KINGDOM OF TONGA

INFORMATION COLLECTION AND PRELIMINARY SURVEY FOR THE FORMATION OF DISASTER RECOVERY PROJECTS AGAINST VOLCANIC ERUPTIONS AND TSUNAMI DAMAGE IN KINGDOM OF TONGA

FINAL REPORT

OCTOBER 2023

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

ORIENTAL CONSULTANTS GLOBAL CO., LTD.
PACIFIC CONSULTANTS CO., LTD.

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Executive Summary

1. Background

On January 15, 2022, a large-scale eruption occurred from the submarine volcano Hunga Tonga-Hunga Ha'apai (HTHH) located about 65 km north of Nuku'alofa, the capital of Tonga. Severe damages such as communication infrastructure failure occurred.

In response to the Tongan government's request for emergency assistance, the Government of Japan provided JICA emergency relief supplies in collaboration with the Self-Defense Forces, e. g., drinking water, food, equipment for removing ash, and personal protective equipment. However, based on the current situation where Tonga is always considered as the world's top country in terms of disaster vulnerability, the JICA Study Team will seamlessly develop activities, not only to let Tonga recover from the damage brought about by the recent disaster, but also use it as the scientific basis to manage future similar disasters. After confirming the reproducibility of similar disaster based on scientific evidence, it is required to carry out a reconstruction plan based on the Build Back Better (hereinafter referred to as "BBB") vision according to reproducibility.

2. Project Outline

Project Name: Information Collection and Preliminary Survey for the Formation of Disaster Recovery Projects against Volcanic Eruptions and Tsunami Damage in Kingdom of Tonga

Project Purpose: The purpose of this survey is to collect and analyze information necessary for the formation of concrete cooperation projects in the future, such as measures to prevent the spread of damage and support for medium- to long-term disaster prevention measures.

Survey Area: The survey will be conducted all over Tonga, with Tongatapu Island and 'Eua Island as priority target areas.

Counterparts of Tonga

The following are the main counterpart (hereinafter "C/P") institutions.

- Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECCC)
- Ministry of Lands and Natural Resources (MLNR)
- National Spatial Planning Authority Office (NSPAO)

Other related organizations involved in this survey are as follows:

- Ministry of Infrastructure (MOI)

- Ministry of Public Enterprises (MPE)
  - Tonga Port Authority (PAT), Tonga Water Board (TWB), Tonga Power Limited (TPL), Tonga Communications Corporation (TCC)

Domestic Support Committee

The Domestic Support Committee was formed by JICA. It was proceeded with the investigation and advised from the support committee members at key points from the start of the investigation. The domestic support committee has hold 19 times since the start of the project.

3. Basic Information Collection and Analysis

Hunga Tonga-Hunga Ha'apai Volcanic Eruption and Tonga Tsunami (HTHH Disaster) Recovery and Resilience Building Plan 2022 – 2025

This recovery plan is formulated by the government of Tonga with the support of neighboring countries and donors. NEMO serves as the coordinating body, confirming the damage situation and coordinating the necessary support at meetings for each cluster. This recovery plan prioritizes four areas: housing recovery, food security and livelihoods, tourism industry, and public infrastructure, as the damage caused by the tsunami and ashfall. The Tongan government will also focus on mobilizing resources to carry out recovery efforts in priority sectors across the affected islands of Tongatapu, 'Eua and Ha'apai.

Damage Situation on Tongatapu Island

The damage was most severe in the west end of the island and the tsunami can be seen running up to a height of more than 10m in the west end of the island, but in the north central part of the island, the tsunami was only slightly higher than the seawall (for example, the tsunami height was M.S.L.+4.2 m against the sea wall height of M.S.L+2.6 m).

Damage Situation on 'Eua Island

The tsunami washed away the area surrounding the port as it moved northward from the south side of the island, causing more damage to the new port in the northeast than to the old port located south of the port. There was no major damage to the sheet pile type quay itself, and there was relatively little damage to the quay and other port structures, but the masonry and breakwater on the northwest side sustained significant damage. The bridge that suffered the most damage this time (a bridge with small box culverts lined up and paved on top). It had a wall-shaped concrete structure to prevent waves, probably added later, were severely damaged.

Damage Situation on Ha'apai Island

The port of Ha'apai was repeatedly repaired by the World Bank in 2012-14 and 2018, but it was again damaged by Cyclone Tino in January 2020 and the recent HTHH tsunami. Concrete structures were damaged, and backfill crushed stones and sediment flowed out at several locations.

Disaster Situation on Vava'u Island

The port of Vava'u is a good natural harbor surrounded by mountains on all sides, and waves from the open ocean do not directly enter the bay, so there was little damage from the recent eruption and tsunami.

4. Support for Formulation of BBB Vision

BBB Vision Seminar

The Government of Tonga and JICA jointly held a seminar to set out the Government of Tonga's BBB vision and to present the BBB as a necessary concept when considering future development projects.

The approval process of BBB vision in Tonga were carried out to receive parliamentary in order to legislate the BBB Vision as a policy of the National Spatial Planning Agency. The approval process had been underway at the Cabinet meeting since around July 2022, and the BBB Vision was brought to the Cabinet once again and approved at the Cabinet meeting on June 16, 2023.

Implementation of Multi-hazard Assessment Based on BBB Vision

The hazards covered by in this study are volcanic tsunamis and ash fall, as well as seismic tsunamis, earthquakes, storm surges/high waves, and strong winds (due to cyclones).

Table-1 shows the intensity and frequency of each hazard level and the concept of disaster management plans and countermeasures. This concept was introduced as a step-by-step approach to disaster management measures against earthquakes and tsunamis, based on the lessons learned from the 2011 Tohoku Pacific Coast Earthquake, and is used in Japan for measures against various hazards.

Table 1 Hazard Level and Frequency

Hazard level	Hazard Intensity and Frequency	Countermeasures
Level 1 (L1)	High intensity and frequency Hazards that occur more frequently than the largest class of hazards Cause significant damage despite low hazard intensity. Tens to hundreds of years occurrence cycle	Implement structure measures to protect human life, property, and the economy.
Level 2 (L2)	Largest class hazard Hazards that occur infrequently but can cause devastating damage once they occur. Hundreds to thousands of years occurrence cycle	Prioritize lifesaving. Integrate and implement moderate and comprehensive measures to evacuate residents

Source: Based on Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the "2011 off the Pacific coast of Tohoku Earthquake", JICA Study Team made

Tsunami Analysis, Storm Surge Analysis

Based on the tsunami caused by the HTHH volcano occurred in January 2022, it will use numerical analysis to examine both frequently occurring seismic tsunamis and volcanic tsunamis. Since the country is situated in a cyclone-prone area, storm surges caused by cyclones will be considered. The detailed results of each analysis are listed in Appendix 3-2.

Past Tsunami/storm Surge Hazards

In Tonga, tsunami hazards include volcanic tsunamis caused by submarine volcanic eruptions and volcanic mountain collapses, and tsunamis caused by earthquake faults in the Tonga Trench located in eastern Tonga (seismic tsunamis).

Many volcanoes are located on the west side of Tonga's islands, and although the frequency of volcanic eruptions is low, there is a possibility of volcanic tsunamis occurring in Tonga.

There have been records of numerous earthquakes since 1913, and among them, eight earthquakes of magnitude 8.0 or higher, which are thought to cause large tsunamis. Therefore, the possibility of seismic tsunamis occurring is high.

Cyclones hit Tonga every year, and storm surges occur frequently. According to NOAA's IBTrACS, since 1947, there have been seven cyclones of Category 4[1] or higher and 17 of Category 3 or higher that have passed around Tongatapu Island, meaning a huge cyclone strikes once every five years.

Based on the analysis results of volcanic tsunamis, it will examine the hazard level of tsunamis. In the case of a tsunami of the same size as the 2022 HTHH volcano, the required height of the seawall will be M.S.L.+4m at Nuku'alofa and M.S.L.+12m at Ohonua, which is significantly higher than the current seawall (M.S.L.+2m).

Based on the results of seismic tsunami analysis, the required height of the seawall for tsunamis of M8 or higher is M.S.L.+1.3m at Nuku'alofa and M.S.L.+1.4m at Ohonua. +2m), which indicates that the current seawall can be appropriate.

Probable storm surge anomalies were calculated using tidal level from 1947 to 1990 and tidal level anomalies calculated from tidal level observation data from 1991 to 2021 as extreme value data. The probable tidal level anomaly was 80 cm with a probability of 100 years. The height of past earthquakes and tsunamis in Ohonua, 'Eua Island, was around 1 to 2 meters at H.W.L., and they have occurred several times in about 100 years. Therefore, past seismic tsunamis can be said to be hazard level 1 tsunamis that should be dealt with through structure measures.

When a volcano of the same scale as the HTHH in January 2022 occurs elsewhere, the expected height of a volcanic tsunami in Ohonua, 'Eua Island, is 2.7 to 12 meters at H.W.L. At Ohonua, no tsunami exceeding 3 meters has occurred in the past 100 years, except the tsunami caused by the HTHH volcano in 2022, and it is unlikely that a volcano of the same size as the HTHH volcano will occur repeatedly in about 100 years. Therefore, a volcanic tsunami of the same scale as the HTHH volcano

[1] Category is a classification of tropical cyclones based on the Saffir-Simpson Hurricane Wind Scale. Category 3 is a tropical cyclone with maximum wind speeds of 50 to 57 m/s, and Category 4 is a tropical cyclone with maximum wind speeds of 58 to 69 m/s that is expected to cause extensive damage.

is classified as a hazard level 2 tsunami (the largest class of tsunami), which requires evacuation measures and other measures.

The storm surge tide level deviation due to cyclones in the last 30 years (1991-2021) with observation records was approximately 0.7m. The extreme value statistical results of storm surge tide level deviation show that even with a 100-year probability deviation considering H.W.L., the deviation is M.S.L.+1.6m (storm surge tide level deviation 0.8m), which is not much different from the storm surges of the past 30 years. Based on the results of this study, it seems appropriate to set the hazard level 1 storm surge, which should be addressed with structure measures, at the 100-year probability of tidal level deviation.

The required height of the seawall is determined by taking into consideration the waves, tide level, and water level rise above the reef, which are set as planted forces by Isaac (1982).

Hazard level 2 Storm Surge and Tsunami Study

For the volcano shown in Table 3.2.19 of the main text, the inundation area is calculated using the tide level as H.W.L. (M.S.L.+0.8m) as an adverse condition, and its maximum envelope area is taken as the inundation area of hazard level 2. The inundation depth was particularly deep in the northwestern part of Tongatapu Island, exceeding 5 meters. In some parts of Nuku'alofa, the flooding depth exceeded 2 meters, so major damage is expected. Furthermore, on 'Eua Island, Ohonua Port has been flooded with water exceeding 5 meters, but the inundation area is limited to low in coastal areas.

Regarding tsunami hazard maps, there is “The Southwest Pacific Tsunami Risk Assessment Capacity Strengthening (Phase 3) Tsunami Simulation Map” created in 2012 by the SOPAC project. Among these, the case where an M8.7 earthquake occurs in the center of the Tonga Trench (east of Tongatapu Island), which is adopted in the "Preparatory Survey on the Plan for the Introduction of the National Early Warning System and Strengthening of Disaster Prevention Communication Capacity in the Kingdom of Tonga" (JICA).

Unlike seismic tsunamis, the fault of the source of the tsunami is located on the east side of Tongatapu Island, so the inundation area and inundation depth on the east side is large. The inundation depth of Nuku'alofa is greater than the inundation depth of a volcanic tsunami, and in some places the inundation depth is more than 3 meters.

According to storm surge calculations, the inundation area is approximately the same in each case under worst case conditions, with the inundation depth in urban areas being less than 1m at the largest, and less than 1.5m in port areas.

Island countries like Tonga may be greatly affected by rising sea levels due to future climate change, including increased damage from flooding. Therefore, based on the IPCC Sixth Assessment Report, it created a hazard level 2 scenario based on the amount of sea level rise in Tonga in SSP1-2.6 (scenario to limit temperature rise to less than 2 Celsius within sustainable development). was examined.

Creation of Multi-hazard Maps

Hazard maps were created for the analyzed tsunamis and storm surges. Hazard maps are used for evacuation, so they must indicate the greatest hazards. Therefore, a multi-hazard map was created based on the case showing the maximum inundation area and inundation depth among the tsunami and storm surge hazards considered this time.

If the case that gives the maximum inundation area differs depending on the location, the maximum envelope of inundation range and depth for each case is shown.

Direction of Disaster Cuntermeasures

Based on the results of hazard analysis, it is recommended to take measures against tsunamis and storm surges in the following directions.

Table-2 Disaster Management Direction

Hazards	Disaster Management Direction
Volcanic Tsunami	➢ For Level 1 scale events (tsunamis caused by small-scale eruptions, such as the 2022 HTHH volcanic eruption), structural measures will be implemented in coordination with earthquake and tsunami surge countermeasures. ➢ For Level 2 scale events (tsunamis caused by volcanic eruptions of the same scale as the 2022 HTHH eruption, but happening in other submarine volcanoes), extensive flooding is anticipated. Therefore, the primary focus will be on enhancing soft measures, such as evacuation, to ensure the protection of lives.
Seismic Tsunami	➢ For Level 1 scale events (frequent tsunamis caused by earthquakes of M8 class), protection can be provided with the current seawalls. Therefore, the existing seawalls will be maintained. ➢ For Level 2 scale events (maximum class of earthquakes in the M8 to M9 range causing tsunamis), extensive flooding is anticipated. Therefore, the primary focus will be on enhancing soft measures, such as evacuation, to ensure the protection of lives.
Storm Surge	➢ For Level 1 scale events, storm surges caused by cyclones that hit once every few years to several decades, measures will be taken by maintaining (including improving) the current seawalls. ➢ For Level 2 scale storm surges caused by cyclones, similar to tsunamis, extensive flooding is anticipated. Therefore, the primary focus will be on enhancing soft measures, such as evacuation, to ensure the protection of lives.

Source: JICA Study Team

5. Consideration of Individual Coastal Disaster Risk Reduction Projects

Nuku'alofa Seawall Restoration Plan

A comparative study was conducted of masonry, reinforced concrete, and CSG materials.

'Eua Island Cost-way Restoration Plan

In Site Recovery Plan

There is a level difference of approximately 1m between the box part (M.S.L.+4.5m) and the existing road part on both banks (M.S.L.+5.5m). Although it is a subsidence area, the cross-sectional area under the box is small, and the impact of driftwood and gravel flowing from the upstream valley during heavy rains and cyclone floods is large. It is also necessary to consider how to cross the river at the same level.

New Bridge Construction Plan

According to the survey map, the valley is deep, with a height difference of about 15m between the existing roads on both sides of the valley. The span length of the middle bridge will be 45m, and a steel bridge will have to be used.

6. On-going Projects and Already Implemented Projects, Formulation of New Projects

In addition to the proposals for new support projects that were formulated in this survey, the proposals include projects that were formulated under a separate study from the Ministry of Health, Labor and Welfare, “2022 Water Supply Project Planning Guidance Project (Phase 1) Kingdom of Tonga Water Supply Reconstruction Assistance Plan.” there is Appendix 5-1 shows the project.

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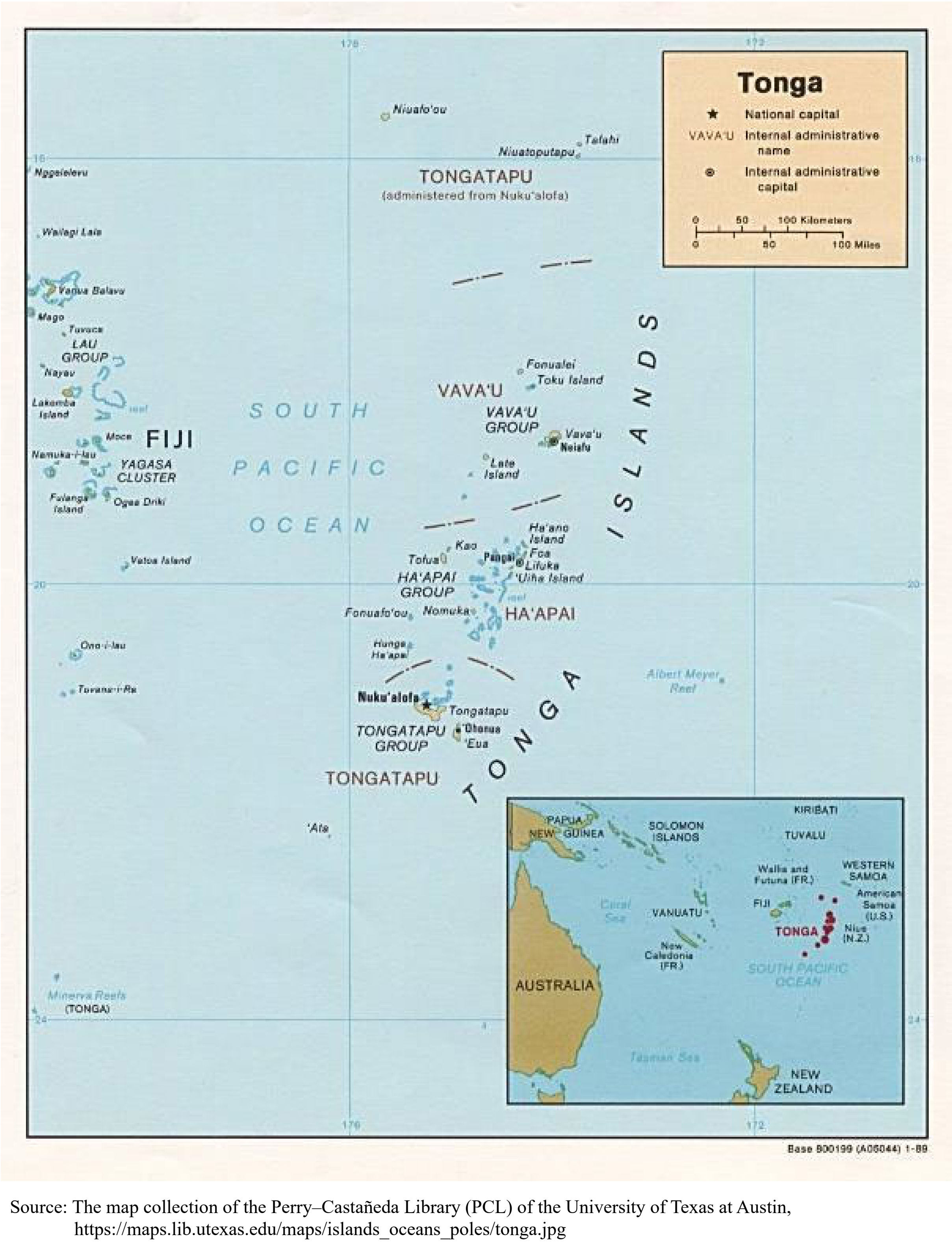
Abbreviations

Abbreviation	Definition
ADB	Asian Development Bank
BBB	Build Back Better
BCP	Business Continuity Plan
CBDRM	Community-based Disaster Risk Management
CCT	Conditional Cash Transfer
CD	Capacity Development
CEO	Chief Executive Officer
CHARM	Comprehensive Hazard and Risk Management
CMT	Centroid Moment Tensor
COVID-19	Coronavirus disease 2019
C/P	Counterpart
CSG	Cemented Sand and Gravel
DCP test	Dynamic Cone Penetration test
DEM	Digital Elevation Model
DEMC	District Emergency Management Committee
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
ECHO	European Civil Protection and Humanitarian Aid Operations
ERCC	Emergency Response Coordination Center
FAO	Food and Agriculture Organization
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Oceans
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information System
GNI	Gross National Income
GOT	Government of Tonga
GPS	Global Positioning System
GRADE	Global Rapid Post Disaster Damage Estimation
HMAF	His Majesty's Armed Forces
HP	Home Page
HTHH	Hunga Tonga-Hunga Ha'apai
H.W.L.	High Water Level
IBTrACS	International Best Track Archive for Climate Stewardship
ICT	Information and Communication Technology
IDMC	Internal Displacement Monitoring Center

IPCC	Intergovernmental Panel on Climate Change
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency
JNAP2	Joint National Action Plan 2 on Climate Change and Disaster Risk Management 2018-2028
LAN	Local Area Network
LiDAR	Light Detection and Ranging
L.W.L.	Low Water Level
M/M	Minutes of Meetings
MAFF	Ministry of Agriculture, Forestry and Fisheries
MCA	Multi-Criteria Analysis
MEFS	Ministry of Emergency and Fire Services
MEIDECCC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications
MET	Ministry of Education and Training
MIA	Ministry of Internal Affairs
MJP-J	Ministry of Justice and Prisons-J
MLNR	Ministry of Lands and Natural Resources
MoFNA	Ministry of Finance and National Planning
MOH	Ministry of Health
MOI	Ministry of Infrastructure
MOP	Ministry of Police
MORDI Tonga Trust	Mainstreaming of Rural Development Innovation Tonga Trust
MPE	Ministry of Public Enterprises
M.S.L.	Mean Sea Level
Mw	Moment Magnitude
NDC	National Disaster Council
NDRMO	National Disaster Risk Management Office (formerly the National Emergency Management Office)
NEMC	National Emergency Management Committee
NEMO	National Emergency Management Office
NEMP	National Emergency Management Plan
NEOC	National Emergency Operation Committee
NERC	National Emergency Recovery Committee
NGO	Non-Governmental Organization
NHK	Nippon Hoso Kyokai (Japan Broadcasting Corporation)
NIIP	National Infrastructure Investment Plan
NOAA	National Oceanic and Atmospheric Administration
NP	Number Penetration

NSPAO	National Spatial Planning Authority Office
NZ	New Zealand
O&M	Operation and Maintenance
OCG	Oriental Consultants Global Co., Ltd
OLA	Office of the Legislative Authority
PAT	Ports Authority Tonga
PDM	Project Design Matrix
PMO	Prime Minister’s Office
PMU	Project Management Unit
PO	Plan of Operation
PREP	Pacific Resilience Program
PRIF	Pacific Regional Infrastructure Facility
RC	Reinforced Concrete
R/D	Record of Discussions
RTK	Real-time kinematic
SDGs	Sustainable Development Goals
SET	Skills and Employment for Tongans Project
SMS	Short Message Service
SOPAC	South Pacific Applied Geoscience Commission
SPC	Pacific Community
SREM	Strategic Roadmap for Emergency and Disaster Risk Management
SSP	Shared Socioeconomic Pathways
STOC	Storm surge and Tsunami simulator in Oceans and Coastal areas
TAL	Tonga Airports Limited
TAMA	Tonga Asset Management Association
TCC	Tonga Communication Corporation
TCL	Tonga Cable Limited
TCRTP	Tonga Climate Resilient Transport Project
TFES	Tonga Fire & Emergency Services
TGS	Tonga Geology Service
TMCL	Tonga Market Corporation Limited
TMS	Tonga Meteorological Service
TOP	Tongan Pa’anga
TOR	Terms of Reference
TPL	Tonga Power Limited
TSDF	Tonga Strategic Development Framework
TVET	Technical and Vocational Education and Training
TTI	Tupou Tertiary Institute
TWB	Tonga Water Board

UN	United Nations
UNDP	United Nations Development Program
UNDRR	United Nations Office for Disaster Risk Reduction
UNICEF	United Nations International Children's Emergency Fund
UNISDR	United Nations International Strategy for Disaster Reduction
UN OCHA	United Nations Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development
USGS	United States Geological Survey
VEI	Volcanic Explosivity Index
VEMC	Village Emergency Committee
VERC	Volcanic Eruption Recovery Committee
WAL	Waste Authority Limited
WASH	Water, Sanitation and Hygiene.
WB	World Bank
WCDRR	World Conference on Disaster Risk Reduction
WG	Working Group



Source: The map collection of the Perry–Castañeda Library (PCL) of the University of Texas at Austin, https://maps.lib.utexas.edu/maps/islands_oceans_poles/tonga.jpg

Project Area

1. Introduction

1.1. Background of the Project

Kingdom of Tonga (hereinafter referred to as "Tonga") is an island country consisting of 172 large and small islands located in Polynesia in the South Pacific Ocean. It has an exclusive economic water area of 700,000 km2, a land area of 720 km2, and a population of about 104,000 (2019, World Bank). Its GNI per capita is US $ 5,000 (2019, World Bank). Tonga consists of four islands, Niuas, Vava'u, Ha’apai and Tongatapu. The largest island, the southern Tongatapu Islands, consists of Tongatapu Island, where the capital Nuku'alofa is located, and 'Eua Island, which is located about 40 km southeast of Tongatapu Island. More than 80% of the total population inhabits these islands. Tonga's main industries are primarily agriculture, fishing and tourism, accounting for about 20% of GDP. Although it has a warm climate with an average annual temperature of 24 °C and annual rainfall of 1,700 mm, Tonga suffers from cyclone damage every year. and it is prone to many natural disasters, such as earthquakes, due to active volcanic islands and submarine volcanoes. In World Risk Report (2021), Tonga is the country with the third highest risk of disaster damage in the world.

