Economics of Adaptation to Climate Change

SAMOA

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SAMOA

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Acronyms

ADB	Asian Development Bank
CIM	Coastal infrastructure management
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIVA	Dynamic and interactive vulnerability assessment
ENSO	El Niño southern oscillation
GCM	General circulation model
IFPRI	International Food Policy Research Institute
MNRE	Ministry of Natural Resources, Environment, and Meteorology
MWCSD	Ministry of Women, Community and Social Development
NAPA	National Adaptation Program of Action
NCAR	National Center for Atmospheric Research
NCCCT	National Climate Change Country Team
NOAA	National Oceanic and Atmospheric Administration
SDS	Strategy for the Development of Samoa
SLR	Sea level rise
SPSLCMP	South Pacific Sea Level and Climate Monitoring Project
SRES	Special Report on Emissions Scenarios

Note: Unless otherwise noted, all dollars are U.S. dollars.

Acknowledgments

The EACC study was conducted by a partnership consisting of the World Bank (leading its technical aspects); the governments of The Netherlands, The United Kingdom, and Switzerland (funding the study); and the participating case study countries. The EACC study includes a global study and seven country studies including the Samoa study.

The Samoa Country Study was coordinated by Laurent Cretegny, Sergio Margulis, and Kiran Pandey. This report was written by Gordon Hughes with contributions and other material provided by Laurent Cretegny, Simon Bannock, Michele Daly, Erwin Kalvelagen, Peter King, Thakoor Persaud, Isikuki Punivalu, Graeme Roberts,and Fernanda Zermoglio (consultants). The peer reviewers were Jan Bojo, Kirk Hamilton, Ian Noble, and Michael Jacobsen. Robert Livernash provided editorial services, Jim Cantrell contributed editorial input and coordinated production, and Hugo Mansilla provided editorial and production support.

The study team would like to thank the partnership, which initiated, funded and actively engaged with the study team through its multiyear journey. The team is also grateful for the active engagement throughout the study of the government of Samoa, in particular the Ministry of Natural Resource, Environment, and Meteorology, Ministry of Finance, Ministry of Agriculture and Fisheries, Ministry of Women, Community and Social Development, Ministry of Works, Infrastructure and Transport, Samoa Water Authority, Samoa Bureau of Statistics, Samoa Tourism Authority, and the Land Transport Authority. We would also like to thank Robert Livernash for editorial services and Hugo Mansilla for production support.

ONE

Overview

Over the last two decades Samoa has suffered major damage from two cyclones in 1990–91, minor damage from a third cyclone in 2004, and an earthquake tsunami in 2009. Changes in the scale and impact of these types of natural disasters are likely to be important consequences of climate change for the country because the increases in sea level and in average sea surface temperatures will increase the intensity and damage from major storms. Other potential impacts are linked to changes in the weather patterns associated with El Niño Southern Oscillation (ENSO) events. The primary concern focuses on the impact on agriculture, especially in periods of lower precipitation following strong El Niño episodes.

This study examines the consequences of an increase in average temperatures of up to 1°C by 2050 and up to 2.75°C by 2100 for the frequency and intensity of major cyclones that hit the islands. Estimates of the economic damage caused by storms in the past have been used to calibrate a damage function that yields an estimated increase in the expected value of economic damage as the peak wind speeds for storms with return periods of 10, 50, or 100 years rise over time. In this framework the key element of adaptation is to ensure that buildings and other assets are designed to standards that enable them to cope with the greater wind stresses and more intense precipitation associated with worse storms.

The impact of climate change on agriculture is uncertain. Historical data show that variations in ENSO indices are correlated with variations in precipitation in the following months. There is also a weaker correlation between El Nino events and declines in production of taro (the staple crop of Samoa) and rises in agricultural imports. If climate change increases the magnitude and/or frequency of strong El Niño events, this would have an effect on agriculture. Still, the potential scale of the impact seems likely to be small relative to existing risks due to weather variability, disease, and external market conditions.

A macroeconomic model of the interactions between climate and the economy suggests that the present value of the damage to the Samoan economy through 2050 due to climate change—and without additional adaptation—may be \$104–\$212 million; this is equivalent to 0.6–1.3 percent of the present value of GDP over the same period. The model assumes that sound development policies are adopted to minimize the impact of existing weather risks and other natural hazards along with those from climate change. The loss of income falls on consumption rather than investment, so the reduction in the present value of consumption is estimated at 0.9–1.9 percent.

The starting point for examining adaptation options is the observation that the Samoan economy is resilient to storms with a return period of 10 years but suffers significant damage from storms with a greater return period, i.e., storms of greater severity. This 10-year threshold is low by international standards. The analysis suggests that raising the threshold to 50 years would generate benefits that greatly outweigh the costs involved even without any consideration of climate change, reducing the expected annual value of storm losses from 5.5 percent to 0.7 percent of GDP. Implementing measures to ensure that buildings, infrastructure, and similar assets are able to withstand storms with a return period of up to 50 years is a clear "no regrets" strategy. It is justified even without climate change, but it will also greatly reduce the economic impact of climate change under the climate scenarios that were examined. These actions can quicken the attainment of development of goals including the MDGs.

The corollary of this strategy is to ensure that design standards are adjusted to take account of prospective changes in the distribution of storms as a consequence of climate change. This leads to the adoption of forward-looking design standards rather than ones based on current climate conditions as an adaptation strategy. In practical terms this means that buildings and other assets constructed in the near future should be designed to withstand wind speeds up to 160 kph —the projected 50-year storm in the decade 2050–59 under the Commonwealth Scientific and Industrial Research Organisation (CSIRO) scenario—rather than 148 kph (the 50–year storm under current climate conditions). Strictly, the design standards will vary for different climate scenarios, and the additional costs of complying with the worst scenario may be viewed as a form of insurance against uncertainty over future climate outcomes.

For agriculture the key element of an adaptation strategy is to increase expenditures on research, development, and advisory services to mitigate the higher risks that are likely to be associated with climate change. Again, this is building upon policies that would form part of a sound development strategy. Samoan agriculture was hit hard by the taro blight in the mid-1990s, which devastated taro production and eliminated taro export revenues for nearly 15 years. Vulnerability to disease, pests, and storm damage means that diversification of both crop varieties and crops is an important element in any policy to limit the impact of these risks on agricultural households. Since climate change is likely to reinforce these risks, the appropriate level of expenditure will be higher to reflect the greater value placed upon risk reduction.

The Government of Samoa has undertaken extensive consultations to identify community priorities for adaptation to climate change under the National Adaptation Program of Action (NAPA). These include protection of community water supplies, support of agriculture and forestry sectors, implementation of coastal infrastructure management plans and integrated catchment management. This study applies a cost-benefit test to assess the appropriate timing of adaptation projects identified in the National Adaptation Program of Action (NAPA). Some of these projects—e.g., upgrading water systems—are good development projects under current climate conditions. However, large investments in relocating coastal infrastructure should only be implemented if and when the reduction in the expected value of storm damage exceeds the annualized costs. If a 50-year storm design standard were implemented, the analysis suggests that this type of adaptation may not be justified before 2050 based on climate change considerations because the general gain from reducing storm damage is not sufficient to warrant additional expenditures. However, these actions may be justified as a measure to reduce the risks associated with non-climate hazards (for instance risk of tsunamis associated with earthquakes).

The overall cost of adaptation is much higher under the CSIRO scenario than under the National Center for Atmospheric Research (NCAR) scenario because the former projects a much greater increase in the severity of flooding and storms. Under the CSIRO scenario, the cost of adaptation would rise from $3.3 million per year in 2010–19 to $10.9 million per year in 2040–49. The main cost arises from looking forward to the end of the century in setting the design standards for buildings and infrastructure constructed in the 2030s and 2040s.

The Government of Samoa, with external assistance, is implementing a program to act on community priorities for adaptation to climate change, especially with respect to activities which have a large overlap between development and adaptation benefits. On the other hand, implementing an overall approach to adaptation based on an assessment of the risks associated with storms and other natural hazards is hampered by limitations in the collection and interpretation of consistent and relevant information. It will be important to focus on strengthening the government's capacity to develop early warning systems, to effectively utilize these warning systems to prepare for and prevent losses, to develop, update and implement design standards, and other measures required to mitigate the damage caused by projected changes in the frequency and severity of storms.

TWO

Vulnerability to Climate Change

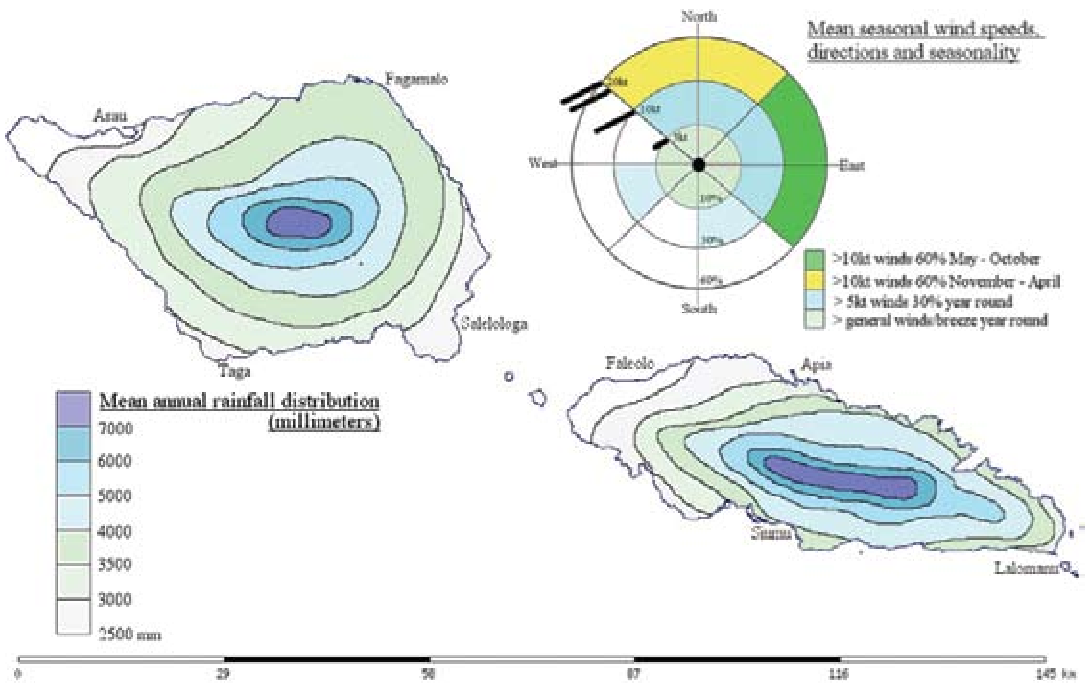
Background

Samoa is a small island country located in the South-West Pacific between latitudes 13°–15°S and longitudes 168°–173°W. It has four main inhabited islands and six small uninhabited islands with a total land area of 2,935 sq. km. The two main islands are Savai'i (the larger of the two but much less densely populated) and Upolu (Figure 1). The population is approximately 183,000 and is projected to increase slowly to about 210,000 by 2050. Average life expectancy at birth was 72.8 years in 2006, which is higher than the median for Pacific Island countries. About 76 percent of the population live on the island of Upolu. The capital and only significant urban center is Apia in North Upolu with a population of about 40,000.

The islands are volcanic in origin, so the topography includes mountains up to 1,850 m as well

FIGURE 1 MAIN ISLANDS IN SAMOA

FIGURE 2 THIRTY-YEAR CLIMATE AVERAGES FOR RAINFALL AND WIND DISTRIBUTION



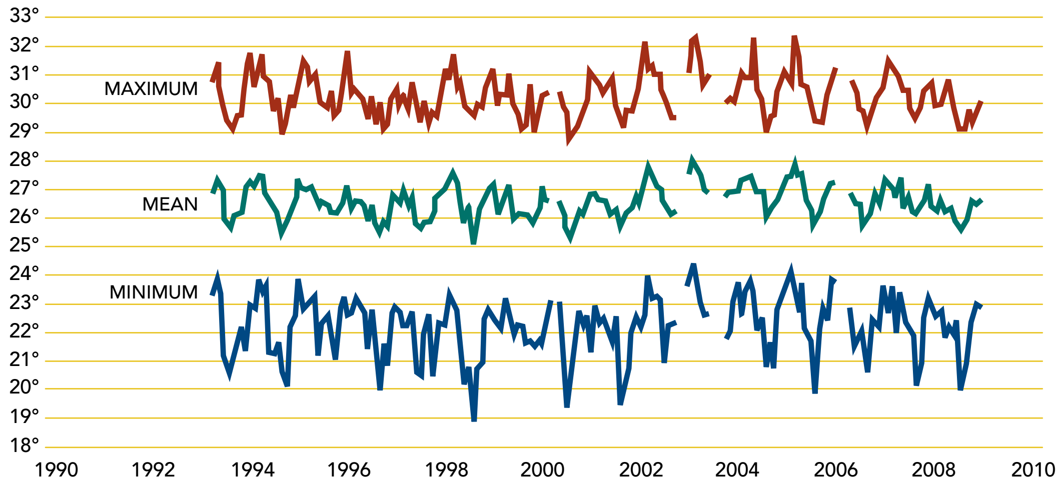
Source: MNRE, Meteorology Division - Figure 2 in Government of Samoa (2005)

as low-lying coastal areas. About 70 percent of the country's population live in the coastal zone. The coastal zone is vulnerable to sea level rise, and all areas are subject to damage caused by the high winds, storm surges, and torrential rainfall associated with severe tropical cyclones. It is estimated that two cyclones—Ofa in 1990 and Val in 1991—caused damage to agriculture, infrastructure, and other assets valued at 2.5 to 3 times the country's GDP in 1990.

The climate is tropical with a wet season from November to April and a dry season from May to October. Temperatures vary little over the year with a typical daily range of 24° to 32°C. Average annual rainfall is high at 3,000 mm; about two-thirds of annual rainfall falls in the wet season. Severe tropical cyclones tend to occur in the period from December to February. The islands are also affected by dry spells that coincide with the El Niño Southern Oscillation (ENSO). Figure 2 shows the geographical distribution of annual precipitation and wind speeds based on historic averages from 1961 to 1990, while Figure 3 shows temperatures in Apia over the last two decades.

A review of historical climate trends for Apia suggests that the daily maximum temperature increased by about 0.7°C over the 20th century while the daily minimum temperature increased by 0.2°C. Average annual precipitation decreased by about 49 mm over the century. There is some evidence that the severity and/or the frequency of tropical cyclones have increased in the SW Pacific; see Chapter 1 of World Bank (2006).

