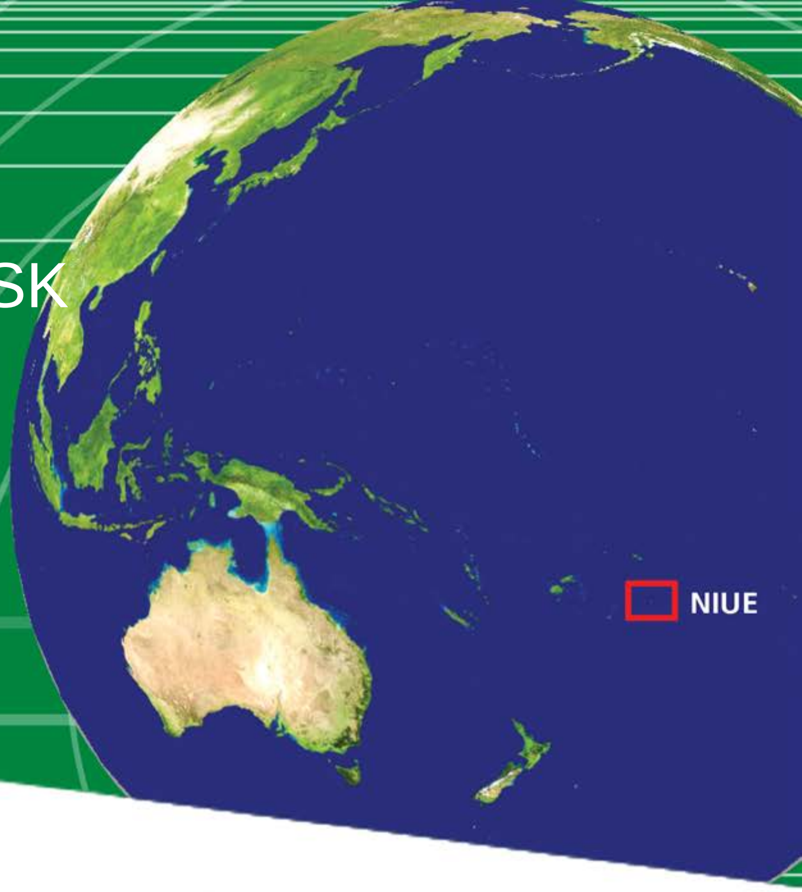
CURRENT AND FUTURE TROPICAL CYCLONE RISK IN THE SOUTH PACIFIC



COUNTRY RISK PROFILE: NIUE

JUNE 2013

- *Niue has been affected by devastating cyclones on multiple occasions, e.g. 1990 tropical cyclone Ofa, 2004 tropical cyclone Heta. The current climate average annual loss due to tropical cyclones represents about 5.8% of the country's GDP.*
- *End-of-century future climate projections indicate a 14.8% increase in average annual losses from tropical cyclones compared to the current climate.*
- *By 2100, larger increases in losses are projected for more extreme events (> 50-year return period). Losses for 1-in-50 year tropical cyclones are projected to increase by nearly 30% according to the mean estimate, and by 160% in the worst case climate change scenario.*
- *Compared to the current climate, damages to buildings and infrastructure from tropical cyclones are projected to increase by 16% by 2100.*
- *The proportion of the population affected by future tropical cyclones is projected to increase compared to the current climate.*
- *The main contributor to current and future building and infrastructure loss is wind, with only minor contributions from storm surge and flood.*
- *Maximum wind speeds produced by tropical cyclones in Niue are projected to increase slightly by end-of-century.*

Pacific Catastrophe Risk Assessment and Financing Initiative
in collaboration with
Pacific-Australia Climate Change Science and Adaptation Planning Program

Australian AID

BETTER RISK INFORMATION FOR SMARTER INVESTMENTS

PROJECT GOAL

Contributing to the third phase of the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI), this project is supported by the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program with co-financing from the Global Fund for Disaster Risk Reduction. The primary goal of the project is to improve understanding of the risks posed by tropical cyclone hazards (winds, floods, and storm surge) to key assets in the Pacific region, under current and future climate scenarios. A clearer understanding of the current level of risk in financial terms - and the way that risk will change in the future - will aid decision makers in prioritising adaptation measures for issues such as land-use zoning, urban infrastructure planning, and ex-ante disaster planning.