On January 15, 2022, a large-scale eruption occurred from the submarine volcano Hunga Tonga-Hunga Ha’apai (HTHH) located about 65 km north of Nuku'alofa, the capital of Tonga. Severe damages such as communication infrastructure failure occurred.

In response to the Tongan government's request for emergency assistance, the Government of Japan provided JICA emergency relief supplies in collaboration with the Self-Defense Forces, e. g., drinking water, food, equipment for removing ash, and personal protective equipment. However, based on the current situation where Tonga is always considered as the world's top country in terms of disaster vulnerability, the JICA Study Team will seamlessly develop activities, not only to let Tonga recover from the damage brought about by the recent disaster, but also use it as the scientific basis to manage future similar disasters. After confirming the reproducibility of similar disaster based on scientific evidence, it is required to carry out a reconstruction plan based on the Build Back Better (hereinafter referred to as "BBB") vision.

Based on the contents of the BBB vision currently under consideration by JICA, to promote the transformation of Tonga into a disaster-resistant country, the current state of disaster risk is understood, and the possibility of similar disasters occurring in the future is considered. These are carried out for the purpose of collecting and analyzing information necessary for the formation of cooperation projects in the future, such as measures to prevent the spread of damage in the event of a disaster and support medium- to long-term disaster prevention measures.

1.2. Outline of the Project

(1) Project Name

Information Collection and Preliminary Survey for the Formation of Disaster Recovery Projects against Volcanic Eruptions and Tsunami Damage in Kingdom of Tonga

(2) Project Purpose

In response to the recent volcanic eruption, earthquake and tsunami in Tonga, this survey grasps the current state of disaster risk in the country and when similar disasters occur in the future to promote the creation of a disaster-resilient country based on the BBB Vision.

The purpose of this survey is to collect and analyze information necessary for the formation of concrete cooperation projects in the future, such as measures to prevent the spread of damage and support for medium- to long-term disaster prevention measures.

(3) Survey Area

The survey will be conducted all over Tonga, with Tongatapu Island and 'Eua Island as priority target areas.

(4) Counterparts of Tonga

The following are the main counterpart (hereinafter "C/P") institutions.

- Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECCC)
- Ministry of Lands and Natural Resources (MLNR)
- National Spatial Planning Authority Office (NSPAO)

Other related organizations involved in this survey are as follows:

- Ministry of Infrastructure (MOI)
- Ministry of Public Enterprises (MPE)
  - Tonga Port Authority (PAT), Tonga Water Board (TWB), Tonga Power Limited (TPL), Tonga Communications Corporation (TCC)
- Ministry of Health (MOH)

(5) Domestic Support Committee

1) Domestic Support Committee list

Table 1.2.1 lists the members of the Domestic Support Committee.

Table 1.2.1 Domestic Support Committee List

No.	Name	Organization	Group
1	Osamu Kamigaichi	Japan Meteorological Business Support Center	C
2	Masato Iguchi	Disaster Prevention Research Institute, Kyoto University	B
3	Setsuya Nakada	National Research Institute for Earth Science and Disaster Resilience Volcanic Disaster Resilience Research Division	A
4	Naotaka Chikasada	National Research Institute for Earth Science and Disaster Resilience Earthquake and Tsunami Research Division	C
5	Hiroshi Inoue	National Research Institute for Earth Science and Disaster Resilience Multi Hazard Risk Assessment Research Division	B、C
6	Takao Ohminato	Earthquake Research Institute, The University Tokyo Volcano Research Center	A
7	Mie Ichihara	Earthquake Research Institute, The University Tokyo	A
8	Kenji Nogami	Volcano and Earthquake Research Division Tokyo Institute of Technology	B
9	Toshitsugu Fujii	Mount Fuji Research Institute Yamanashi Prefecture Government	B
10	Fumihiko Imamura	International Research Institute of Disaster Science	C、D
11	Nobuhito Mori	Disaster Prevention Research Institute, Kyoto University	C、D
12	Taro Arikawa	Chuo University, Faculty of Science and Engineering	C, D

Source: JICA Study Team

The Domestic Support Committee has been divided into Groups A to D according to their specialties. The items to be examined and the results of each group are shown below. The analysis was carried out using the results of the Domestic Support Committee.

Table 1.2.2 Grouping of Domestic Support Committees and Main Point of Study

Group	Point of Study	Results	Remarks
A	Volcano activities	• Collection of non-public information such as publications and materials • Detailed time series of eruption (especially the first 30 minutes) • Correlation between radio waves and earthquakes and the beginning of eruptions • Understanding eruptions from their source. • Possible eruption mechanisms considering gravity currents that caused disconnection of submarine cable. • A possibility of DAS (distributed acoustic sensing) technology using the existing submarine cables for monitoring seismicity around HTHH was shown	Since the January 2022 eruption was due to a violent interaction of magma with the shallow sea water, leaving deep depression behind, it is unlikely the similar eruption at HTHH recurs on a 100-year time scale.
B	Volcanic eruption damage investigation and countermeasures	• History of eruptions of 21 submarine volcanoes near Tonga • Evaluation of the impact of eruptions on urban areas • Inputs to Group C (Tsunami-inducing submarine volcanoes near Tonga) • Countermeasure menu for ash fall and tsunami	Eruptions affects residential areas in Tonga are judged to occur more than once every 100 years.

Group	Point of Study	Results	Remarks
C	Analysis and investigation of submarine volcanic tsunamis	• Collection of existing materials such as damage investigation reports • Numerical analysis of tsunami propagation • Presentation of volcanic tsunami generation model • Presentation of volcanic tsunami propagation analysis results • Past Seismic Tsunami (from USGS seismic catalog) in Tonga Trench	Simulation is ongoing with high-resolution DEM and the digital bathymetry provided by Tonga side
D	Historical and long-term assessment of cyclones and storm surges near Tonga	• Arrangement of storm surge caused by cyclone passing around Tonga • Survey of past impacts of storm surges on Tonga (storm surge inundation maps and damage) • Review of current storm surge measures: dikes, monitoring and warning systems, hazard maps and evacuation plans. • Expected and Future Possibilities of Storm Surge Damage • Effects of global warming in this region (sea level rise, changes in occurrence frequency and intensity of cyclones) based on IPCC 6th Assessment Report. • Propose the direction of storm surge countermeasures and ensure consistency in cooperation with Group C	Simulation is ongoing with high-resolution DEM and the digital bathymetry provided by Tonga side

Source: JICA Study Team from the Domestic Support Committee Power Point Presentation

2) Major meetings conducted by the Domestic Support Committee

The Domestic Support Committee conducted reports and inquired the JICA Study Team since the start of investigation.

Table 1.2.3 records the Domestic Support Committee meetings.

Table 1.2.3 Major Meetings Held by the Domestic Support Committee

No.	Date	Time	Summary	Style	Note
1	2022/4/7	At 16:00	Policies from April onwards and matters to be handed over to consultants.	Online	
2	2022/4/12	At 8:00	Consultation regarding the probability and scale of a submarine volcano collapse.	Online	
3	2022/5/13	At 10:00	Explanation on the progress of the Tonga BBB recovery and recovery support.	Online	
4	2022/5/13	At 17:00	Consultation with Professor Nakada regarding future initiatives.	Online	
5	2022/6/1	At 11:00	Research cooperation on Tonga.	Online	
6	2022/6/9	At 9:00	Research cooperation on Tonga.	Online	
7	2022/6/15	At 8:30	Regarding Professor Shane Cronin's analysis results.	Online	
8	2022/7/22	At 17:00	Consultation for research schedule.	Online	
9	2022/7/29	At 10:30	Discussion on tsunami analysis in the nation of Tonga.	Online	
10	2022/8/1	At 7:50	Settings of L1 and L2.	Online	

No.	Date	Time	Summary	Style	Note
11	2022/8/1	At 13:00	Discussion on high tide analysis in the nation of Tonga.	Online	
12	2022/8/12	At 10:00	Research results presentation meeting.	Online	
13	2022/8/23	At 8:00	Settings of L1 and L2.	Online	
14	2023/1/18	At 17:30	Progress report.	Online	
15	2023/2/2	At 17:00	Progress report.	Online	
16	2023/2/19	At 16:00	Utilization of the tsunami database.	Online	
17	2023/4/27	At 8:30	Discussion on L1 and L2, explanation of hazard analysis results.	Online	
18	2023/5/18	At 9:00 At 17:00	Report on the hazard analysis results.	Online	Implemented in two phases.
19	2023/6/9	At 9:00	Reporting session on disaster recovery efforts following the Tonga volcanic eruption.	Online	

Source: JICA Study Team

3) Major Meetings conducted by JICA Study Team

The survey had workshops and seminars during a specific period.

Table 1.2.4 lists the major meetings conducted by the JICA Study Team.

Table 1.2.4 Major Meetings Conducted by JICA Study Team

No.	Date	Time	Summary	Style
1	2022/3/20	14:00-15:40	Build Back Better Vision Kick-off Meeting The CEOs of relevant government agencies and representatives are invited and explained the overview of the project and the necessity of the Tonga version of BBB Vision, as well as provided an explanation of the draft version.	Online and Face to Face
2	2022/8/17	10:00-12:30	2022 HTHH Eruption and Recovery Seminar BBB Vision Seminar The prince was invited, and an explanation about BBB Vision was given by the NSPAO. An explanation of Japan's efforts for BBB Vision was also provided by Japanese Specialist. The online meeting was attended by related government agencies in Japan, and after its conclusion, there was coverage from NHK.	Online and Face to Face
3	2023/5/23	9:00-13:00	Explanation of hazard analysis results. The discussion about the L1 and L2 settings was conducted by the JICA study team. Furthermore, three divided groups consolidated opinions on the hazard analysis results.	Online and Face to Face
4	2023/8/29	9:00-13:00	Draft Final Report Explanation Workshop The JICA study team explained the hazard analysis results and discussed how they would be reflected in future policies in Tonga.	Online and Face to Face

Source: JICA Study Team

2. Collection and Analysis of Basic Information

2.1. Development Plans

2.1.1. Tonga Strategic Development Framework 2015-2025 (TSDF II)

The Tonga Strategic Development Framework 2015-2025 (A More Progressive Tonga: Enhancing Our Inheritance) is the top national plan that provides the development framework for Tonga. It consists of 7+1 national outcomes and 29 organizational outcomes (grouped under five pillars) that together plan to guide Tonga's development through 2025.

The national impact sought within the TSDF II vision is "a more progressive Tonga that supports a higher quality of life for all". By focusing on inclusive and sustainable growth, Tonga aims to ensure long-term progress that is broader and more equitable for all.

(1) The Seven National Outcomes

A. a more inclusive, sustainable, and dynamic knowledge-based economy
B. a more inclusive, sustainable, and balanced urban and rural development across island groups
C. a more inclusive, sustainable, and empowering human development with gender equality
D. a more inclusive, sustainable, and responsive good governance with law and order
E. a more inclusive, sustainable, and successful provision and maintenance of infrastructure and technology
F. a more inclusive, sustainable, and effective land administration, environmental management, and resilience to climate and risk
G. a more inclusive, sustainable, and consistent advancement of our external interests, security and sovereignty

In support of the seven national outcomes, there are 29 TSDF II organizational outcomes, shown in Appendix 2-1. These are grouped into five pillars which, working together, support the National Outcomes.

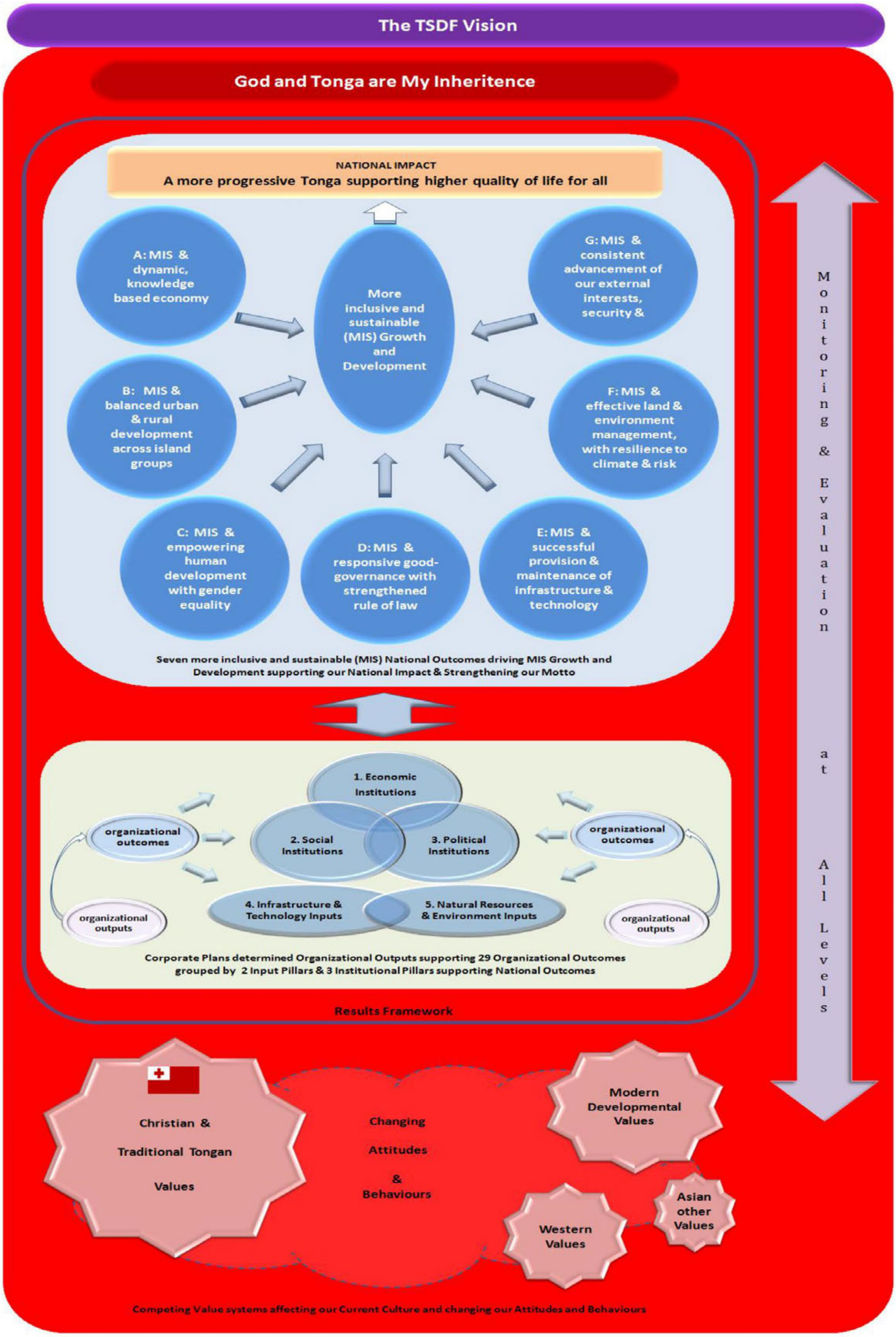
(2) Five Pillars

Three Institutional Pillars:

1. Economic Institutions
2. Social Institutions
3. Political Institutions

Two Input Pillars:

4. Infrastructure and Technology Inputs
5. Natural Resource and Environment Inputs



Source: Tonga Strategic Development Framework 2015-2025

Figure 2.1.1 TSDF Vision

Table 2.1.1 indicates the extent to which each organization supports each outcome. Cells marked with dark squares indicate that a particular organizational achievement provides significant support for that national achievement, medium colors indicate moderate support, light colors indicate partial support, and white indicates no contribution.

Table 2.1.1 Organizational Outcomes Grouped by Pillars Supporting National Outcomes

Pillars		National Outcomes => / Organizational Outcomes	More inclusive, sustainable and... A: ...dynamic & knowledge based economy	B: ...balanced urban & rural development across island groups	C: ... empowering human development with gender equality	D: ... responsive good-governance with strengthened rule of law	E: ... successful provision & maintenance of infrastructure & technology	F: ... effective land admin & environment management, with resilience to climate & risk	G: ... consistent advancement of our external interests, security and Sovereignty
1. Economic Institutions	1.1	Improved macroeconomic management & stability with deeper financial markets	significant	partial	partial	moderate	none	none	partial
	1.2	Closer public/private partnership for economic growth	significant	moderate	moderate	moderate	partial	partial	none
	1.3	Strengthened business enabling environment	significant	moderate	partial	moderate	partial	partial	partial
	1.4	Improved public enterprise performance	significant	moderate	partial	partial	moderate	moderate	none
	1.5	Better access to, and use of, overseas trade & employment, and foreign investment	significant	moderate	moderate	none	none	none	significant
2. Social Institutions	2.1	Improved collaboration with & support to civil society organizations and community groups	partial	significant	significant	partial	partial	partial	none
	2.2	Closer partnership between government, churches & other stakeholders for community development	partial	moderate	significant	partial	none	partial	partial
	2.3	More appropriate social & cultural practices	moderate	moderate	significant	partial	none	partial	partial
	2.4	Improved education & training providing life time learning	moderate	moderate	significant	moderate	moderate	partial	partial
	2.5	Improved health care and delivery systems (universal health coverage)	moderate	moderate	significant	partial	none	none	none
	2.6	Stronger integrated approaches to address both communicable & non-communicable diseases	moderate	moderate	significant	partial	partial	partial	partial
	2.7	Better care & support for vulnerable people, in particular the disabled	partial	moderate	significant	partial	partial	partial	none
	2.8	Improved collaboration with the Tongan diaspora	moderate	moderate	moderate	partial	none	partial	significant
3. Political Institutions	3.1	More efficient, effective, affordable, honest, transparent & apolitical public service focussed on clear priorities	moderate	moderate	moderate	significant	moderate	moderate	moderate
	3.2	Improved law & order and domestic security appropriately applied	moderate	moderate	partial	significant	none	partial	partial
	3.3	Appropriate decentralization of government admin with better scope for engagement with the public	partial	significant	moderate	significant	partial	partial	none
	3.4	Modern & appropriate Constitution, laws & regulations reflecting international standards of democratic processes	moderate	moderate	moderate	significant	moderate	moderate	partial
	3.5	Improved working relations & coordination between Privy Council, executive, legislative & judiciary	partial	partial	partial	significant	partial	partial	none
	3.6	Improved collaboration with development partners ensuring programs better aligned behind gov't priorities	moderate	moderate	moderate	moderate	moderate	moderate	significant
	3.7	Improved political and defence engagement within the Pacific & the rest of the world	moderate	moderate	moderate	moderate	moderate	moderate	significant
4. Infrastructure & Technology Inputs	4.1	More reliable, safe and affordable energy services	moderate	moderate	partial	none	significant	moderate	partial
	4.2	More reliable, safe, affordable transport services	moderate	moderate	partial	partial	significant	moderate	significant
	4.3	More reliable, safe and affordable information & communication technology (ICT) used in more innovative ways	moderate	moderate	moderate	moderate	significant	moderate	significant
	4.4	More reliable, safe and affordable buildings and other structures	moderate	moderate	moderate	none	partial	significant	none
	4.5	Improved use of research & development focussing on priority needs based on stronger foresight	significant	partial	significant	partial	moderate	moderate	none
5. Natural Resources & Environment Inputs	5.1	Improved land use planning, administration & management for private & public spaces	moderate	significant	moderate	significant	partial	significant	partial
	5.2	Improved use of natural resources for long term flow of benefits	significant	moderate	partial	partial	partial	significant	partial
	5.3	Cleaner environment with improved waste recycling	partial	moderate	moderate	partial	none	significant	partial
	5.4	Improved resilience to extreme natural events and impact of climate change	significant	moderate	significant	partial	moderate	significant	moderate

Level of support from Organizational Outcome to National Outcome: significant / moderate / partial / none

Source: Tonga Strategic Development Framework 2015-2025 Page 2

2.1.2. National Infrastructure Investment Plan 2020-2030 (NIIP3)

In 2010, the Tonga formulated a 10-year plan for priority infrastructure investment (NIIP1) with the support of the Pacific Regional Infrastructure Facility (PRIF) to promote infrastructure development. Since then, NIIP2 Phase 1 (2013-2023), NIIP2 Phase 2 (2015-2025), and NIIP3 (2021-2031) have been revised.

The Cabinet approved the Tonga National Infrastructure Investment Plan 2021-2030 (NIIP3) in August 2021. However, situations changed due to several catastrophes, such as the tsunami caused by the HTHH eruption on January 15, 2022, the volcanic ash fall, and the COVID-19 pandemic. The NIIP3 was revised to consider and solve the current problems in Tonga. 47 projects were created, of which 21 are direct solutions and 7 are partially related to the HTHH eruption. In April 2023, the NIIP3 incorporated the original and new projects.