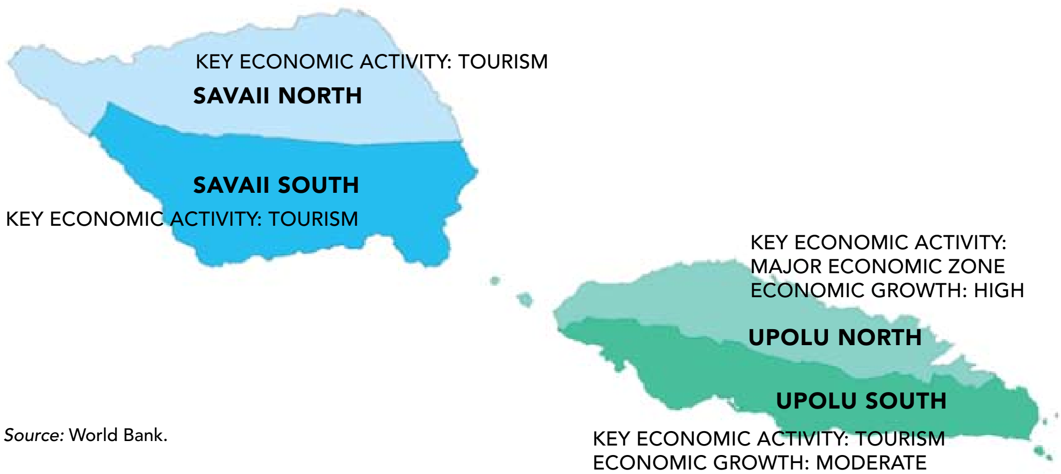
FIGURE 3 MONTHLY TEMPERATURES IN APIA, 1993-2008



Source: SPSLCMP data; Figure 18 in SPSLCMP (2008).

FIGURE 4 REGIONS OF SAMOA USED IN THE CLIMATE-ECONOMY MODEL

CLIMATIC HAZARDS: WINDS, LIMITED OR ERRATIC RAINFALL



Source: World Bank.

This study has divided the country into four regions: Savai'i North (SN), Savai'i South (SS), Upolu North (UN), and Upolu South (US). This allows for regional differences in climate scenarios, economic activity, and incomes in the climate-economy model. Figure 4 illustrates the regional division and highlights the major economic characteristics of each region. Upolu North contains Apia and has the highest population, including all of the urban population.

TABLE 1 PROJECTED CHANGES IN CLIMATE VARIABLES BY GCM AND REGION

		Baseline values for NoCC				Deviations in 2050 relative to NoCC			
Climate model	Region	Total precipitation (mm)	Precipitation Dec–Feb (mm)	Precipitation Nov–Apr (mm)	Mean temperature (°C)	Total precipitation (mm)	Precipitation Dec–Feb (mm)	Precipitation Nov–Apr (mm)	Mean temperature (°C)
NCAR	Savai'i North	2,958	1,062	1,921	26.87	-17	-39	5	0.99
NCAR	Savai'i South	3,002	1,107	1,971	26.86	-19	-41	3	0.99
NCAR	Upolu North	3,048	1,154	2,024	26.83	-21	-42	0	0.99
NCAR	Upolu South	2,929	1,090	1,942	26.67	106	-8	118	0.97
CSIRO	Savai'i North	2,958	1,062	1,921	26.87	277	43	197	0.81
CSIRO	Savai'i South	3,002	1,107	1,971	26.86	343	65	215	0.83
CSIRO	Upolu North	3,048	1,154	2,024	26.83	344	68	218	0.83
CSIRO	Upolu South	2,929	1,090	1,942	26.67	335	66	213	0.83

Source: World Bank analysis; see World Bank (2009); NoCC= no climate change

Projections of Climate Change – Global Scenarios

Samoa is covered by four of the 0.5° grid cells for which projections of climate variables have been downscaled from the results of the general circulation models (GCMs) used in this study. These can be mapped to the four regions shown in Figure 4 with the largest population in the grid cell centered on 13.75°S, 171.75°W, which corresponds to Upolu North and covers Apia. The Global Wet (NCAR) and Dry (CSIRO) scenarios differ little with respect to the increase in the annual average temperature (Table 1). The Global Wet scenario projects an increase of 0.97–0.99°C by 2050 for the four regions, while the Global Dry scenario for 2050 projects an increase of 0.81–0.83°C by 2050 for the four regions. Since the differences between regions are much smaller than the standard errors of the projections, it is reasonable to assume a uniform increase of about 1°C for the Global Wet scenario and about 0.8°C for the Global Dry scenario. Changes in average daily maximum and daily minimum temperatures (not shown) are almost identical to the changes in average daily mean temperatures.

The situation is rather more complicated for precipitation. Notwithstanding its name, the Global Wet scenario projects changes in total annual precipitation by region in the range -21 to +106 mm by 2050 with a value of -21 mm for Upolu North. In contrast, the Global Dry scenario projects changes in the range +277 to +344 mm by 2050 with a value of +344 mm for Apia. There are also changes in the seasonal distribution of rainfall. For example, total precipitation for December–February—the prime period for cyclones—falls by about 40 mm by 2050 in the Global Wet scenario, whereas precipitation during the rainy season from November to April is stable or increases slightly in Upolu South. Thus, the dry season becomes drier while the transitional months of the wet season become wetter in this scenario. The shift is not as marked for the Global Dry scenario but still roughly one-half of the increase in annual precipitation occurs during the transitional months of the wet season.

Observation and modeling suggest that higher global temperatures, including sea surface temperatures, will mean that the peak wind speeds and probably precipitation and flooding associated with severe cyclones will increase. This is equivalent to a shift in the tail of the distribution of extreme weather events (see Annex 1). These considerations point to a more frequent return period of cyclones with the severity of Cyclones Ofa and Val, which had a devastating impact on Samoa in 1990–91 (see Section 3). However, since these cyclones rank second and third in the list of the most damaging cyclones in the South Pacific region as a whole in the last 50 years, it is very difficult to quantify the potential change in exposure to extreme storm damage for different scenarios.

There is a separate but less well–documented concern that the severity—and perhaps the frequency—of ENSO cyclical variations in weather conditions will increase. This could mean that the severity of ENSO dry periods may increase, especially under the Global Wet scenario for which average precipitation during the dry season is expected to fall. This is discussed further in Section 3.

Sea Level Rise

The South Pacific Sea Level and Climate Monitoring Project (SPSLCMP) has collected sea level and climate data for Samoa since 1993. The most recent country report published in December 2008 gives an average increase in sea level of 4.9 mm per year at Apia.[1] If sustained over the 21st century this would imply an increase of 54 cm from 1990 to 2100, which is a little greater than the assumption of 40 cm used for the low sea level rise (SLR) scenario in the coastal protection component of the global study. The main scenario included in the global estimates assumes a rise of 87 cm from 1990 to 2100. Other forecasts for sea level rise in the South Pacific are considerably more pessimistic. Evidence about changes in the height of storm surges is even more difficult to obtain, but recent trends indicate that the difference between average sea level and the maximum value of hourly sea level measured in each year has been increasing at about 3 cm per decade (Young 2007).

The main earthquake zone in the South Pacific lies about 200 km south of Samoa, with more than 12 earthquakes of magnitude 7 or greater since 1900. This means that the risks to coastal infrastructure associated with climate change must be assessed in a framework of vulnerability to other natural shocks.

Data collected by SPSLCMP show 18 separate tsunami events over 15 years, with the largest trough-to-peak height of 570 cm after an earthquake near the Kuril Islands in November 2006. The tsunami that followed the magnitude 8.1 earthquake, which occurred about 190 km south of Apia in September 2009, is reported as having a trough-to-peak height of 140 cm in Apia. The waves that struck parts of South Upolu were much greater; for example, the tsunami generated a trough-to-peak height of 314 cm in Pago Pago (American Samoa), and there were reports of waves of up to 450 cm in parts of Upolu.

1 Figures for another sea level gauge yield an average increase of 2.1 mm per year over a longer period, but this estimate is regarded as less reliable because of less precision and poorer datum control.

THREE

Impacts of Climate Change and Natural Hazards

Historical Experience

Over the last two decades Samoa has suffered serious economic shocks caused by four major natural disasters. The worst of these were two severe cyclones in successive seasons—1989–90 and 1990–91—which caused massive damage to infrastructure and other assets.

CYCLONE OFA (FEBRUARY 1990)

Cyclone Ofa was classified as a Category 4 hurricane with wind speeds up to 215 kph. It struck Samoa as the storm was strengthening and continued to affect Samoan waters during the worst phase of the storm. Extensive damage occurred along the northern coasts of both Upolu and Savai'i. A review of the damage on Upolu caused by the storm reported seven deaths; major damage to buildings and infrastructure caused by waves that inundated coastal zones and high winds inland; disruption to shipping and communications, partly caused by damage to infrastructure and partly as a consequence of the beaching of the country's main passenger/cargo ferry; and loss of reclaimed land, plus damage to agricultural assets such as plantations caused by flooding and wind (Rearic 1990). A comparison of the severity of the storm with a theoretical 100–year storm by the Apia Observatory suggested a return period of about 25 years with a storm surge of 1.6 m and onshore sustained wind velocity of 130 kph.

CYCLONE VAL (DECEMBER 1991)

Cyclone Val was classified as a Category 5 hurricane with wind speeds up to 240 kph. It was judged to be the most destructive storm to hit the Samoan islands in the 20th century because of its intensity, irregular path, and slow speed (Fairbairn 1997). Damage was caused by a combination of high winds, heavy rains, and wave action. The duration of the cyclone and the shifts in wind direction exacerbated the destructive effects of high winds, so that crops and plantations, natural vegetation, buildings, and other structures all suffered extensive damage. The main effects of high waves were felt on the south coasts of Upolu and Savai'i, an unfortunate complement to the impact of Cyclone Ofa. The storm was reported as having caused 12 deaths in Samoa. It defoliated a high proportion of trees on the main islands, and caused the complete loss of nearly 50 percent of coconut trees. Analysis of wind speeds and the associated storm surge suggested that the storm had a return period of about 100 years, with an onshore sustained wind velocity of 165 kph.

CYCLONE HETA (JANUARY 2004)

Cyclone Heta passed near to or struck Samoa, American Samoa, Tonga, and Niue over a period of about a week from January 2 to January 8, 2004. Samoa was relatively fortunate, since the center of the storm passed about 110 km west of the country at a point when it was still classed as a Category 2 hurricane. Even so, sustained wind speeds of 110 kph were reported in Apia with gusts up to 145 kph. Damage on Samoa included the loss of or disruption to power, water, and telecommunications on Savai'i plus limited flooding in Apia. On the other hand, Alofi—Niue's capital city—was devastated by the direct impact of Cyclone Heta, which at that stage was classified as a Category 5 hurricane.

TSUNAMI (SEPTEMBER 2009)

In the early morning of September 29, 2009, an earthquake of magnitude 8.1 in the Kermadec-Tonga Subduction Zone (part of the Pacific Ring of Fire) generated a tsunami that struck the southern coastal areas of Samoa about 10 minutes after the earthquake. It is reported that the waves caused damage up to 14 m above sea level on the coast of South Upolu and traveled up to 0.7 km inland. Twenty coastal villages in the south and southeast of Upolu were mostly destroyed, with widespread damage to transport, power, and telecommunications infrastructure. About 5,300 people were affected, with 3,000 losing their homes.

The reported death toll caused by the tsunami in Samoa was 155—more than 5 times the total number of deaths caused by cyclones from 1990 to 2010. One lesson is that loss of life and economic damage caused by natural disasters are not closely correlated. Geological events such as earthquakes and tsunamis, which are concentrated in their impact and occur with little or no warning, cause much heavier loss of life relative to their economic costs than weather events for which effective disaster planning and warning systems can minimize loss of life, though they cannot prevent widespread structural damage with high economic costs.

Modeling the Frequency of Extreme Events

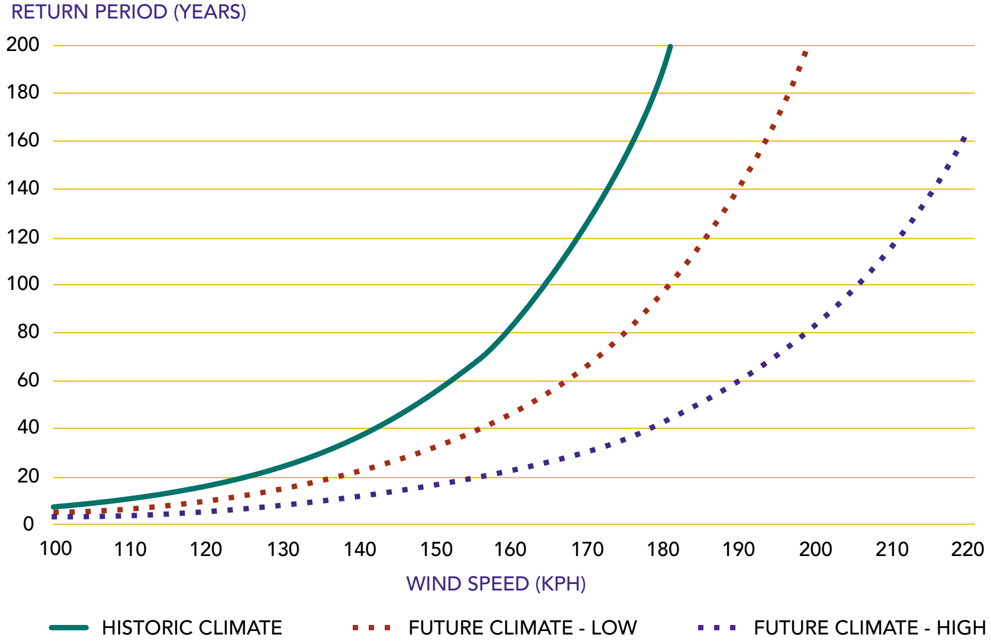
Statisticians and others interested in analyzing natural hazards such as tropical storms, floods, or earthquakes have developed standard methods of modeling the distribution of extreme events over a period of time. Suppose that the severity of tropical storms is measured by its peak wind speed measured over a period of 10 minutes and that S_t^* denotes the peak wind speed for the worst storm in year *t*. This is closely correlated to the amount of wind damage caused by the storm and is likely to provide a reasonable proxy for storm damage caused by rain and flooding since higher wind speeds tend to be associated with more intense precipitation over periods of 6 to 12 hours.

The probability that a storm with a wind speed greater than *S* will occur in year t at a particular location—prob ($S_t^* \geq S$)—is usually assumed to follow the cumulative distribution function for some variant of the generalized extreme value (GEV) distribution (Annex 1). The return period of a cyclone with peak wind speed *S* is the reciprocal of this probability. Carter (1990) examines the return period for cyclones in the South Pacific, the Samoa 5-degree square, and Apia.[2]

The "historic" curve in Figure 5 shows the estimated return periods for peak wind speeds of cyclones during the 20th century, while the

2 Unfortunately, the expressions given in the paper for peak wind speed, wave height, etc., as a function of the return period—equations (4) to (8)—are clearly wrong, though the graphs appear to be correct. For example, using Figure 4 the text states that the wind speed with a 40–year return interval is 77 knots, whereas equation (4) yields a value of 438 knots (p. 15). Thus, the return periods quoted in the text have been used to derive correct values of the Gumbel distribution parameters used for the calculation of historic return periods in Figure 5.

FIGURE 5 ILLUSTRATION OF CYCLONE RETURN PERIODS BY PEAK WIND SPEED



"future" curve illustrates how the return periods might fall if it is assumed that both the location and scale parameters of the storm distribution increase by either 10 percent (Future climate–low) or 25 percent (Future climate–high) due to climate change. These increases correspond to the range for the year 2100 discussed below. The changes have the effect of reducing the return period of a storm with a peak wind speed of 165 kph (89 knots) from 100 years to approximately 55 years for the low scenario and 26 years for the high scenario.

