million the average value currently used by the United States Environmental Protection Agency (EPA 1999). Similarly to the procedure illustrated above, the value of a statistical life can be computed as a percentage of the per capita GDP:

US$5.8 million / US$22,000 = 26,364 percent of per capita GDP

Applying this percentage to the per capita GDP for Fiji (US$1,790):

26,364 percent x US$1,790 = US$417,900

According to table A.39, an epidemic affecting 1,011 people is likely to result in one fatality. Extrapolating this fatality rate to the baseline case:

$$1 / 1{,}011 = 0.00099$$

$$0.00099 \times 3{,}700 = 3.7$$
$$0.00099 \times 24{,}000 = 23.7$$

Thus, the fatality rate in the baseline case is assumed to range from 3.7 to 23.7 deaths. Using the estimated willingness to pay to avoid premature fatality:

US$417,900 x 3.7 = US$1,546,200
US$417,900 x 23.7 = US$9,904,230

The estimated willingness to pay to avoid premature fatality in the baseline case is therefore estimated at ***US$1.5 to US$9.9 million.***

4.5. Total Baseline Costs of a Dengue Fever Epidemic in Fiji. Adding the estimates of sections 4.1 to 4.2 together gives the following baseline costs for a dengue fever epidemic in Fiji:

	US$ million
a. Medical costs	0.5-3.3
b. Lost Productivity due to Illness	0.2-1.3
c. Willingness to Pay to Avoid Illness	0.2-1.1
d. Willingness to Pay to Avoid Premature Fatality	1.5-9.9
Total	***US$2.4-15.6 million per epidemic***

Since the costs were based on 1998 estimates of GDP and medical costs, the baseline costs are expressed in 1998 US dollars.

This estimate illustrates the potential value of loss of lives compared to other medical costs of a dengue fever epidemic. Insofar as fatalities caused by cyclones were not computed, it can be seen that the real costs of climate change on public health are likely to be substantially higher than the estimates of this analysis indicate.

Step 5: Estimate the Potential Impacts of Climate Change. To assess the potential impact of climate change on future dengue fever epidemics, two figures are needed: (i) the estimated increase in number of cases predicted by the climate change models; and (ii) the forecasted increase in population. These can be derived from tables A.4 and A38:

	Baseline (mid-1990s)[a]	*2025*	*2050*	*2100*
Population	772,655	+44-57%	+63-110%	+66-198%
Number of cases/epidemic	3,700-24,000	+10%	+20-30%	+40-100%

Note: a. Population baseline is based on 1996 census. The baseline number of cases is based on the 1989/90 and 1997/98 dengue fever epidemics.

> *Example:* From table A.4, The projected population at the end of the century is 1,280,000 (in a low population growth scenario) to 2,300,000 (in a high population growth scenario). This is equivalent to an increase of 66 and 198 percent relative to the baseline population:
>
> (1,280,000 / 772,655) -1 = 1.66 - 1 = 66 percent
> (2,300,000 / 772,655) - 1 = 2.98 -1 = 198 percent
>
> These growth rates can then be applied to the baseline costs (US$2.4-$15.6 million) to derive the costs of dengue fever epidemics in the future.

In order to derive the average annual cost of climate change in Viti Levu, the following calculations need to be made (see table A.40):

- Determine the average costs of future epidemics
- Assess the incremental costs that can be attributed to climate change
- Transform these incremental costs into annual averages
- Compute the equivalent costs for Viti Levu

5.1. Determine the Cost per Epidemic in the Future. To determine the costs of future epidemics (expressed in 1998 dollar value), one simply multiplies the baseline cost per epidemic with the population growth rate and projected increase in the number of cases (see third row in table A.40).

> *Example:* The cost per epidemic in 2100 is:
>
> | | | |
> |---|---|---|
> | US$2.4-$15.6 million *(1998 baseline)* | x 1.66 to 2.98 = *(population growth)* | US$4.0 to US$46.2 million *(future costs adjusted by population growth)* |
> | US$4.0-$46.2 million *(future costs adjusted by population growth)* | x 1.4 to 2.0 = *(projected increase in number of cases)* | US$ 5.6 to US$93.0 million *(future costs adjusted by population growth and projected increase in number of cases)* |

5.2. Assess the Incremental Costs due to Climate Change. The above costs reflect the total average economic costs of future epidemics under climate change conditions. To compute the *incremental* impact of climate change, one needs to subtract the baseline costs from this estimate.