In the NIIP3, each project is scored according to five indicators to determine priority of the projects. Some indicators include natural resources and environment, and disaster prevention. The NIIP3 organizes projects to be implemented from 2021 to 2030.

(1) Selection of priority project in NIIP3

In the revised version of the NIIP3, Chapter 2 explains the impact of the HTHH eruption from economic, social aspects, and government initiatives during reconstruction, and Chapter 3 discusses the necessary infrastructure projects. The four priorities categorized in the project are housing rehabilitation, food security and livelihoods, tourism, and public infrastructure.

The NIIP3-HTHH list includes 47 projects and other projects totaling 99 priority projects. Projects are scored and prioritized accordingly: Group 1 (G1) is 75.6 or above, Group 2 (G2) is 75.6 to 61, and Group 3 is 60 or below.

(2) Position of NIIP3 in the planning system in Tonga

In August 2021, the Cabinet approved the Tonga National Infrastructure Investment Plan 2021-2030 (NIIP3), discussing government priorities of all infrastructure sectors. Since it is consistent with the Second Tonga Strategic Development Framework (TSDF II) from 2015 to 2025, it is considered the highest priority in the project list.

(3) Priority projects indicated in NIIP3

Based on the above lessons learned, NIIP3 was formulated. There were 230 projects listed from consultations with ministries and utilities. From this, a simplified list of 146 projects was created, excluding duplicates and non-NIIP projects. Based on this list, 34 projects were grouped that are ready to be prioritized within the next year, with 53 as reserved projects for later consideration.

Reflecting on the fact that NIIP2 was unbalanced towards specific fields, such as transportation and energy, NIIP3 has taken care to balance the five pillars of TSDF (economy, society, politics, infrastructure, resources, and environment) and target areas.

Table 2.1.2 Priority Projects Indicated in NIIP3

MDA or PE Propose	Project title	Cost TOP '000	Pillar No.	Island Group*					
				T	E	H	V	N	K
TPL	Nuku'alofa Power Network Upgrade Project (NNUP) Area 3, 4 and 5	34,160	4.2	■					
TWB	Centralized Tonga Water Board and Village Water Supply Tongatapu	103,389	4.2	■					
TPL	Additional/Replacement Generators (TBU, Vv, Hp and 'Eua)	6,000	4.2	■	■	■	■		
MEIDECC	Multi-Hazard Early Warning/Emergency Operations Centre (Niuas)	15,000	5.0					■	
WAL	Convert dump sites to new structured landfill, Ha'apai & 'Eua	8,000	4.2		■	■			
TWB	Improved Water Supply System in Vava'u (Greater Neiafu)	14,748	4.2				■		
TCL	New international secondary / redundancy internet cable	35,000	4.2						■
TWB	Improved 'Eua Water Supply System	6,705	4.2		■				
TCC	Upgrade and Expansion 'Eua Mobile and Fixed Networks	2,960	4.2		■				
HMAF	Upgrade Touliki coastal protection structure	3,000	5.0	■					
TMCL	Talamahu (TBU, Nuku'alofa) and 'Utukalungalu (VV) Market upgrade	5,000	1.0	■			■		
WAL	Close (Kalaka) and establishing new landfill(s) Vava'u	12,000	4.2				■		
PAT	First New Tug boats	20,022	4.1	■					
TCC	Upgrade and Expansion Niuas Mobile Networks	2,627	4.2					■	
MEIDECC	New Warehouses for NEMO (one Vava'u, Eastern District, TT)	2,000	5.0	■			■		
MPFS-FED	Upgrade Fire Station 1, Nuku'alofa	2,630	5.0	■					
MOH	Upgrading of a new Public health building (Tongatapu)	5,000	2.0	■					
MOI	Overlay of Asphalt Concrete on Primary Roads in Tongatapu	20,000	4.1	■					
TAL	Upgrade/expande carpark, pedestrian access Fua'amotu Airports	1,000	4.1	■					
TAL	New Fire Tender Fua'amotu	2,100	4.1	■					
MOH	Upgrading of Vava'u Hospital (Prince Ngu Hospital)	40,000	2.0				■		
MOI	Fanga'uta Evacuation Bridge and Roads	150,000	4.1	■					
MET	TIST & TMPI extension/upgrade building (more inclusive for student)	6,000	2.0	■					
PAT	New Wharfs for Small Outer Island	16,000	4.1	■		■	■		
MET	New Junior Campus for Tupou College	10,000	2.0	■					
MAFF	Improve existing & build new MAFF Packing Facilities (HACCP cert.)	1,800	1.0	■					
MJP-J	New Law Court Complex (Supreme and Magistrate)	13,500	3.0	■					
OLA	New Fale Alea (Parliament House and Office Complex)	25,000	3.0	■					

TSDF Pillar 1: Economic institutions	1.0	* T: Tongatapu
TSDF Pillar 2: Social institutions	2.0	E: 'Eua
TSDF Pillar 3: Political (governance) institutions	3.0	H: Ha'apai
TSDF Pillar 4: Infrastructure & technology Inputs (transport)	4.1	V: Vava'u
TSDF Pillar 4: Infrastructure & technology Inputs (utilities)	4.2	N: Ongo Niua
TSDF Pillar 5: Natural resources and environmental inputs	5.0	K: Kingdom Tong

Source: National Infrastructure Investment Plan 2020-2030 (NIIP3)

2.2. Disaster Management Plan, Disaster Monitoring Plan

2.2.1. Strategic Roadmap for Emergency and Disaster Risk Management (SREM) 2021 - 2023

This roadmap was prepared jointly by NEMO and disaster prevention related agencies. This roadmap was also prepared with the cooperation of PIEMA (The Pacific Islands Emergency Management Alliance), SPC, and the governments of Australia and New Zealand. It also supports the implementation of the Tonga Strategic Development Framework 2015-2025. This roadmap consists of six outcomes and will be implemented from 2021 to 2023.

One of the purposes of this roadmap is to support the proposed amendments to the Disaster Risk Management Bill that have been submitted. The existing Emergency Management Act was created with emergency response in mind, as well as disaster mitigation activities, post-disaster recovery and reconstruction. It also aims to apply a cluster system, which is one of the proposals of the new Disaster Risk Management Bill.

In addition, NEMO, as a disaster prevention agency, plans to formulate a disaster risk management policy framework under the new bill.

(1) Vision of SREM

The Government of Tonga and its partners are coordinating efforts to ensure effective and efficient emergency and disaster risk management service delivery.

(2) Outcome of SREM

Outcome 1 Tonga has fully functioning Emergency Operation Center supported by an established emergency coordination and communications system.

Outcome 2: Tonga's emergency and disaster risk management sector is more inclusive.

Outcome 3: Government policy, planning, budget, and procurement processes actively support the mainstreaming of disaster risk management in Tonga.

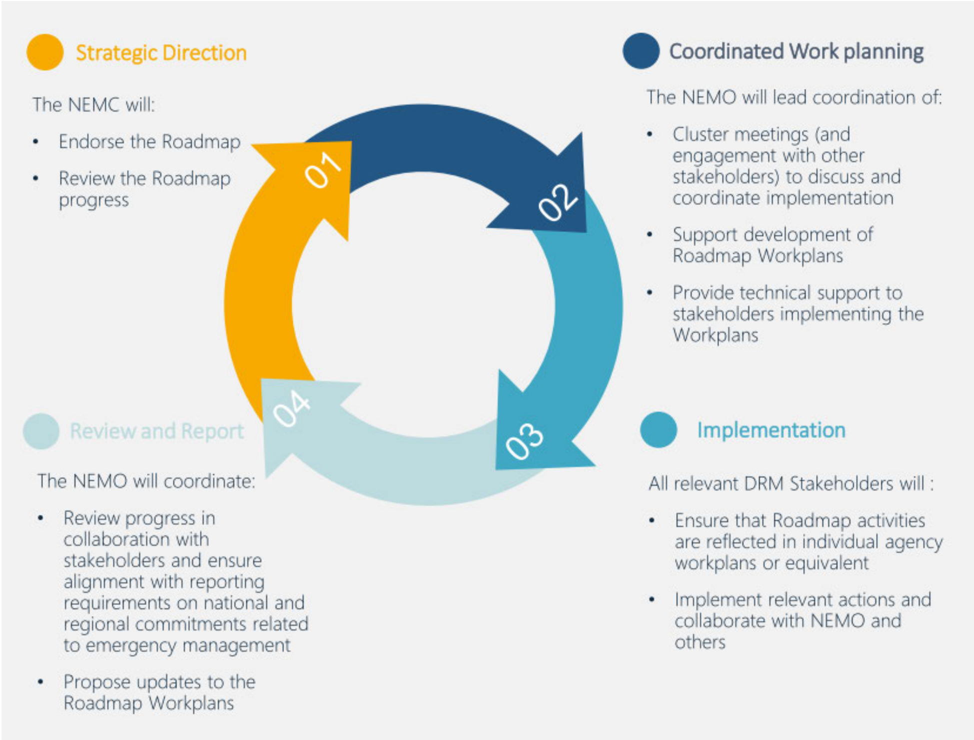
Outcome 4: The cluster system in Tonga is fully institutionalized and strengthened.

Outcome 5: Tonga has clear standards and guidelines for evacuation process management with increased safety and security of evacuation Center.

Outcome 6: Tonga practices participatory village emergency and disaster risk management planning and implementation.

(3) Implementation and Monitoring

Roadmap implementation is coordinated by NEMO and guided by NEMC. Each Roadmap Workplan is assigned to either a NEMO or Cluster Lead to take action and report on its progress. Work plan leaders report progress through NEMO at annual NEMC meetings. The following diagram shows the roadmap implementation and monitoring cycle.



Source: Strategic Roadmap for Emergency and Disaster Risk Management (SREM) 2021 – 2023

Figure 2.2.1 Project Cycle of SREM

2.2.2. Hunga Tonga-Hunga Ha'apai Volcanic Eruption and Tonga Tsunami (HTHH Disaster) Recovery and Resilience Building Plan 2022 - 2025

This is a recovery plan formulated by the Government of Tonga in response to the recent disaster with support from neighboring countries and donors. NEMO serves as a coordinating body, and during meetings of each cluster in specific fields, confirms the damage situation and summarizes the necessary support.

(1) Overview of damage and restoration budget

About 600 buildings were damaged by the tsunami, including at least 300 houses on Tongatapu, Eua, Pronoia, Mango and Nomuka islands. An IOM survey found that 1,525 people in 317 households have been displaced. According to the World Bank's tally, the budget required to realize the recovery plan is US$90.4 million .

(2) Restoration vision, goals, and guidelines

Vision for Recovery: "Recovery with Greater Resilience"

Goal:

Built: Build resilience and safer platforms to natural disasters, and meet the ongoing challenges of climate change (tropical cyclones, sea level rising, tsunamis, global pandemic, etc.) while addressing economic aspect

Economic: A more inclusive, sustainable, and dynamic knowledge-based economy

Social: A more inclusive, sustainable, and empowering human development with gender equality

Cultural: Develop a deeper appreciation of Tonga's inheritance and wealth in the form of people, land, and strong Christian and traditional values that underpin its culture. These must be passed on to children in an improved condition. This requires the Tongans to be wise and prudent in the use of inherited wealth.

Natural: Improve land use planning, management, and administration with stronger and more appropriate enforcement that ensures better provision of public and private spaces, ensures more appropriate placement of infrastructure, better protection of the environment, and limits risk, so as to improve safety conditions for communities and businesses, all while working in harmony with a better application of the traditional land management system.

Principles:

Spirituality: It is embedded within the foundations of the nation's Christian and cultural values as reflected in the motto "God and Tonga are my inheritance."

Building Back Better: Promote better quality infrastructure, which is less costly and longer lasting, prioritizing resilient and climate change sensitive planning and design, supported by improved asset management and maintenance.

Pro-Poor and Inclusive: Support all Tongans to have access to healthy diets and safe food through improving and increasing local production while reducing food imports.

Ensuring Sustainability: Improved collaboration with, and support to, social and civil society organizations promoting the development of groups which encourage greater involvement by all members of the society, a wider range of community activities, social and sporting events, healthy lifestyle, and viable livelihoods in more inclusive and effective ways.

Collaboration and Coordination: Closer partnership between government, churches, development partners and other stakeholders providing services to communities and support to community development to help promote stronger communities, better inclusion of all groups and human development. Good access to new knowledge, progressive ideas, trade, employment opportunities as well as foreign investment and development assistance that is accessible to all are essential.

Protecting the environment: More reliable, safe, affordable, and widely available energy services built on an appropriate energy mix moving towards increased use of renewable energy.

(3) Priority Areas of Recovery Plan

Based on the initial assessment of damages, cluster-specific reviews have followed results; four sectors have been prioritized as recovery and reconstruction interventions in the affected areas of Tongatapu, Ha'apai and 'Eua. However, other sectors are also presented in this report.

The four priority sectors identified by the Government of Tonga for recovery in the affected areas are as follows:

- Housing Recovery
- Food Security and Livelihood
- Tourism Industry
- Public Infrastructure

(4) Recovery Plan Implementation

The Government of Tonga and humanitarian partners provided emergency assistance to affected communities since the very beginning of the disaster. Several bilateral partners (like New Zealand, China, Japan, United Kingdom, and Australia) had also joined the government efforts and delivered relief items, grants, logistical and technical support as and when required. The Deputy Prime Minister and NEMO through NEMC took the lead and coordinated the overall response. At the same time, several line ministries also coordinated their specific and overlapping cluster activities involving their cluster members and other partners and stakeholders.

The Plan is more of a recovery and reconstruction in nature. In total, out of 42 activities, 7 were articulated, addressing needs in 9 national clusters.

Appendix 2-2 shows the objectives of the recovery plan budget for each cluster.

Table 2.2.1 Recovery Plan Budget by Cluster

Cluster/Sector	Allocated (TOP)	Requested (TOP)	Lead Agencies	No of Activities
WASH	1,000,000	15,000,000	MOH	7
Education	2,940,000	8,000,000	MEIDECCC	1
Shelter (Emergency/ Transitional)	700,000	700,000	MOI	3
Safety & Protection	2,100,000	5,000,000	MIA	5
Food Security /Livelihood	700,000	700,000	MAFF/MOF	10
Logistics	5,000,000	968,863	MOP	1
		2,000,000	HMAF	
		600,000	TFES	1
		2,431,137	NEMO	2
Essential Services	2,100,000	10,211,072	MPEs/PEs	7
Economic and Social Recovery	2,000,000	6,000,000	Finance	1
Emergency Telecommunication	1,000,000	1,000,000	MEIDECCC	4
GRAND TOTAL	**17,540,000**	**52,611,072**		**42**

Source: HTHH Disaster Recovery and Resilience Building Plan 2022 – 2025

(5) Monitoring and Evaluation

Monitoring and evaluation method for this Recovery Plan reflect the TC Gita Disaster Recovery Plan. The Prime Minister's Office will review and report publicly on the implementation of the HTHH

Disaster Recovery and Resilience Building Plan 2022-2025, recovery programmers and progress towards milestones.

In consultation with government ministries, Volcanic Eruption Recovery Committee (VERC), NERC and the sector clusters, the Prime Minister's Office will capture recovery activity indicators into its existing Monitoring and Evaluation Framework to best gauge recovery progress.

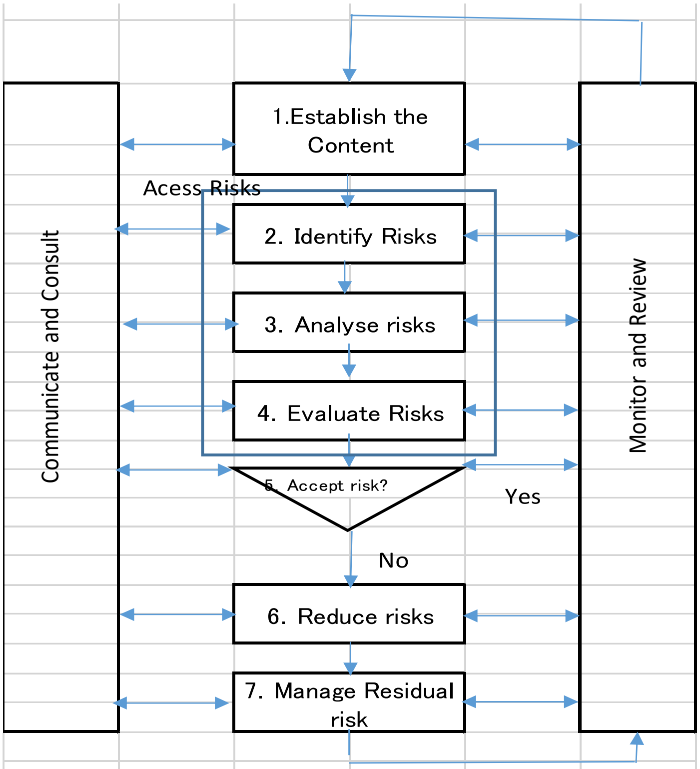
2.2.3. Various disaster management plans

(1) National Emergency Management Plan

The National Emergency Management Plan was prepared in 2009 based on the Emergency Management Act 2007. The law was compiled based on the results of discussions in the Emergency Management Committee in accordance with the law. The plan consists of three parts: Part A is an overview of the country of Tonga, Part B is disaster risk management, and Part C is an emergency response plan.

a) Part B Disaster Risk Management

The project was analyzed using the Comprehensive Hazard and Risk Management (CHARM) tool developed by the South Pacific Applied Geosciences Commission (SOPAC) Climate Change Adaptation Plans.



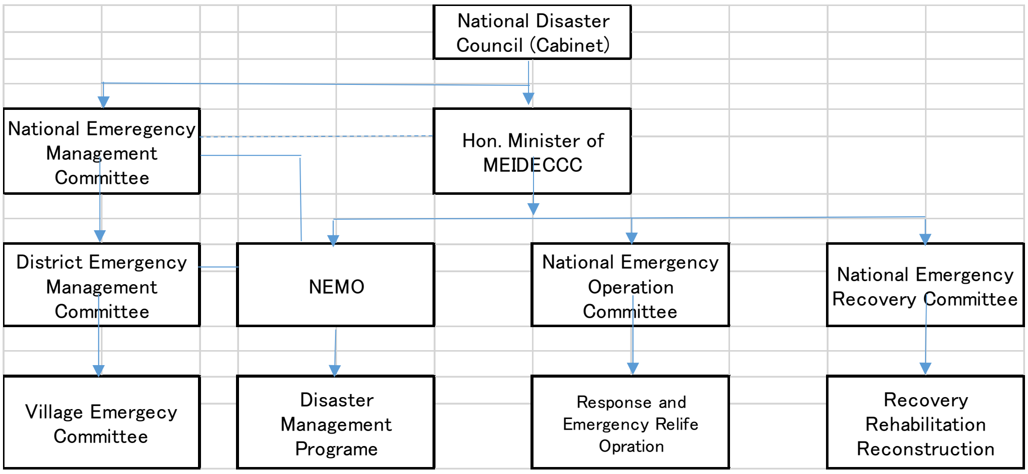
Source: National Emergency Management Plan

Figure 2.2.2 CHARM Risk Management Process Overview

(2) National Response Plan

Tonga's national level emergency response is led by NEMO and is being carried out around the clock. NEMO is staffed with active personnel and works 24 hours a day, 365 days a year. Local and village crisis management committees are in charge.

The emergency response system of Tonga is shown below.



Source: National Emergency Management Plan

Figure 2.2.3 Structure of Organization of the Emergency Response System of Tonga

The emergency response plan describes the role of each ministry and general response procedures. In addition to these plans, actual emergency response is implemented in accordance with detailed procedure manuals and plans.

2.3. Climate Change Management Plan

2.3.1. Joint National Action Plan 2 on Climate Change and Disaster Risk Management (JNAP 2) 2018-2028

(1) Outline of the JNAP 2

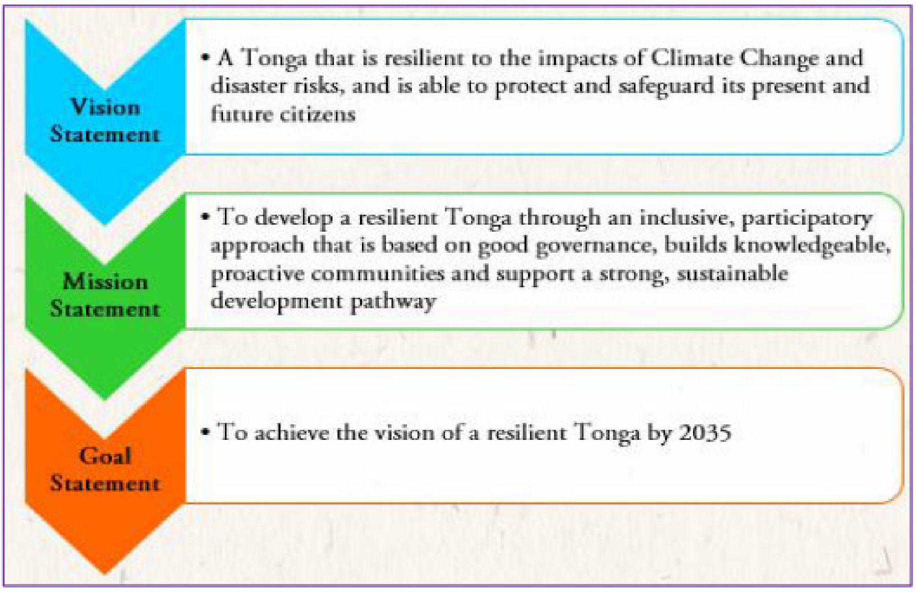
The Government of Tonga formulated and implemented the Joint National Action Plan on Climate Change and Disaster Risk Management (JNAP) for the five-year period 2010 to 2015. The main tasks re to improve the organizational structure of the Government, establish a climate change fund, and formulate climate change policies.

Joint National Action Plan 2 on Climate Change and Disaster Risk Management 2018-2028 (JNAP 2) has been established in May 2018 with financial support from the EU. This plan is in line with the Climate Change Policy formulated in 2016, presenting a vision, mission, and goals, and 10 basic policies, making it a 10-year plan. In addition, six goals are indicated, and a project is formed for each goal. These projects cost a total of approximately $150 million.

The Government of Tonga is implementing these plans, with MEIDECCC as the main agency in charge, and the National Emergency Management Committee (NEMC), which is also a disaster management organization, as the implementing agency.

(2) Vision, Mission, and Goal Statement

JNAP 2 adapted the following vision, mission, objectives, and guiding principles from the Tonga Climate Policy (2016). The Policy and JNAP 2 provide the overarching framework and strategic actions for climate change in Tonga.



Source：Joint National Action Plan 2 on Climate Change and Disaster Risk Management (JNAP 2)

Figure 2.3.1 Vision, Mission, and Goal Statement of JNAP 2

The 10 basic policies indicated in JNAP2 are as follows.

