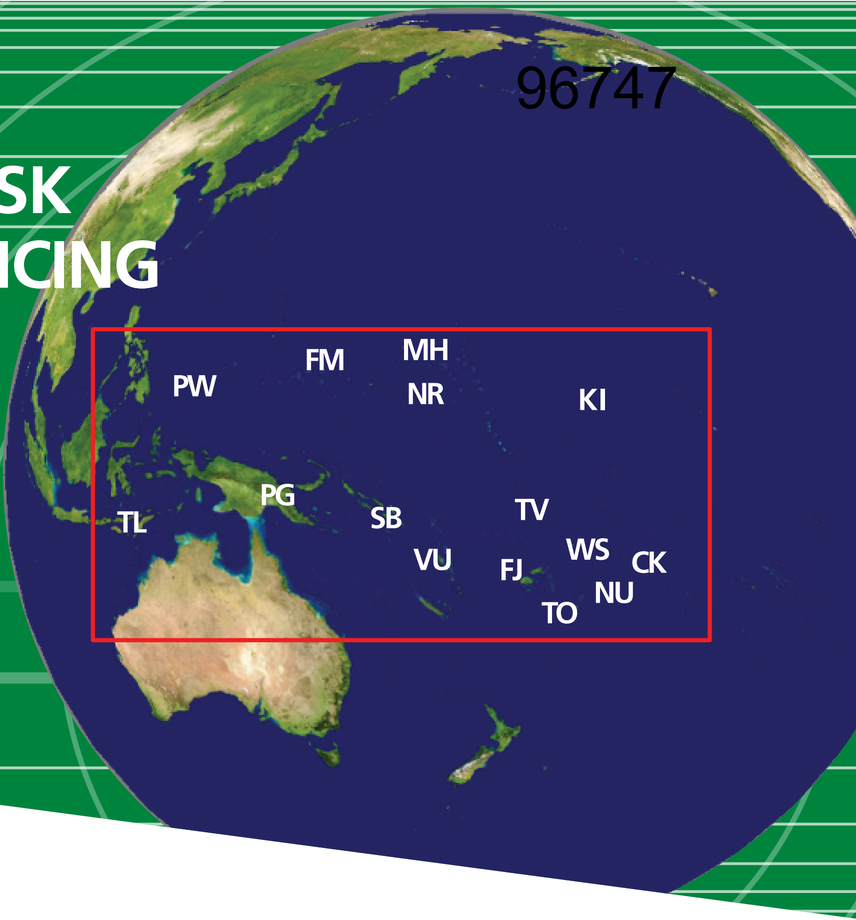
PACIFIC CATASTROPHE RISK ASSESSMENT AND FINANCING INITIATIVE



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RISK ASSESSMENT METHODOLOGY

The Pacific Region is prone to many natural hazards that threaten populations and cause significant economic losses due to damage to the built environment and crops. An extensive study has been conducted to analyze the risk from tropical cyclones, earthquakes, and tsunamis. This included the generation of detailed exposure information to locate and characterize over 3.5 million buildings and infrastructure in 15 Pacific Island Countries[1] (PICs). The impact that historical events have had on the people and assets of these countries has been investigated to understand the extent of adverse consequences that possible future events may bring. Ten thousand simulations of potential future annual tropical cyclone and earthquake activity in the Pacific Region have been carried out to estimate risk in terms of monetary loss and casualties. The country risk profiles derived from this study can be used to improve the resilience of these 15 PICs to natural hazards.

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[1] Cook Islands, Fiji, Kiribati, Micronesia, Nauru, Niue, Palau, Papua New Guinea, Republic of the Marshall Islands, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu and Vanuatu

GENERAL OVERVIEW

The Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) provides a comprehensive and uniformly executed tropical cyclone and earthquake risk assessment study for the following 15 Pacific Island Countries (PICs) (Figure 1): Cook Islands (CK), Federated States of Micronesia (FM), Fiji (FJ), Kiribati (KI), Republic of the Marshall Islands (MH), Nauru (NR), Niue (NU), Palau (PW), Papua New Guinea (PG), Samoa (WS), Solomon Islands (SB), Timor-Leste (TL), Tonga (TO), Tuvalu (TV), and Vanuatu (VU).