Example: The baseline costs are US$2.4-$15.6 million. The cost of an epidemic in 2100 are US$5.6-$93.0 million. Hence, the incremental costs due to climate change are:

(US$5.6-$93.0 million) - (US$2.4-$15.6 million) = US$3.2 - $77.4 million per epidemic.

5.3. Transform Incremental Epidemic Costs into Annual Averages. For the last 30 years, there have been 8 dengue fever epidemics in Fiji (Basu and others 1999), a frequency of once every 3.75 years. It is expected that under future climate change conditions, dengue fever may become endemic (occurring every year). However, this change is to a certain extent already captured in the expected increase in the number of cases, which is based on the estimated increase in epidemic potential. To add to that an increase in the frequency of epidemics could introduce double counting. For the purposes of the analysis, the baseline frequency of epidemics was assumed to remain unchanged from the baseline conditions.

To compute the annual average costs due to climate change, the incremental costs due to climate change are simply divided by 3.75.

Example: The incremental costs due to climate change in 2100 are US$3.2-$77.4 million per epidemic. The annual average costs are therefore:

US$3.2-$77.4 million / 3.75 = US$0.9-$20.6 million

5.4. Compute the Equivalent Costs for Viti Levu. The above estimates apply to Fiji as a whole. To compute the average incremental costs of climate change on dengue fever epidemics in Viti Levu, the numbers need to be adjusted by 77 percent, the proportion of the total Fijian population that resides in Viti Levu. This is a conservative assumption, as the incidence of dengue fever is likely to be higher under the crowded conditions of Viti Levu's towns, and Viti Levu is expected to grow faster than other places in Fiji. However, to remain consistent with the assumptions used in impacts on other sectors, a simple population adjustment was used.

Example: Adjusting the incremental annual costs due to climate change in 2100 to Viti Levu:

US$0.9-$20.6 million x 0.77 = US$0.7-$15.9 million (see table A.40)

The results are summarized in table A.40.

Table A.40 Estimated Costs of Climate Change on Dengue Fever in Viti Levu (millions of 1998 US$)

	Baseline (mid-1990s)	*2025*	*2050*	*2100*
Population	772,655	+44-57%	+63-110%	+66-198%
Number of Cases per Epidemic	3,700-24,000	+10%	+20-30%	+40-100%
Costs per Epidemic (US$ million)	2.4-15.6	3.8-26.9	4.7-42.6	5.6-93.0
Incremental Costs per Epidemic due to Climate Change (US$ million)	—	1.4-11.3	2.3-27.0	3.2-77.4
Annual Incremental Costs of Climate Change (US$ million)	—	0.4-3.0	0.6-7.2	0.9-20.6
Annual Incremental Costs of Climate Change in Viti Levu (US$ million)	**—**	**0.3-2.3**	**0.5-5.5**	**0.7-15.9**

Impacts of Climate Change on Diarrheal Disease

Diarrheal diseases are caused by a range of pathogens and influenced by many different factors. The marked seasonality of diarrhea occurrence and association of diarrhea with rainfall extremes in Fiji suggests a relationship with climate: the first three months of the year─which are typically the warmest and wettest─are also those when diarrheal diseases are typically the most common.

The CSIRO Global Circulation Model used in this study projects an increase in precipitation along with gradual warming (table A.1). If the assumption is made that the increased incidence of diarrheal disease in the first three months of the year is related to the warmer and wetter conditions typical of these months, then the longer, warmer and wetter conditions induced by climate change would be expected to result in an increased incidence of diarrheal disease. Scenarios of increased climate variability and extremes are also relevant, as an increase in the frequency and severity of droughts and floods in Viti Levu would likely result in a higher incidence of diarroeal disease.

Analysis of monthly reports of diarrhea in infants between 1978 and 1989 in Fiji suggests that the effect of climate cannot be distinguished statistically from seasonal patterns. 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 diarrhea incidence.