EXPOSURE AND POPULATION

The building assets considered in this study include residential, commercial, public and industrial buildings, while the infrastructure assets include major ports, airports, power plants, bridges and roads. The major crops in Niue are taro, coconut, yam, and sweet potato, among others.

Table 1: Summary of Population and Exposure in Niue (2010)

Total Population	1,480
GDP Per Capita (USD)	10,680
Total GDP (million USD)	15.8
Total Number of Buildings	1,108
Number of Residential Buildings	919
Number of Public Buildings	89
Number of Commercial, Industrial, Other Buildings	100
Hectares of Major Crops	1,618

As estimated and detailed in the previous phase of the project, the replacement value of all assets in Niue is 250 million USD of which about 70% represents buildings and 30% represents infrastructure. This study did not take into account future economic or population growth. Table 1 includes a summary of the population and exposure in the island

AIR TROPICAL CYCLONE MODEL

AIR has developed a South Pacific catastrophe parametric model to evaluate the tropical cyclone risk for 15 countries in the region. Historical data was used to build a stochastic catalogue of more than 400,000 simulated tropical cyclones, grouped in 10,000 potential realisations of the following year's activity in the basin. The catalogue provides a long-term view of tropical cyclone activity in the region. It was built to physically and statistically reflect the most credible view of current risk based on the historical record, including frequency, intensity, and track evolution. The model estimates hazard (wind speeds and flooding levels) and damage (losses) for all events in the catalogue.

CURRENT CLIMATE

Niue is located south of the equator in an area known for the frequent occurrence of tropical cyclones with damaging winds, rains and storm surge. The country has been affected by devastating cyclones on multiple occasions during the past few decades. For example, tropical cyclone Heta in 2004 devastated the entire country, and caused two fatalities with estimated losses greater than five times the national GDP. Similarly, tropical cyclone Ofa in 1990 caused significant damage to crops, buildings and infrastructure.

The country's current tropical cyclone risk profile has been derived from an estimation of the direct losses to buildings, infrastructure and major crops, as caused by wind and flooding due to rain and storm surge. 'Losses' in this report refers to the direct costs needed to repair or replace damaged assets *plus* the emergency costs that governments may sustain as a result of providing necessary relief and recovery efforts (e.g. debris removal, setting up shelters for those made homeless, or supplying medicine and food).

The average expected losses per calendar year are referred to as the *Average Annual Loss* or *AAL* (see Appendix). The current climate AAL value is 0.9 million USD. The percentage distribution for the different assets considered is shown in Figure 1.

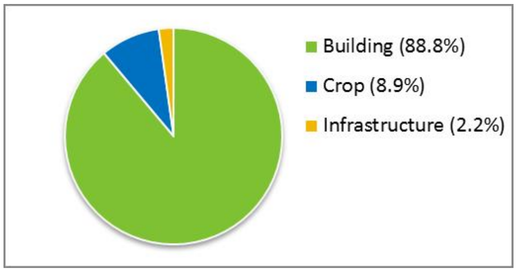


Figure 1: Contribution to total Average Annual Loss (AAL) from the three types of assets considered

The model also estimates losses from more infrequent tropical cyclones that are stronger and more damaging such as 50, 100 and 250 year return period (RP) events (see Appendix). The current losses from such events are: 9.3 million USD (50 year RP), 22.4 million USD (100 year RP) and 44.1 million USD (250 year RP), respectively.

FUTURE CLIMATE

As part of the project, Geoscience Australia (GA) analysed general circulation model outputs from a total of 11 different Global Climate Models (GCMs), from two successive generations of GCM experiments referred to as CMIP3 and CMIP5. The models in the two frameworks are forced by different emission scenarios: the A2 scenario[1] for CMIP3 models and the RCP 8.5 scenario[2] for CMIP5 models. Both A2 and RCP 8.5 represent high emission scenarios.

Results from the latest generation CMIP5 models, for which no dynamical downscaling was required, indicate that these models tend to perform better at replicating the behaviour of tropical cyclones in the current climate, especially for the Southern Hemisphere. Thus, more confidence should be placed in the results from the CMIP5 framework. The results outlined in the following sections are based on the CMIP5 models.

The Mean Estimate reflects results obtained after averaging output over all five models under the same climate framework. Figure 2 displays the relative frequencies for different storm categories, for both current and future climates.