Table 2.3.1 Guiding Principles

	Basic Policy	Summary
1	A resilient Tonga for the future	A Resilient Tonga requires a redesigned approach that brings together traditional knowledge and values with up-to-date knowledge and technology, in order to address the realities of climate change and disaster risks.
2	Strong leadership and good governance	The realization of a Resilient Tonga will require clear, strong and consistent governance.
3	Strong leadership and good governance	A holistic, multi-faceted, multi-sectoral and multi-hazards risk approach will be adopted. Inherent in this approach will be the precautionary principle, early warnings and effective and efficient response and recovery.
4	Integration and mainstreaming	The design and development of a Resilient Tonga will require proactive changes involving an integrated approach to adaptation and mitigation (reducing greenhouse gas emissions) and disaster risk management. This will be mainstreamed into all applicable laws, policies, plans and activities from national to local level.
5	Community ownership, stakeholder participation and collaboration	The realization of a Resilient Tonga will require strong community ownership, participation of all stakeholders, and collaboration between all government ministries as well as the private sector and civil society.

	Basic Policy	Summary
6	Equity and fairness	Initiatives, programs and projects will ensure the equitable accessibility and distribution of all benefits, information and support to marginal and disadvantaged groups, recognizing their differing vulnerabilities and capabilities to climate change and disasters.
7	Gender inclusivity	In recognizing that men and women face different social, environmental, and economic situations, gender issues will be considered in all planning and implementation processes. A better understanding of the vulnerabilities and capacities of different gender groups to deal with climate change and disasters will be promoted.
8	On-going capacity development	On-going capacity development will be required at all levels to ensure a sustained effort towards the common goal of building resilience.
9	Long-term sustainability	Initiatives and programs will be designed to deliver long-term, positive, environmental, social, and economic benefits that are founded on ensuring self-sufficiency at all levels of Tongan society.
10	Multi-disciplinary science and evidence-based responses	Policy formulation, planning and action will be based on scientifically and technically sound data, information and knowledge combine with the value of traditional knowledge.

Source: Joint National Action Plan 2 on Climate Change and Disaster Risk Management (JNAP 2)

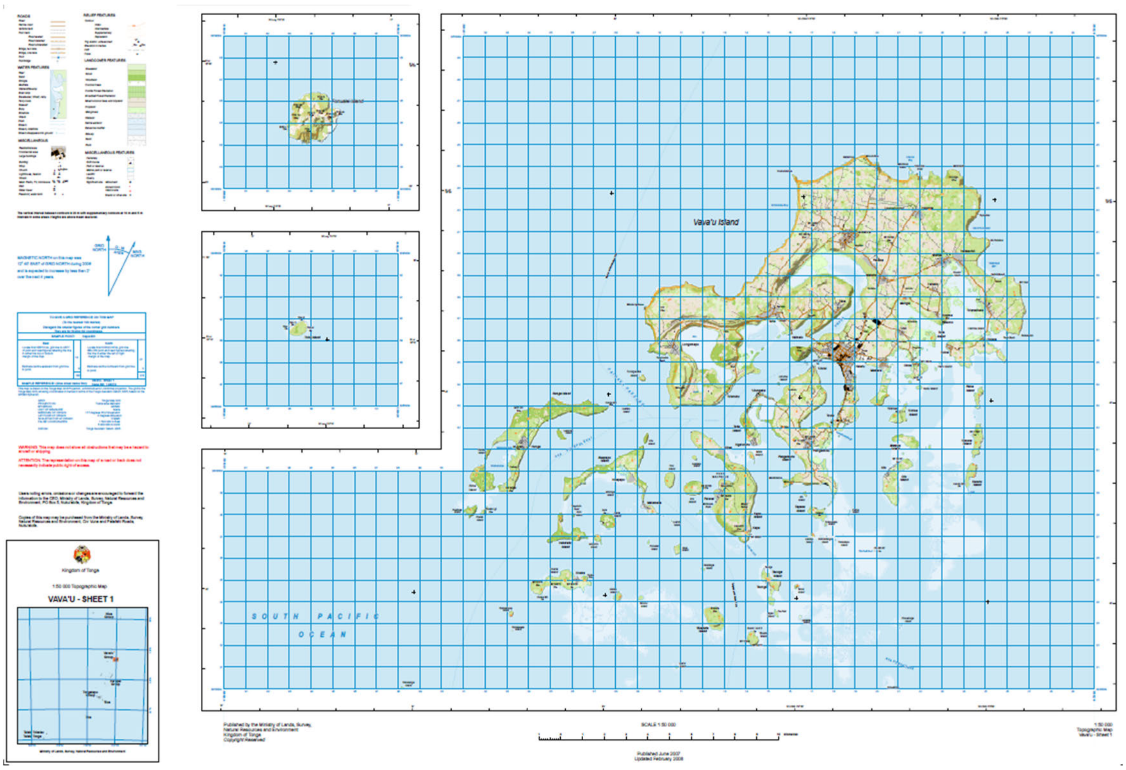
2.4. Topographical Maps and Satellite Images

Topographical maps, satellite images, and GIS data collected from the Tongan government and others are shown below.

2.4.1. Topographical Maps

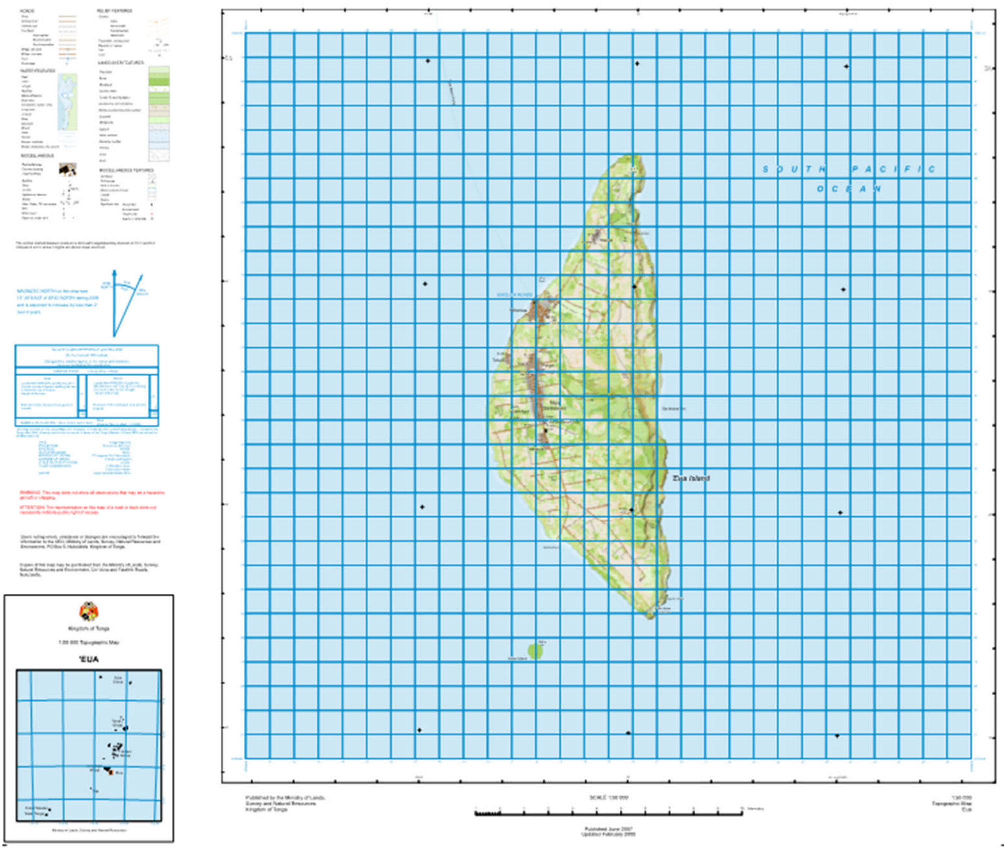
Topographical maps have been published by the Ministry of Land, Survey, Natural Resources and Environment for the main islands of Vava'u, Ha’apai, 'Eua and Tongatapu (Figure 2.4.1 -Figure 2.4.4).

The Vava'u Islands consist of the main island of Vava'u and dozens of surrounding islands. Because of volcanic activity, the topography of the Vava'u Islands is very complicated, with many ups and downs. The Ha'apai Islands also consist of dozens of islands. The topography is relatively flat on the eastern side, such as Lifuka Islands, but on the western side, Tohua Island and Kao Island are volcanic and the topography is steep. On Tongatapu Island, the northern central area where Nuku'alofa is located, is generally lower in elevation and flat. The southern and eastern parts of the island are higher in elevation and have cliffs, while the western part has gentle landforms. 'Eua Island is overall higher and is surrounded by cliffs, with the northwestern part where Ohonua Harbor is located, being the only area with a flat topography.



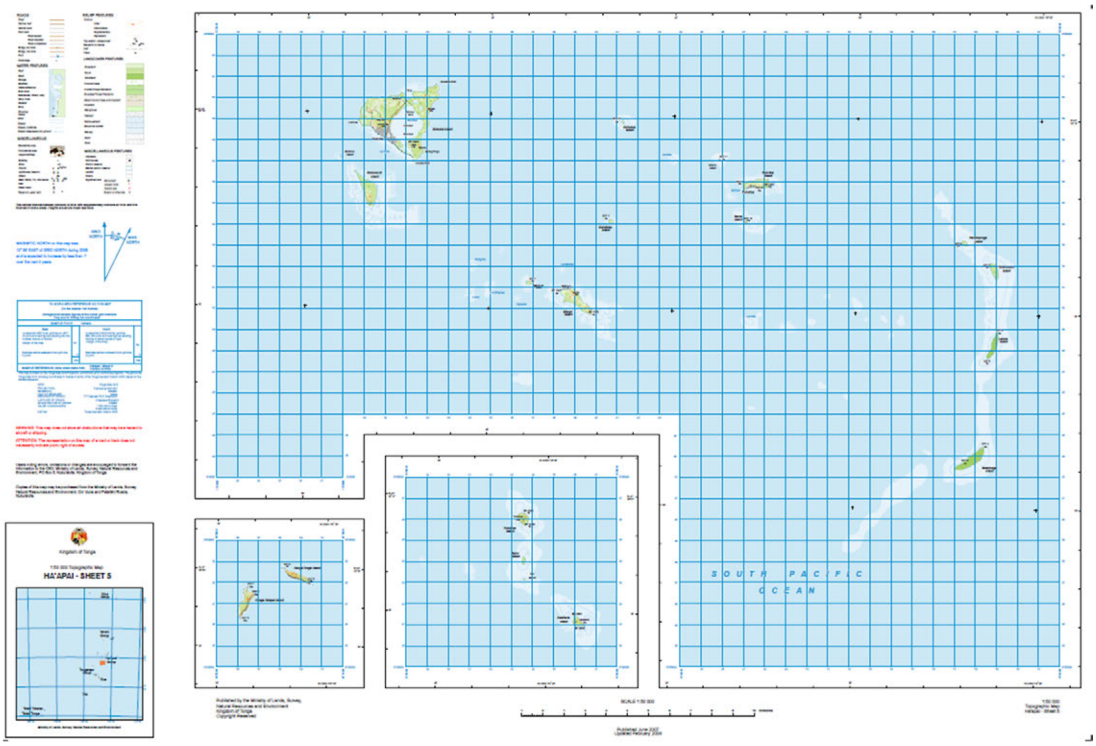
Source: Ministry of Lands, Survey, Natural Resources and Environment

Figure 2.4.1 Topographic map of Vava'u Islands



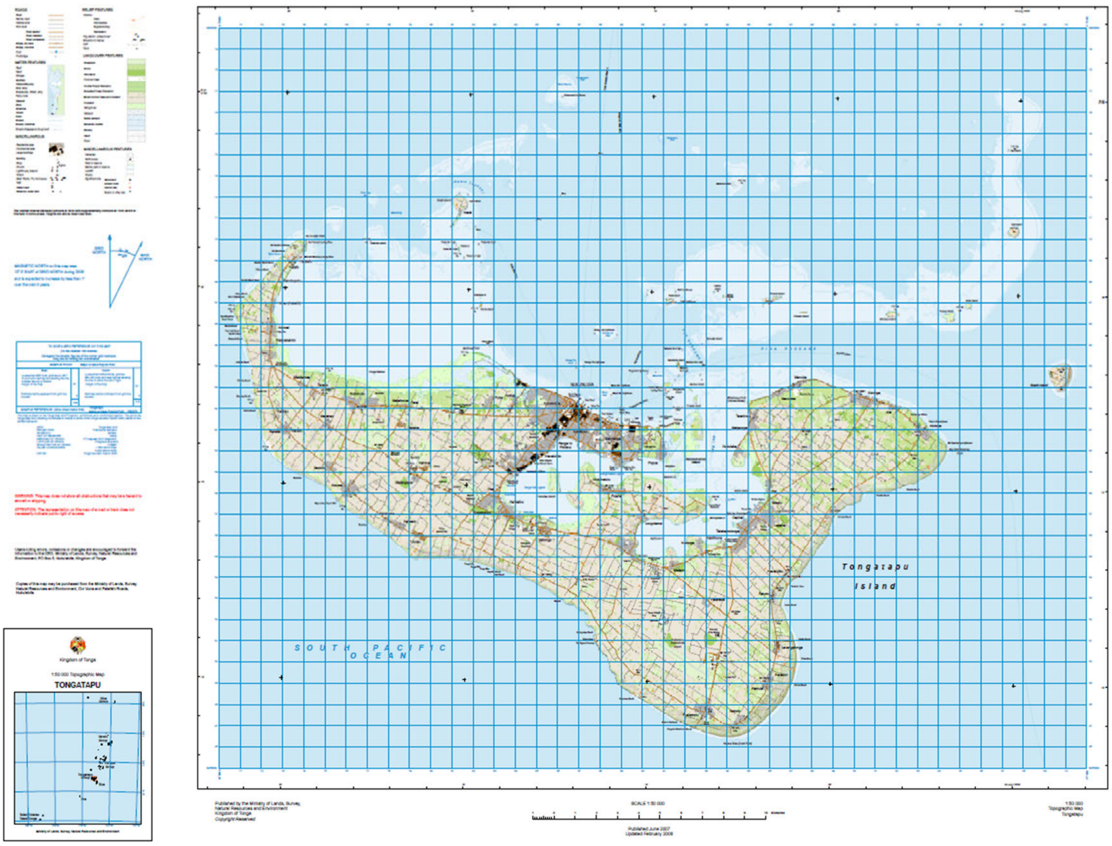
Source: Ministry of Lands, Survey, Natural Resources and Environment

Figure 2.4.2 Topographic Map of Vava'u Islands



Source: Ministry of Lands, Survey, Natural Resources and Environment

Figure 2.4.3 Topographic Map of Ha'apai



Source: Ministry of Lands, Survey, Natural Resources and Environment

Figure 2.4.4 Topographic Map of Tongatapu Islands

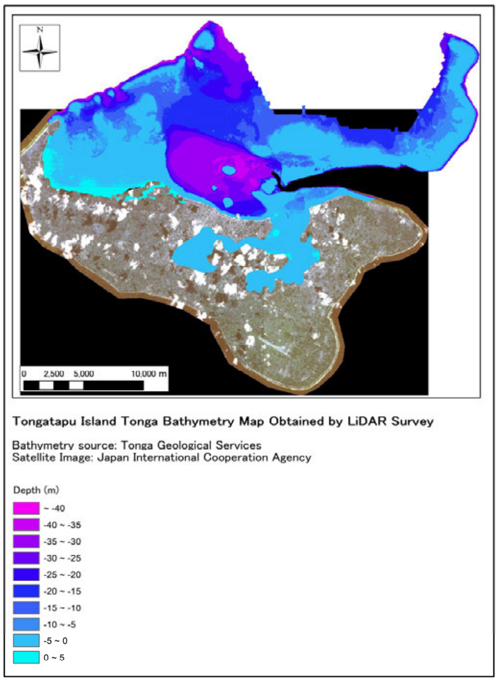
2.4.2. Satellite Images

Satellite imagery of the entire country of Tonga has been compiled by JICA study team as part of the result of "Survey of Damage Caused by Undersea Volcanic Eruption in Tonga". Based on the comparison of the satellite images between before and after tsunami, the inundation was estimated.

Bathymetric data, important for the future study of storm surge and tsunami hazard, were collected. The data were organized for Tongatapu Island and 'Eua Island, which were the main islands under the study.

(1) Bathymetry in shallow water area (LiDAR data)

LiDAR data were mainly acquired for shallow-water areas in Tongatapu Island by Tonga government. The acquired bathymetry distribution is shown below (Figure 2.4.5). For the northern part of Tongatapu Island, shallow-water areas with water depths of 5 m or less are widespread. However, no data were acquired for 'Eua Island.



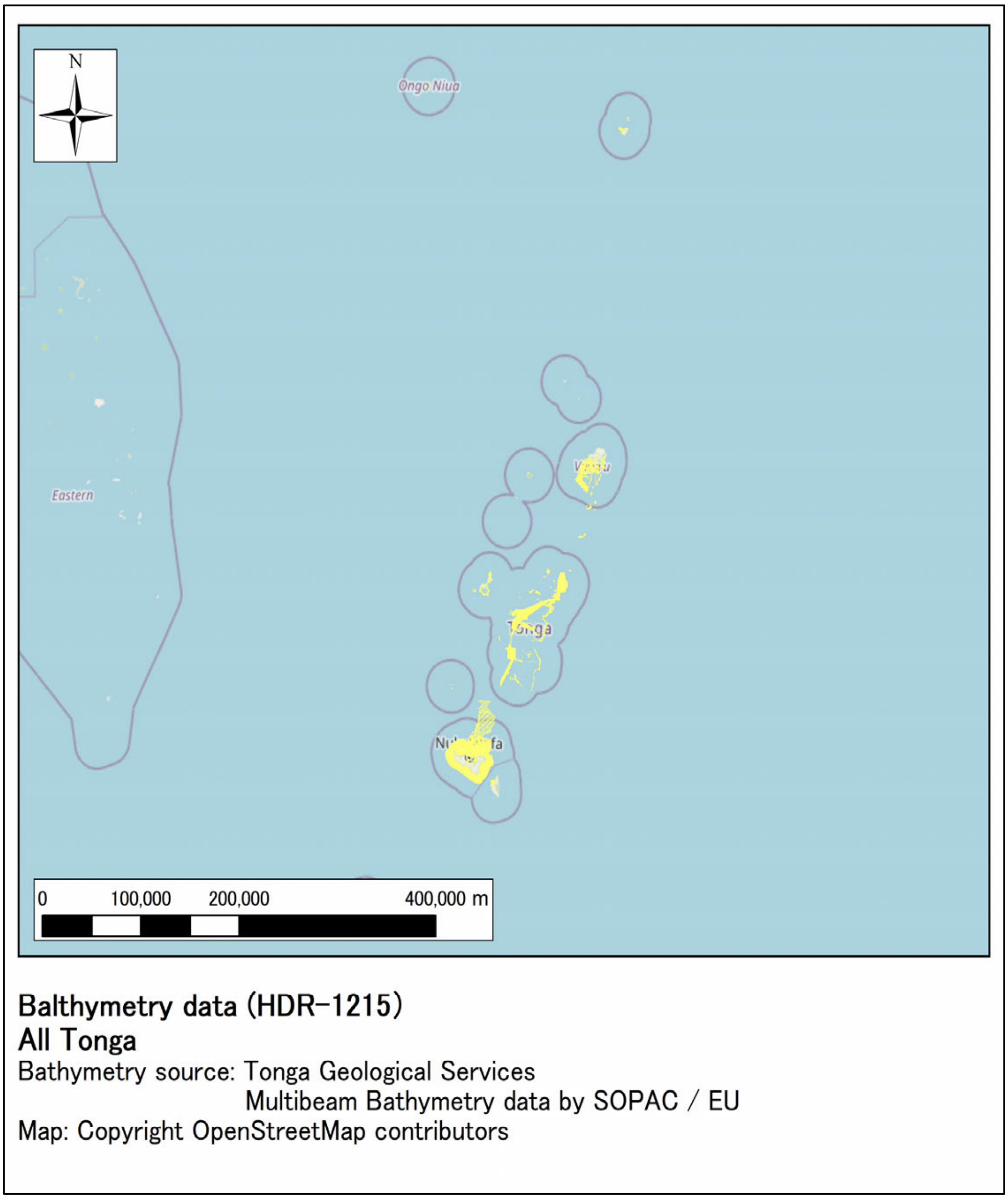
Sources: Tonga Geological Services and JICA Study Team

Figure 2.4.5 Tongatapu Island Bathymetry Map (LiDAR Survey)

(2) Wide area bathymetric survey data

Bathymetric survey data for a wide area were compiled by the South Pacific Applied Geoscience Commission (SOPAC, now part of the Pacific Community (SPC) since 2011) consisting of data at 90m, 30m, 10m, and 5m resolutions. Although the data were obtained over a large area, bathymetric data are only available for the area around the main island, and there are no bathymetric data for the deeper areas. Only the entire obtained bathymetric data (Figure 2.4.6) and the data around Tongatapu Island and 'Eua Island (Figure 2.4.7 - Figure 2.4.10) are shown below.

Note that the bathymetry values have a resolution of up to 5 m, but the acquisition range is almost the same between each resolution. GEBCO[2] data were used for the deeper water areas in the numerical simulations described below.