The analysis of climate change impacts on diarrheal disease involves two major steps:

Step 1: Assess the Expected Increase in the Number of Cases due to Climate Change. To estimate the impact of temperature changes on diarrhea incidence, one can use a simple regression:

Diarrhea disease = f (average temperature)

where:

"Diarrhea disease" are the monthly reports of infant diarrhea in Fiji during 1978-89; and
"Average temperature" are average monthly temperatures recorded for Fiji

The results of this regression indicate that an increase in temperature of 1°C is associated with 100 additional reports of infant diarrhea per month, with a probability of error of less than 5 percent. Data for 1990-1991 are missing, but the model was a good predictor of 1992-1998 diarrhea reports: the correlation coefficient between model predictions and true values was 0.47, with a probability of this correlation being due to chance alone of less than 0.1 percent. Since the true incidence of diarrhea is likely to be at least 10 times the number of reported cases, an increase of 1°C is estimated to be associated with at least 1000 additional cases per month based on Fiji's current population. This result can also be used, albeit with lower confidence, to estimate the potential impacts on children and adult diarrhea.

Thus, an increase of 1°C is estimated to be associated with 12,000 additional cases of diarrhea per year (1,000 cases x 12 months per year), based on the current population.

Step 2: Estimate the Economic Costs of Climate Change. The costs of diarrheal disease can be estimated based on the value of loss productivity due to disease. It is assumed that each diarrhea episode lasts 2-5 days, or 3.5 days on average, which is consistent with world health estimates. The incremental annual costs attributable to climate change can then be estimated as follows:

- Compute the increase in the number of annual diarrhea cases due to climate change
- Estimate the total number of days of lost productivity per year
- Compute the costs of lost productivity
- Adjust the estimates to the population of Viti Levu.

2.1. Compute the Increase in the Number of Annual Diarrhea Cases due to Climate Change. As seen above, a 1°C increase in temperature is associated with an estimated 12,000 incremental cases of diarrhea a year. To estimate the impact of climate change, it is necessary to adjust the number of cases first by the expected population growth, and second by the expected change in temperature.

Example: In 2050, the Fijian population is projected to grow by 63 to 110 percent (1.63-2.10 fold), and the temperature is projected to increase by 0.9-1.3 °C. Hence, the incremental number of annual diarrhea cases attributable to climate change are as follows:

12,000 x (1.63 to 2.10) = 19,560 to 25,200 *(increase in number of diarrhea cases in the 2050 Fijian population due to a 1 °C increase in average temperature)*

19,560 to 25,200 x (0.9 to 1.3) = 17,604 to 32,760 *(increase in number of diarrhea cases in the 2050 Fijian population due to the temperature changes predicted by the climate change models)*

2.2. Estimate the Total Number of Days of Lost Productivity per Year. The number of days of lost productivity is simply the incremental number of annual diarrhea cases due to climate change times 3.5 days (the estimated average duration of the episodes):

Example: In 2050, the total number of days of lost productivity due to climate change is:

17,604 to 32,760 x 3.5 days = 61,674 to 114,660 days of lost productivity

2.3. Compute the Costs of Lost Productivity. As seen in the dengue fever estimates, the average cost of a day of lost productivity is US$6.88. It can be argued that many of the diarrhea cases involve children. However, the estimate of US$6.88 takes into account the productivity value of an average day for the entire Fijian population (including those that do not work) and is therefore considered to be a valid estimate.

Example: In 2050, the annual costs of lost productivity would be:

61,674 to 114,660 days x US$6.88 per day = US$0.4 to US$0.8 million

Since the projected increases in the number of diarrhea cases are yearly values, no adjustment is necessary to estimate the annual costs of climate change.

2.4. Adjust the Estimates to the Population of Viti Levu. As it was done for dengue fever, the costs of lost productivity caused by climate change need to be adjusted by a factor of 0.77, to account for the proportion of the population that resides in Viti Levu.

> *Example:* In 2050, the costs of climate change in terms of lost productivity due to diarrheal disease in Viti Levu are:
>
> US$0.4 to US$0.8 million x 0.77 = US$0.3 to US$0.6 million

The results are summarized in table A.41 below:

Table A.41. Estimated Costs of Climate Change on Diarrheal Disease in Viti Levu (millions of 1998 US$)

	Baseline (mid-1990s)	*2025*	*2050*	*2100*
Population	772,655	+44-57%	+63-110%	+66-198%
Temperature Change	—	+0.5-0.6° C	+0.9-1.3° C	+1.6-3.3° C
Increase in Annual Cases due to Climate Change	—	8,640-11,304	17,604-32,760	31,872-118,008
Total Number of Lost Productivity Days	—	30,240-39,564	61,674-114,660	111,552-413,028
Annual Incremental Costs of Climate Change in Fiji (US$ million)	—	0.2-0.3	0.4-0.8	0.9-2.8
Annual Incremental Costs of Climate Change in Viti Levu (US$ million)	—	**0.2**	**0.3-0.6**	**0.6-2.2**

The overall impact of climate change on the health sector of Viti Levu is summarized in table A.42.