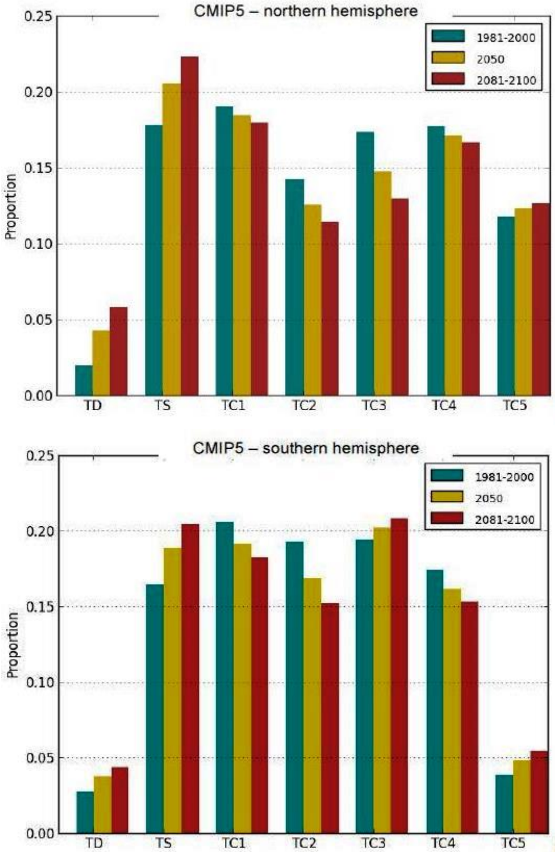


Figure 2: Mean Estimate relative proportion of TC intensity – multi model ensemble for CMIP5 models in the Northern and Southern Hemispheres. Classification is based on central pressure using a Cp-based Saffir-Simpson Hurricane Intensity Scale

For both hemispheres, there is an expected future increase in the relative frequency of tropical depressions, tropical storms, and category 5 storms and a general decrease in the number of storms in the other categories. Most notable is the increase in category 5 storms (and category 3 storms in the southern hemisphere) which may have a measurable impact on observed losses in the region. There is also a slight equatorward movement of tropical cyclone tracks in the northern hemisphere and poleward movement of tropical cyclone tracks in the southern hemisphere.

Future loss projections

Of the five individual models analysed, generally three models suggest large increases in losses and two

[1] http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=98
[2] http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0148-z.pdf

models suggest decreases in losses. The significant divergence in the individual model results indicates a large range of model estimates. Figure 3 shows end-of-century individual model projections for Exceedance Probability (EP – see Appendix) (blue) along with the current climate EP (green).

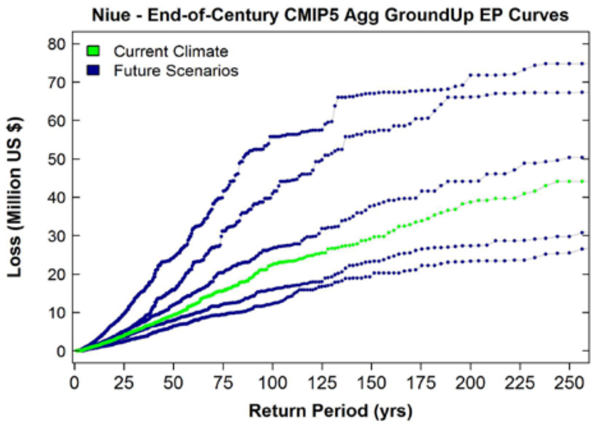


Figure 3: End-of-century EP-curves for individual CMIP5 models compared to the current climate EP-curve (green curve)

Any analysis of future model projections should consider estimates of the ensemble mean (the 'Mean Estimate' of all models), the full range of model results, and the worst case climate change scenario. The individual model that projects the greatest increase in losses as compared to the current climate defines the worst case scenario for the country.

In general, there is an increase in losses projected from tropical cyclones for the future climate. Figure 4 contrasts the end-of-century Mean Estimate projection with the current climate. The two EP-curves are generally distinct from each other and indicate an increase in future losses for medium to high return periods (> 20 year return period). Lower frequency events (> 50 year return period) are projected to cause larger increases in losses in the future climate.