Economic Damage Caused by Natural Disasters

Table 2 summarizes estimates of the economic damage—expressed as one-off capital losses—caused by the natural disasters that have affected Samoa over the past two decades. The estimates are based upon (a) reports of damage to buildings, infrastructure, and other assets shortly after the event, and (b) the present value (using a real discount rate of 5 percent) of the shortfall in GDP relative to the trend rate of economic growth prior to the shortfall in economic growth.[3]

Such figures must be treated with some caution. It is often unclear how the value of damage to capital assets is obtained. The usual procedure is to estimate the cost of repairing or replacing damaged assets, but this is rarely carried out on a like-for-like basis. Existing assets may be old and will have been partly or fully depreciated. They are usually less efficient or they may be less suitable for current requirements. Indeed, owners may decide that it is not economic to replace them. Hence, the economic value of assets that

3 For example, over the years 1992–94 GDP fell 7–8 percent below the cyclically adjusted trend in GDP, apparently as a consequence of the combined effects of Cyclones Ofa and Val. The shortfall was about 12 percent for agricultural GDP in 1994 since agricultural assets, particularly coconut palms, were severely affected by Cyclone Val. However, by 1996 both total and agricultural GDP had recovered to match the pre-disaster trends.

TABLE 2 ECONOMIC DAMAGE CAUSED BY RECENT NATURAL DISASTERS IN SAMOA

Event	Return period Years	Asset damage US$ million, 2005 prices	Loss of GDP US$ million, 2005 prices	Total GDP US$ million, 2005 prices	Loss as percent of GDP	Notes
Cyclone Ofa	25	166	15	161	113	Buildings & infrastructure
Cyclone Val	100	388	36	163	260	30% agricultural assets
Cyclone Heta	10	1	4	236	2	Limited damage
Tsunami 2009	50	54	50	277	38	Buildings, infrastructure & tourism

Source: World Bank estimates

are damaged is likely to be significantly less than their replacement or even repair costs.

Similarly, the estimates of the loss of GDP caused by Cyclones Ofa and Val shown in the table are somewhat overstated, because they include the impact of the taro blight, which affected crop production from 1994 onward and delayed the full recovery from the disasters by up to two years. Further, the higher rate of economic growth associated with recovery from the damage caused by the storms persisted after the recovery and the long-term rate of economic growth clearly increased in the late 1990s. The storms were certainly not a benefit in disguise, but their long-term impact has been reduced by pushing the Samoan economy toward sectors that appear to support a higher long-term rate of economic growth. These considerations mean that the estimates shown in Table 2 set an upper bound on the economic losses associated with storms of different return periods.

Policies to minimize the economic damage caused by cyclones will require the adoption of building standards capable of withstanding much greater wind stresses or relocating infrastructure so that it is less susceptible to damage caused by flooding and/or wave action. These measures will also reduce the impact of geological events, though the attraction of coastal areas for tourism will inevitably mean that people and assets are vulnerable to events triggered by earthquakes.

Estimating the Costs of Adapting to Climate Change

The technical basis for calculating the change in the expected value of storm damage as a consequence of a shift in the probability distribution of cyclones is set out in Annex 1. This focuses attention on two components of the costs of adapting to climate change:

A. The changes in design standards required to ensure that new or upgraded assets can resist the higher wind speeds to which they are likely to be exposed as a consequence of the shift in the distribution of storms hitting Samoa. This approach is built into the estimates of the costs of adaptation for infrastructure and related assets prepared for Samoa under the global analysis of the cost of adaptation. These global estimates include an allowance for the increased costs of maintenance and/or accelerated replacement of existing assets because they were built to lower design standards and are more likely to be damaged by storms with higher wind speeds.

B. Expenditures and investments for other measures to adapt to climate change that were identified in the NAPA. These are discussed in more detail in Section 4 below.

There is, however, an important constraint on any detailed examination of the impact of climate change or the costs of adaptation. It is clear that a key feature of climate change for Samoa is the possibility that the distribution of extreme weather events—primarily cyclones but also ENSO droughts—will shift to more frequent or severe cyclones hitting the islands. Unfortunately, the empirical evidence on how the distribution might shift over time for different climate scenarios is very limited (IWTC 2006).

The damage caused by tropical cyclones is due to a combination of high winds and precipitation leading to flooding. Both Emanuel (2005) and Knutson, et al. (2010) emphasize the link between sea surface temperatures and cyclone intensity, with higher ocean temperatures being associated with both higher sustained wind speeds and higher rainfall. Generally, changes in sea surface temperatures follow changes in average land temperatures but with a considerable lag. For this analysis there is little alternative other than to rely upon changes in average land temperatures as the basis for distributing changes in storm intensity up to 2050 and 2100.

In the most recent assessment of probable shifts in the intensity and frequency of cyclones as a result of climate change, Knutson, et al (2010) suggest that the overall intensity of cyclones may increase by 2–11 percent in the period to 2100, with the main driver being the increase in ocean temperatures. This change may involve a decrease in the frequency of cyclones but with a large margin of uncertainty (6–34 percent) offset by an increase in the frequency of the most intense cyclones. In addition, increases on the order of 20 percent are likely in the intensity of precipitation within 100 km of the storm for the most severe cyclones.

To capture the uncertainty about changes in both the peak wind speeds and precipitation associated with any shift in the distribution of cyclones by intensity, a range of values has been used. As a low estimate—linked to the relatively dry NCAR scenario for Samoa—it has been assumed that the key parameters of the distribution increase by 4 percent to 2050 and by 10 percent to 2100. These figures fall within the range identified by Knutson, et al. (2010) and they correspond to the increases in average temperatures for this scenario combined with the middle of the range of the sensitivity of cyclone intensity to ocean temperatures.[4] As a high estimate—linked to the relatively wet CSIRO scenario for Samoa—it has been assumed that the key parameters of the distribution increase by 8 percent to 2050 and by 25 percent to 2100. These figures allow for a strong shift toward more intense cyclones and a greater intensity of precipitation associated with such cyclones. The assumptions for the CSIRO scenario are intended to provide a worst-case scenario for the change in the distribution of cyclones given current knowledge.

The analysis has also taken account of a significant change in the distribution of precipitation over the year, especially for the CSIRO scenario. Total precipitation during the rainy season averaged over the grid cells is 1,965 mm for the NoCC scenario and increases to 2,175 mm for the CSIRO scenario. This is likely to increase the overall probability of severe flooding during the rainy season and will require higher design standards for buildings, roads, storm water drainage, and similar infrastructure to cope with an increase in the intensity and volume of rainfall. Hence, the calculations of the cost of adaptation include an allowance for the costs of providing greater resilience to flooding linked to precipitation in the rainy season. This is separate from and additional to the costs associated with the increase in precipitation intensity associated with severe cyclones.

4 The statement prepared by a WMO expert group (IWTC 2006) states that both theory and observation support a conclusion that the intensity of tropical cyclones will increase by 3–5 percent per 1°C rise in sea surface temperature. Emanuel (2005) uses a figure of 5 percent in considering changes in his power dissipation index for tropical cyclones.

The Potential Impact of Climate Change on the Agricultural Sector

The agricultural sector in Samoa is a crucial source of employment—providing the main occupation for 32 percent of the workforce in the 2006 Census—but is a much smaller contributor to GDP. Agriculture and fishing accounted for 10 percent of GDP at constant prices in 2008, down from 20 percent in 1988, before hurricanes Ofa and Val and the taro blight. Value-added in agriculture and fishing at constant prices reached a peak in 1996 and fell by 30 percent from 1996 to 2004. Since 2004 agricultural output has grown but less rapidly than the rest of the economy, so that value-added in agriculture on its own has fallen from 8.1 percent to 6.2 percent of GDP over the five-year period 2004–09. This share is likely to fall below 5 percent in the decades up to 2050.

Research into the potential impacts of climate change on crop yields and viability in Samoa and other South Pacific islands is very limited. The general assessment seems to be that an increase of 1°C in average temperatures and minor changes in total precipitation up to 2050 will not have a large effect on yields of the main crops such as taro, bananas, and coconuts; see, for example, the analysis for Vita Levu, Fiji in World Bank (2000). The changes are within the range of variation observed across countries where the same or similar varieties are grown.[5] Nonetheless, uncertainty about the effects of climate change would warrant expenditures on agricultural research and development as an insurance policy.

A separate concern has been expressed about the prospect of more severe dry periods associated with ENSO events. Again, the evidence on this issue is limited and open to different interpretations. Annex 2 provides details of a statistical analysis of the links between ENSO events, precipitation, and agricultural production. This confirms that strong El Niño periods lead to a reduction of about 18 percent in precipitation in the months that follow, with little difference between the impact in the wet and dry seasons. If climate change were to lead to a 50 percent increase in the variation between normal and extreme ENSO conditions, then strong El Niño periods might be associated with a reduction of up to 27 percent in precipitation. However, there is one important qualification. The analysis also indicates that the influence of ENSO events on precipitation may have been declining since 1950. If this apparent trend is real and continues in future, the impact of climate change on the variability of ENSO-related precipitation would be small.

In any case, the relationship between ENSO-related changes in precipitation and agricultural production has not been large in the past. The second part of the statistical analysis looked at the extent to which ENSO events have been associated with fluctuations in crop production, crop yields, and trade in agricultural products. Again, the results confirm that there is a link primarily driven by the impact of ENSO events on taro production. A typical strong El Niño event has been associated with a decline of 5–8 percent in taro production and an increase of 3–5 percent in the value of agricultural imports. The effects might rise to a decline of 8–12 percent in taro production and a rise of 5–7 percent in agricultural imports if the climate change were to lead to a 50 percent increase in the variation between normal and extreme ENSO conditions.

To put these potential changes in context, the trend rate of growth in agricultural imports has been 6.2 percent per year over the last two decades, while variations in agricultural production caused by the cyclones in 1990–91 or the taro blight were an order of magnitude greater than the potential variations associated with the effect of climate change

5 This is documented in the relevant data sheets from FAO's Ecocrop database, which can be accessed at: http://ecocrop.fao.org/ecocrop/srv/en/home.

TABLE 3 LOSSES DUE TO CLIMATE CHANGE WITHOUT ADAPTATION

	No adaptation	
	NCAR (1)	CSIRO (2)
Present value @ 5 percent, $ million	103.9	212.4
Annualized equivalent, $ million per year	5.9	12.1
Loss/benefit as percent of baseline GDP	0.6%	1.3%
Loss/benefit as percent of baseline consumption	0.9%	1.9%

Source: World Bank estimates.

on the intensity of ENSO events. This means that a sound strategy for reducing the effects of existing weather and agricultural risks on farmers and the economy should be the starting point for adapting to climate change. Crop diversification, reliance upon varieties that can cope better with dry periods or resist wind damage, the development of alternative sources of employment and income, and similar measures will limit the damage caused by existing risks and facilitate adaptation to climate change. It will then be easier and less expensive to implement additional measures to reduce vulnerability to risk if concerns about changes in the severity of ENSO events due to climate change are sustained by evidence from experience over the coming decades.

Model of Climate-Economy Interactions

A simple climate-economy model has been used to examine the impact of climate change on economic activity and the effects of spending on adaptation measures. The key features of the model are:

(a) There are four regions, North and South Upolu/Savai'i, with populations and value-added derived from the 2006 census.

(b) Total output in each region is calculated using a Cobb-Douglas production function in capital and labor, with the capital share calibrated to match input shares and investment in 2006.

(c) Growth rates for population and GDP without climate change correspond to the baseline data used for the Global Track estimates. These assumptions determine the growth in capital stock and total factor productivity.

(d) Gross investment is calculated assuming a standard depreciation rate applied to the current capital stock plus net capital accumulation.

(e) Total consumption is equal to total output minus climate damage, adaptation costs, and gross investment. The present value in 2010 of total consumption from 2010 to 2050 is used to assess the impact of climate change and the effects of adaptation.

The expected value of the economic damage caused by cyclones is calculated in the manner described in Annex 1 using the shifts in the probability distribution of storms by 2050 for the NCAR and CSIRO scenarios based on changes in average temperature. To maintain investment and economic growth, the damage caused by storms has the effect of reducing consumption, so that the cost of climate change for each scenario is measured as the reduction in the present value of consumption in USD at 2005 prices over the period 2010–50. Without any adaptation, Table 3 shows that the loss of consumption is $104 million for the NCAR scenario or $212 million for the CSIRO scenario. The annualized equivalent is $5.9 million per year for the NCAR scenario and $12.1 million per year for the CSIRO scenario.

FOUR

Adaptation Plans and Costs

Samoa has a rapidly developing and increasingly sophisticated framework of strategies, plans, and regulations that have developed over time to meet international conventions, international monitoring and reporting requirements, and governance best practice goals. Many of the older national-level strategies have been developed at different times as a result of different drivers, but an effort has been made to integrate planning in different sectors with a broad development strategy. An institutional reform in 2003, which merged 26 departments into 13 ministries, provided the opportunity to review and update some of the legislation.

Adaptation to climate change as a concept and priority is reflected through all government and planning levels, most noticeably in high-level plans and strategies. Translating these general goals into regular corporate and departmental plans is more difficult, though the programs and projects under way are consistent with development priorities and could be considered as adaptation activities.

Strategy for the Development of Samoa (SDS) (2008–12)

The overarching document in Samoa that guides all other development is the Strategy for the Development of Samoa (SDS) (2008–12), which seeks to "ensure sustainable economic and social progress." The SDS provides a framework on national priorities under key development sectors. The government has identified seven goals under this framework. Climate change is mentioned in Goal 7: Environmental Sustainability and Disaster Risk Reduction.

In the SDS under Goal 7, climate change adaptation is identified as a cross-cutting issue alongside environmental sustainability. Adaptation to climate change is linked with deforestation and cyclone frequency (natural disasters). Mitigation activities are also identified and linked to renewable energy priorities. The primary focus is on the link between climate change and disaster management, which reflects the critical concern that climate change will lead to increased frequency and intensity of storms. Coastal communities in Samoa are already at high risk from cyclones, and their vulnerability to coastal inundation and erosion has already been assessed.

Priority activities to address Goal 7 in the related areas of climate change and disaster management are to "implement the Disaster Management Act 2007 through various programs and projects aimed at both climate mitigation (greenhouse gas reductions) and disaster readiness." Increasing resilience to the adverse impacts of climate change will be addressed through continued work on coastal management and adaptation programs for vulnerable villages and other coastal locations, as well as activities such as promotion of energy-efficient building design.

The environment is to feature prominently as a cross-cutting consideration in all planning activities, including the formulation of sector plans. There will be a focus on improved environmental management, compliance, and monitoring in 2008–2012, with the Ministry of Natural Resources, Environment and Meteorology (MNRE) the key implementing agency (including for climate change adaptation). The Planning and Urban Management Act 2004 aims to "implement a framework for planning the use, development, management and protection of land in Samoa in the present and long-term interests of all Samoans and for related purposes." Under the act, any development activity requires a development consent with a supporting environmental impact assessment (EIA) unless a sustainable management plan or regulations provide otherwise. The capacity of the Planning and Urban Management Agency to enforce the regulations and undertake or facilitate a greater level of community consultation will need to be strengthened for this to occur.

National Adaptation Program of Action (NAPA) (2005)

NAPA and its development were discussed in the desk-top study by Beca (2010). NAPA is the key document for the identification of the most urgent and immediate adaptation needs from the adverse impacts of climate change. Samoa was one of the first countries to receive funding from the Global Environment Facility (GEF) to develop its NAPA, which took two years of comprehensive information and data collection, as well as extensive countrywide consultation.