Table A.42. Estimated Annual Economic Impact of Climate Change on Public Health in Viti Levu, Fiji, 2025-2100 (millions of 1998 US$)

	Estimated Incremental Economic Costs due to Climate Change		
	2025	*2050*	*2100*
Cyclones and Droughts[a]	Likely to be substantial		
Dengue Fever	0.3-2.3	0.5-5.5	0.7-15.9
Diarrheal Diseases	0.2	0.3-0.6	0.6-2.2
Nutriton-Related Illnesses	+	+	+
Total Estimated Costs	**0.5-2.5**	**0.8-6.1**	**1.3-18.1**

Notes: — Not available.
\+ No quantifiable data available, but damages likely to be substantial.
a. The effect of cyclones and droughts on health could not be calculated, but the overall impact of cyclones was captured on the water resources section.

Tarawa

The potential impacts of climate change on public health in Tarawa were analyzed quantitatively for ciguatera poisoning and dengue fever. Apart from preliminary work on ciguatera, however, there were no available studies examining the relationship between health and climate change in Kiribati. Hence, no economic analysis could be performed, and the findings of this report need to be interpreted in light of these limitations.

Impacts of Climate Change on Dengue Fever

Kiribati has two vectors for dengue fever, *Aedes aegypti* and *Aedes albopictus.* There have been four recorded outbreaks of dengue fever , in 1971/72, 1974, 1980/81, and 1988. South Tarawa has several factors which contribute to dengue fever risk. It is the main international port of entry into Kiribati. The crowded urban areas of Betio, Bairiki and Bikenibeu increase the risk of transmission. Discarded container items such as tins, empty bottles and used tyres as well as unscreened rainwater tanks, home flower vases, tree holes, and shells provide habitat for the vectors and increase the epidemic risk. The current climate with an average temperature of 31^{o} C and average monthly rainfall of 500 mm is highly suitable for vector survival and multiplication.

In the analysis of dengue fever, it was postulated─as for Viti Levu─that temperature is an important determinant of epidemic risk where a capable vector population is present. According to Patz et al. (1998), epidemic potential is negligible below 23^{o} C, escalates rapidly from about 30^{o} C and drops precipitously at about 40^{o} C due to a rapid increase in mosquito mortality. This relationship between temperature and epidemic potential was used to model changes in epidemic potential in the PACCLIM model (table A. 43):

Table A.43. Potential Impact of Climate Change on Dengue Fever in Tarawa, Kiribati

Likely Changes	Baseline (1990)	2025	2050	2100
Projected Changes in Epidemic Potential	0.18	0.20	0.22-0.24	0.25-0.36
Percentage Change from the Baseline	─	11%	22-33%	39-100%

Note: Ranges represent the best guess and worst case scenarios. Only the CSIRO GCM model was used here.

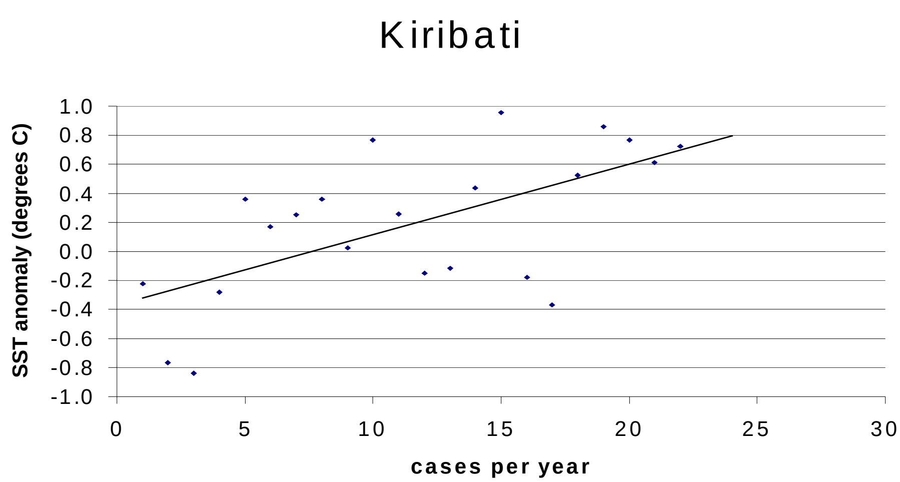
Given Tarawa's limited size, high population densities and availability of vector breeding sites, it is likely that the vast majority of the population in South Tarawa would be exposed during an epidemic─even in the absence of climate change. Consequently, while climate change could increase the transmission efficiency, and therefore the rate at which the epidemic grows, it may not greatly affect the total number of cases produced by an epidemic. Climate change, however, may influence the numbers, density and distribution of the vector. It is also likely that the impact of climate change worldwide could increase the prevalence of all dengue virus serotypes, leading to a higher incidence of severe forms of dengue fever. Moreover, given that smaller vector populations will be able to sustain an epidemic, future efforts at vector control will need to reach increasingly higher levels of the vector population in order to achieve the same result in terms of epidemic risk reduction.