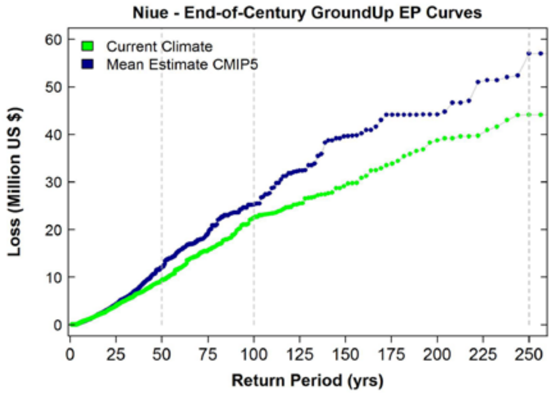


Figure 4: End-of-century EP-curve for the future Mean Estimate (blue curve) compared to the current climate EP-curve (green curve)

Mean Estimate projections indicate that, by end-of-century, losses from a 1-in-50 year event will increase by 29.9% compared to the current climate, while the worst case scenario (most upper curve in Figure 3) suggests a much more significant increase in loss of 160%.

Table 2: Loss estimates (USD) for current climate and future end-of-century Mean Estimate and worst case scenario

CMIP5 (Total Loss)	AAL	50yr RP	100yr RP	250yr RP
Current Climate	908,673	9,289,099	22,426,503	44,122,538
Future Mean Estimate	1,042,715	12,067,650	25,249,897	56,971,338
Future Worst Case	1,917,165	24,234,081	55,752,673	74,778,917

Table 2 contrasts current climate losses with the future Mean Estimate and worst case scenario estimate across different return periods.

The worst case climate change scenario consistently projects significant loss increases when compared to the current climate across all return periods considered as well as the AAL.

Mid-century v end-of-century future loss projections by different assets

Projected future losses from tropical cyclones were examined for mid-century and end-of-century across different assets (buildings, infrastructure, crops and population). There is an overall increase in Mean Estimate end-of-century losses compared to the current climate. The AAL increases from 0.9 million USD to 1.1 million USD by mid-century, and 1.0

million USD by end-of-century, increases of 22.8% 14.8%, respectively.

Table 3 contrasts the AAL and the 50, 100 and 250 year RP losses from current and future climate, for both 2050 and 2100 time periods, across the different assets at risk. The total loss (AAL) represents the sum of the building, infrastructure and crop AALs.

Larger end-of-century loss increases occur for buildings and infrastructure while smaller changes are observed for crops, across different return periods. More people are affected (in terms of casualties and fatalities) by future tropical cyclone risk than under the current climate.

Note that no adjustment to account for future economic or population growth was considered for any of the assets.

It is uncertain why the tropical cyclone risk for Niue is projected to increase more in 2050 than in 2100. A hypothetical explanation could be related to the different changes in latitude imposed under the two climate projections; this could result in a different number of storms of different intensities impacting the country at the two time periods. Further investigation will be necessary to fully understand this finding.

Table 3: Percent changes between future climate loss projections for mid-century and end-of-century and the baseline, for different return periods, by different assets. Baseline loss numbers are expressed in USD

Mean Estimate		AAL	50yr RP	100yr RP	250yr RP
Total Loss	Current Climate	908,673	9,289,099	22,426,503	44,122,538
	Future 2050 (%)	+22.8	+34.2	+19.7	+32.7
	Future 2100 (%)	+14.8	+29.9	+12.6	+29.1
Building	Current Climate	807,225	8,651,420	21,463,175	42,794,500
	Future 2050 (%)	+25.1	+35.8	+20.0	+33.0
	Future 2100 (%)	+16.4	+31.0	+11.3	+28.9
Infra-structure	Current Climate	20,181	268,287	499,091	994,294
	Future 2050 (%)	+25.3	+31.7	+33.3	+35.8
	Future 2100 (%)	+16.4	+30.8	+29.2	+20.7
Crop	Current Climate	81,267	561,785	663,241	746,084
	Future 2050 (%)	-1.0	+4.2	+2.8	+3.6
	Future 2100 (%)	-1.9	-1.0	+1.5	+4.5
Population Affected	Current Climate	2	17	21	23
	Future 2050 (%)	+3.6	+5.9	+4.8	+4.3
	Future 2100 (%)	+1.1	+11.8	+4.8	+8.7

Wind, flood and surge contributions to total loss estimates

The analysis captures the effects of three hazards associated with tropical cyclones: strong winds, precipitation-induced flooding and coastal flooding due to storm surge. Tropical cyclone winds can be very destructive and in most cases they are the main cause of damage and subsequent losses.