Significantly, NAPA led to:

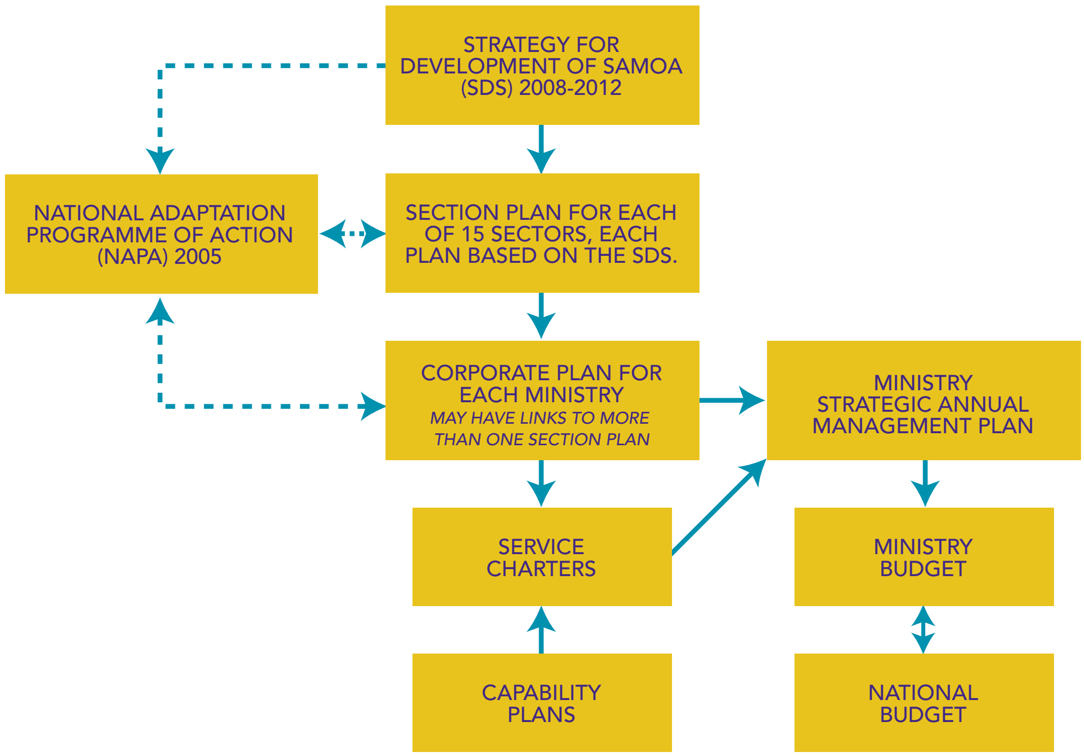
- The creation of the Samoa National Climate Change Country Team (NCCCT) and NAPA Task Team, both cross-sectoral teams comprising representatives from mainly government departments but also NGOs and other interests
- The preparation of a Climate Synthesis Report, which assessed the current vulnerability and potential increase in climate hazards and associated risks of critical sectors
- Discussion of adaptation needs and priorities
- Consideration of whether and how to separate climate change adaptation activities from other development activities.

The relationship of the NAPA to the SDS and its potential for influence on the development of sector plans is shown in Figure 6.

From interviews with participants and others, a number of issues were identified:

- The original Climate Risk Profile was based on fairly limited climate data available at the time. This has been identified as an issue and improving climate monitoring features as a priority program area. An updated Climate Risk Profile has now been prepared (Young 2007).
- The ranking of activities was based on a consensus approach rather than a more objective multicriteria analysis or similar method outlined in the annotated guidelines for the preparation of NAPA. In part, this was a consequence of the lack of good information on both the economics and effectiveness of adaptation options. A consensus-based approach fitted in well with the cultural norms of working together. Limited understanding among the community of climate change and of the effect of different adaptation activities influenced the ranking of

FIGURE 6 LINKS BETWEEN THE NAPA AND THE SDS WITH REPORTING RELATIONSHIPS



Source: Beca International Consultants Ltd (2010)

alternatives. For example, construction of seawalls features as an urgent community need, even though other strategies emphasize the role of more cost-effective measures.

- Economic assessments were limited to analyses of cost-effectiveness, feasibility, and long-term sustainability by activity rather than overall.

- There was an extensive series of countrywide workshops, but some were not particularly well-attended.

- The ready availability of donor funds for adaptation projects has been a disincentive to develop clear priorities among potential projects and programs. Everything gets funded sooner or later. Projects are designed so that they clip onto existing programs largely funded through bilateral agreements and sector pool funds. Figure 7 illustrates the approval process. Assistance in setting priorities—stages 1 to 3—would improve the allocation of funds.

- The significance of the energy sector has been downplayed, possibly as a result of a lack of information but also possibly due to responsibility for it being in another ministry (Ministry of Finance). While energy featured on the original list of sectors, it was dropped from the final ranked list. The comment was made that energy priorities were being met through a different strategy and as part of climate change mitigation programs.

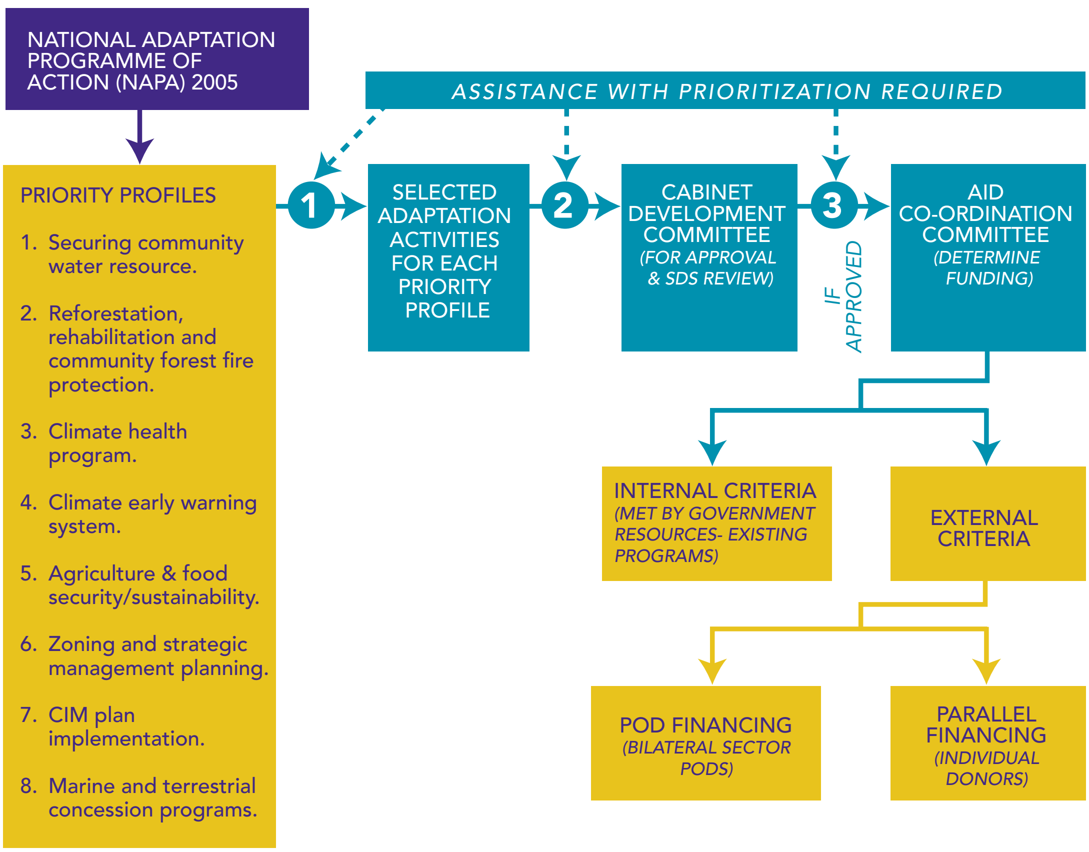
- The NAPA has a high level of awareness among agencies and there is commitment to, and support for, its implementation by MNRE.

Coastal Infrastructure Management Strategy and Plans

The Samoa Coastal Infrastructure Management (CIM) Strategy (2001) provided a series of national and local priorities for coastal management. The strategy developed objectives, policies, and implementation methods for hazard and environmental information-gathering and monitoring, education and awareness-raising, use and management of resources, and for undertaking intervention actions. The CIM Strategy set out the need for coastal infrastructure management plans (CIM Plans) and defined goals, objectives, policies, and implementation methods across a broad range of coastal considerations (Daly et al. 2010).

The CIM plans were supported by the compilation of data on the state of coastal resources based upon (a) a survey of Samoa's 403 km coastline; (b) mapping the extent and condition of natural environments (such as landforms, mangroves, and lagoons); (c) identifying natural resources (such as aggregate and offshore sand resources); and (d) mapping coastal hazards (coastal inundation and erosion). The analysis of coastal hazards focused

FIGURE 7 APPROVAL PROCESS FOR ADAPTATION PROJECTS



Source: Beca International Consultants Ltd (2010) on reducing tsunami risks as well as climate-related hazards.

The project resulted in a total of 41 CIM plans highlighting vulnerable areas and identifying priority actions to reduce community vulnerability. Adaptation activities took account of community consultations and *fa'a Samoa*: a traditional model of community decision making by consensus under the leadership of the *matai* (chief). Community priorities were based on strong anecdotal (history and traditional knowledge) and physical evidence (such as hazard zone mapping). "Hard", i.e. physical, measures—such as coastal protection and road relocation—were subjected to an economic analysis to determine their level of viability.

Implementation of the CIM plans—progressively working through the list of prioritized mitigation and adaptation options per village—has been identified in the NAPA as a priority. The next stage will be to develop a prioritization tool to rank projects within villages and between districts.

The interviews highlighted the following points:

- Implementation of the CIM strategy and plans is viewed, particularly by MNRE, as a key element in adapting to climate change.
- The CIM plans have been used to guide recovery in the regions of Samoa affected by the 2009 tsunami.
- The CIM plans are being referred to during the consenting process for new developments in order to ensure they are not located in previously identified hazard zones.
- Awareness of the CIM plans and the value of the outcomes of the consultation is declining in other ministries and agencies due to staff changes, time, and other project priorities. There is a likelihood of duplication of effort in other (smaller) projects if awareness of the CIM plans and value of the consultation is lost.
- Coastline monitoring at a number of points was established as a baseline to measure coastline morphology changes. There was no evidence that this monitoring was continuing.

Updating and implementing the CIM plans should be a priority. This would include updating the plans, prioritizing the actions, and undertaking actions of high priority.

Evidence of Prioritization and Sequencing: Donor Influence

NAPA provided a ranked list of sectors and preferred adaptation actions for each. There was no attempt to prioritize the actual adaptation actions themselves. Activities were grouped into programs, some of them cross-cutting, and all have been funded (or partially funded) through available donor funds.

Donors are engaging more in partnership with government, whereby donor support is guided and designed by the government. There is considerable effort on building capacity to allow for the proper management of provided resources, although capacity remains an issue. There are also numerous country strategies (some specific to climate change) and donors have organized themselves into supporting specific sectors based on their country strategies; for example, the European Union (EU) for water sector projects.

Currently there is little incentive to prioritize or sequence beyond the level currently afforded by the NAPA process, as most projects eventually get funded through available funding mechanisms. However, both the government and the donors spoken to recognize the need for better prioritization to make the best use of the available funds.

Adaptation and Design Standards for Infrastructure

As discussed in Section 3, the key component of adaptation to climate change is the revision of design standards and associated planning requirements to ensure that buildings and infrastructure are capable of coping with the peak wind speeds and precipitation associated with storms that have a return period of *X* years under future climate conditions. The reference to *X* rather than some specific number makes the point that choosing an appropriate value of *X* involves an economic tradeoff that needs detailed investigation. Buildings that will withstand storms with a higher value of *X*—that is, higher wind speeds—cost more, but the expected annual value of damage will be lower. Rich countries tend to use return periods of 50 or 100 years in setting design standards for most infrastructure and buildings, but the additional cost may not be warranted in Samoa.

A reasonable interpretation of the damage caused by cyclones that have hit Samoa in the past is that the average design standard for the country's capital stock was rather low—a return period of about 5 years—up to 1990, so that Cyclones Ofa and Val caused massive damage. Following those cyclones, the replacement assets are capable of withstanding storms with a return period of 10 years—such as Cyclone Heta—with minimal damage.[6] Estimating the cost of adaptation depends on answering two questions:

- Does a return period of 10 years offer the right balance between actual costs of construction and the expected damage caused by storms now and in the future? Or, would it be better for Samoa to adopt a higher value for the return period—say 20 or 50 years—when setting minimum design standards?

- What will be the additional costs of constructing public assets—buildings and infrastructure—in compliance with the efficient design standard—that is, a return period of 10, 20 or 50 years—under the future climate scenarios?

The time and resources required to answer these questions in detail are beyond the scope of this case study. Nonetheless, it is possible to give an initial assessment on the evidence that is available. Since the issue is critical for Samoa's response to climate change, the initial analysis should be confirmed and/or refined by more detailed investigation in future.

Managing climate risks. A simple test can be used to consider whether the current design standards based on a 10-year period (peak wind speed of 108 kph) is appropriate. This is based on comparing the reduction in the expected annual losses from storm damage if a higher design standard were adopted with the annualized value of the additional investment and operating costs required to construct and maintain assets to the higher standard. If new design standards were based on protecting buildings and other assets from storms with return periods up to 50 years (peak wind speed of 148 kph) the model indicates that the expected annual value of storm losses would fall from about 5.5 percent of GDP to about 0.7 percent of GDP, giving an expected annual benefit of 4.8 percent of GDP or about $30 million per year in 2008. In the long run, the cost of adopting such design standards, calculated using the methods described below, will be 2–3 percent of the annualized cost of the capital stock, which is less than $5 million per year in 2008.

6 It is important to be careful in interpreting what this means. Many buildings in Samoa have been built to design standards that enable them to withstand storms with a historic return period of 50 or more years. However, this is not true of the country's entire capital stock. In practice, the design standard for some buildings and infrastructure is much lower, so that a storm like Cyclone Ofa with a historic return period of 25 years would cause substantial damage if it were to occur now. What matters is the minimum design standard across either all assets or the public assets that are covered by this study. Hence, the focus is on those assets that are most vulnerable to storm damage rather than those that have already been built to a standard that will enable them to cope with storms with a historic return period of 50 or 100 years.

It is clear that moving to a design standard of 50 years will generate benefits that outweigh the costs by a large margin. On the other hand, applying the same method to a move from design standards based on a 50-year return period to ones based on a 100-year return period yields results that are much less clear. The additional benefits would only be $3–4 million per year, while the additional costs would be $2–3 million per year. On this basis, the analysis of the costs of adaptation considers two scenarios:

Scenario A: Adaptation takes place on the basis of maintaining design standards at their existing level—for storms with a return period of 10 years—up to 2050. However, there is one further aspect of adaptation to reflect the impact of climate change. Instead of being designed to withstand current storms with a return period of 10 years, which might be appropriate without climate change, it is assumed that they are constructed to withstand equivalent storms over the life of the assets; for simplicity, a period of 50 years ahead is used. This forward-looking basis for setting design standards confers significantly greater protection today than at the end of the life of the assets, which is appropriate since the destruction of an asset is much more costly when it is new than when it is near the end of its economic life. Under this scenario, the peak wind speed for which buildings and other assets are designed increases gradually from 115 kph now to 125 kph in 2050.