Impacts of Climate Change on Ciguatera Poisoning

Kiribati has one of the highest incidences of ciguatera in the Pacific (Lewis and Ruff 1993). Ciguatera is contracted by ingesting reef fish contaminated with ciguatoxins, produced by dinoflagellate organisms that accumulate as they move up the food chain. Symptoms can last from days to even months. Lewis (1992) suggests that a small increase in ciguatera poisoning in several Pacific Island countries may be related to El Niño event. It is likely that climate is only one of several factors affecting ciguatera, others being reef disturbance and pollution.

A study of ciguatera in eight Pacific Island countries found positive correlations between the annual incidence of ciguatera and local warming of the sea surface in one group of islands (including Kiribati) which experienced local warming during El Niño conditions (Hales et al. 1999). The study found a statistically significant relationship between sea surface temperature and the reported incidence of ciguatera fish poisoning in Kiribati (figure A.9).

Figure A.9. Relationship Between Sea Surface Temperature and Incidence of Ciguatera in Kiribati



Source: Hales et al. (1999).

This relationship was used in PACCLIM to model future changes in ciguatera incidence based on projected future trends in temperature. As Sea Surface Temperature is not a parameter available in PACCLIM, projected changes in atmospheric temperature at sea level were used as a proxy. The results are shown on table A. 44:

Table A.44. Potential Impact of Climate Change on Ciguatera Incidence, Kiribati

Likely Changes	Baseline (1990)	2025	2050	2100
Predicted Number of Reported Cases[a]	7	21-24	32-43	49-101
Predicted Ciguatera Incidence[b]	35-70	105-240	160-430	245-980

Note: Ranges represent the best guess and worst case scenarios for both the CSIRO and the DKRZ models (which gave similar results).

a. Incidence rate per 1000 population

b. Assuming a reporting rate of 10-20 percent.

These results should be interpreted with considerable caution, as the model has not been validated and the data set from which it was derived was limited. It is possible that many other unknown factors may influence the incidence of ciguatera, and that low present reported incidence rates may result in a high degree of error in future projections. The overall impact of climate change on ciguatera should be measured perhaps not in terms of the number of cases but rather in terms of how people respond to increase risk, including changes in diet, decreased protein intake, loss of revenue from fisheries, etc. Unfortunately, no data were available to permit an estimate of the economic value.

G. Impacts on Regional Tuna Fisheries

The analysis of the possible impacts of climate change on tuna fisheries was done based on recent studies of impact of ENSO on tuna resources in the western central Pacific ocean and on simulation results from a spatial population dynamics model, SEPODYM. In this model, the movement of tuna and the effects of environmental variability are considered. Movement is governed by a diffusion-advection equation in which the advective term is proportional to a habitat gradient index that is a function of forage density (linked to primary productivity) and sea surface temperature. Sea surface temperature, ocean currents, and primary production are used in the model to delineate tuna spawning areas, transport larvae and juveniles, and stimulate tuna forage distribution.

The economic impacts of climate change and variability on regional tuna fisheries could only be assessed qualitatively. Nonetheless, it is worthwhile to compare the present condition of the fishery with the likely future conditions, particularly with regards to (a) changes in total tuna abundance; (b) changes in spatial distribution (and consequently benefit sharing among coastal states); and (c) changes in the economic incentives of the fleet.

The Present

The abundance of tuna stocks in the Central and Western Pacific is influenced by the primary productivity of the ocean, which in turn varies with ENSO events. In general, El Niño years tend to result in a higher than average recruitment of skipjack tuna in subsequent months, while La Niña events tend to result in higher recruitment of albacore tuna in subsequent years. The relationship is less clear for yellowfin and bigeye tuna, which are more widely distributed.