Unlike the wind, which decreases in intensity as the storm moves inland, the intensity of storm-related precipitation and accumulated runoff can increase in inland regions and consequently also lead to significant damage to property.

The storm surge represents the sea water forced ashore due to the rise in sea level accompanying any approaching intense storm. A significant storm surge event can have devastating effects on-shore.

Both sea level and precipitation changes under future climates are not considered in this study.

The main contributor to building and infrastructure loss is wind, with only minor contributions from storm surge and flood. Figure 5 explores the *relative changes* in contributions to total loss split by hazard between the current and the Mean Estimate future climate.

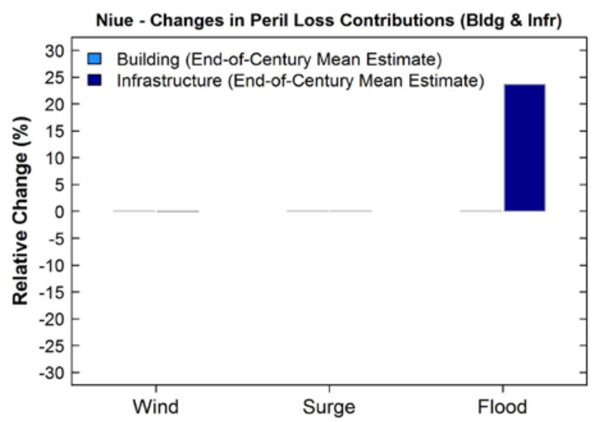


Figure 5: Percent changes between the end-of-century future climate and the current climate for Wind, Surge and Flood loss contributions to total loss, for buildings (light blue) and infrastructure (dark blue)

The only notable change is an increase in the flood contribution to the total loss for infrastructure. However, it is important to note that the reported change for flood is calculated between very small initial numbers and, ultimately, wind remains the main contributor to total loss for both assets.

Wind hazard maps for end-of-century climate compared to current climate

The wind hazard increases slightly for the 100 year return period under future climate, as shown in Figure 6. The 100 year return period winds, which represent an event that has a 40% chance of being equalled or exceeded once in 50 years, are capable of generating severe damage to buildings, infrastructure, and crops with consequent large economic losses.

Figure 6 depicts the end-of-century 100 year mean RP wind speed, expressed as maximum 1-minute sustained winds in km/h, for the current climate (top panel) and future projection (bottom panel). For example, for south-eastern Niue, the 100 year RP wind speed increases from 183.2 km/hr to 192.3 km/hr by the end of century.

The wind level changes are less dramatic than the changes in total losses because a small change in wind speed can result in significantly larger damage costs.

The current climate wind patterns in Niue are generally maintained under future climate projections (e.g. higher winds are exhibited on the east side of the island compared to its north-west side).

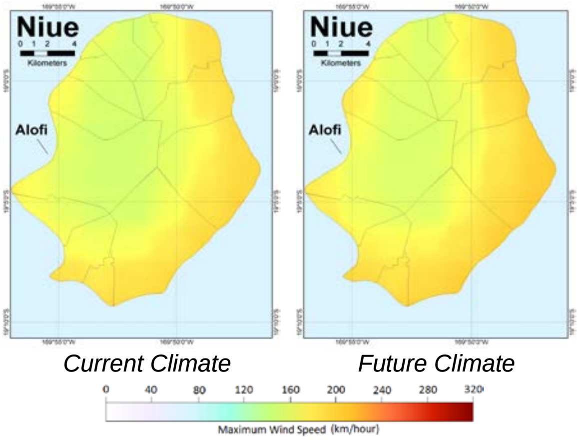


Figure 6: 100 year mean return period winds (maximum 1-minute sustained winds in km/h) for the current climate (top panel) and the future climate (bottom panel)

SUMMARY

The evaluation of the current and future climate tropical cyclone risk in the South Pacific region was carried out using Geoscience Australia's analysis of tropical cyclone activity along with AIR's catastrophe model developed specifically for the region. The risk model allows for the translation of the climate change induced effects observed in the frequency, intensity and path of tropical cyclones into direct loss results for the region and individual countries.