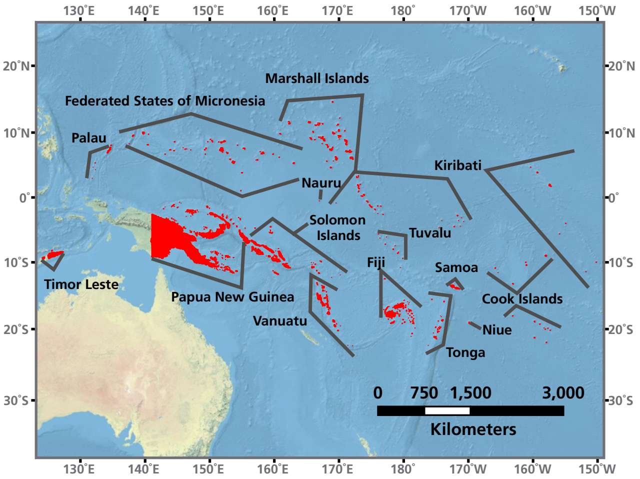

Figure 1: Location of the 15 PICs.

The Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) is a joint initiative between the Secretariat of the Pacific Community (SPC), the World Bank and the Asian Development Bank, with financial support from the Government of Japan and the Global Facility for Disaster Reduction and Recovery (GFDRR) and technical support from AIR Worldwide, New Zealand GNS Science and Geoscience Australia. The risk profiles for the 15 PICs have been developed to help these countries mitigate their tropical cyclone and earthquake risk.

TROPICAL CYCLONE AND EARTHQUAKE RISK ASSESSMENT METHODOLOGY

The catastrophe models used to perform the risk analyses for the 15 PICs adopt the state-of-the-art methodology summarized in Figure 2. Every step of the methodology is heavily based on empirical data collected in the region, as described later.

This study considers the devastating effects of wind, flood, and storm surge induced by tropical cyclones. It also considers the effects of earthquake ground shaking and tsunamis. Earthquakes and tropical cyclones are the most prominent hazards in the Pacific Islands Region. Other hazards, such as weaker but still potentially damaging local storms and volcanic eruptions, are not included in this study. Also, the risk due to tropical cyclones and tsunamis is computed assuming current climate conditions and sea levels. The effects of climate change on risk, which can be addressed using a similar methodology, are left to future investigations.

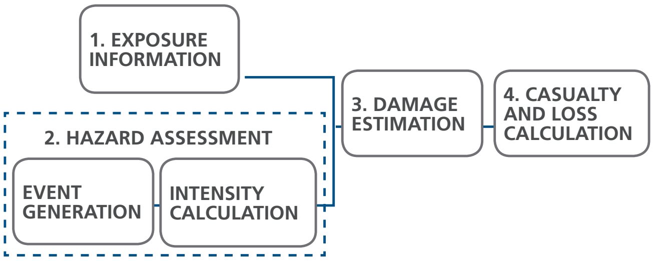

Figure 2: Risk modeling methodology.

EXPOSURE INFORMATION

The initial step of the risk analysis process shown in Figure 2 is the characterization of the assets and distribution of population exposed to tropical cyclone and earthquake hazard.

The 2010 projected population of the 15 PICs is reported in Table 1. A GIS-based population database was created in order to geographically identify the population most at risk in each PIC. This database, which was compiled from data sets of many sources, such as the bureaus of statistics from the countries' government and the SPC, provides population counts within each administrative boundary identified in Table 1.

Table 1: Population and administrative boundaries for each PIC.

Country	2010 Projected Population	Administrative Boundary Levels				
Cook Islands	19,800	Group	Island	Electoral Boundary	Census District	Enumeration Area
Fiji	846,800	Province	Tikina	Enumeration Area	-	-
Federated States of Micronesia	111,600	State	Municipality	Electoral District	-	-
Kiribati	101,400	Group	Island	Village	-	-
Marshall Islands	54,800	Atoll	Islet	-	-	-
Nauru	10,800	Island	District	-	-	-
Niue	1,500	Village	-	-	-	-
Palau	20,500	State	Hamlet	-	-	-
Papua New Guinea	6,405,600	Province	District	Local Government Level	Census Unit	-
Samoa	182,900	Island	Region	District	Village	-
Solomon Islands	547,500	Province	Ward	Enumeration Area	-	-
Timor-Leste	1,066,600	District	Subdistrict	Suco	-	-
Tonga	103,400	Division	District	Village	Census Block	-
Tuvalu	10,000	Island	Village	-	-	-
Vanuatu	245,900	Province	Island	Area Council	Enumeration Area	-