The spatial distribution of tuna is also affected by ENSO events. As the Western Pacific Warm Pool—and the highly productive 'cold tongue' that separates it from the eastern equatorial Pacific—extends eastwards during El Niño events, tuna (in particular skipjack) migrate eastwards, and countries like Kiribati and Samoa experience higher purse seine catches (figures A.10-11). Conversely, countries in the western Pacific like the Solomon Islands and the Marshall Islands enjoy higher catches during La Niña years (figure A.12).

Figure A.10. Movement of Tagged Skipjack Tuna in the Central and Western Pacific with ENSO

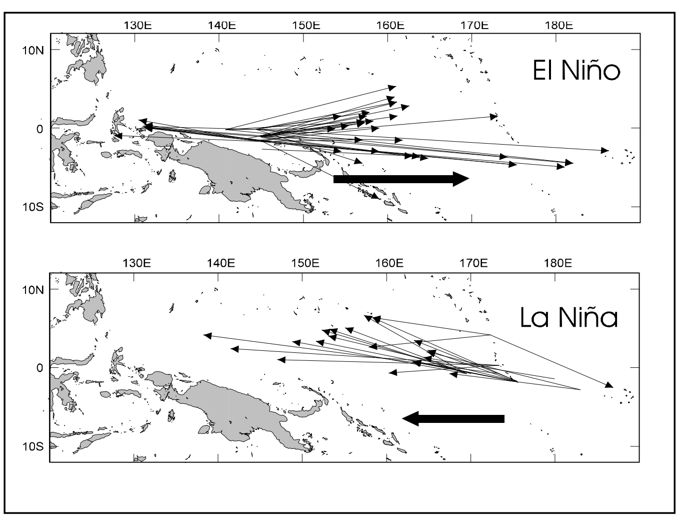
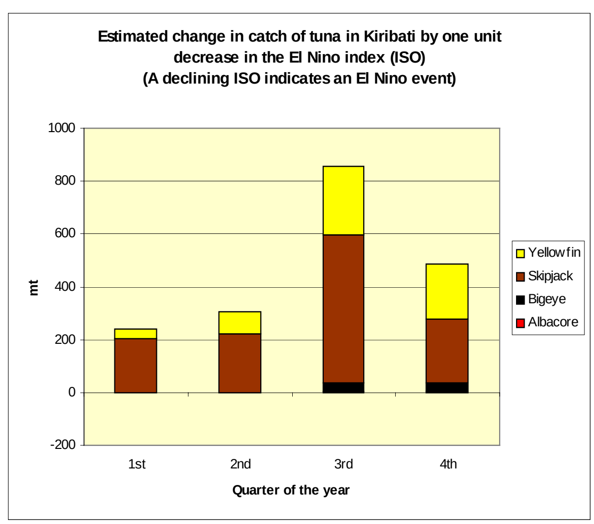
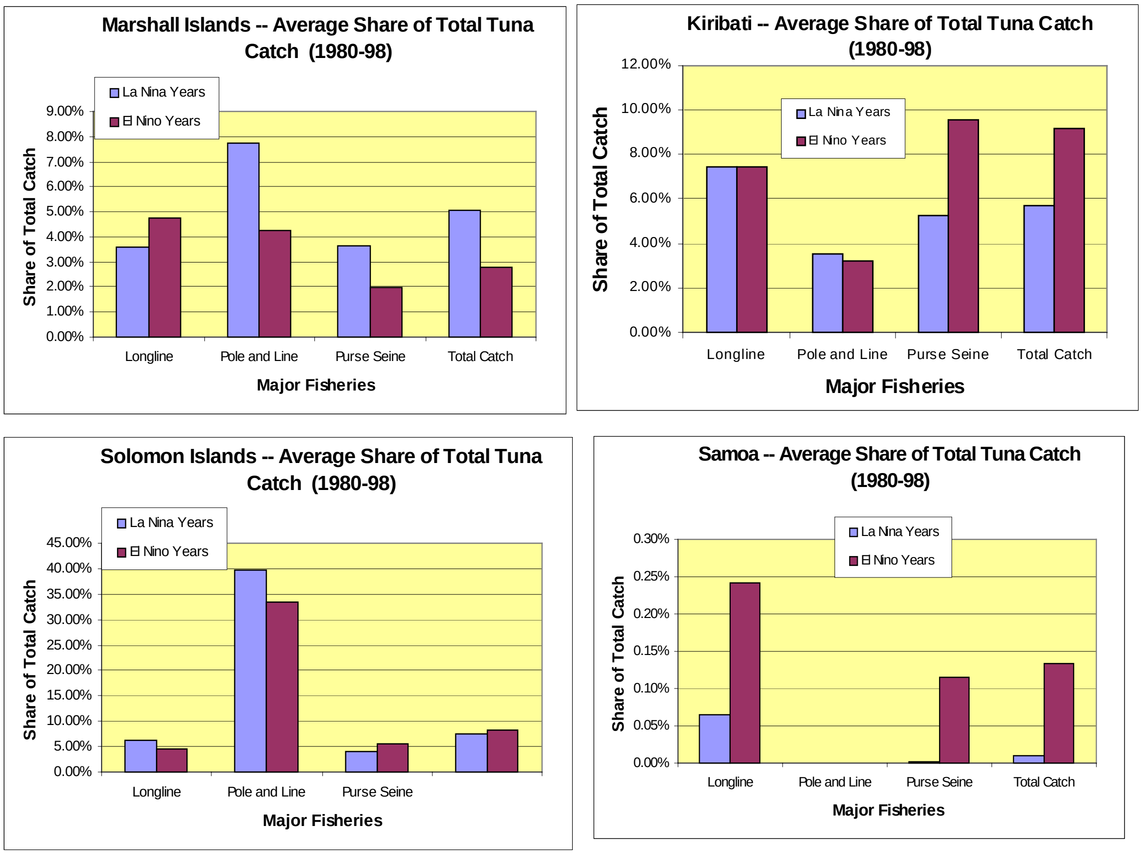