Scenario B: Adaptation is combined with the gradual implementation of forward-looking design standards based on storms with a return period of 50 years. Part of the gross cost of adaptation that is calculated by the model arises because of the progressive shift from a 10- year basis for design standards to a 50-year basis between now and 2050. This component is estimated by applying the same method of analysis to the development baseline with no climate change. Hence, it is possible to assess the separate costs of (a) upgrading design standards over a period of 40 years, and (b) adapting to climate change over the same period. The first of these components involves an increase in the peak wind speed for which buildings are designed from 108 kph to 148 kph, while the second component extends this to 170 kph in 2050.

The costs of adaptation. The infrastructure analysis carried out for the global study—see chapter 5 in World Bank (2009)—has been modified to take account of the specific circumstances of Samoa, particularly in the use of (a) average temperature as a proxy for the shift in the probability distributions of storms under the two climate scenarios, and (b) total precipitation during the rainy season as a proxy for the damage caused by flooding. The key concept is that building standards are updated in discrete steps to take account of expected changes in weather stresses over the life of a building or other asset. For each update in building standards, additional costs of construction and maintenance are incurred and these make up the costs of adapting to climate change. For Samoa it has been assumed that building standards are updated for each 10 kph increment in peak wind speeds with a 50-year return period. The extra costs cover both improvements in resistance to wind damage and protection against flood damage. For assets in place in 2010, it has been assumed that the annual cost of maintenance over the remainder of their life is increased by 50 percent of the base cost of maintenance for each 10 kph increment in the current 50-year wind speed. This assumption is designed to reflect additional spending on measures to strengthen buildings to make them more resilient to potential storms in the immediate future, and is based on recommendations for Caribbean countries with histories of severe hurricane damage.

This modified approach has been used for all buildings including housing. The standard assumptions—reflecting changes in maximum temperatures, annual and maximum monthly precipitation, and so on—have been used for other assets such as roads, bridges, electricity, and water systems. Allowance has also been made for improvements in urban storm drainage to enable this to limit the flooding and associated damage caused by more intense precipitation during storms.

As shown in Table 1, the NCAR and CSIRO climate scenarios generate rather similar projections for the increase in average temperature, so that the costs of adaptation under the two scenarios will not differ by much. To get a better sense of the range of possible costs of adaptation, a range of values has been used in analyzing the costs associated with a shift in the probability distribution of storms. The range is generated by combining the range of parameter values for the increase in storm intensity per 1°C increase in sea surface temperature and the range of values for the increase in average temperature. For the NCAR climate scenario, it has been assumed that the key parameters of the probability distribution increase by 4 percent up to 2050 and by 10 percent up to 2100. For the CSIRO climate scenario, the equivalent assumptions are increases of 8 percent to 2050 and 25 percent to 2100. Inevitably, these are only approximations, but the ranges for 2050 and 2100 provide a reasonable indication of the degree of uncertainty when assessing the costs of adaptation to climate change.

TABLE 4 ADAPTATION COSTS BY INFRASTRUCTURE CATEGORY FOR 10-YEAR STANDARD (DECADE AVERAGES WITHOUT DISCOUNTING, $ MILLION PER YEAR AT 2005 PRICES)

	2010-19	2020-29	2030-39	2040-49
A. NCAR CLIMATE SCENARIO				
Education and health	0.01	0.02	0.03	0.08
Electricity and telecoms	0.01	0.02	0.03	0.06
Housing	0.00	0.01	0.00	0.25
Municipal	0.05	0.08	0.14	0.36
Other transport	0.01	0.01	0.01	0.05
Roads	0.03	0.19	0.07	0.03
Water and sewers	0.00	0.00	0.00	0.02
Total	0.11	0.33	0.28	0.84
Total excl. housing	0.11	0.32	0.28	0.59
B. CSIRO CLIMATE SCENARIO				
Education and health	0.09	0.16	0.25	0.39
Electricity and telecoms	0.05	0.08	0.12	0.16
Housing	0.45	0.93	1.64	2.79
Municipal	0.76	1.25	1.95	2.69
Other transport	0.06	0.11	0.19	0.31
Roads	0.52	0.68	0.82	0.93
Water and sewers	0.02	0.03	0.05	0.08
Total	1.94	3.23	5.02	7.33
Total excl. housing	1.49	2.31	3.38	4.54

Source: World Bank estimates.

TABLE 5 ADAPTATION COSTS AS PERCENT OF BASELINE EXPENDITURES CSIRO CLIMATE SCENARIO AND 10-YEAR STANDARD

	2010-19	*2020-29*	*2030-39*	*2040-49*
Education and health	1.3	1.9	2.5	3.2
Electricity and telecoms	0.6	0.8	1.0	1.2
Housing	2.6	3.7	4.9	6.3
Municipal	2.4	3.1	3.7	4.6
Other transport	1.6	2.3	3.0	3.7
Roads	3.4	4.3	5.2	6.2
Water and sewers	0.7	0.9	1.3	1.7
Total	2.2	3.0	3.7	4.7
Total excl. housing	2.1	2.8	3.3	4.0

Source: World Bank estimates.

The costs of adaptation for each category of infrastructure reported in the tables cover both (a) the incremental costs of implementing new design standards to ensure that new (and replacement) infrastructure assets can cope with greater weather stresses associated with higher wind speeds, precipitation, and temperatures; and (b) the higher costs of maintenance for existing infrastructure assets as a result of the same weather stresses.

Table 4 shows the costs of adaptation for Samoa for the two climate scenarios under the assumption that the current 10-year basis for design standards is retained. The costs of adaptation are much higher for the CSIRO scenario, partly because this involves protection against higher peak wind speeds and partly because the level and pattern of precipitation is an important driver of some of the costs of responding to climate change. The main costs are incurred for housing and municipal infrastructure, which covers public buildings and storm water drainage.

Table 5 shows the relative magnitude of these adaptation costs under the CSIRO scenario when expressed as a percentage of the cost of providing the relevant services in the baseline scenario. The increases in costs are about 6 percent for housing and roads in the period 2040–49. Over the whole period from 2010 to 2050, the increase is 3.2 percent for infrastructure excluding housing and 3.6 percent including housing. As might be expected, the burden of adaptation rises over time as the probability distribution of severe storms shifts.

Table 6 shows the net costs of adaptation to climate change for the two climate scenarios on the assumption that the 50-year design standard has been or is being implemented. The total costs are about 12 percent higher than the total costs of adaptation for the 10-year standard, partly because the base investment costs are higher due to the stricter design standards and partly because the higher return period means a larger increase in peak wind speeds due to climate change. Nonetheless, the overall cost of adaptation is small relative to the benefits of reducing the expected values of losses caused by storms.

Coastal Protection

The global analysis for coastal protection is based upon use of the dynamic and interactive vulnerability assessment (DIVA) model to estimate the costs of sea walls, beach nourishment, estuarial flood protection, and port upgrades (World Bank 2009). An important feature of the DIVA analysis

TABLE 6 ADAPTATION COSTS BY INFRASTRUCTURE CATEGORY FOR 50-YEAR STANDARD (DECADE AVERAGES WITHOUT DISCOUNTING, $ MILLION PER YEAR AT 2005 PRICES)

	2010-19	*2020-29*	*2030-39*	*2040-49*
A. NCAR CLIMATE SCENARIO				
Education and health	0.01	0.05	0.06	0.08
Electricity and telecoms	0.01	0.05	0.06	0.06
Housing	0.00	0.15	0.19	0.25
Municipal	0.05	0.23	0.31	0.36
Other transport	0.01	0.03	0.04	0.05
Roads	0.03	0.19	0.07	0.03
Water and sewers	0.00	0.01	0.02	0.02
Total	0.11	0.70	0.75	0.84
Total excl. housing	0.11	0.55	0.55	0.59
B. CSIRO CLIMATE SCENARIO				
Education and health	0.11	0.18	0.30	0.44
Electricity and telecoms	0.08	0.11	0.17	0.20
Housing	0.55	1.07	1.93	3.16
Municipal	0.86	1.39	2.22	2.98
Other transport	0.08	0.13	0.22	0.36
Roads	0.52	0.68	0.82	0.93
Water and sewers	0.03	0.04	0.07	0.10
Total	2.22	3.60	5.72	8.16
Total excl. housing	1.67	2.53	3.79	5.00

Source: World Bank estimates.

is that expenditures on coastal protection are subject to a cost-benefit test that examines whether the value of the assets protected from the effects of sea level rise and storm surges is sufficient to justify the costs involved. In the case of Samoa, the cost-benefit test is only satisfied for expenditures on port upgrades. This finding seems to be consistent with the analysis undertaken for the CIM Strategy, which indicated that other measures—such as moving infrastructure and other assets—are more cost-effective than building sea walls in providing protection against the combination of sea level rise and storm surges.

The results of the DIVA analysis for Samoa are shown in Table 7. Relatively small expenditures—up to $40,000 per year at 2005 prices under the High SLR scenario—are required to upgrade the port at Apia, but otherwise no expenditures can be justified. The consequence is that some people will be affected by flooding in the absence of coastal protection. The average number affected will increase to about 170 per year in the decade 2040–49 under the High SLR scenario. Other, less expensive, measures or compensation for the resulting damage will be required to offset this impact of climate change.

NAPA adaptation options

The study reviewed NAPA and identified the adaptation activities in order of the priority given

TABLE 7 COSTS OF COASTAL PROTECTION AND RESIDUAL DAMAGE FROM DIVA MODEL (DECADE AVERAGES WITHOUT DISCOUNTING, $ MILLION PER YEAR AT 2005 PRICES)

	Total costs and residual damage			
	2010-19	2020-29	2030-39	2040-49
LOW SLR SCENARIO				
Port upgrades	0.017	0.017	0.017	0.017
Sea walls	0.000	0.000	0.000	0.000
Beach nourishment	0.000	0.000	0.000	0.000
Land loss (sq km per year)	0.000	0.000	0.000	0.000
People flooded (000s per year)	0.000	0.010	0.080	0.160
MEDIUM SLR SCENARIO				
Port upgrades	0.032	0.032	0.032	0.032
Sea walls	0.000	0.000	0.000	0.000
Beach nourishment	0.000	0.000	0.000	0.000
Land loss (sq km per year)	0.000	0.000	0.000	0.000
People flooded (000s per year)	0.010	0.010	0.090	0.170
HIGH SLR SCENARIO				
Port upgrades	0.042	0.042	0.042	0.042
Sea walls	0.000	0.000	0.000	0.000
Beach nourishment	0.000	0.000	0.000	0.000
Land loss (sq km per year)	0.000	0.000	0.000	0.000
People flooded (000s per year)	0.010	0.010	0.100	0.170

Source: World Bank estimates.

both to the relevant sectors and the project goals (Table 8). This exercise provided the basis for identifying specific projects and programs that would be consistent with the NAPA and the CIM plans. The details of these projects together with estimated costs are given in Table 9.

Many of the activities and projects identified in Tables 8 and 9 are really development policies or projects in the sense that they would almost certainly be justified without any concern about climate change. This is particularly the case for improvements in water supply, health programs, agriculture, and even tourism. Samoa's vulnerability to natural disasters under current conditions means that many activities would fall into the category of implementing effective policies for disaster planning and management. This highlights the difficulty of drawing clear distinctions between development aid and assistance with adaptation to climate change.

Nonetheless, in order to illustrate how decisions can be made about which adaptation options should implemented and when, all of the options in Table 9 have been included in the analysis. This involves a series of steps.

(a) The adaptation costs in Table 9 are converted to annualized values. No conversion is required for recurrent costs, but capital costs are converted using annualization rates based upon a 5 percent discount rate and life spans from 10 years—for studies and similar measures—to 40 years for coastal infrastructure. The annualization rates include an allowance

TABLE 8 PRIORITY ADAPTATION ACTIVITIES BASED ON NAPA

Rank	*Sector*	*Goal*	*Activities*
1	Water	Securing community water resources	A. Develop water purification programs for communities B. Develop watershed management program for other communities C. Alternative water storage systems D. Restoration of coastal springs
2	Forestry	Reforestation, rehabilitation, and forest fire prevention	A. Sustainable forest management B. Forest fire prevention program
3	Health	Climate health cooperation program	A. Establish climate health cooperation program
4	All	Climate early warning system	A. Develop climate early warning system and emergency measures
5	Agriculture	Agriculture and food security	A. Investment in annual crops and home vegetable farming B. Alternative farming systems
6	Urban settlements	Zoning & strategic planning	A. Strengthen zoning, disaster planning, and urban planning to increase resilience to cyclone damage
7	Coastal infrastructure	Implement Coastal Infrastructure Management Plans for highly vulnerable districts	A. Implement coastal zone management B. Coastal infrastructure protection, incl. sea walls C. Relocation of roads D. Relocation of communities and associated infrastructure
8	Biodiversity & environments	Conservation programs for highly vulnerable marine and terrestrial areas	A. Establish conservation areas and marine reserves
9	Tourism	Sustainable tourism	A. Develop sustainable tourism policy and ventures

Source: Beca International Consultants Ltd based on Government of Samoa (2005).

for maintenance costs at 1 percent of capital expenditure for fixed assets.

(b) In the case of studies and policy measures, it is assumed that other measures with an equivalent cost will be implemented to sustain the benefits of the initial policy changes. Further, it is assumed that physical assets—coastal infrastructure and improvements to water supply systems—are replaced at the end of their working life. Thus, implementation of any adaptation measure represents a permanent commitment to annual expenditure equal to the annualized value of the project cost.

(c) Detailed cost-benefit analysis of each measure requires an estimate of the proportion of damage associated with climate change that would be mitigated by implementing the measure. This implies a level of detailed documentation and analysis of the effects of the various adaptation options that is not available in this case study. In addition, it is necessary to make explicit assumptions about how far the measures should be treated as development or adaptation policies. For example, improving water supplies and building new schools would generate significant benefits even if there were no climate change. Strictly, these non-climate benefits should be deducted from the gross project cost to obtain an estimate of the net cost of adaptation, which has to be compared with the climate benefits that are generated. None of this is easy and it is certainly not practical with the information that is available for Samoa. Instead, it has been assumed that the total annualized cost of the adaptation options for each region (dominated by the costs of relocating coastal infrastructure) can be used as a proxy for the

TABLE 9 POTENTIAL ADAPTATION OPTIONS FOR NAPA AND CIM PLANS

Region	Key sector	Adaptation measure	Cost ($ 000 at 2005 prices)	Type
North Savai'i	Water	Improve water treatment at source for existing boreholes	120	Capital
	Health	Education, monitoring, and control of pest plants and animal species that would otherwise adversely impact upon health and biodiversity	40	Annual
	Coastal infrastructure	Build new school away from coastal flood hazard zone	1,000	Capital
	Tourism	Develop and support inland ecotourism venture	50	Capital
	Agriculture	Identify and establish village/home-based vegetable farming areas	120	Capital
	Agriculture	Strategy and farming adviser	40	Annual
South Savai'i	Water	Improve water storage capacity of villages for use in drought periods	150	Capital
	Health	Education, monitoring, and control of pest plants & animal species that would otherwise adversely impact upon health and biodiversity	40	Annual
	Coastal infrastructure	Place remaining overhead electrical lines underground	1,000	Capital
	Tourism	Development and implementation of a Sustainable Tourism Charter for Savai'i	100	Capital
	Tourism	Adviser on sustainable tourism for businesses and villages	40	Annual
	Agriculture	Increase efficiency of existing plantation areas	80	Capital
	Agriculture	Inspection management and advisory program	40	Annual
North Upolu	Water	Repair leaks in reticulated water supply network	100	Annual
	Health	Collection of better health, meteorological, environmental, and socioeconomic data for health planning, incl. development of a health vulnerability indicator	65	Capital
	Coastal infrastructure	Provide addition access road inland to reduce reliance upon coast route	23,000	Capital
	Tourism	Development and implementation of a Sustainable Tourism Charter for Upolu	100	Capital
	Tourism	Adviser on sustainable tourism for businesses and villages	55	Annual
	Urban development	Develop structure plan for Apia to encourage appropriate urban design and land use	400	Capital
South Upolu	Water	Develop an integrated watershed management program with villages in the catchment	115	Capital
	Health	Develop early intervention health services to deal with water and vector-borne diseases	150	Capital
		Upgrade clinic and fund district nurse	40	Annual
	Coastal infrastructure	Relocate village inland out of coastal hazard zone, incl. expansion of power grid, sealing inland plantation roads, water supply reticulation, and telecommunications	32,000	Capital
	Tourism	Develop and support inland ecotourism venture	50	Capital
	Agriculture	Identify and implement sustainable management of fish and shellfish resources	80	Capital
	Agriculture	Strategy and adviser position	40	Annual

Source: Beca International Consultants Ltd (2010).