The building exposure database includes a comprehensive inventory of residential, commercial, public, and industrial buildings in the 15 PICs. It includes building location, number of stories, replacement cost, and structural characteristics that affect the vulnerability to natural perils. The spatial distribution of the estimated 3.5 million buildings in the database, which covers all known built areas, was assembled at a varying level of resolution and accuracy. In general, buildings were either manually digitized from high-resolution satellite imagery and surveyed in the field (about 80,000 in 11 PICs); manually digitized from high-resolution satellite imagery but not field verified (about 450,000); inferred using image processing techniques and/or census data or extracted from datasets acquired from government and other sources (about 3 million). To maximize the benefits of data collection within the constraints of budget and time, most of the field-surveyed buildings were located in coastal urban areas which are more easily accessible, are more prone to tropical cyclone and earthquake hazard, have more variety of building types and usage, and have more costly structures.

An example of the building footprint digitization exercise in Port Vila, Vanuatu, and a photograph of one of the inspected buildings are shown in Figure 3. For each building visited, the field inspectors compiled a detailed inventory of building characteristics, including: structure type, number of stories, roof type, foundation type and state of repair. The data collected in the field was used to infer the characteristics of buildings whose location was either digitized or statistically derived. The unit replacement cost values for different buildings were collected from a variety of sources, including a regional construction cost management firm, governmental reports, interviews with local experts, and historical disaster reports.

Figure 3: Digitized roof footprints of building in Port Vila, Vanuatu, and a picture of a building taken by the field inspectors.

The infrastructure database, which was assembled using similar techniques as those used for buildings, comprises a detailed and extensive inventory of major assets, such as airports, ports, power plants, dams, major roads, and bridges. For example, Figure 4 shows the major infrastructure assets in Papua New Guinea. In addition to their locations, the infrastructure database also includes estimates of the replacement costs of such assets.

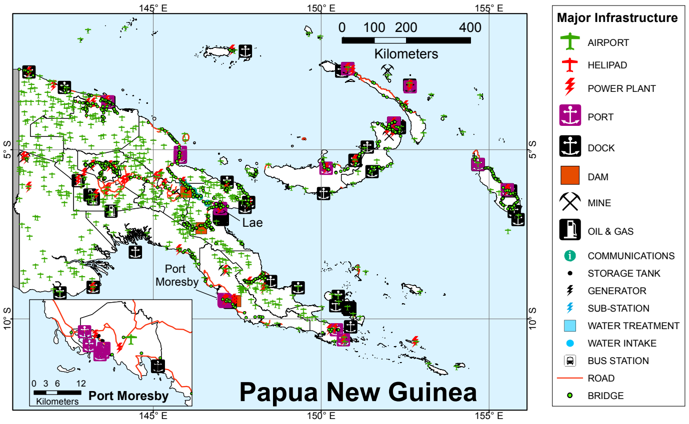

Figure 4: Location of major infrastructure assets in Papua New Guinea.

The spatial distribution of major cash crops in each PIC was derived from moderate- and low-resolution satellite imagery using image-detection techniques. To the extent possible, results were validated by virtual "truthing" using high-resolution imagery and ground "truthing" in Fiji, Tonga, and Vanuatu. Additional validation was performed using agricultural census data, ancillary data collected during the course of the project, and feedback from local experts. The unit replacement cost of different cash crops was derived from crop production budgets issued by local governments. An example of a land use/land cover map—one output of the analysis—is displayed in Figure 5, which shows the major crops for Samoa.