Figure A.11. Estimated Change in Tuna Catch in Kiribati with Intensification of El



Sources: Lehodey et al. (1997), SPC, and background reports to this study.

Figure A.12. Share of Total Tuna Catch Captured by Coastal States During ENSO



In Kiribati, a decline of one unit in the Southern Oscillation Index (indicating a move towards El Niño conditions) has led, on average, to a 200-800 metric tons increase in average tuna catch. Such relationship is much harder to discern for the total tuna catch of the Central and Western Pacific.

An important factor in determining the future impact of climate change is the degree of dependency of coastal states on fisheries. Micronesian countries like Kiribati, the Federated States of Micronesia, and the Marshall Islands are much more vulnerable to changes in relative abundance of tuna stocks than countries such as Fiji, Samoa, and the Solomon Islands, where the economies are more diversified (table A.44).

Table A.45. Coastal States' Relative Dependence on Fisheries

Coastal States	*Fisheries as a Percentage of GDP*	*Fisheries as a Percentage of Exports*
Kiribati	13	27
Federated States of Micronesia	2	89
Marshall Islands	9	89
Fiji	5	6
Samoa	6	47
Solomon Islands	6	23

Sources: IMF and country economic statistics. See Volume III of this report.

The Likely Future

Climate change is likely to affect the tuna fisheries of the Central and Western Pacific in two major ways: first, the average sea surface temperatures may evolve toward a 'mean El Niño' state. Second, inter-annual variability (alternating between El Niño and La Niña events) may increase.

A mean state El Niño would impose a permanent change in the system which has not been observed until now. Thus, while the historical evidence suggests that countries in the central Pacific (such as Kiribati) might benefit from a redistribution of the stocks, modeling results indicate the opposite effect. The primary productivity of the upwelling system in the central and eastern equatorial Pacific is likely to decline, affecting the abundance of bigeye and adult yellowfin population. Tuna stocks may redistribute to higher latitudes and toward the western equatorial Pacific. Countries in the central Pacific, such as Kiribati, are likely to suffer disproportionally as a result.

While purse seine catches are not expected to be significantly affected, the decline in bigeye and adult yellowfin stocks could lead to over-exploitation. Worldwide demand for sashimi has risen steadily. A reduction in catch in the central Pacific could lead to higher prices, further placing pressure on the resources. The difficulties in adapting sufficiently rapidly to new conditions may be particularly challenging if it turns out that the increased variability scenario comes into effect. The need to compensate for losses due to a drop in catch during one season may lead to over-fishing in the next period. Distant water fishing nations' fleets would be able to move among EEZs to capitalize on these variations; for domestic fleets, however, these increased fluctuations could be particularly difficult. Stronger regional collaboration among coastal states in tuna management will be needed to counteract these trends.