Sources: Tonga Geological Services, JICA Study Team

Figure 2.4.6 Bathymetric Data of whole Tonga

[2] GEBCO: General Bathymetric Chart of the Oceans, https://www.gebco.net/

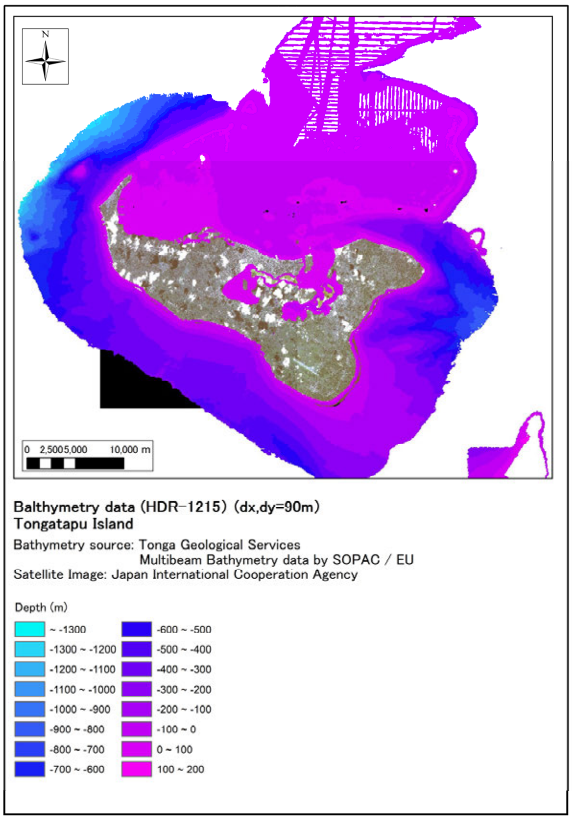


Figure 2.4.7 Bathymetric Data for Tongatapu Island (Resolution 90m)

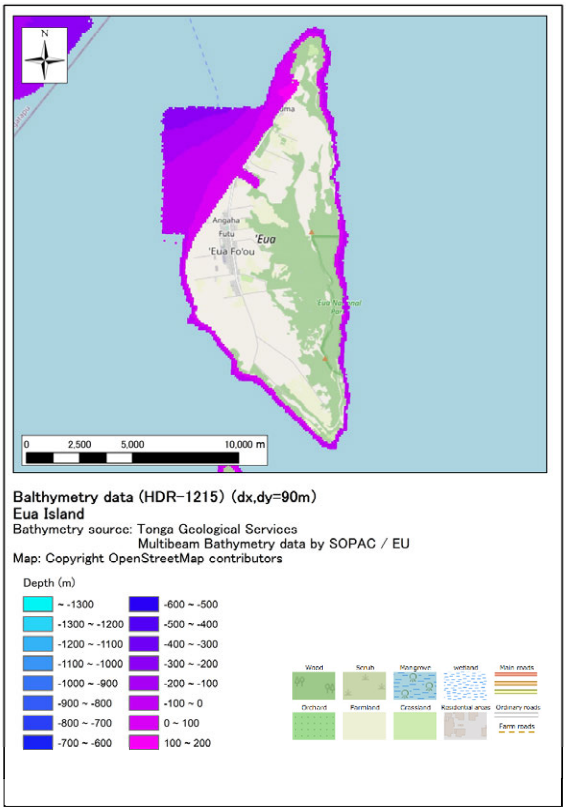


Figure 2.4.8 Bathymetric data for 'Eua Island (Resolution 90m)

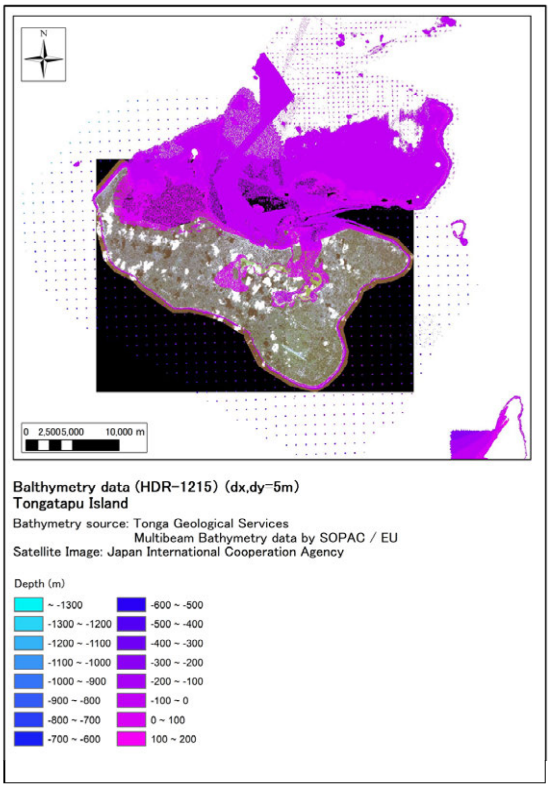


Figure 2.4.9 Bathymetric Data for Tongatapu Island (Resolution 5m)

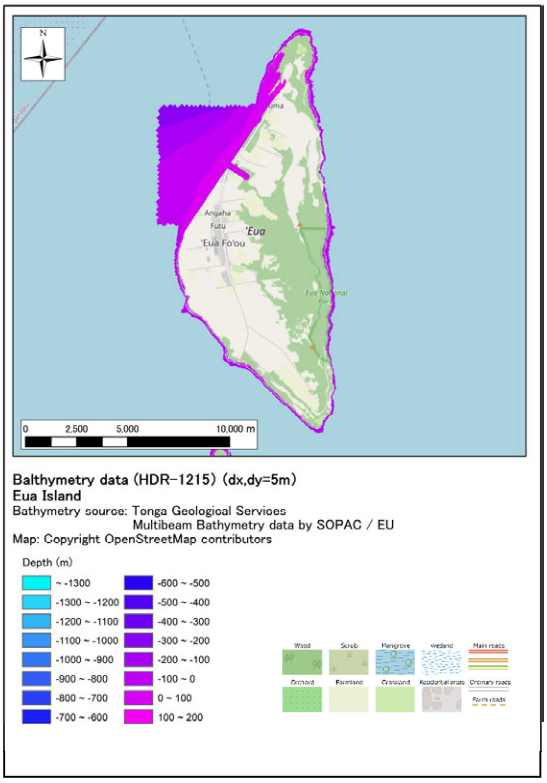


Figure 2.4.10 Bathymetric Data for 'Eua Island (Resolution 5m)

Sources: Tonga Geological Services, JICA Study Team

2.4.3. Exposure Information

GIS data on various infrastructures, such as roads and public buildings, were collected from the Tonga government and organized as exposure information for hazards to be considered in the future. The results are shown below. The background map for each data is basically a topographic map. But for 'Eua Island, a satellite image was used because no topographic map was available. The target for organizing exposure information was Tongatapu Island and 'Eua Island.

(1) Roads

The road network of Tongatapu Island extends over the entire area. The road network is especially dense in the Nuku'alofa City, where the population is concentrated. In the southern and eastern parts of Tongatapu island, which are relatively high in elevation, there are no major roads along the low-lying areas near the coast. There are only access roads to the coast at regular intervals. Because the east side of 'Eua Island is hilly, the road network is concentrated on the west side of the island and is particularly dense near Ohonua at the estuary and Pangai - Kolomarié on the hillside.

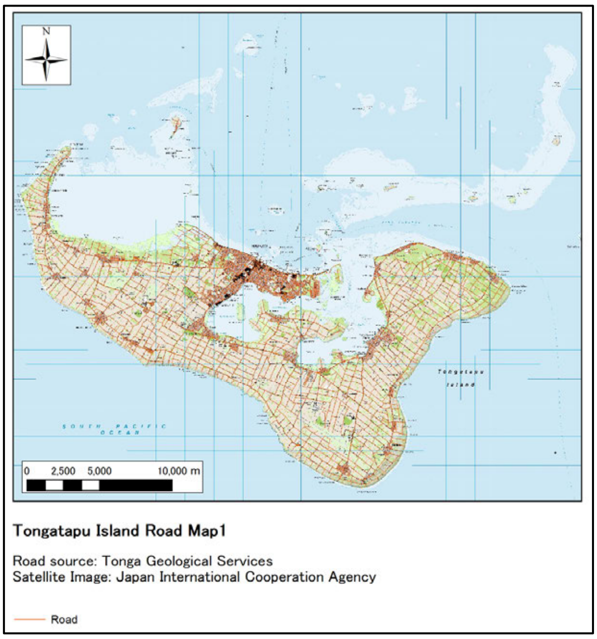


Figure 2.4.11 Tongatapu Island Road Network

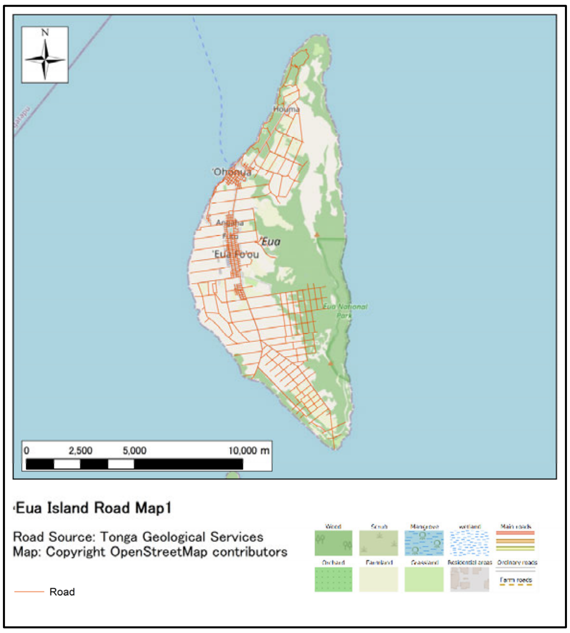


Figure 2.4.12 'Eua Island Road Network

Sources: Tonga Geological Services, JICA Study Team

(2) Critical Facilities

The layout of critical facilities is shown below. Police stations and medical institutions are located in populated areas. In addition, shelters are located in major settlements in Tongatapu Island. Regarding the layout, 'Eua Island is similar, but has fewer facilities than Tongatapu Island. As a side note, not all-important facilities are located at higher elevations, but some are located at lower elevations.

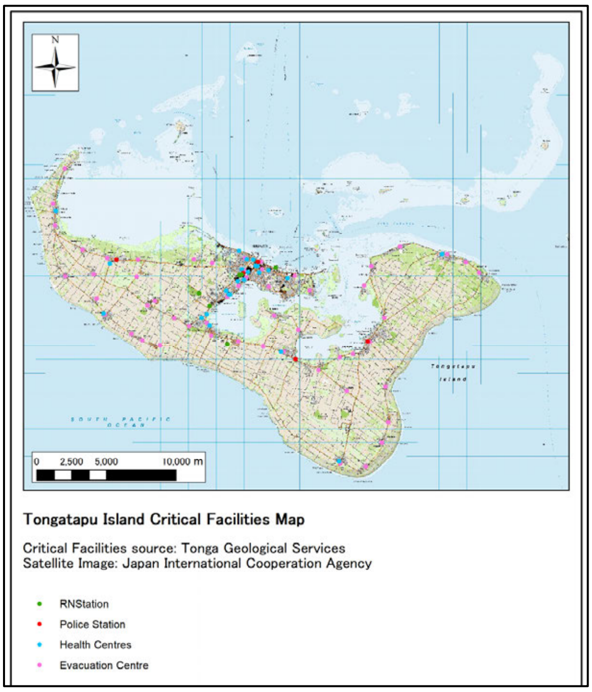


Figure 2.4.13 Critical Facilities Map in Tongatapu Island

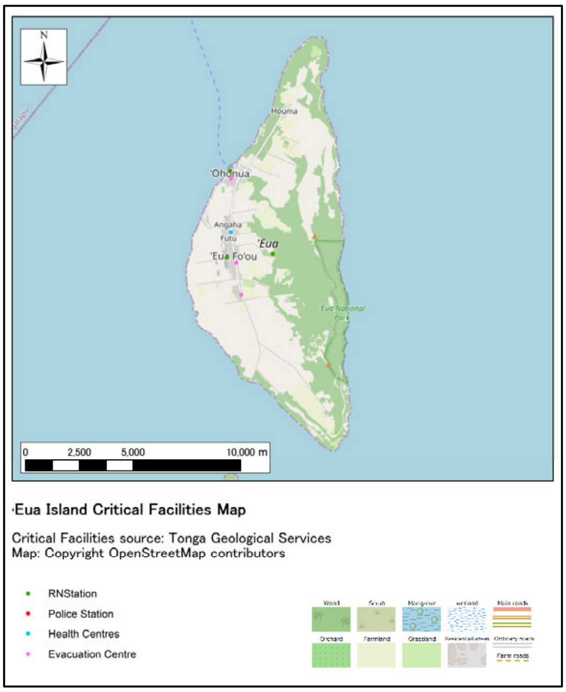
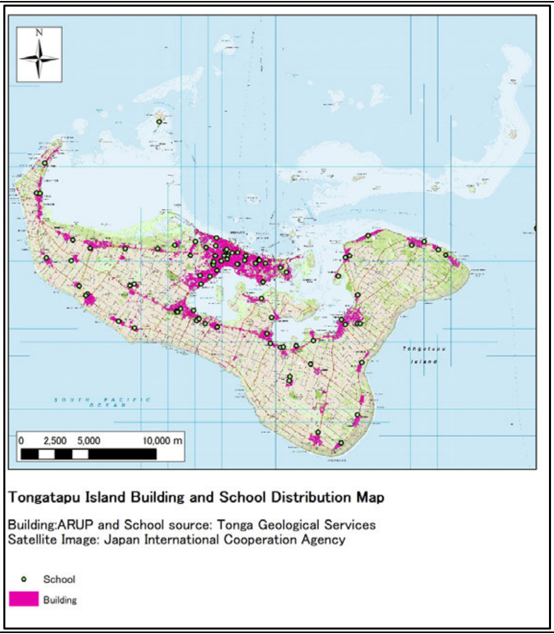


Figure 2.4.14 Critical Facilities Map in 'Eua Island

Sources: Tonga Geological Services; JICA Study Team

(3) Buildings and Schools

The building and structure location maps are shown below (Figure 2.4.15 - Figure 2.4.16). Buildings are concentrated in villages, and schools are located in only one village. Nuku'alofa City has a particularly high concentration of buildings and schools. 'Eua Island is not shown because of lack of building data.



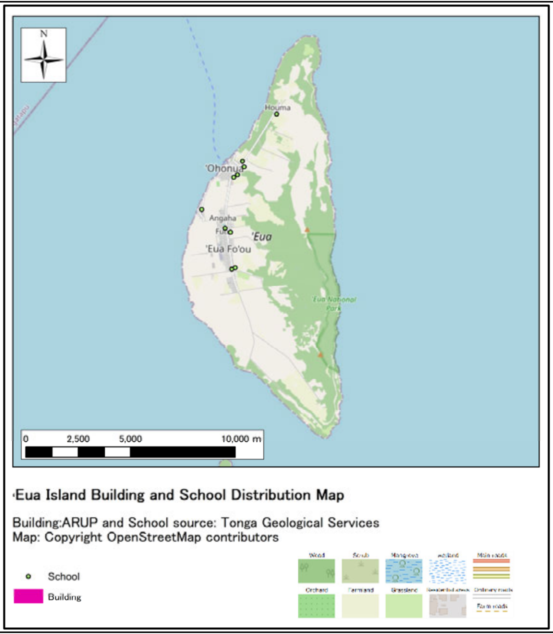
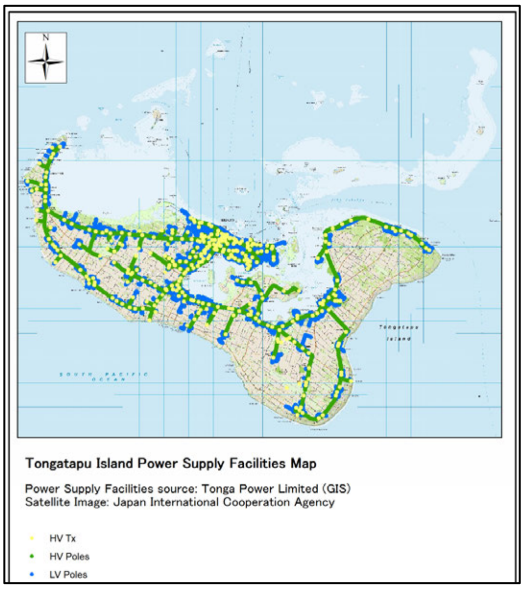


Figure 2.4.15 Buildings and Schools Distribution Map in Tongatapu Island	Figure 2.4.16 Buildings and Schools Distribution Map in 'Eua Island

Sources: Tonga Geological Services; JICA Study Team

(4) Power Facilities

The layout of power facilities and the solar streetlight facility in Tongatapu Island is shown in Figure 2.4.17and Figure 2.4.18



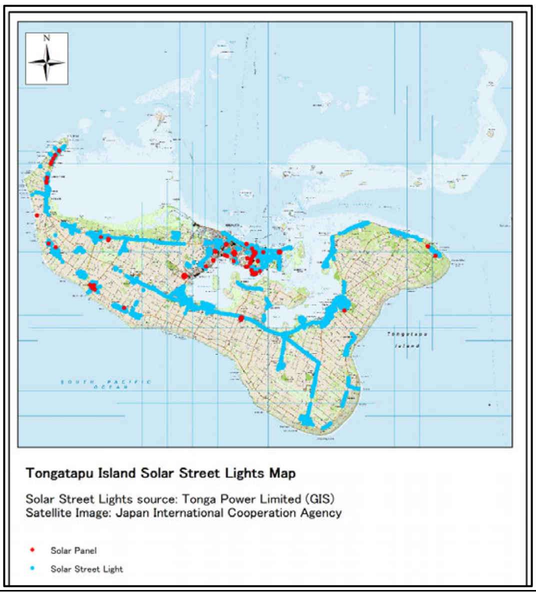


Figure 2.4.17 Power Generation and Feeding Facility in Tongatapu Island	Figure 2.4.18 Street Lights Map in Tongatapu Island

Sources: Tonga Power Limited, JICA Study Team

(5) Water Supply Facilities

The locations of water supply facilities, and of wells and water supply facilities in Tongatapu are shown in Figure 2.4.19 and Figure 2.4.20. On Nuku'alofa City, Tongatapu Island, the water supply is provided by a water supply system using wells. The 'Eua Island are in Figure 2.4.21 and Figure 2.4.22.

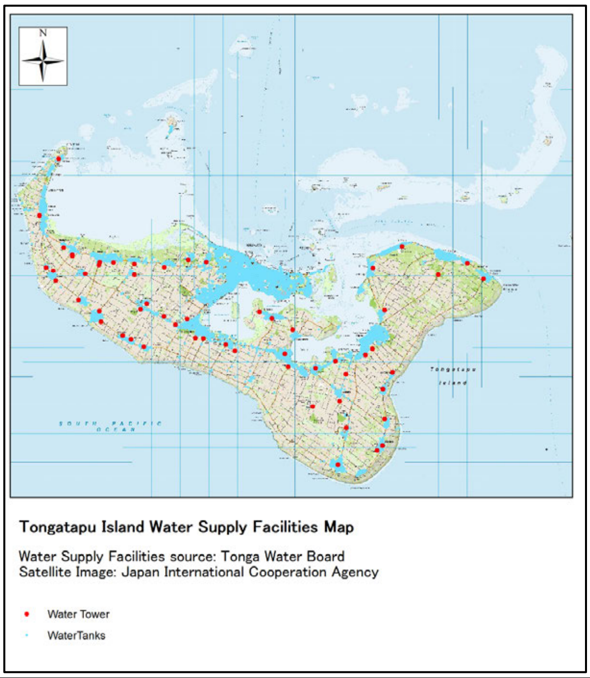


Figure 2.4.19 Water Supply Facilities in Tongatapu Island

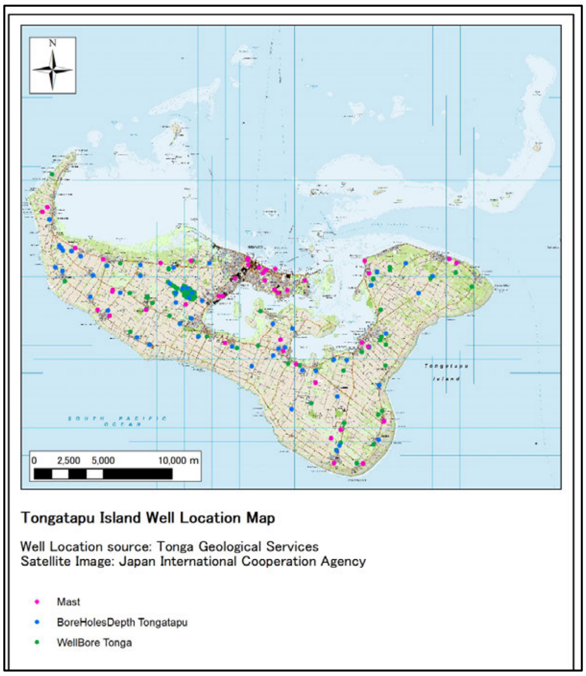


Figure 2.4.20 Well Locations in Tongatapu Island

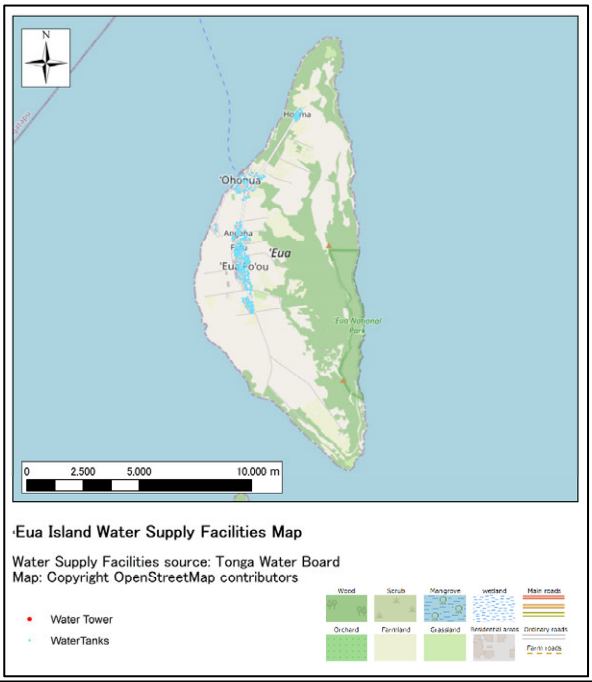


Figure 2.4.21 Water Supply Facilities in 'Eua Island

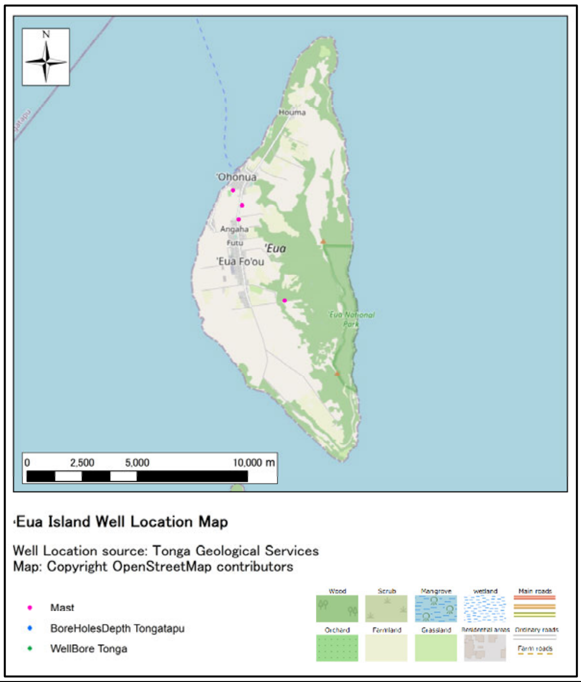
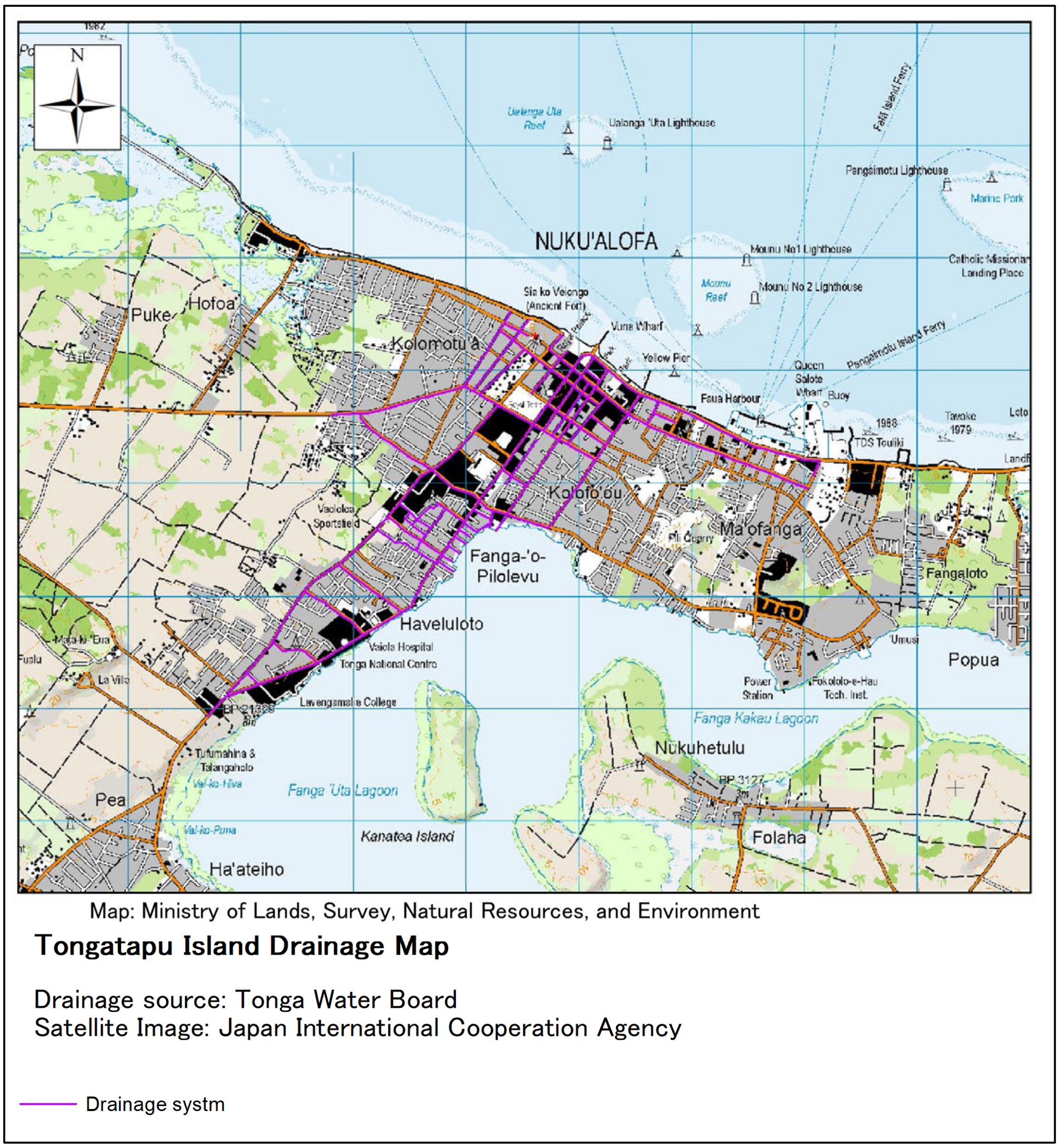


Figure 2.4.22 Well Locations in 'Eua Island

Sources: Tonga Water Board, JICA Study Team

(6) Drainage facilities

The location of the drainage facilities is shown in Figure 2.4.23. Only Nuku'alofa City has detailed data of drainage facilities.