TABLE 10 DATES FOR IMPLEMENTATION OF NAPA ADAPTATION MEASURES BY REGION

	Upolu North	*Upolu South*	*Savai'i North*	*Savai'i North*
A. DESIGN STANDARDS FOR 10-YEAR RETURN PERIOD				
NCAR	2045–49	> 2050	2035–39	2035–39
CSIRO	2035–39	> 2050	2025–29	2025–29
B. DESIGN STANDARDS FOR 50-YEAR RETURN PERIOD				
NCAR	> 2050	> 2050	> 2050	> 2050
CSIRO	> 2050	> 2050	> 2050	> 2050

Source: World Bank estimates.

costs of fully adapting to climate change in the region.

(d) The assumptions outlined in (c) mean that the cost-benefit decision rule for adaptation involves a set of simple comparisons of the annualized costs of the adaptation options for each region against the damage due to climate change in the region. Provided that the direction of change of estimated damage does not reverse, once implementation of adaptation options becomes economic there will be no reason to alter the decision in future.

Table 10 shows the period during which the NAPA adaptation measures should be implemented in order to obtain the most efficient balance between the costs of climate change and the costs of adaptation under the two climate scenarios on alternative assumptions about the set of design standards that are adopted. The results indicate that the NAPA projects are not urgent when considered purely in terms of adaptation to climate change. Some of the projects have significant development benefits that would justify the required expenditures without any climate change, but the lesson is to focus on the design and implementation of the projects that are beneficial under any climate scenario. This conclusion is reinforced by the significant differences in optimal timing under the alternative combinations of design standards and climate scenarios.

A second conclusion is that the projects proposed for Upolu South—in particular the relocation of coastal infrastructure—are hard to justify over the next 40 years under any of the scenarios. But, again there is another consideration. Upolu South was the region most severely affected by the 2009 tsunami and is most vulnerable to the impact of future earthquakes and the resulting tsunamis. Relocating coastal infrastructure may be justified as a measure to reduce the risks associated with non-climate hazards. The lesson is that it is important to focus on climate change within the context of other natural hazards and broader development goals.

Agriculture

Based upon the potential impact of climate change on agriculture discussed earlier, two types of public expenditure would contribute to the capacity of the agricultural sector in Samoa to adapt to climate change. The estimates given here are very broad and are intended only as an indication of orders of magnitude.

Agricultural research and development. An increase in spending on agricultural research and development would provide farmers with a wider range of crop varieties and cultivation options to respond to the risks associated with climate change, including a greater degree of weather variability within and between seasons and changes in patterns of pests and/or diseases. The EACC global study of agriculture carried out by the International Food Policy Research Institute (IFPRI) estimated that spending on agricultural research and development would need to increase by 25–30 percent relative to the baseline of no climate change to hold levels of malnutrition constant under the NCAR and CSIRO scenarios.

As a general indication of the cost of adaptation, it has been assumed that public spending on agricultural research, development, and advisory services, which amounted to $1.6 million in 2007, should be increased by 30 percent to fund additional activities to mitigate the effects of climate change. This is applied to a baseline level of expenditure that is assumed to increase at 2.5 percent per year in real terms. This estimate of the cost of adaptation rises from an average of $0.58 million per year in the decade 2010–19 to $1.22 million per year for 2040–49.

Agricultural asset insurance. Storms damage or destroy agricultural assets including livestock, trees, machinery, and some irrigation facilities. These are not protected by the adoption of design standards designed to enable buildings and other infrastructure to withstand more severe storms. Hence, the shift in the probability distribution of storms will lead to higher expected losses of agricultural assets when severe storms occur. While farmers may be expected to bear the costs of such losses up to some threshold, it is likely that the government will offer implicit or explicit insurance for the losses associated with the worst storms as a way of supporting agriculture. Thus, the cost of adaptation will include the increase in the expected value of losses due to the shift in the probability distribution of storms due to climate change.

The scale of this item is estimated by calibrating a loss function on the following assumptions: (a) the threshold for farmers up to which farmers bear losses is 90 kph (a storm return period of five years under historic climate conditions); (b) a damage function similar to that used for economic losses with a power of 1.5 for the increase in damage for increases in wind speed above the threshold; (c) an average capital-output ratio (excluding land) of 3 for agriculture; and (d) losses of 20 percent of agricultural assets for a storm with a peak wind speed of 165 kph (based on the losses caused by Cyclone Val). On this basis, the expected cost of asset insurance associated with storm damage will increase from 0.95 percent of agricultural value-added without climate change to 1.15 percent for the NCAR scenario in 2050 and 1.37 percent for the CSIRO scenario. The increase in insurance costs is relatively small, reaching an average of $0.28 million per year for 2040–49 for the CSIRO scenario.

Adaptation Costs and Benefits

Table 11 is an extended version of Table 3 with the addition of the costs of climate change if adaptation measures are implemented as discussed in this section under the two alternative assumptions about design standards. In this case the cost of climate change with adaptation for each region is the minimum of (a) the climate damage estimated using the appropriate damage function, and (b) the annualized cost of adaptation measures.

The most important observation is that the adoption of 50-year design standards reduces the impact of climate change on consumption by 80-90 percent under both of the climate scenarios. This is a classic example of a "no regrets" strategy: It can be justified in economic terms even without climate change, but its net benefits are even larger if climate change occurs. Additional adaptation measures further reduce the impact of climate change so that the net cost is equivalent to $0.3 million per year on an annualized basis after allowing for the cost of implementing the

TABLE 11 THE IMPACT OF CLIMATE CHANGE WITH AND WITHOUT ADAPTATION

	No adaptation		*With adaptation*		*Benefit of adaptation*	
	NCAR (1)	*CSIRO (2)*	*NCAR (3)*	*CSIRO (4)*	*NCAR (5)*	*CSIRO (6)*
A. DESIGN STANDARDS FOR 10-YEAR RETURN PERIOD						
Present value @ 5 percent, $ million	103.9	212.4	34.8	24.5	69.1	187.9
Annualized equivalent, $ million per year	5.9	12.1	2.0	1.4	3.9	10.7
Loss/benefit as percent of baseline GDP	0.6	1.3	0.2	0.2	0.4	1.2
Loss/benefit as percent of baseline consumption	0.9	1.9	0.3	0.2	0.6	1.7
B. DESIGN STANDARDS FOR 50-YEAR RETURN PERIOD						
Present value @ 5 percent, $ million	19.9	37.0	4.5	5.4	15.4	31.6
Annualized equivalent, $ million per year	1.1	2.1	0.3	0.3	0.9	1.8
Loss/benefit as percent of baseline GDP	0.1	0.2	0.0	0.0	0.1	0.2
Loss/benefit as percent of baseline consumption	0.2	0.3	0.0	0.0	0.1	0.3

Source: World Bank estimates.

TABLE 12 TOTAL COST OF ADAPTATION FOR 10-YEAR DESIGN STANDARDS BY SCENARIO AND DECADE (DECADE AVERAGES WITHOUT DISCOUNTING, $ MILLION PER YEAR AT 2005 PRICES)

	2010–19	*2020–29*	*2030–39*	*2040–s49*
NCAR SCENARIO				
Coastal protection	0.032	0.032	0.032	0.032
Infrastructure excl housing	0.108	0.320	0.277	0.589
Housing	0.000	0.007	0.001	0.252
Health	0.044	0.000	0.000	0.000
Agriculture	0.606	0.826	1.110	1.475
Fisheries	0.379	0.640	0.901	1.163
NAPA projects	0.000	0.000	0.150	1.179
Total	1.169	1.825	2.472	4.689
CSIRO SCENARIO				
Coastal protection	0.032	0.032	0.032	0.032
Infrastructure excl housing	1.491	2.307	3.381	4.544
Housing	0.449	0.927	1.635	2.789
Health	0.023	0.000	0.000	0.000
Agriculture	0.608	0.834	1.126	1.500
Fisheries	0.379	0.640	0.901	1.163
NAPA projects	0.000	0.169	1.370	2.329
Total	2.982	4.909	8.445	12.357

Source: World Bank estimates.

TABLE 13 TOTAL COST OF ADAPTATION FOR 50-YEAR DESIGN STANDARDS BY SCENARIO AND DECADE (DECADE AVERAGES WITHOUT DISCOUNTING, US$ MILLION PER YEAR AT 2005 PRICES)

	2010–19	*2020–29*	*2030–39*	*2040–49*
NCAR scenario				
Coastal protection	0.032	0.032	0.032	0.032
Infrastructure excl housing	0.108	0.552	0.552	0.589
Housing	0.000	0.152	0.193	0.252
Health	0.044	0.000	0.000	0.000
Agriculture	0.606	0.826	1.110	1.475
Fisheries	0.379	0.640	0.901	1.163
NAPA projects	0.000	0.000	0.000	0.000
Total	1.169	2.202	2.788	3.510
CSIRO scenario				
Coastal protection	0.032	0.032	0.032	0.032
Infrastructure excl housing	1.667	2.533	3.794	5.002
Housing	0.548	1.069	1.929	3.158
Health	0.023	0.000	0.000	0.000
Agriculture	0.608	0.834	1.126	1.500
Fisheries	0.379	0.640	0.901	1.163
NAPA projects	0.000	0.000	0.000	0.000
Total	3.257	5.108	7.782	10.855

Source: World Bank estimates.

measures. In present value terms the combination of adopting 50-year design standards and associated adaptation yields a net benefit of $88 million under the NCAR scenario with a relatively small increase in cyclone intensity and one of $181 million under the CSIRO scenario with a relatively high increase in cyclone intensity.

Finally, Tables 12 and 13 show the total cost of adaptation for Samoa by decade and climate scenario for the 10- and 50-year design standards. In addition to the items that have already been discussed in this section, these costs include expenditures on health and fisheries based on the calculations prepared for the EACC global analysis. These are not linked to changes in the probability of cyclones, so that they have not been included in the climate-economy model. In the case of health, the expenditures are required to offset the projected impact of changes in temperature and precipitation on the incidence of diarrhoeal diseases, after controlling for income and economic development. In the case of fisheries, the expenditures are calculated as the amount of compensation required to offset the reduction in the value-added generated by fishing in Samoa's exclusive economic zone because of climate change (World Bank 2009).

The decline in fish catches is the largest element of the cost of adaptation for the NCAR scenario. The total cost of adaptation is quite small in this scenario. In contrast, the total cost of adaptation in the CSIRO scenario is much higher than for

the NCAR scenario and increases by 3.5–4.5 times from 2010–19 to 2040–49. This growth is driven partly by the increase in the cost of protecting buildings from storm damage and partly by the implementation of the NAPA projects—in particular the relocation of coastal infrastructure—in the second half of the period under review. Underpinning these increases is the projected risk in the peak wind speed associated with 1-in-50-year storms after 2050 in this climate scenario because this determines the design standards required to ensure that buildings and other structures can cope with predicted wind stresses during their economic lives.

Tables 12 and 13 include estimates of the additional costs of upgrading design standards for housing. This is a departure from the coverage adopted for the global analysis. As a general principle, the EACC study focuses on adaptation within the public sector and for public assets. The boundary between public and private assets varies from country to country, but in most countries housing is predominantly owned and managed by individuals rather than public organizations, and housing has been treated as lying outside the scope of public assets in estimating the global cost of adaptation.

Notwithstanding this general principle, the reality is that damage to a significant proportion of a country's housing stock caused by a major storm—or, similarly, major earthquakes—invariably leads to public intervention and support to repair or replace damaged housing. This is true in countries as diverse as the United States, Honduras, or Haiti after major natural disasters. The manner in which governments bear much of the cost of dealing with the damage caused by natural disasters varies from emergency grants to subsidized insurance arrangements, but the practice is nearly universal. If the public sector is likely to pay for much of the cost of repairing storm damage, then it would be sensible for the public sector to bear part or most of the cost of ensuring that such damage is minimized by the adoption of more stringent design standards. Providing tax incentives or subsidies to offset the incremental cost of ensuring that houses are more resilient to future storms would be a worthwhile investment for the Samoan government in terms of the long-run consequences for public revenues and expenditures. Because of the particular nature of climate risks in Samoa, housing adaptation has been included in the overall cost of adaptation in this case study.

FIVE

Institutional and Social Analysis

Incorporation of Existing Data on Potential Risks and Hazards

Typically, explicit data and information on potential risks and hazards are limited to a narrative of existing data, an analysis of trends (where sufficient data exists), and a qualitative assessment of vulnerability and risk. Examples of this would be NAPA and the National Disaster and Emergency Management Plan (2005). The use of data to guide policy changes is not yet well-developed, partly because of the lack of baseline monitoring data over a sufficient period, but also due to a lack of awareness about how to interpret information in a way that is meaningful for policy and planning.

A number of projects are attempting to better integrate information into policy:

- The CIM plans integrated environmental information, hazard, and risk information into the plans and based mitigation options directly on the vulnerability and risk profile of the villages concerned.

Monitoring the effect of changing climate on crop suitability. Approximately 60 thematic maps are being produced based on different crops and projected climate changes to determine what areas will be more suitable than others in the future for different crop types.

From the interviews and information reviewed, a number of observations can be made:

- Samoa has developed its own Climate Synthesis Report, which summarizes trends and analyzes data from Samoa's climate monitoring stations. There are other stations being established (through Electric Power Corporation) that in time will provide additional data. EPC and MNRE (Meteorological Division) are working together, and information from EPC's network will be available to MNRE. Accessibility of this data to external (non-profit) agencies is currently limited and consequently difficult.

- There is still not enough information to allow for local trend analysis or tools to support decision making.

- Environmental data continues to be expanded and collected—examples include a forest inventory, water availability, and coastal hazard maps. Socioeconomic information—such as land valuation and the Human Development Index—is more limited. NAPA identifies climate monitoring (including climate early warning systems) as a priority. One senior MNRE official commented that more training was needed for staff in cost-benefit analysis.

- There is scope for more work integrating climate science with climate change adaptation policy.