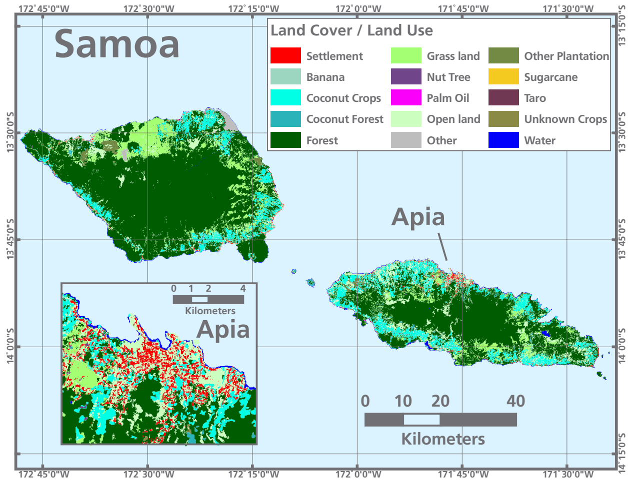

Figure 5: Land cover/land use map for Samoa with the locations of major cash crops.

The millions of building and infrastructure assets and the hundreds of thousands of hectares of cash crops with their characteristics and location are included in a geo-referenced database. To date, this database is the most comprehensive exposure dataset for this part of the world. ***The estimated total replacement cost of all the assets in the 15 PICs is about 113 billion USD, an amount that comprises 94 billion USD in buildings, 15 billion USD in infrastructure assets, and 4 billion USD in major crops***. A breakdown of the replacement costs by country is shown in Table 2. ***The exposure database, as well***

as the hundreds of satellite imageries acquired, organized, and processed for this project, are hosted and maintained by the Applied Geoscience and Technology division of SPC. This wealth of data can support multiple applications, such as in urban and development planning that benefit both public and private stakeholders.

Table 2: Replacement costs by country.

Country	Total Replacement Cost (million USD)			
	Buildings	Infrastructure	Cash Crops	Total
CK	$1,296.8	$117.6	$7.8	$1,422.2
FJ	$18,865.2	$3,093.9	$216.1	$22,175.3
FM	$1,729.0	$312.8	$5.8	$2,047.6
KI	$1,006.1	$164.2	$11.3	$1,181.5
MH	$1,404.1	$285.9	$5.7	$1,695.7
NU	$173.8	$74.0	$1.2	$248.9
NR	$410.6	$42.0	$0.1	$452.7
PG	$39,509.0	$6,639.1	$3,060.7	$49,208.8
PW	$1,338.5	$159.9	$2.5	$1,500.8
SB	$3,058.7	$420.3	$117.1	$3,596.1
TL	$17,881.3	$2,160.6	$102.9	$20,144.8
TO	$2,525.2	$259.4	$31.9	$2,816.5
TV	$229.3	$39.7	$1.2	$270.2
VU	$2,858.4	$420.0	$56.0	$3,334.4
WS	$2,147.9	$467.4	$24.7	$2,639.9
Total	$94,434.0	$14,656.6	$3,645.0	$112,735.4

HAZARD ASSESSMENT

The estimation of the hazard is the second building block in the risk assessment methodology shown in Figure 2. The Pacific Region is prone to a variety of natural hazards. Areas both north and south of the equator are known for the frequent occurrence of tropical cyclones accompanied by damaging winds, rains, and storm surge; typically between the months of October and May in the South Pacific and throughout the year in the North Pacific. In the last 60 years, the Pacific Region from Taiwan to New Zealand in latitude and from Indonesia to east of Hawaii in longitude has experienced more than 2,400 tropical cyclones—or about 41 per year. Almost 1,000 of these formed south of the equator and more than 1,400 formed north of the equator.

The tracks of these historical tropical cyclones are shown in Figure 6. Many of these storms have impacted one or more of the PICs, causing widespread destruction, high economic losses, and many casualties (injuries and fatalities). The catalog of historical storms was assembled starting from the dataset of the International Best Tracks Archive for Climate Stewardship project, which is endorsed by the World Meteorological Organization, with data from meteorological agencies across the region. These organizations include the Joint Typhoon Warning Center (JTWC), the Australia Bureau of Meteorology (BoM), and the Fiji Meteorological Service.