For both hemispheres, numerical models predict a future increase in the relative frequency of tropical depressions, tropical storms, and category 5 storms and a general decrease in the number of storms in the other categories (Figure 2). Most notable is the regional increase in category 5 storms.

The financial impacts are measured using metrics such as the Average Annual Loss (AAL) or the 100 year return period loss. For planning purposes, it is useful to understand both average annual losses as well as possible losses from extreme events.

The Mean Estimate (Table 3) suggests increases in future losses as compared to the baseline. Larger increases in losses are projected for lower frequency events (> 50 year RPs - Figure 4).

Losses from a more extreme (50-year RP) event, according to the Mean Estimate projection, will increase by 29.9% compared to the current climate, while the worst case scenario suggests a much more significant increase in loss of 160% (Table 2).

The largest changes in loss are observed for buildings and infrastructure, while crops have smaller changes compared to the other assets (Table 3). The proportion of the population affected by future tropical cyclone risk increases compared to the current climate.

The main contributor to total losses to buildings and infrastructure is wind, with only minor contributions from storm surge and flood. There is a slight increase in the flood contributions to total loss (Figure 5) for future climate. Similar to the current climate, the wind hazard remains the main contributor to loss for both assets.

The end-of-century Mean Estimate projects slightly stronger winds compared to the current climate (Figure 6). The current climate general wind hazard patterns are maintained across the country.

Models from both the CMIP3 and CMIP5 global climate model runs were analysed in this project. The

CMIP5 models demonstrated greater skill and performance in replicating current climate conditions, and reporting of damage and loss has therefore focused on results from the CMIP5 framework.

There is consistent divergence, in the resulting EP-curves for individual models under the same framework (Figure 3) indicative of significant model uncertainty. The mean changes in future losses compared to the baseline are too small to be considered statistically significant when measured against the range of model estimates.

There is also the uncertainty associated with the risk model itself that needs to be accounted for. A statistical quantification of the uncertainty around each estimated EP-curve reveals that generally (except for the 150 year return period) the separation between the baseline and the future projection is not large enough to be considered statistically significant.

APPENDIX

Classification of tropical cyclones

A tropical cyclone represents an atmospheric low-pressure system with a spiral arrangement of thunderstorms that produce strong winds and heavy rain. The table below describes the categorisation of storms based on maximum sustained winds and minimum central pressure as used in this study.

Classification	1-minute sustained wind speed (km/h)	Minimum central pressure (hPa)
Tropical Depression (TD)	<= 62	>= 1005
Tropical storm (TS)	63-118	1005-995
Category 1 (TC1)	119-153	995-980
Category 2 (TC2)	154-177	980-965
Category 3 (TC3)	178-208	965-945
Category 4 (TC4)	209-251	945-920
Category 5 (TC5)	>= 252	< 920

Definition of key metrics used to describe future risk changes

Several key metrics are utilised in order to evaluate the change in losses/risk between the current climate and the future climate: Average Annual Loss (AAL), Return Period (RP) Loss, Exceedance Probability (EP) curve.

- Average Annual Loss (AAL). AAL represents the sum of all losses observed in the domain divided by all realisations of next-year activity (10,000 years); AAL thus refers to the average loss that can be expected to occur per year.
- Return period (RP) loss. The X-year return period loss is the loss that can be expected to occur or be exceeded on average once every X years. Highlighted for this analysis are the 50 year (2.0% exceedance probability), 100 year (1.0% exceedance probability) and 250 year (0.4% exceedance probability).
- Exceedance Probability curve (EP- curve). An EP-curve represents the probability curve that various levels of loss will be exceeded. By inverting the exceedance probability to obtain corresponding return periods, the EP-curve then represents the various levels of loss associated with different return period events. An EP-curve is obtained by sorting all losses largest to smallest observed over a domain, assigning a rank to all entries (1 being the largest loss, 2 being the second largest loss etc.), and then dividing the ranking by the total number of years (10,000).

Loss and damage

The 'losses' referred to in this report represent the 'damages'; (i.e., the direct ground up-losses before the application of insurance (zero deductible)), plus an estimation of the emergency losses (i.e., debris removal, setting up shelters for those made homeless, or supplying medicine and food). All estimates of current and future losses in this report are in 2010 dollars.

Australian Government

With financial support from the European Union
In the framework of the ACP-EU Natural Disaster Risk Reduction Program
managed by the GFDRR

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