- There is considerable scope for more data and information collection in the private sector. For example, the Samoa Tourism Authority could expand the information it uses (currently limited to arrivals/ departure information compiled by the Bureau of Statistics) by building its relationship with the Samoa Hotel Association and improving relations with local hotel operators. Information needs include occupancy rates and accommodation stock (number of beds and rooms). With the right incentives and commercial confidentiality protected, this information could be collected by the hotels themselves for little effort and aggregated by the STA or the Hotels Association.

- Information management is an issue in Samoa and needs considerable investment. Information is not always stored in robust databases, integrated, or shared across ministries, and is not always easy to retrieve. Data ownership and access costs (user pays) make accessing this information difficult. A number of examples of discrepancies and lost data emerged during the visit, for example:

  - There were discrepancies in immigration data (10,000 cards not accounted for affecting arrivals statistics).
  - The car registration database (providing number and type of vehicles on the road) was corrupted and all data was lost. Currently this is on a manual system and needs integrating, for example, with police databases.
  - Site-specific (land-based) information is stored on a yearly basis (rather than site basis), making correlating historical and current land use activity, ownership, hazards, etc. needed for development consents very difficult. A lot of information has been lost, archiving is difficult, and security is an issue. Much of this information is needed to support disputes at the land titles court.

Consistency Across and Within Sector Plans

A comprehensive assessment of all available plans could not be completed in the time available. However, the impression from the interviews and from the few plans accessed is that there is relatively good vertical and horizontal integration within and across government departments. A number of sector plans have been developed as part of the SDS, the development of which has involved various agencies (both inside and outside government) with interests and responsibilities in that particular sector. Sector plans inform corporate plans, which in turn inform capability plans—all of which are linked to budget development. Strategies such as the NAPA provide a coordinating and integrating role across the sector plans.

While input into the development of a sector plan doesn't necessarily translate to horizontal integration, the establishment of a number of cross-agency committees and task groups—such as the Disaster Advisory Committee (DAC) and the Samoa National Climate Change Country Team (NCCCT)—provide forums for ongoing discussion and promote integration. Some of these committees, such as DAC, are a statutory requirement.

Local Perspectives

Samoa's cultural context is an important factor when selecting adaptation measures. The traditional model of community decision making is by consensus under the leadership of the *matai* (chief). The authority of a village *matai* and customary land ownership rights are respected, so negotiations between the government and village *matai* can often take a long time. There is a commitment to supporting village-based consultations, which include women and young adults. Raising awareness of climate change and other development concerns through village-based consultation is an effective and sustainable way of supporting the traditional decision-making model. Nevertheless, women and migrants in the poorer communities remain among the most vulnerable groups. Stakeholders at workshops held during the preparation of the NAPA identified the following areas as critical to a strategy for adapting to climate change: the protection of community water supplies, early warning systems, support for agriculture and forestry sectors, implementation of coastal infrastructure management plans, and integrated catchment management.

A consultation program across the entire country funded by UNDP and led by the Ministry of Women, Community and Social Development (MWCSD) has started. It is envisaged that this will lead to the implementation of small-scale projects designed to reduce vulnerability to climate change. This Community Centered Sustainable Development Program (CCSDP) will complement the earlier CIM plan consultation by focusing on village activity such as tourism markets, food security, women in business, and disaster risk reduction initiatives. There is an opportunity for the outcomes of this consultation to feed into any planned update of the CIM plans. Activities that may be supported under the CCSDP include:

- Planting trees and mangroves to reduce coastal erosion
- Establishing conservation areas (marine or terrestrial) and/or coral gardens to increase resilience to coral bleaching
- Increasing the resilience of water resources through the restoration of natural springs and more efficient water uses
- Securing food production by introducing new varieties and more resistant crops, or rezoning agriculture and training farmers on sustainable land management
- Limiting casualties from cyclones by implementing early warning systems
- Promoting alternative sources of energy
- Climate-proofing ecotourism enterprises
- Introducing improved fishing methods to respond to the impact of climate change on marine ecosystems.

Much of this represents a continuation of the priorities and proposals put forward in the CIM plans and NAPA. Project costs are typically small. As discussed in Section 4, there is a large overlap between activities that would be undertaken to promote social and/or economic development and those that contribute to adaptation to climate change.

Implementation—How is it Working in Practice?

The overall impression in Samoa is that climate change adaptation and development issues are being addressed and implemented at the "business-as-usual" level, although the distinction between climate change adaptation, mitigation, sustainable development, and common sense is merged.

At the "business-as-usual" level, there is a mixed awareness of climate change adaptation as a driver. The awareness was higher in government agencies than in the private sector (although not many truly private sector agencies were interviewed as part of the project).

It is recommended that the private sector be encouraged to participate in and buy into climate change adaptation activities more through the multisector groups and committees that have already been established to foster integration.

SIX

Lessons and Future Work

Samoa is a small island nation with most of its population and infrastructure located along the coast, and like other SIDS, it is highly vulnerable to extreme weather events. However, Samoa is also among the most climate-resilient Pacific island countries, and there is much to learn from the way it is approaching climate change and related development issues. Over the last decade it has focused on increasing the capacity of its institutions, which are necessary for the implementation of soft approaches to adaptation, including land-use controls and coastal infrastructure management.

The key lessons that may be drawn from this country study are:

- Extreme weather variability in the coastal zone will involve significant costs for either investments in coastal protection or the relocation of assets. In the longer term, the relocation of assets—or even whole villages—may be the best option, as it can shift economic activity such as tourism, crops, and other businesses away from the coast.

- Uncertainty about climate outcomes and a lack of baseline data have led to a focus on the collection of information in Samoa. More effort is needed to support the collection and analysis of this information and use of the information to inform decision making.

- Good development policies are a foundation for climate change adaptation. The participatory consultations undertaken across the country in developing plans for managing coastal infrastructure are continuing with a focus on other development and adaptation issues.

- The key adaptation measure identified in the study is the adoption of forward-looking design standards that will enable buildings and other assets to cope with storms with higher peak wind speeds and associated precipitation under alternative climate scenarios. At present, peak wind speeds above 110 kph may cause significant damage. If the standard were raised to 135 kph by 2050—equivalent to a 1-in-10 year storm in 2100 for the CSIRO scenario—the expected losses from climate change would be greatly reduced.

- The analysis also suggests that the country should consider, as an urgent matter of good development policy even in the absence of climate change, the adoption of design standards that would enable buildings and infrastructure assets to cope with 1-in-50 year storms without significant damage. The benefits of this change would greatly outweigh the implementation costs. It would require the immediate adoption of standards to ensure that buildings and other assets can withstand storms with a peak wind speed up to 160 kph without damage and a gradual increase in this threshold to 185 kph in 2050. This is a clear example of a "no regrets" strategy for adaptation because it is justified without climate change, but it will also substantially reduce the future costs of adapting to climate change.

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ANNEX ONE

Storm Return Periods and Economic Damages

The Samoa country study has focused on the impact of and adaptation to changes in the distribution of tropical storms that strike the country as a consequence of climate change. Since the modeling relies upon concepts such as the "return period" of storms with different impacts, this annex is intended as a very brief introduction to the basic analysis of extreme events. It focuses on the probability distribution for cyclones characterized by their peak wind speeds sustained over land for a period of at least 10 minutes: referred to as peak wind speeds. Peak wind speeds are closely correlated with structural and economic damage caused by high winds, storm surges, intense rainfall, and flooding.

In any year (t), Samoa is struck by a series of more or less severe storms ($n=1, \dots N_t$) with peak wind speed for each storm denoted by S_{tn}. The maximum peak wind speed in year t is $S_t^* = max\ (S_{tn})$ for given t. The analysis focuses on the characteristics of the distribution of S_t^* over many years. It is standard to use some variant of the generalized extreme value (GEV) to describe the distribution of extreme values of natural events such as floods, storm surges, wind speeds, earthquakes, etc. (Evans, Hastings, and Peacock 2000). In this case, the two parameter version of the GEV distribution, also known as the Gumbel distribution, will be used because of the limited data that is available. The two parameters are location α (the mode of the distribution) and scale β > 0.[7] The probability of a storm with a peak wind speed of $S^* \geq S$ is:

$$prob(S^* \geq S) = 1 - \exp\left\{-\exp\left(\frac{-(S-\alpha)}{\beta}\right)\right\}.$$

The return period of a storm with peak wind speed of S is the reciprocal of prob (S* ≥ S). Thus, the peak wind speed for a storm with a return period of N years is: [8]

$$S(N) = \alpha - \beta\ \ln[\ln(N) - \ln(N-1)].$$

The economic damage caused by a storm with peak wind speed S is assumed to be a power function of the positive difference between S and the wind speed that buildings are designed to resist without damage, denoted by S_D, i.e.

$$D = \gamma\ [\max(S - S_D, 0)]^{\lambda}\ Y$$

7 In the three-parameter variant of the GEV distribution, the inner exponential is replaced by a power function using a shape parameter γ. The two-parameter variant is a special case of the three-parameter specification with γ=0.

8 Carter (1990) examines the return period for cyclones in the South Pacific, the Samoa 5-degree square, and Apia. Unfortunately, the expressions for wind speed, wave height, etc. as a function of the return period— equations (4) to (8)—are clearly wrong, though the graphs appear to be correct. For example, using Figure 4, the text states that the wind speed with a 40-year return interval is 77 knots, whereas equation (4) yields a value of 437.7 knots (p. 15).

where Y is total GDP and the parameters γ and λ are chosen to reflect the actual economic damage caused by storms that have affected Samoa in the past. Until Cyclones Ofa and Val, it seems that design standards in Samoa meant that assets were typically able to cope with storms with a 5-year return period—$S_D \approx 90$ kph—but improvements since the early 1990s mean that Cyclone Heta, a storm with a 10-year return period, caused minimal economic loss, implying that $S_D \approx 108$ kph. On this basis, the damage parameters are estimated as $\lambda = 1.5$ and $\gamma = 0.0041$.

The expected value of the economic damage caused by storms in any year is

$$E(D) = \int_{S_D}^{S_M} p(S)D(S)dS$$

where $p(S)$ is the probability density function for peak wind speed S, $D(S)$ is the damage function for S, and S_M is the maximum wind speed used for the calculation. A discrete approximation is used in place of the continuous integral with steps of 1 kph. The value of S_M corresponds to the peak wind speed with a return period of 200 years since there is insufficient data to calibrate either the probability distribution or the damage function beyond this level.

The impact of a shift in the probability distribution of storms on the expected value of storm damage can be largely offset by changing the design standards that are applied when building new assets. As an illustration, Figure 1 in the main text shows the effect of increasing both the location parameter α and the scale parameter β by 15 percent. This reduces the return period for a storm with a peak wind speed of 165 kph from 100 years to 40 years. If there were no change in design standards, then the expected value of annual storm damage would increase from 4.8 percent of GDP to 11.6 percent of GDP using the base design standard of a 1–in–10 year storm, which corresponds to $S_D \approx 108$ kph.

However, if the design standard is adjusted to maintain the 1–in–10 year storm assumption, then S_D would be increased to 125 kph and the expected value of storm damage would be 5.4 percent of GDP. The specification of the damage function means that the proportional adjustment in S_D required to hold expected damage constant is somewhat greater than the proportional change in the parameters of the probability distribution. In this case the design standard S_D would have to be 128 kph to restore the expected damage to about 4.8 percent of GDP.

Three points should be noted:

A These calculations only apply to damage that can be prevented by implementation of appropriate design standards. The potential damage to agricultural assets such as coconut plantations will increase if peak wind speeds with a 10- or 50-year return period increase. This is addressed separately.

B Existing assets have been built to older design standards and will suffer more damage than new assets. In some cases their remaining economic life may be relatively short, so that the increased risk of storm damage may be relatively small. The calculations assume that a tradeoff is made between the options of accelerated depreciation (early replacement) of long-lived assets that do not meet the new design standards or incurring higher costs of maintenance and repairs as a consequence of more serious storm damage.

C In some cases, the best strategy is to ensure that buildings and infrastructure assets are located out of harm's way. This is particularly true for vulnerability to storm surges and flooding caused by intense rainfall. Thus, when thinking about design standards it is important not just to focus on resistance to wind damage but also to ensure that planning and development policies take proper account of the impact of changes in the severity and frequency of storms in future.

ANNEX TWO

El Niño Events and Agricultural Production

There is evidence that ENSO events have been associated with periods of drought, but the nature and magnitude of their impact on agricultural production in Samoa has not been investigated. This could be important if climate change were to alter the frequency or character of ENSO events. To rectify this gap, a time series analysis of the links between indices of ENSO cycles, precipitation, and agricultural production has been carried out.

The analysis is based upon the following data:

(a) Agricultural production and trade statistics for 1961–2008 for Samoa extracted from FAOSTAT, including area harvested (hectares), yields (tons per ha), total production (metric tons), export quantities (tons), export values ($ 000s), and import values ($ 000s). The analysis of crop production focused primarily on Samoa's three main crops—taro, bananas, and coconuts (both nuts and oil)—with more limited examination of yams, mangoes, papayas, pineapples, and avocadoes. The analysis of trade focused on the value of exports and imports of (a) all agricultural products, and (b) food and animals.

(b) Monthly precipitation (mm) by 0.5 degree grid cells covering eight countries and dependencies in the South Pacific—American Samoa (ASM), Fiji (FJI), Niue (NIU), Tokelau (TKL), Tonga (TON), Tuvalu (TUV), Wallis and Futuna (WLF), and Samoa (WSM)—for 1901–2006 extracted from the CRU TS 3.0 historical climate database. Grid cells were

TABLE A2.1 AVERAGE VALUES OF ENSO INDICES BY ENSO EVENT CLASS

ENSO category	ENSO code	*Average value of index for each ENSO event class* SOI 1901–2009	TNI 1901–2009	ONI 1950–2009	MEI 1950–2009
Strong El Niño	SE	-2.30	-0.15	1.08	1.42
Moderate El Niño	EN	-1.15	-0.53	0.68	0.69
None	N	0.02	-0.48	-0.15	-0.07
Moderate La Niña	LN	1.14	0.07	-0.75	-1.05
Strong La Niña	SL	2.11	0.82	-1.22	-1.33

linked to countries and estimates of the 2000 population in each grid cell. Using this information, population-weighted average precipitation average was calculated for each country on a monthly basis from 1901 to 2005. Models specified in terms of the logs of monthly or seasonal precipitation generally performed best and are reported here.

(c) Monthly values of four ENSO indices are extracted from the NCAR and National Oceanic and Atmospheric Administration (NOAA) databases. All of the indices are constructed as standardized deviations from monthly normal values, though methods of standardization vary. Two indices—the Southern Oscillation Index (SOI), based upon atmospheric pressure at sea level for Tahiti and Darwin (using the Trenberth standardization); and the Trans Niño Index (TNI) reflecting the gradient of sea surface temperatures—are available for months from roughly 1870 onwards. The other two—NOAA's Oceanic Niño Index (ONI) based on sea surface temperatures, and Wolter's Multivariate ENSO Index (MEI) based on a set of different atmospheric and ocean indices—are available for the period from 1950. Table A2.1 shows the average values of the four indices for five categories of the ENSO. It should be noted that the TNI is designed to be approximately orthogonal to the primary ENSO indices, so it is used as an additional variable in the model with the SOI index.

The ONI and MEI are reported as moving averages of data for three months (ONI) or two months (MEI). In the analysis of monthly precipitation, the monthly values of SOI and TNI were converted to 2-month moving averages when assessing the relative performance of alterative ENSO indices in the models. The treatment of the ENSO indices in modeling seasonal precipitation is discussed in detail below.