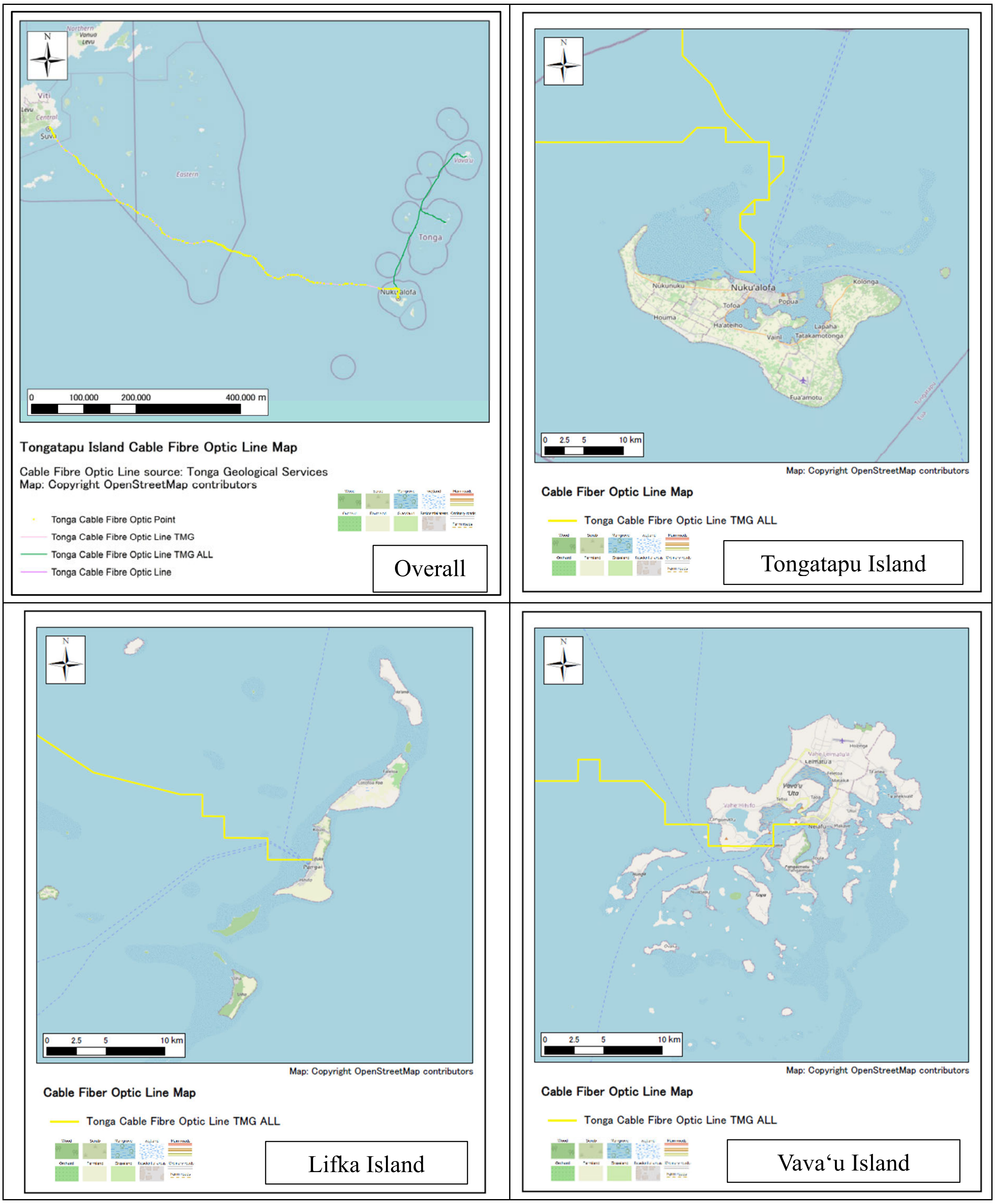


Sources: Tonga Water Board, JICA Study Team

Figure 2.4.23 Drainage Facility Map in Nuku'alofa City

(7) Submarine Cables

A diagram of the submarine cable arrangement is shown in Figure 2.4.24. Submarine cables are connected from Australia to Tongatapu Island and from Tongatapu Island to other islands. Both submarine cables were reported to have been cut by the 2022 HTHH volcanic eruption, but the cables connecting internationally was recovered on February, and others are recovered on July 2022.

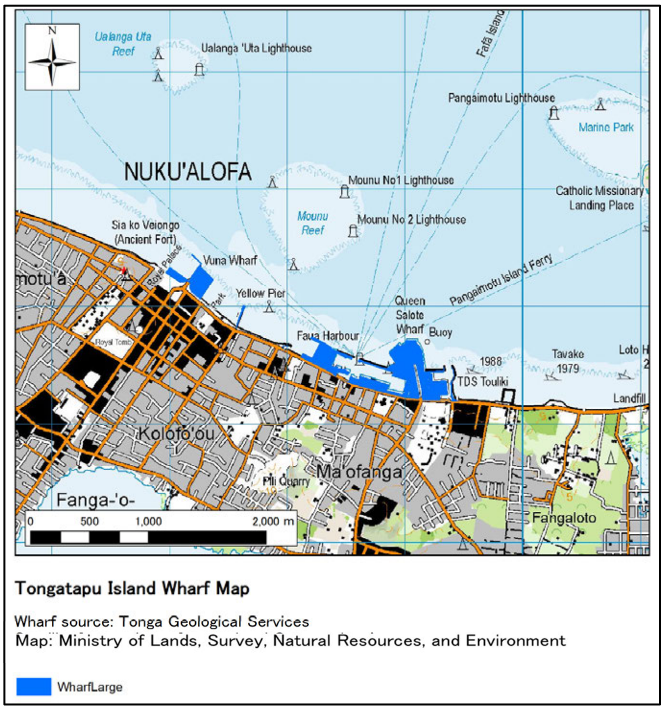


Sources: Tonga Geological Services, JICA Study Team

Figure 2.4.24 Fiber Optic Line Map

(8) Port Facilities

The location of port facilities in Tongatapu and 'Eua Islands are shown in Figure 2.4.25 and Figure 2.4.26. Tongatapu Island has a large port facility at Nuku'alofa City, while 'Eua Island has a port facility at Ohonua, which is located at the mouth of a river.



Sources: Tonga Geological Services, JICA Study Team

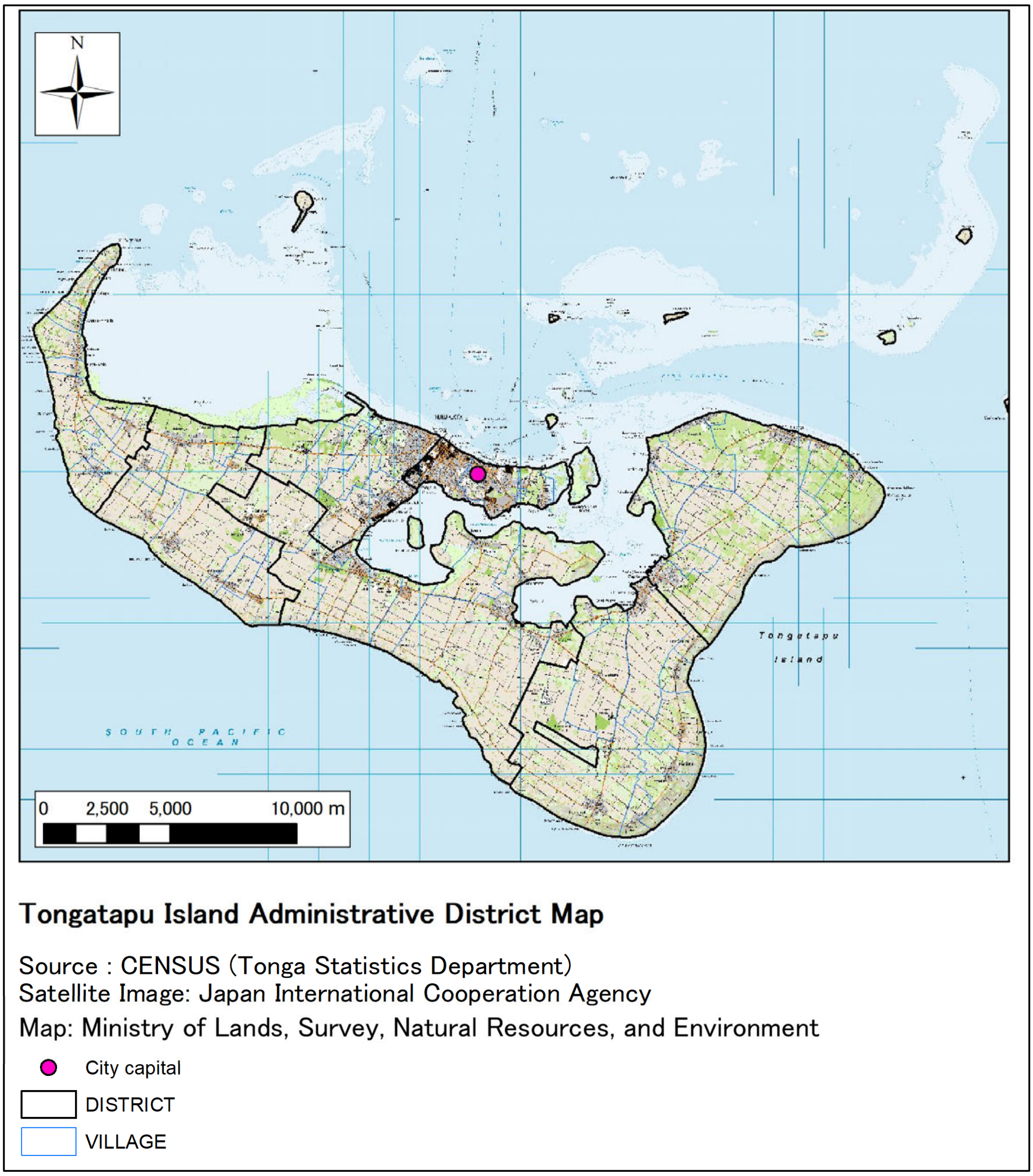
Figure 2.4.25 Port Facilities in Tongatapu Island

Sources: Tonga Geological Services, JICA Study Team

Figure 2.4.26 Port Facilities in 'Eua Island

(9) Administrative Districts

A map of the administrative districts of Tongatapu Island is shown in Figure 2.4.27. Tongatapu Island is divided into regions, which are further divided into villages.

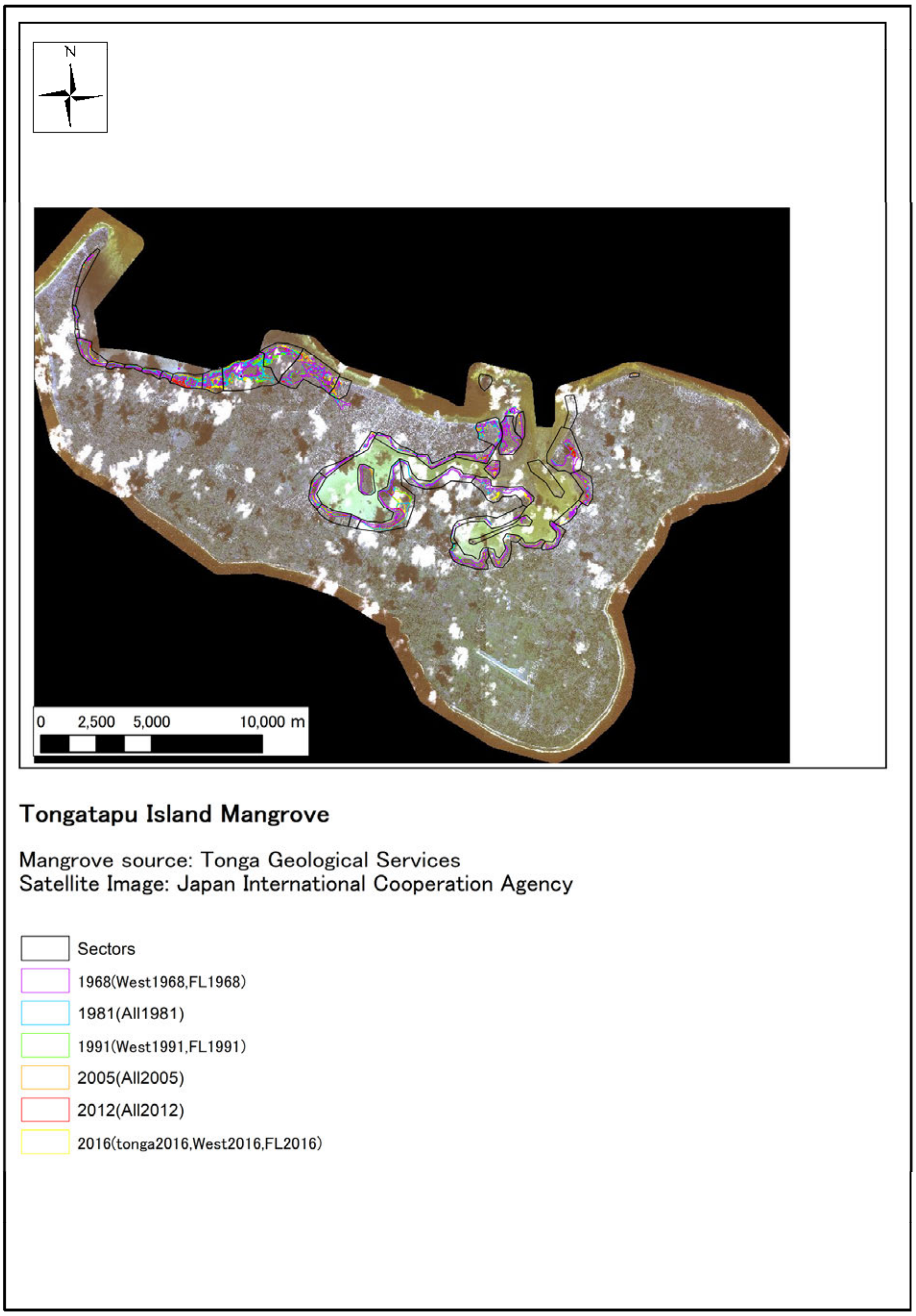


Source: Tonga Statistics Department, JICA Study Team

Figure 2.4.27 Administrative District Map in Tongatapu Island

(10) Mangroves

The distribution of mangroves has been surveyed since 1968. The distribution map of mangroves on Tongatapu Island is shown in Figure 2.4.28. Mangroves are mainly distributed in the northwestern and central lagoons of Tongatapu Island.

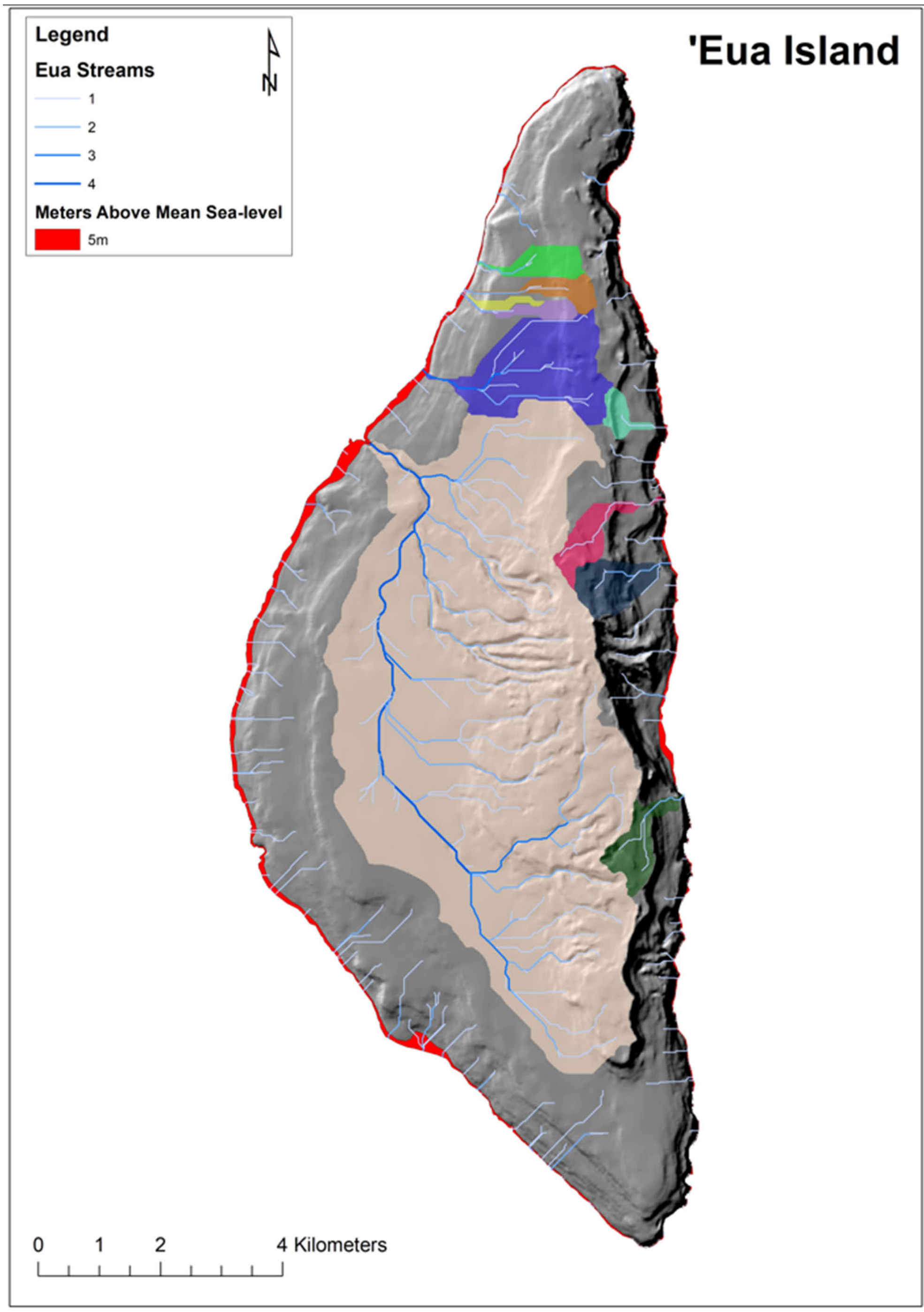


Sources: Tonga Geological Services, JICA Study Team

Figure 2.4.28 Mangrove Distribution Map in Tongatapu Island

(11) Rivers ('Eua Island)

'Eua Island has a river that empties into the sea in front of Ohonua village, which is the center of the island (Figure 2.4.29). 'Eua Island is a hilly island with no low-lying areas except at the mouth of the river, which flows into the west from the hills in the eastern part of the island. Port facilities are located at the mouths of the rivers.