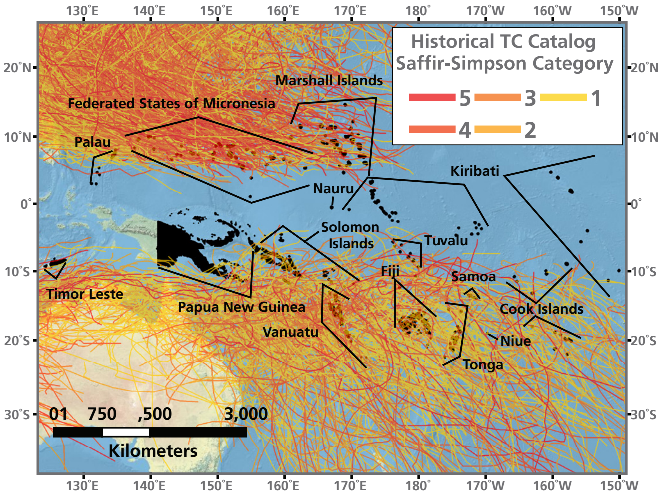

Figure 6: Tracks of the about 2,500 historical tropical cyclones in the Pacific islands Region in the last 60 years. The maximum wind speeds generated by these events range from 74-95 mph for a Category 1 storm to greater than 155 mph for a Category 5 storm.

The Pacific Island Region is surrounded by the Pacific "ring of fire," where approximately 90% of the world's earthquakes and 80% of the world's largest earthquakes occur. Large earthquakes that occur on the ring of fire are capable, under certain circumstances, of generating major tsunamis that can travel great distances. Some of the PICs, such as Papua New Guinea, Tonga, the Solomon Islands, and Vanuatu, are located on top of or close to the sources of these earthquakes. Others, such as the Cook Islands, the Republic of the Marshall Islands, and Kiribati are more distant (Figure 7). No PIC, however, is completely immune to the far reaching effects of earthquake-induced tsunamis.

The spatial and temporal occurrence and severity of past events have been used as a guide to simulate potential tropical cyclones and earthquakes that may affect the PICs in the future. This step is called "Event Generation" as shown in Figure 2. The simulated events are not necessarily identical to those that occurred in the past but are statistically consistent. ***The catalog of simulated events, which spans the entire Pacific basin, contains more than 400,000 tropical cyclones and about 7.6 million earthquakes, grouped in 10,000 potential realizations of what may happen in the next year.*** The catalog of simulated earthquakes also includes large magnitude events in South and North America, Japan and the Philippines, as these could generate tsunamis capable of causing damage in the PICs.

Mathematical models are then used to estimate the intensity of the simulated events in the affected region (see "Intensity Calculation" in Figure 2). These effects are wind speed, precipitation, and coastal surge for tropical cyclones, and ground shaking for earthquakes. If the earthquakes produce a tsunami, wave height and velocity is estimated as well. The models are based on empirical data and on the underlying physics of the phenomena.

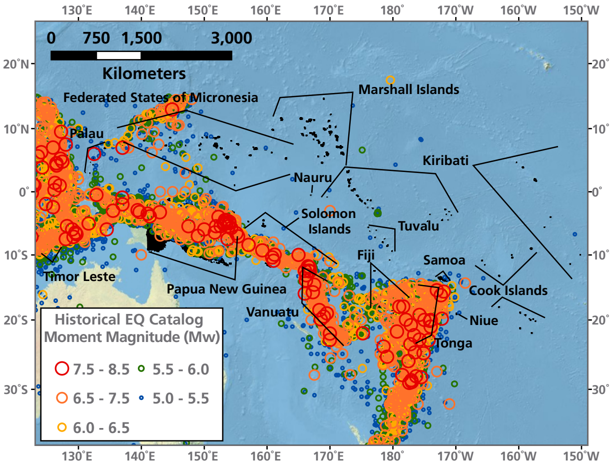

Figure 7: Epicenters of the more than 32,000 significant earthquakes that occurred from 1768 to 2009. The size of the circles is proportional to the event magnitude.

The tropical cyclone and earthquake hazard models have been peer reviewed by scientists at Geoscience Australia, which found them of "***high standard, thorough and representative of best practice.***"

DAMAGE ESTIMATION

The third step in the risk assessment procedure displayed in Figure 2 deals with damage estimation, a task that requires knowledge of the vulnerability of structures and crops, and with the probable casualty rates for occupied structures that are damaged by wind, flood, ground shaking or tsunami.