Table A2.2 provides some simple statistics by ENSO class on total precipitation averaged over grid cells for Samoa for the wet and dry season and four dry season months from June to September. The ENSO classification is assigned by NOAA using data for June to November in each year t from 1933 onwards. The corresponding wet season is defined as November in year *t* to April in year *t+1*, while the corresponding dry season is defined as May-October in year *t+1*. Hence, the statistics in the table are based on data from November 1933 to October 2005.

There are differences between average levels of precipitation in the seasons following different categories of ENSO events, and there is a general tendency for lower precipitation after an El Niño event and higher precipitation after a La Niña event. However, statistically these effects are much stronger for the wet season immediately after the event than for the following dry season. The monthly pattern through the dry season shows differences that are statistically significant in June but not in later months. The implication is that relying upon a simple classification of ENSO events is not an adequate method of capturing the impact of ENSO variations in sea temperature and other weather variables on precipitation. Instead a more detailed analysis based upon explicit analysis of the time profile of ENSO influences is required.

The first step was to examine whether vector autoregression (VAR) models revealed significant lagged cross-country effects in the relationships between precipitation and the ENSO indices. The central idea is that there is a stochastic process that generating a vector of variables—in this case the logs of monthly precipitation for all eight countries—whose evolution over time depend upon their common history. VAR models can be rewritten as more complex time series models for each variable separately, but it is often possible to obtain more parsimonious models and better forecasts by relying upon the VAR specification.

TABLE A2.2 PRECIPITATION STATISTICS BY ENSO CLASS, 1933–2005 (MM)

		Wet season	Dry season	June	July	August	September
Strong El Niño	Average	1,677	1,132	144	177	176	166
	SD	390	408	64	97	119	68
	Min	1,026	442	76	28	32	39
	Max	2,192	1,683	288	322	464	250
Moderate El Niño	Average	1,783	1,104	193	127	177	177
	SD	309	240	68	54	85	96
	Min	1,364	649	101	45	55	67
	Max	2,403	1,402	306	219	337	375
None	Average	1,973	1,092	140	143	160	156
	SD	264	283	66	58	87	95
	Min	1,382	438	40	46	17	3
	Max	2,457	1,672	305	292	339	474
Moderate La Niña	Average	2,201	1,110	168	121	142	194
	SD	342	330	76	58	136	163
	Min	1,790	626	107	70	36	64
	Max	2,557	1,658	326	244	432	479
Strong La Niña	Average	2,338	929	217	104	65	133
	SD	556	238	75	54	53	121
	Min	1,810	666	79	45	17	22
	Max	3,446	1,386	300	202	175	390
All years	Average	1,952	1,086	159	140	154	163
	SD	380	299	72	67	98	101
	Min	1,026	438	40	28	17	3
	Max	3,446	1,683	326	322	464	479
Oneway ANOVA	F-value	6.02	0.56	2.86	1.75	1.91	0.40
by ENSO class	Prob	0.000	0.689	0.030	0.149	0.449	0.805

In this case, almost none of the lagged cross-country effects were statistically significant. Further, the hypothesis of normal errors was decisively rejected in all cases, which may mean that the forecasting performance of the models will be uncertain.

For these reasons, the remainder of the analysis focused on ARMA time series models using data for Samoa on its own. The basic equation that is estimated is:

$$\ln(P_t) = \sum_{s=1}^{12} \alpha_s M_{st} + (\beta_d D_{dt} + \beta_w D_{wt}) I_t + u_t$$

where P_t is precipitation in period t, M_{st} are dummy variables for months $s=1$ … $s=12$ in period t, D_{dt} and D_{wt} are dummy variables for dry and wet seasons in period t, I_t is the ENSO index in period t, and u_t is the error in period t which follows some form of ARMA process. This specification allows for the possibility that the influence of ENSO events may be different during the dry and wet seasons.

TABLE A2.3 COEFFICIENTS ON ENSO INDICES IN EQUATIONS FOR MONTHLY PRECIPITATION

	Sample 1901–2006						*Sample 1950–2006*		
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
SOI	0.058***		0.067***				0.074***		
	(0.010)		(0.010)				(0.016)		
SOI * Dry Season		0.054***		0.059***					
		(0.013)		(0.013)					
SOI * Wet Season		0.061***		0.069***					
		(0.013)		(0.013)					
SOI * 1901–1949					0.037*	0.040**			
					(0.019)	(0.018)			
SOI * 1950–2005					0.075***	0.090***			
					(0.012)	(0.011)			
TNI			-0.0710***						
			(0.013)						
TNI * Dry Season				-0.095***					
				(0.016)					
TNI * Wet Season				-0.043**					
				(0.021)					
TNI * 1901–1949						-0.046			
						(0.036)			
TNI * 1950–2005						-0.084***			
						(0.014)			
ONI								-0.166***	
								(0.033)	
MEI									-0.136***
									(0.026)
Log-likelihood	789.5	789.4	778.7	776.3	787.7	775.2	504.7	503.2	503.9
Test for equality of coeffs									
Chi-square		0.19		4.67	2.95	6.14			
Prob		0.662		0.097	0.086	0.046			

Notes: (a) Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. (b) In addition to the ENSO indices the model includes month dummies and an AR(3) error.

The main results from estimating this model are shown in Table A2.3. The key conclusions that can be drawn from these results are:

- There is a clear and consistent relationship between the ENSO indices (averaged over two or three months) and precipitation. During warm (El Niño) phases of the oscillation, precipitation is below average.
- The Oceanic Niño Index (ONI) yields the best fit for the data from 1950 onwards, but the differences between statistical performance using this index and the two other indices examined for the same period—SOI and MEI—are marginal, so that other considerations may be more important.
- The impact of ENSO variations on precipitation is immediate in the sense that it is not necessary to include lagged values of the averaged ENSO indices to explain variations in precipitation.
- There is no evidence that the impacts of ENSO variations have different relative impacts on precipitation during the wet and dry seasons.
- The inclusion of the TNI index improves the overall statistical performance of the model. A higher value for TNI—that is, a steeper sea temperature gradient—is associated with lower precipitation.
- Some evidence suggests that there is some kind of structural break in the relationships that may have occurred in the middle of the last century. The hypothesis that the coefficients on SOI and TNI before and after 1950 are equal is rejected at the 10 percent level for SOI on its own and at the 5 percent level for SOI and TNI together.

The last of these conclusions suggests the possibility that the basic relationship between ENSO variations and precipitation may have changed or may be changing over time. However, an alternative possibility is that the values of the SOI and TNI indices are less reliable for years before 1950 than for more recent years. To investigate this, two sets of checks were carried out. First, the timing of any structural break was examined by considering breaks at decade intervals from 1930 to 1980. The statistical evidence for a break is strongest for 1950 and marginally less strong for 1940. Any break after 1950 is decisively rejected. The second test was to examine whether the influence of ENSO variations on precipitation indicate sign of trends since 1950. The results of this test are shown in Table 2.4 which looks at decade trends in the coefficients on the ENSO indices. The trend coefficients are significant at the 5 percent level for the SOI index and at the 10 percent level for the ONI index but not for the other indices. However, the direction of the trend in each case is to weaken the effect of ENSO variations on precipitation.

Overall, the results suggest that the data for the SOI index before 1950 may not provide a reliable basis for estimating the relationship between ENSO variations and precipitation in Samoa. The best ENSO index for the period from 1950 onwards is the ONI index. Using equation (8), a typical strong El Niño event will reduce precipitation in the following months by about 18 percent with little difference between its effects in the wet season and the dry season. If the downward trends in the coefficients on the SOI and ONI indices in equations (13) and (15) are accepted, then the impact of a typical strong El Niño event in the current decade (2010–19) may be close to zero (-2 percent for the ONI index to +2 percent for the SOI index).

There is insufficient evidence to assess whether the apparent trend in the relationship between some ENSO indices and precipitation is a consequence of climate change or other natural phenomena. It has been argued—see, for example, Trenberth

TABLE A2.4 DECADE TRENDS IN ENSO INFLUENCE ON MONTHLY PRECIPITATION

	Sample 1950–2005			
	(10)	*(11)*	*(12)*	*(13)*
SOI	0.133***	0.142***		
	(0.031)	(0.029)		
SOI * Decade	-0.0235**	-0.0214**		
	(0.010)	(0.010)		
TNI		-0.0915*		
		(0.049)		
TNI * Decade		0.0037		
		(0.014)		
ONI			-0.264***	
			(0.064)	
ONI * Decade			0.0409*	
			(0.022)	
MEI				-0.184***
				(0.052)
MEI * Decade				0.0205
				(0.018)
Log-likelihood	502.3	494.3	501.4	503.3

Notes: (a) Standard errors in parentheses: *** p < 0.01, ** p < 0.05, * p < 0.10. (b) In addition to the ENSO indices the model includes month dummies and an AR(3) error.

TABLE A2.5 COEFFICIENTS ON ENSO INDICES IN EQUATIONS FOR AGRICULTURAL TRADE

	Agricultural exports				*Agricultural imports*			
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
SOI	0.011	0.011			-0.020**	-0.021***		
	(0.023)	(0.023)			(0.008)	(0.008)		
TNI		-0.000				0.023		
		(0.045)				(0.015)		
ONI			-0.017				0.031**	
			(0.041)				(0.014)	
MEI				-0.010				0.028**
				(0.035)				(0.012)
Log-likelihood	-12.5	-12.5	-12.5	-12.6	30.2	31.6	29.7	29.9

Notes: (a) Standard errors in parentheses: *** p < 0.01, ** p < 0.05, * p < 0.10. (b) In addition to the ENSO indices the model includes dummy variables for years affected by cyclones and the taro blight (1994–1996) plus time and an AR(2) error.

and Hoar (1997)—that there has been a change in the frequency and intensity of ENSO events since the mid-1970s, which may be linked to climate change as a result of the increase in average sea surface temperatures in the Pacific over the last 50 years. If ENSO events become more intense, i.e., the peak values of the ENSO indices become larger, the effect of this on precipitation may be partly or wholly offset by the change in the relationship that seems to be apparent in the data. Thus, it cannot be assumed that the effect of climate change on ENSO events will necessarily have a clear impact on variations in seasonal precipitation in Samoa.

In view of this uncertainty, the second part of the analysis examines the direct link between ENSO indices, crop production, and trade in agricultural products. The results presented here focus on production and yields for taro, coconuts, bananas, pineapples, and papayas, since these are the main Samoan crops by land area and value, while the results for other crops such as yams, mangoes, and avocadoes do not alter any of the conclusions. The analysis of agricultural trade focuses on the values of exports and imports of all agricultural products. Imports of food products account for about 90 percent of imports of all agricultural imports. The share of food products in total agricultural exports has been about 65 percent in recent years, but was as high as 90 percent immediately before the cyclones in the late 1980s. Samoa runs a large deficit on agricultural trade, which has grown from about $15 million per year in the late 1990s to over $40 million per year in 2006–07.

The basic model in this case is:

$$\ln(V_{it}) = \alpha_i + \beta_i I_{t-1} + \gamma_i D_{ct}) + \partial_{ib} D_{bt} + u_{it}$$

where V_{it} is the value of trade or crop production for category i in period t, I_{t-1} is the ENSO index in period t-1, D_{ct} is a dummy variable taking the value 1 in years (1990–92) affected by cyclones Ofa and Val, D_{bt} is a dummy variable taking the value 1 in years (1994–1996) affected by the taro blight, and u_{it} is the error in period t, which follows some form of ARMA process. Since production and trade data is annual, the ENSO indices used in the equations are averages for the months June-November of the previous year; hence the subscript *t-1*.

Table 2.5 shows that ENSO events do not affect the level of agricultural exports to any significant degree, but they do have a significant—though modest—influence on the level of agricultural

TABLE A2.6 COEFFICIENTS ON ENSO INDICES IN EQUATIONS FOR AGRICULTURAL PRODUCTION

	Crop production				*Crop Yields*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*
TARO					
SOI	0.035***	0.039***			0.014
	(0.011)	(0.011)			(0.008)
TNI		-0.039***			-0.020**
		(0.015)			(0.008)
ONI			-0.050***		
			(0.019)		
MEI				-0.047***	
				(0.016)	
COCONUTS					
SOI	0.014	0.015			0.060***
	(0.012)	(0.012)			(0.018)
TNI		-0.008			-0.035**
		(0.016)			(0.018)
ONI			-0.014		
			(0.019)		
MEI				-0.015	
				(0.017)	
BANANAS					
SOI	0.174	0.200*			0.073
	(0.116)	(0.115)			(0.150)
TNI		-0.220			0.064
		(0.158)			(0.150)
ONI			-0.262		
			(0.191)		
MEI				-0.272*	
				(0.164)	
Log-likelihood	239.8	244.6	238.4	238.8	262.4

Notes: (a) Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. (b) In addition to the ENSO indices the model includes dummy variables for years affected by cyclones (1990–92) and the taro blight (1994–1996) plus time and an AR(2) error.

imports. Strong El Niño events are associated with imports that are 3–5 percent higher than in a normal year, with a corresponding reduction in strong La Niña events. The TNI index does not appear to have a significant impact on trade.

This equation was also estimated for the production and yield of each crop on its own to examine the influence of ENSO events on crop production and yields. None of the coefficients on the ENSO indices were significantly different from zero in this single equation specification. So, a VAR version of the model pooling data for the five main crops—taro, coconuts, bananas, pineapples, and papayas—was estimated as an alternative specification so as to allow for the covariance between different crops. Table 2.6 summarizes the results of estimating the VAR models using different ENSO indices. It focuses on production and yields for taro, coconuts, and bananas because the coefficients on the ENSO indices for pineapples and papayas are not significantly different from zero.

The main conclusion is that there is a clear relationship between the ENSO indices and the production of taro. The coefficients mean that a strong El Niño event will cause a fall of 5–8 percent in taro production in the following crop year. There is weak evidence for a large impact on the production of bananas but the results may not be robust. Crop yield—but not production—for coconuts is also influenced by ENSO events, so it seems that farmers are able to offset lower yields by harvesting a greater area of trees.

Overall, the analysis has shown that ENSO events have a significant effect on precipitation in the following months: lower for El Niño, higher for La Niña. In turn, this is reflected in lower or higher production for taro and perhaps for bananas. The effect on coconuts and other crops is small or zero. Finally, the changes in crop production are accompanied by offsetting changes in the value of agricultural imports. This may be due to a combination of higher/lower volumes and higher/lower prices to the extent that ENSO events can have a large impact on agricultural production in the Pacific basin.

If—and this is only a hypothesis at present—climate change leads to more intense or frequent ENSO events, the consequence for Samoa will be greater year-to-year variations in crop production, agricultural incomes, and imports. This is largely a matter of risk management, since the results do not imply that average production, etc., over a series of events will change. Further, the magnitude of the impact of such changes must be put in context. If the intensity of a typical strong El Niño event were to increase by 50 percent, the associated fall in taro production would rise from 5–8 percent to 8–12 percent.

The increase in crop variability is a good reason to encourage farmers to diversify away from relying upon taro as a primary crop, but it is not significant relative to other natural hazards—particularly cyclones and earthquakes—that can have a much larger impact on Samoa's economy. As an illustration of this point, changes in value-added in agriculture and fisheries have been negatively correlated with changes in total GDP since 1995. This reflects the overall decline in the share of agriculture in GDP, together with the fact that the economy has become much more subject to other economic risks.

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