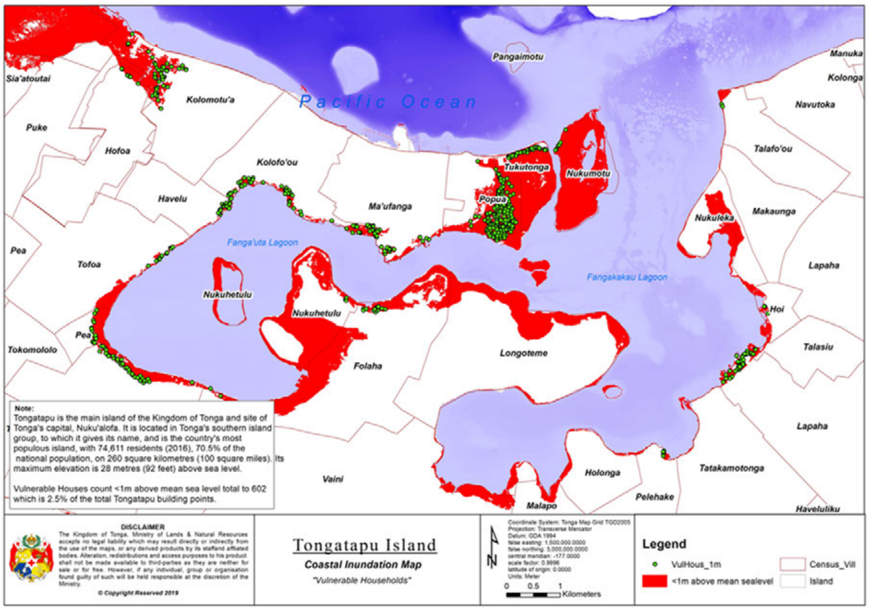
Source: Tonga Geological Services

Figure 2.4.29 Rivers in 'Eua Island

2.4.4. Hazard Map

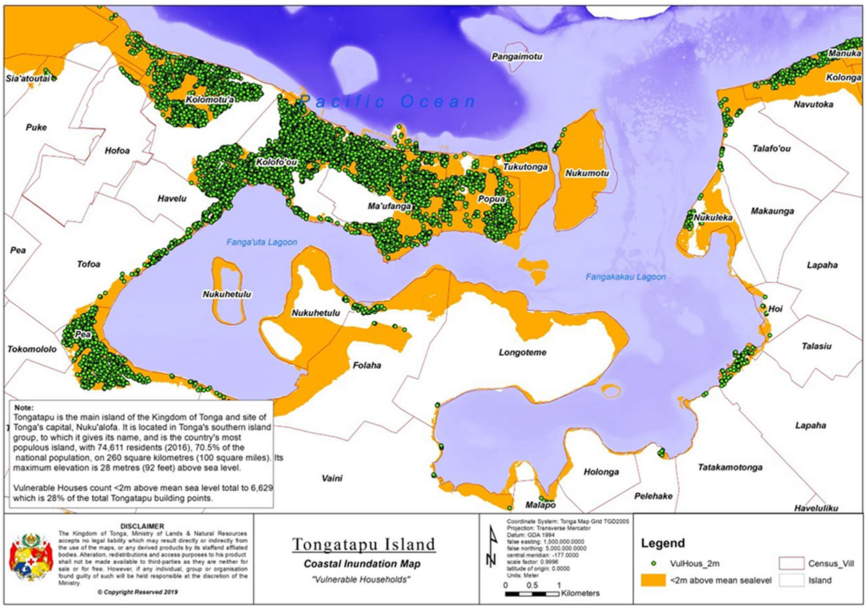
(1) Inundation Map

Inundation hazard maps for the coastal areas prepared by the Government of Tonga are shown in Figure 2.4.30 to Figure 2.4.34. These are risk maps for coastal disasters based on the ground level of Tongatapu Island. The risk of these maps are organized by examining what kind of damage would occur if the water level rises up to 3 meters due to a storm surge or tsunami.



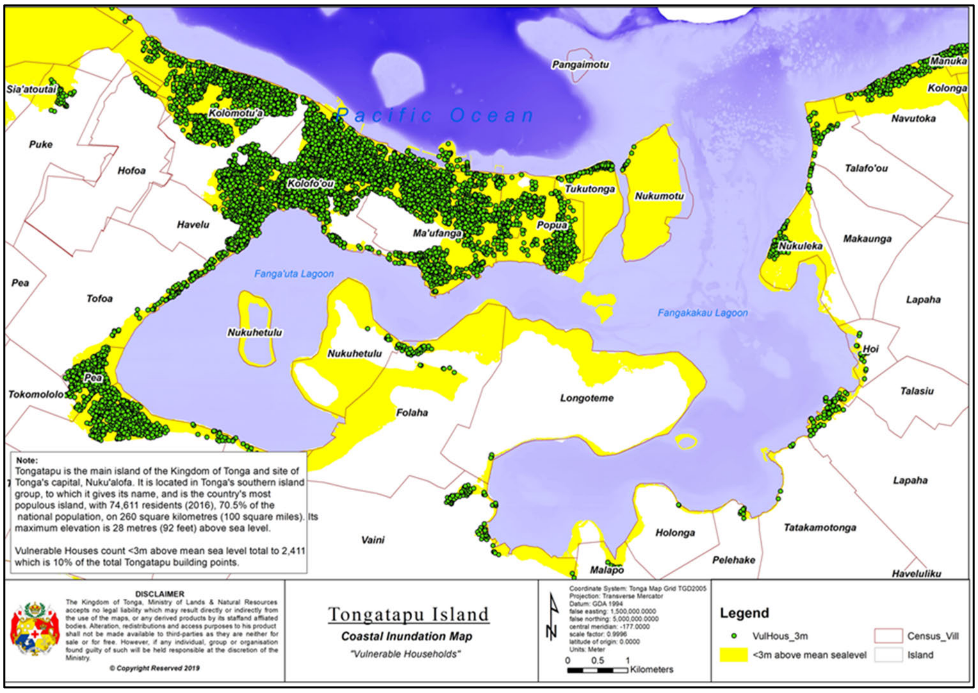
Source: Ministry of Lands and Natural Resources

Figure 2.4.30 Coastal Inundation Map (Water Level Rises to 1 m above Mean Sea Level)



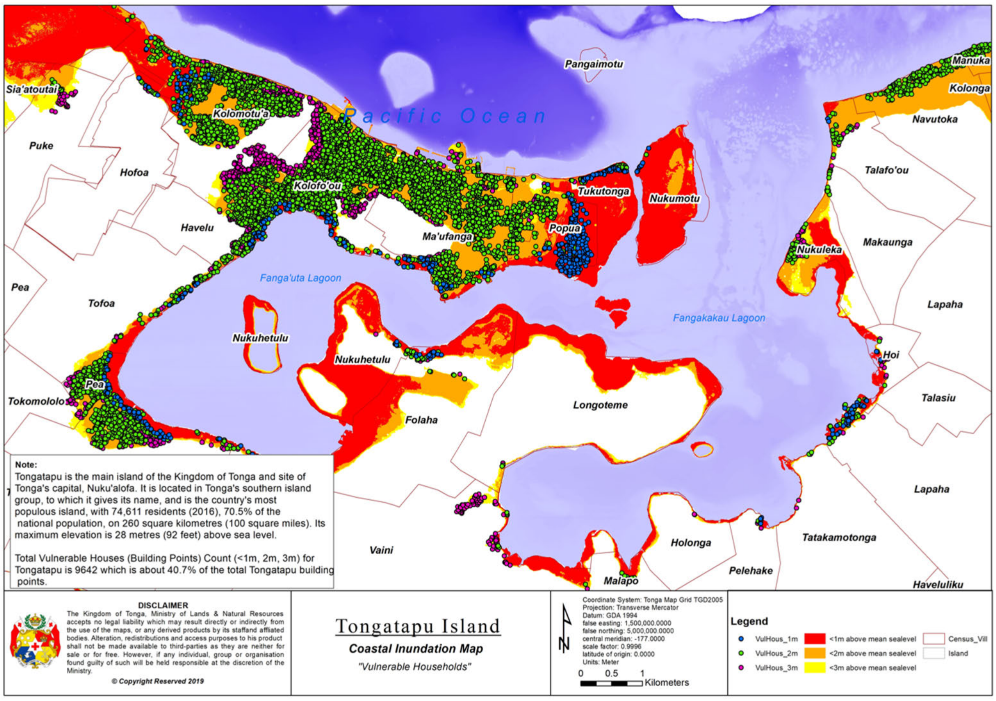
Source: Ministry of Lands and Natural Resources

Figure 2.4.31 Coastal Inundation Map (Water Level Rises 2 m above Mean Sea Level)



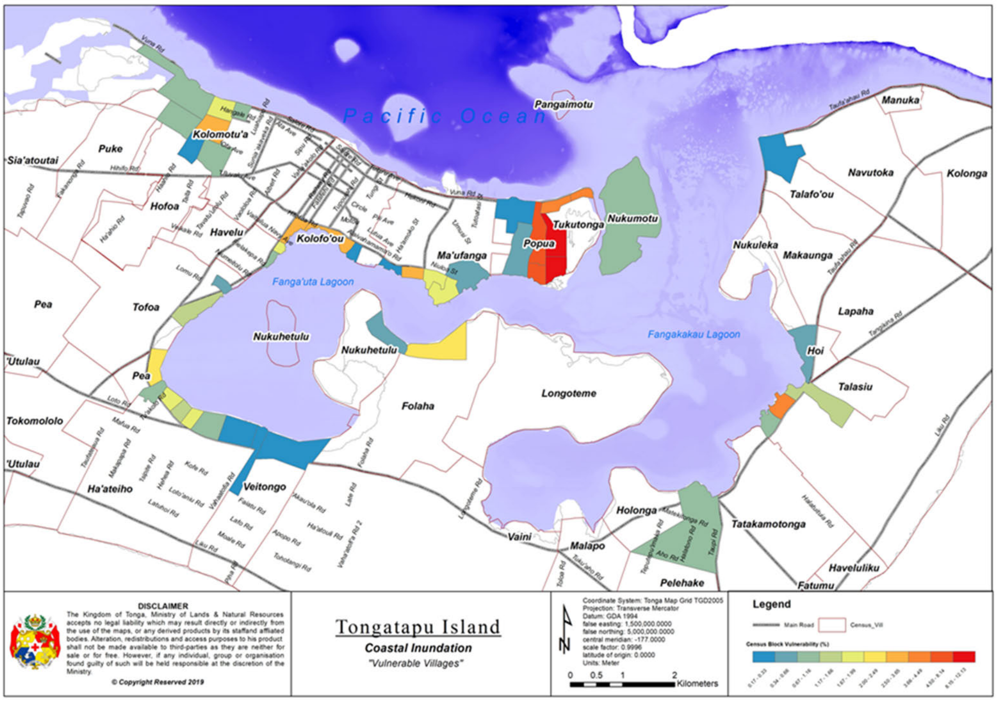
Source: Ministry of Lands and Natural Resources

Figure 2.4.32 Coastal Inundation Map (Water Level Rises 3 m above Mean Sea Level)



Source: Ministry of Lands and Natural Resources

Figure 2.4.33 Integrated Coastal Inundation Map (Water Level Rises 1, 2 and 3m)



Source: Ministry of Lands and Natural Resources

Figure 2.4.34 Villages Vulnerable to Coastal Inundation Hazards (Water Level Rises 3 m above Mean Sea Level)

2.5. Documents Published by International Donors

The list of risk information on the Tonga prepared by other international development partners is presented in Table 2.5.1. Risk assessments for the Tonga have been conducted by other international donors. A risk assessment is mainly concerned with the assumed maximum risk.

Table 2.5.1 Published Risk Information on Tonga

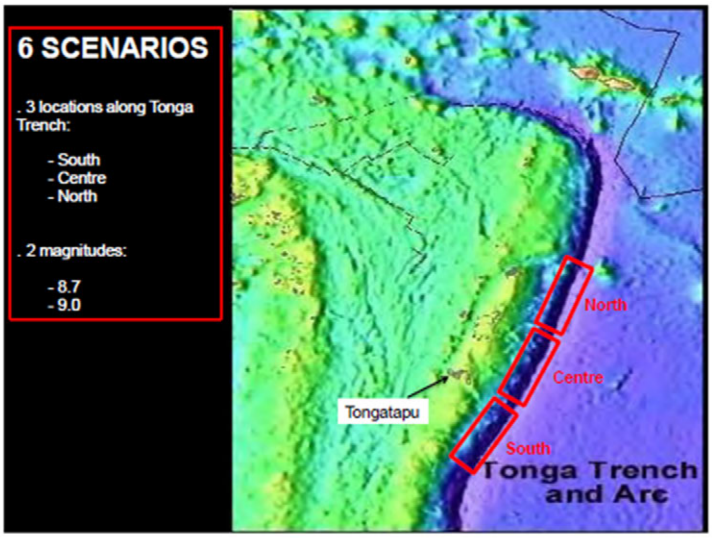
No.	Organization	Data Name	Contents
1.	SOPAC South Pacific Applied Geoscience Commission	Southwest Pacific Tsunami Risk Assessment Capacity Enhancement (Phase 3) Tsunami Simulation Map (SOPAC 2012)	Tsunami risk assessment
2.	IDMC Internal Displacement Monitoring Center	Sudden-Onset Hazards and the Risk of Future Displacement in Tonga	Risk assessment of storm, earthquake, and tsunami disasters
3.	UN OCHA United Nations Office for the Coordination of Humanitarian Affairs	TONGA: Natural Hazard Risks	Risk assessment of earthquakes, volcanoes, and tropical cyclones
4.	ECHO European Civil Protection and Humanitarian Aid Operations	Tonga and Pacific Ocean | Volcanic eruption and tsunami – DG ECHO Daily Map | 17/01/2022	Assessment of the 2022 underwater volcanic eruption of HTHH.

Source: JICA Study Team

2.5.1. South Pacific Applied Geoscience Commission[3] (SOPAC)

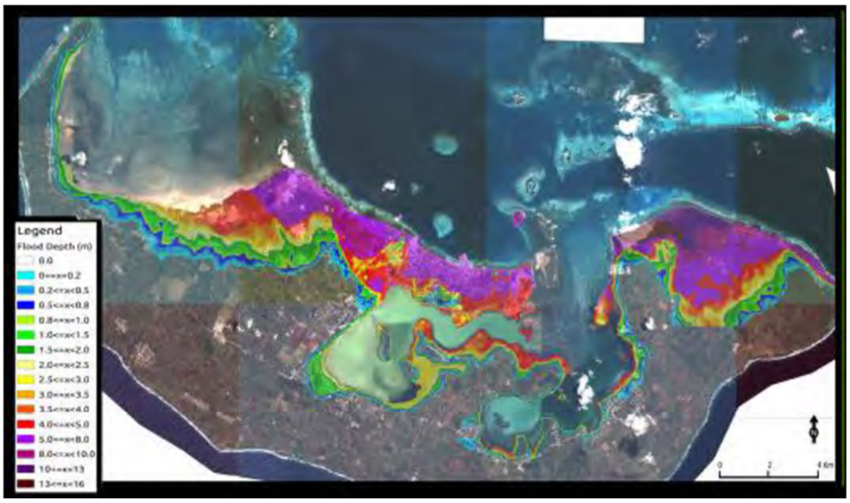
Detailed tsunami hazard maps are available for the Tongatapu Island area, and these are from the Southwest Pacific Tsunami Risk Assessment Capacity Enhancement (Phase 3) Tsunami Simulation Map prepared by SOPAC in 2012.

The tsunami hazard maps produced by SOPAC were based on six scenarios with three tsunami sources (epic enters) in the Tonga Trench, located east of Tongatapu Island: north, central, and south, and with an earthquake magnitude of 8.7 or 9.0 (Figure 2.5.1). The worst of the six scenarios is a magnitude 9.0 earthquake occurring in the middle of the Tonga Trench (Figure 2.5.2), while the lightest scenario is a magnitude 8.7 earthquake occurring on the north side of the Tonga Trench.



Source: SOPAC 2012

Figure 2.5.1 Wave Source Area and Six Tsunami Scenarios

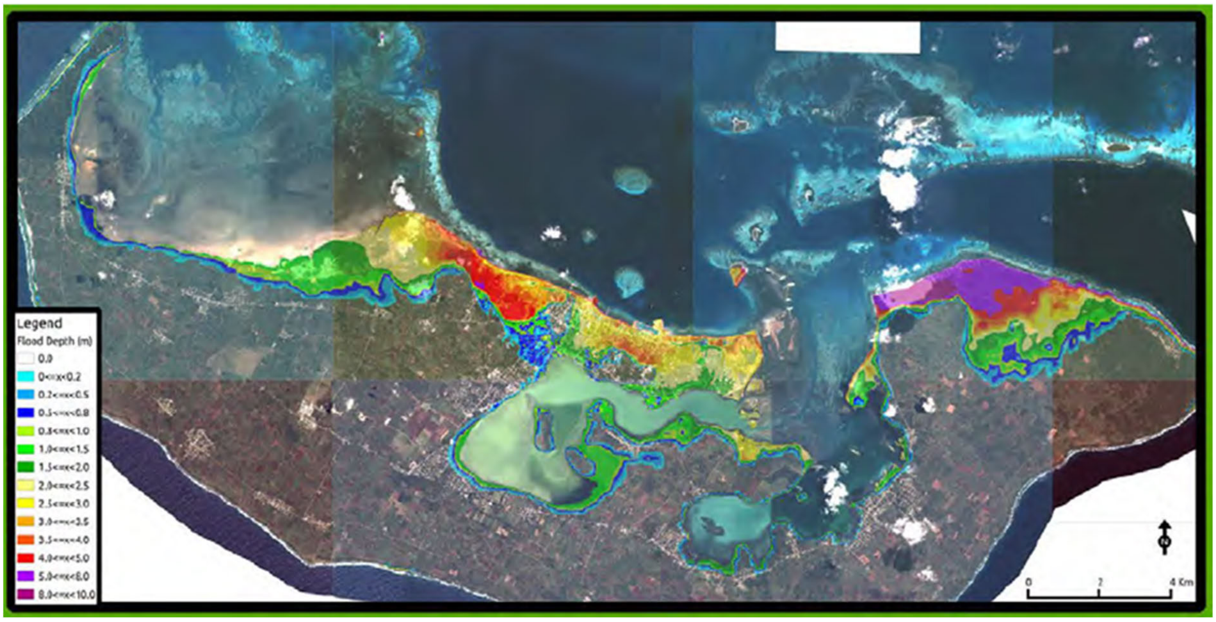


Source: SOPAC 2012

Figure 2.5.2 Maximum Tsunami Inundation Depth (worst-case scenario) for an M9.0 Earthquake in the Center of the Tonga Trench

[3] South Pacific Applied Geoscience Commission

In "The Project for Introduction of Nationwide Early Warning System and Strengthening Disaster Communications" (JICA), the scenario under which facility and equipment planning is to be conducted will be for the "M8.7 earthquake at the center of the Tonga Trench (east of Tongatapu Island)," which is the most likely earthquake and most influential epicenter setting to occur on Tongatapu Island out of the six scenarios assumed in SOPAC 2012 (Figure 2.5.3). In the SOPAC 2012 report, the above worst-case scenario is considered excessive, and it is important to prepare for the possible worst-case scenario for tsunami disaster prevention. However, the probability of such an earthquake is low, so the worst-case scenario of "an M8.7 earthquake in the central Tonga Trench (east of Tongatapu Island)" is adopted. The first reason is that in the past 150 years of disaster records, the largest earthquake was M8.3 in 1977, and there is no record of a M9.0 earthquake. Second, although it is important to prepare for possible worst-case scenarios for tsunami disaster prevention, the probability of such an earthquake is low. Based on the above, JICA Study Team adopted the "M8.7 earthquake at the center of the Tonga Trench (east of Tongatapu Island)" from the six scenarios assumed in SOPAC.



Source: SOPAC2012

Figure 2.5.3 Maximum Tsunami Inundation Depth for an M8.7 Earthquake in the Center of the Tonga Trench

2.5.2. Internal Displacement Monitoring Center[4] (IDMC)

IDMC assesses the risk of hazards for cyclone storm disasters as well as earthquake and tsunami disasters. Each risk map is shown in Figure 2.5.4 to Figure 2.5.6.

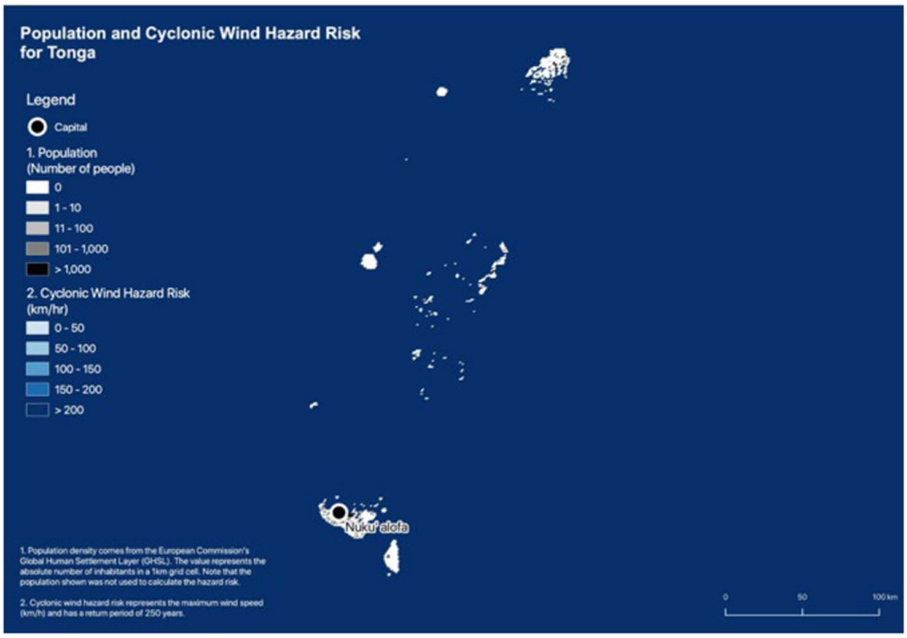
Here are the key assessments:

- Regarding storm hazards, the area around Tonga is risk-assessed to have a maximum wind speed of 200 km/hr. (55 m/s), with a 250-year probability of recurrence.

[4] Internal Displacement Monitoring Center

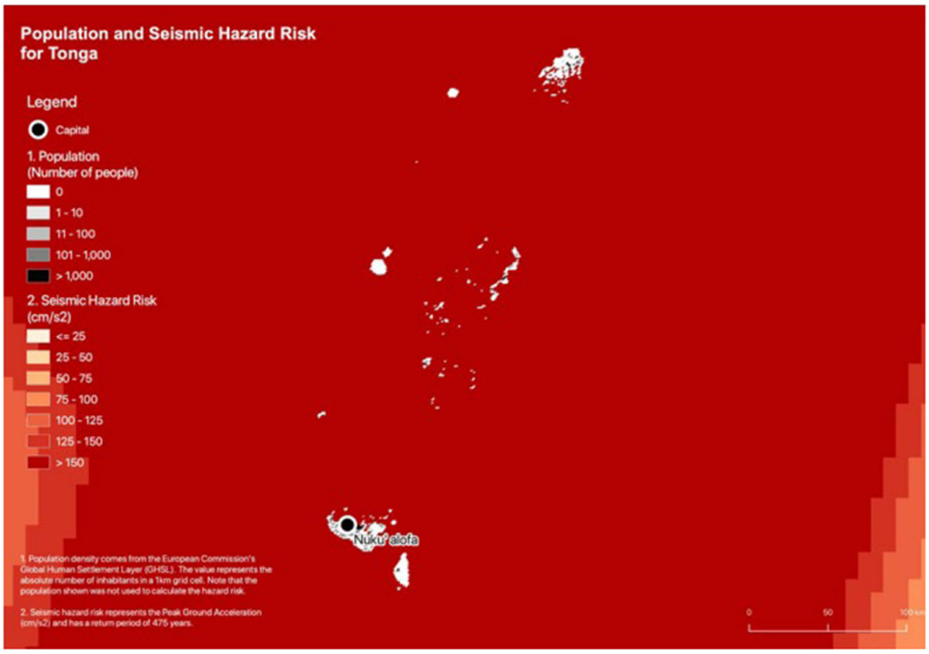
- Regarding seismic hazards, the earthquake ground motion is risk-rated at 150 cm/s2 (150 gal), with a 450-year probability of recurrence.
- Regarding tsunami disasters, wave heights are risk-assessed at 1 to 5 m depending on location, and the probability of their recurrence is estimated at 450 years.