For this purpose, all of the assets in the exposure database of buildings, infrastructure assets, and crops have been categorized in groups of similar vulnerability to earthquakes and tropical cyclones. For example, three types of structures considered are single-story timber, masonry/concrete, and traditional-style buildings. The vulnerability of different types of buildings, infrastructure assets, and crops was derived from damage and loss data from past events in the region corroborated by engineering analyses, when necessary. The vulnerability is measured by a relationship that provides the loss that is expected when an asset (e.g., a structure or a crop) is subject to different levels of ground shaking, water heights, or wind speeds. The loss, which reflects the cost of repairing the damaged asset, is usually expressed as a percentage of the replacement cost of the asset. For example, in the damage function shown in Figure 8, a 100-mph wind is expected to cause moderate to major damage that will take about 20% of the total replacement cost of the asset to repair.

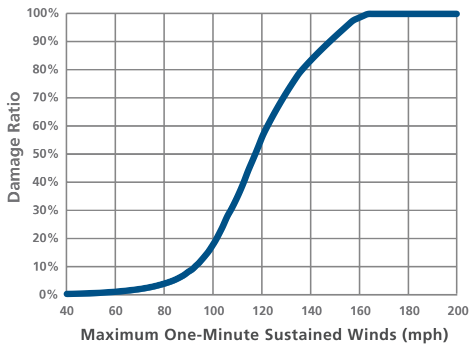

Figure 8: Relationship between wind speed and expected level of losses in a typical building.

In addition to deriving vulnerability relationships that link the intensity of an event to building, infrastructure, and crop economic losses, models were also developed to estimate the number of casualties caused by each type of event. The earthquake ground-shaking casualty model estimates casualties as a function of the shaking intensity and the number of people exposed to such intensities. The tsunami casualty model relates the number of casualties to the number of buildings damaged beyond a certain threshold in the inundation area. The tropical cyclone casualty model predicts the number of casualties as a function of the total economic losses, which are used as a proxy for the number of damaged buildings. All three models are heavily based on empirical data specific to the Pacific Region.

CASUALTY AND LOSS CALCULATION

The risk profiles for each country express the likelihood that adverse consequences of different event severity will occur within a certain time frame (for example, in the next year or in the next 50 years). The risk profiles are developed in the risk module. The adverse consequences are measured in terms of economic losses to buildings, infrastructure and crops, and by the number of casualties among the affected population.

The losses reflect both the cost needed to repair or replace the damaged assets, and the emergency losses that local governments may sustain as a result of providing necessary relief and undertaking recovery efforts. Such efforts include debris removal, setting up shelters for those made homeless, or supplying medicine and food. In this study, emergency losses have been estimated as a fraction of the direct losses. Research[2] on historical tropical cyclones and earthquakes has revealed that an "average" estimate of the emergency losses, as a percentage of the direct losses suffered by residential dwellings, commercial establishments, public buildings, schools, and hospitals, is about 16% for earthquake ground shaking and 23% for tropical cyclones and flood. These percentages were applied in this study. Similarly, a factor of 23% was applied to direct losses caused by tsunamis.

[2] Bitran, 2003.

The risk profiles are derived from the impact estimated for all the simulated future events. For each event of a given location and severity (i.e., a magnitude 8 earthquake offshore Papua New Guinea), the intensity in the nearby region (e.g., the peak horizontal acceleration of the ground predicted at each location) was calculated using the mathematical models mentioned earlier. The level of damage and direct losses for any given asset at any given location in the affected PIC are estimated based on the characteristics of the asset (e.g., timber frame building) and on the level of intensity predicted at that location (e.g., a peak horizontal acceleration equal to 30% of gravity). The total losses for any simulated event are equal to the sum of the losses at all locations affected by that event. The estimation of casualties caused by any event is done in a similar fashion. The loss and casualty calculations are repeated for all the simulated 400,000 tropical cyclones and 7.6 million earthquakes. The risk profiles are obtained by ranking the losses and the casualties of all the simulated events.

Figure 9 shows the direct loss risk profile for earthquakes, tropical cyclones, and for both earthquakes and tropical cyclones for all 15 PICs combined. For example, Figure 9 shows that ***the 15 PICs are expected to collectively observe an annual loss due to earthquakes exceeding about USD 1 billion (that is 6% of the total GDP), on average, once every 200 years.*** Similarly, Figure 10 shows the casualty risk profile for earthquakes, tropical cyclone, and for both earthquakes and tropical cyclones for all 15 PICs combined. The risk profiles of each PIC are included in the country-specific brochures.

The 10,000 simulations of potential future annual tropical cyclone and earthquake activity show that some years will see no significant tropical cyclones or earthquakes affecting any of the PICs, while other years may see one or more devastating events affecting the islands, similar to what has been observed historically. The entire set of simulations enables an assessment of the average risk that the pool of the 15 PICs (or each PIC separately) faces due to these natural perils. The annual direct losses for the pool of 15 PICs averaged over the many realizations of annual activity are shown in Figure 11 separately for earthquakes and for tropical cyclones. The contribution to the average annual loss due to buildings, infrastructure, and crops is also shown. In addition, Figure 12 shows for all 15 PICs separately the average annual losses and their contributions from the different perils. ***The same set of simulations indicates also that the average annual number of injuries and fatalities that is expected every year in these 15 PICs due to earthquakes and tropical cyclones combined is about 2,000.*** The Applied Geoscience and Technology division of SPC is the custodian of software that can reproduce losses and casualty risk estimates at the country level and also at the administrative levels in Table 1 for the entire exposure or subset of the exposure presented herein.

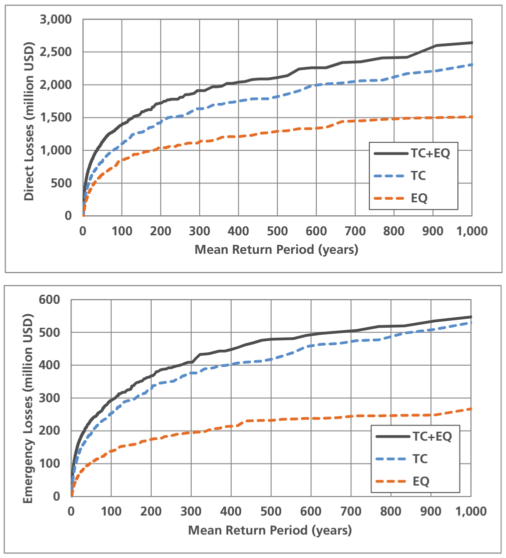

Figure 9: Direct loss risk profiles by peril for all 15 PICs combined. The direct losses in the vertical axis are expected to be exceeded, on average, once in the time indicated in the horizontal axis. The losses are expressed in absolute terms in the top panel and normalized by the total GDP of the PICs in the bottom panel.

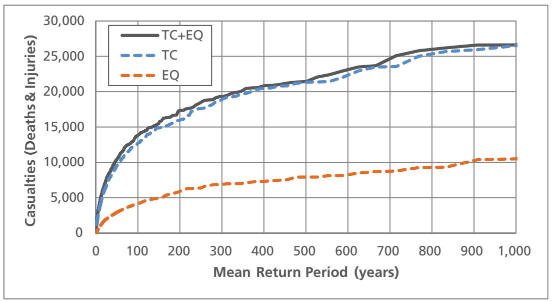

Figure 10: Casualty (deaths plus injuries) risk profiles by peril for all 15 PICs combined. The number of casualties in the vertical axis is expected to be exceeded, on average, once in the time indicated in the horizontal axis.

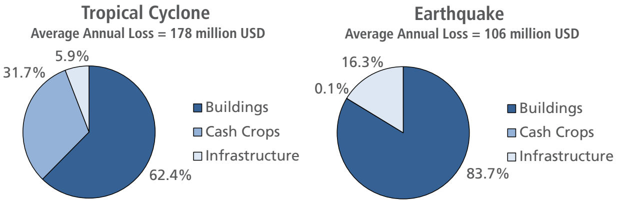

Figure 11: Average annual direct loss caused by earthquakes and tropical cyclones in all the 15 PICs combined.

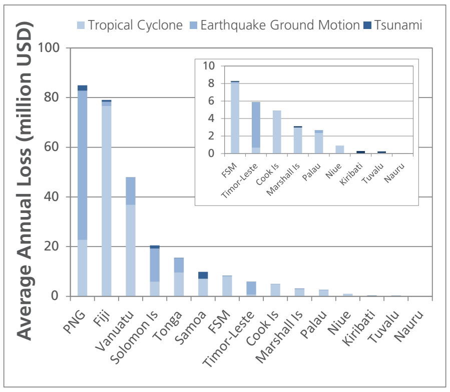

Figure 12: Average annual loss for each of the 15 PICs

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