Risk information is not resolved to allow for consideration of infrastructure resilience measures because of the wide range of the target scale.



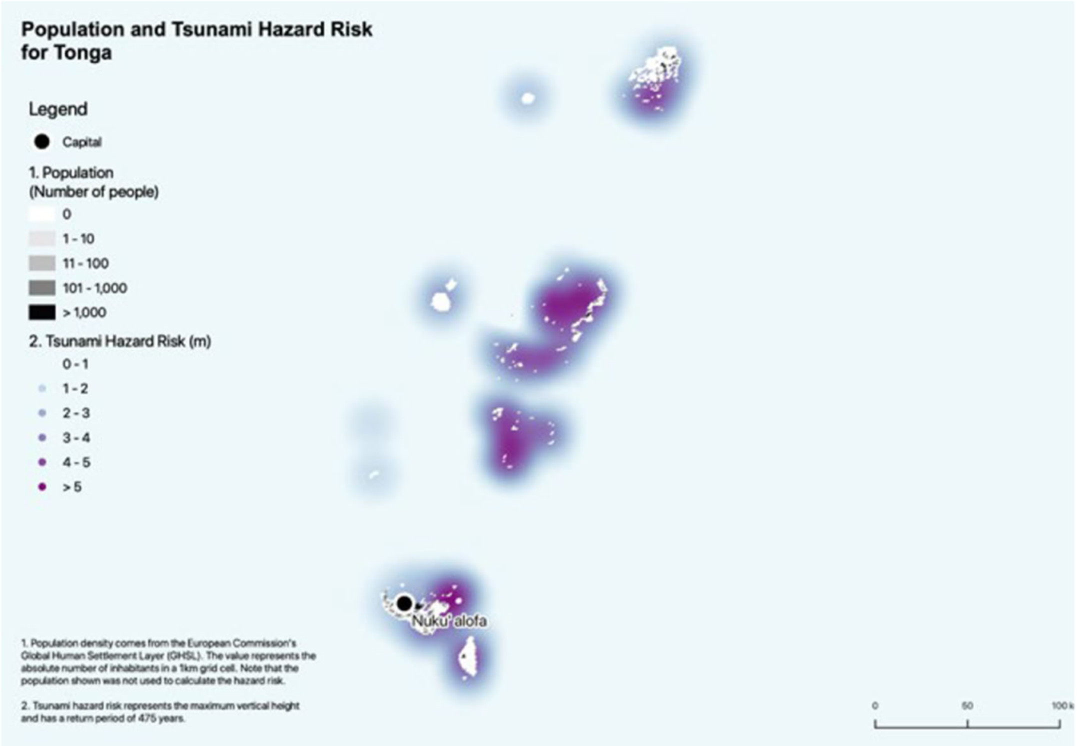
Source: IDMC

Figure 2.5.4 Cyclonic Wind Risk Map



Source: IDMC

Figure 2.5.5 Seismic Hazard Risk Map



Source: IDMC

Figure 2.5.6 Tsunami Risk Map

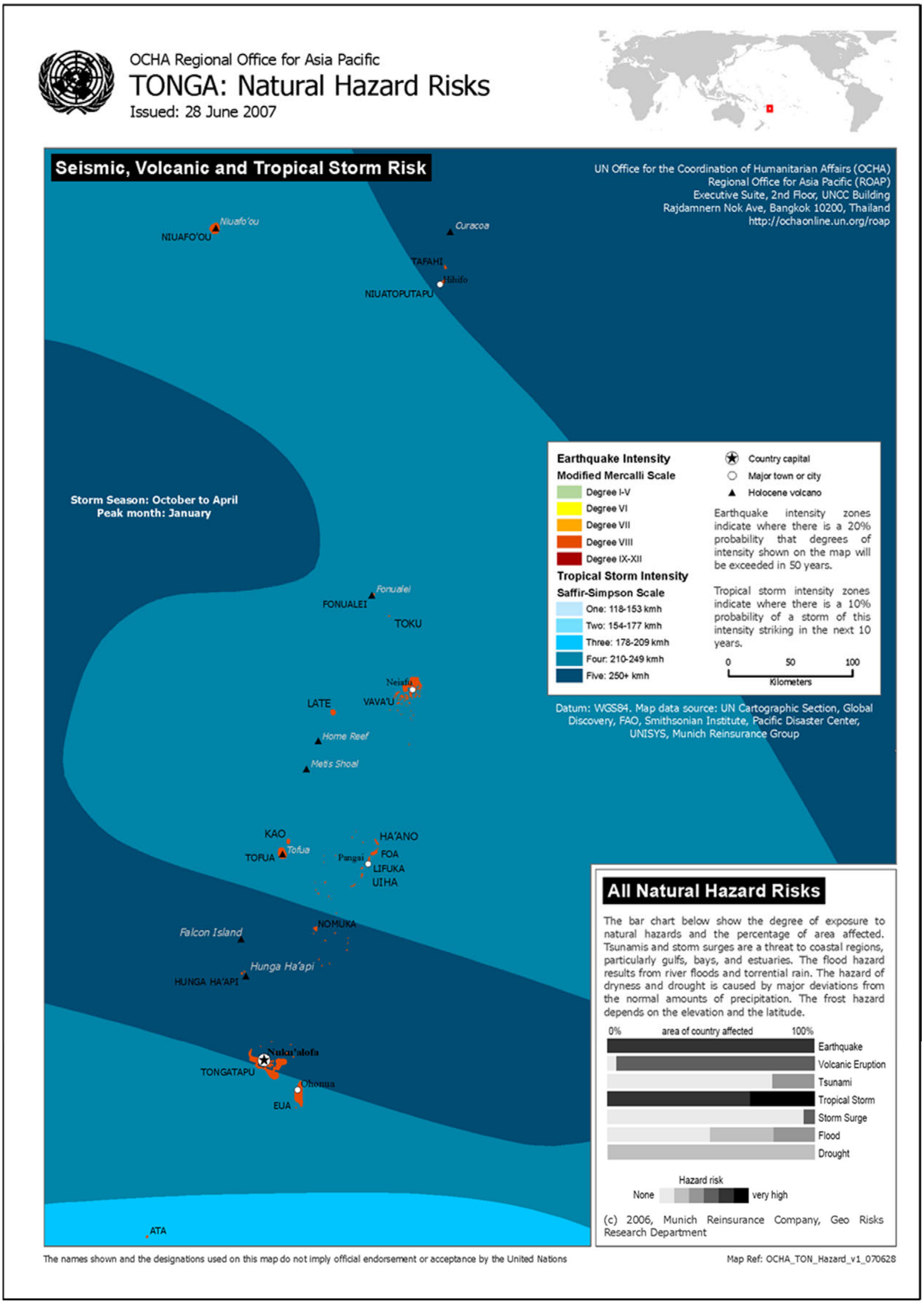
2.5.3. United Nations Office for the Coordination of Humanitarian Affairs[5] (UN OCHA)

UN OCHA assessed the risks of earthquakes, volcanic eruption, and tropical cyclones around Tonga in 2007. The results of the risk assessment are shown in Figure 2.5.7.

Here are the key assessments:

- Regarding seismic hazards, Tongatapu Island is rated VIII on the Mercalli Seismic Intensity Scale, which indicates that extremely strong seismic tremors (94 to 202 gal) could cause heavy furniture to topple over and partially damage many buildings.
- Regarding tropical cyclone hazards, the rating is Category 5 on the Safa-Simpson Hurricane Scale, or wind speed of 250 km/hr. or higher (wind speed of 70 m/s or higher).
- As a result, in Tonga, among all natural disasters, tropical cyclone disasters, earthquake disasters, and volcanic eruptions are considered to have the highest risks, in that order.

[5] United Nations Office for the Coordination of Humanitarian Affairs

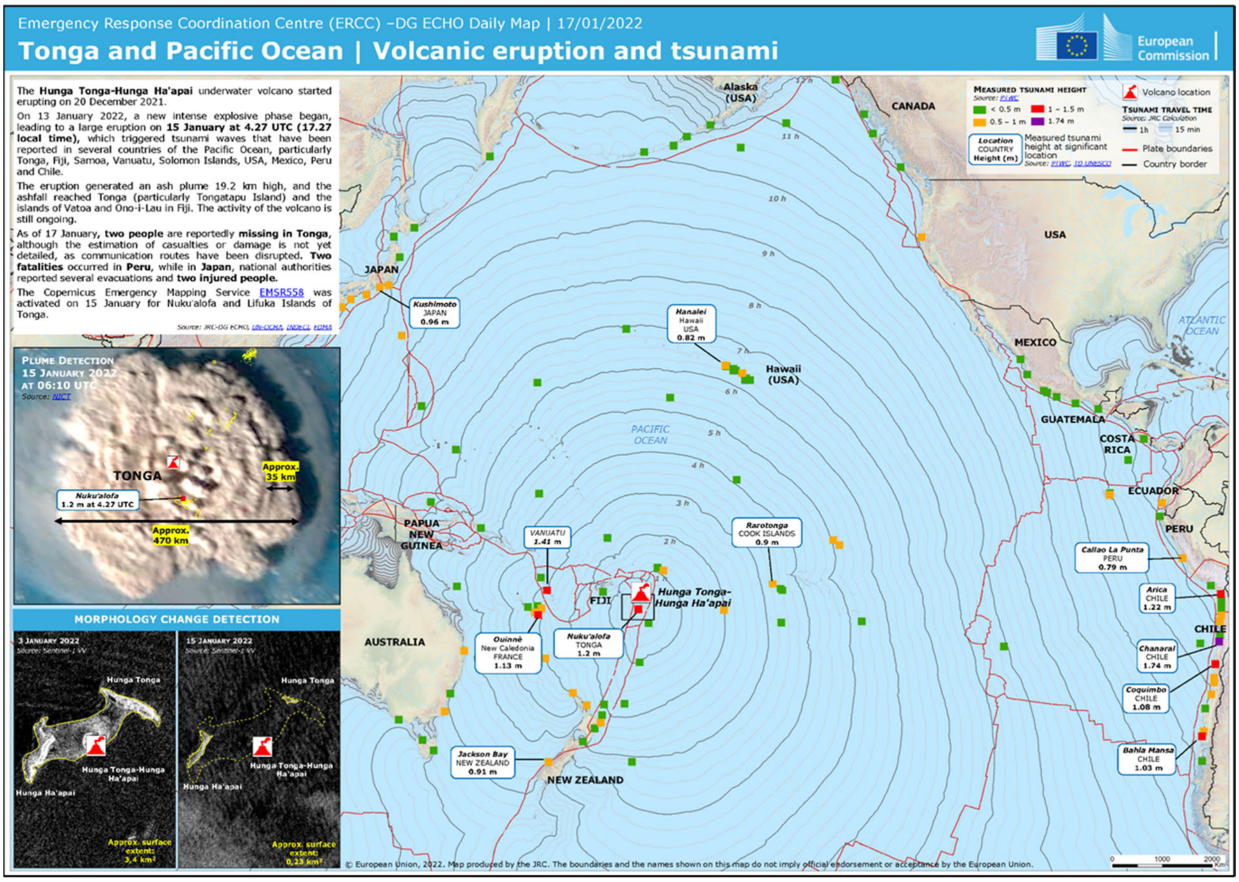


Source: UNOCHA

Figure 2.5.7 TONGA: Natural Hazard Risks

2.5.4. Emergency Response Coordination Center[6] (ECHO)

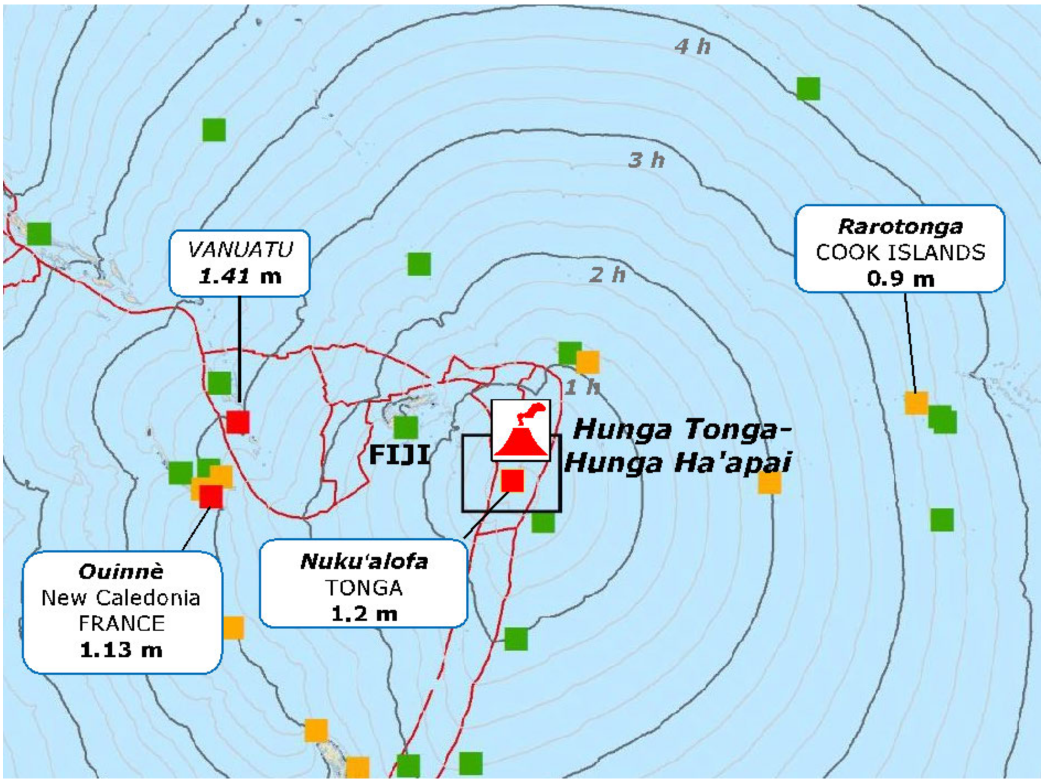
The Emergency Response Coordination Center (ERCC) of the European Civil Protection and Humanitarian Aid Operations (ECHO) organizes the tsunami heights and arrival times along the Pacific coast due to the 2022 eruption of the submarine volcano HTHH. The results are shown in Figure 2.5.8. In addition, an enlarged view of the area near Tonga from the same figure is shown in Figure 2.5.9.



Source: ECHO

Figure 2.5.8 Tonga and Pacific Ocean Volcanic Eruption and Tsunami

[6] European Civil Protection and Humanitarian Aid Operations



Source: ECHO

Figure 2.5.9 Tonga and Pacific Ocean Volcanic Eruption and Tsunami

2.5.5. Disaster – related support for development partners

(1) World Bank

In the same way as other countries provide support immediately after a disaster, WB has supported the formulation of an emergency recovery plan immediately after the HTHH eruption disaster, with NEMO under the MEIDECCC as a counterpart, and by grouping officials from the Tongan ministries and agencies into clusters by field. It was compiled as a National Response Plan in February 2022, one month after the disaster.

Emergency funding for the HTHH eruption was coordinated with ADB, with WB contributing USD 3 million and ADB contributing USD 6 million.

Although it is not a countermeasure for this disaster, as a project that was damaged by the high waves of the recent cyclones, MOI has set up a PMU for road rehabilitation, rehabilitation of port facilities on remote islands, re-pavement of airport runways, etc. However, progress was delayed due to repeated disasters and the impact of COVID-19.

The World Bank's support Ministry of Finance to manage the funds, and under it, there are PMUs in each ministry. 8 projects are in progress shown in Table 2.5.2.

Table 2.5.2 World Bank Projects in Tonga

Project	Cost（USD）	Summary	Components
Tonga Climate Resilient Transport Project （TCRTP）	26.02 mil	The Project focuses on the rehabilitation and resurfacing of the selected priority areas of the road network, completion of port maintenance works etc.	1. Sectoral and Spatial Planning Tools 2. Climate Resilient Infrastructure Solutions 3. Strengthening the Enabling Environment 4. Contingency Emergency Response
Tonga Climate Resilient Transport Project II（TCRTP-II）	35.00 mil	The Project improves the climate resilience and safety of the Recipient's transport sector and in the event of an Eligible Crisis or Emergency, to provide an immediate response to the Eligible Crisis or Emergency	1. Capacity Building on Transport Planning and Policies 2. Climate Resilient and Safe Infrastructure Solutions 3. Project Management 4. Contingency Emergency Response
Pathway To Sustainable Oceans Project	35.00 mil	To improve management of selected fisheries and aquaculture in the Recipient's territory, consulting service, goods and service, training, workshop are provided.	1. Strengthening Fisheries Governance 2. Strengthening the Knowledge Base for Fisheries and Aquaculture 3. Investing in Sustainable Fisheries Management and Development 4. Supporting Effective Project Management
Tonga Digital Government Support Project TDGSP <u>(E-Gov)</u>	18.2 mil	The Project is a Digital Government support project for developing support to ICT infrastructure, information systems, selected citizen e-services, and other frameworks and architectures needed to meet goals and objectives.	1. Enabling Environment and Continuous Improvements 2. Government Enterprise Architecture 3. Core Registries: Civil Registration and National ID Systems 4. Digital Government Infrastructure
Pacific Resilience Program （PREP）[7]	34.07 mil	The Project is a series of projects with a national and regional component that will benefit not only participating countries but also the region. It strengthens early warning, resilient investments and financial protection of Tonga.	1. Strengthening Early Warning and Preparedness 2. Risk Reduction and Resilient Investments 3. Disaster Risk Financing 4. Project and Program Management

[7] Outline of PREP is summarized as follows.

<u>Component 1: Strengthening Early Warning and Preparedness (estimated cost including contingencies: US $11.5 million)</u>

This component supports the following activities: Impact-based forecasting modelling for integration into Tonga and Samoa's Multi-hazard Early Warning Systems; Team Leadership Course Certificate IV in Disaster Risk Management; and Post Disaster Needs Assessment experts to provide training and support as needed.

Nationally implemented Sub-Component 1.1: Investments in Early Warning and Preparedness

Regionally implemented Sub-Component 1.2: Regional TA to strengthen impact forecasting and preparedness.

<u>Component 2: Risk Reduction and Resilient Investments (estimated cost including contingencies: US $15.5 million)</u>

This component supports the following activities: (i) Light detection and ranging (LiDAR) surveys, data acquisition and quality assurance for Tonga and Vanuatu, (ii) Town Planning for two townships in Vanuatu (Tanna & Malekula Islands), and (iii) the Pacific Resilience Nexus Database Platform.

Nationally implemented Sub-component 2.1: Risk Reduction and Resilient Investments

Regionally implemented Sub-Component 2.2: Regional Platform to Support Risk Reduction and Resilient Investment Planning

<u>Component 3: Disaster Risk Financing (estimated cost including contingencies: US $ 5.4 million)</u>

This component supports the following activities: (i) consideration of disaster risk financing for Tonga, (ii) establishment of mutual insurance fund in Oceania

Nationally implemented Sub-component 3.1: Disaster risk financing instruments

Regionally implemented Sub-component 3.2: Development of Mutual Insurance Fund

<u>Component 4: Project and Program Management (estimated cost including contingencies: US $1.5 million)</u>

This component supports the following activities: (i) the Project Management Unit; (ii) the Pacific Regional Program Management Coordination Unit.

Nationally implemented Sub-component 4.1: Project Management

Regionally implemented Sub-component 4.2: Regional Program Management and Coordination

Project	Cost (USD)	Summary	Components
Skills And Employment for Tongan Project （SET）	20.90 mil	The aim of this project is to improve opportunities for secondary school progression and completion and facilitate the transition to jobs in the domestic and overseas labor markets.	1. Conditional Cash Transfer (CCT) program for secondary school enrolment and attendance. 2. Strengthening Technical and Vocational Education and Training 3. Enhancing opportunities for labor migration 4. Project management, monitoring and evaluation, and centralized support
Tonga Safe and Resilient Schools Project （TSRSP）	15.00 mil	The impact of Tropical Cyclone Gita in 2018 highlighted the vulnerability of school infrastructure and the need to improve the resilience of school building infrastructure in order to avoid similar impacts to education facilities in the future.	1. Improving Safety and Resilience of Education Facilities 2. Establishment of Education Management Information System (EMIS) and improved quality of teaching 3. Contingent Emergency Response Component (CERC) - Unallocated project funds may be requested for re-allocation to support response and reconstruction in case of a major crisis or emergency. 4. Statistical Innovation and Capacity Building in Tonga
Statistical Innovation and Capacity Building in Tonga （SICBT）	2.00 mil	The Project's Development Objective is to improve the quality and efficiency of welfare data collection, and accessibility to comparable welfare data in Tonga.	1. Innovation & capacity building in data collection 2. Institutional strengthening 3. Implementation support

Source: World Bank

(2) Asian Development Bank

ADB, in collaboration with other donors, continues to support disaster resilience programs for countries in the Pacific region. Phase 4 is scheduled to begin in 2023.

After the HTHH eruption, a multi-hazard disaster risk assessment was conducted on Tongatapu Island, and the results have already been published. As a result of the hazard risk assessment, two projects are planned. One is a bridge, which connecting Nuku'alofa and Nukuhetulu, not only to improve traffic congestion, but also to be used as an emergency evacuation route). has been approved as a priority project. The port rehabilitation project was also tendered, but the bid was double the planned budget, so the design is being reviewed here as well.

Furthermore, a technical assistance project to support urban resilience, including support for NSPAO, will be launched in 2023.

1) Pacific Disaster Resilience Program (Phase 4)

ADB, along with other donors, is supporting the Tongan government in various disaster recovery projects. It will also provide USD 10 million in funding and technical assistance for natural disaster and emergency relief. The outline is as follows.

Reform Area 1: Policy and institutional arrangements for risk management strengthened

Policy reforms aim to address gaps in policy, planning, and legal frameworks for DRM, climate change, and health emergency management. This includes DRM and health emergency management policies and legislation, national and subnational disaster preparedness plans, and disaster recovery policies and frameworks (including strategies to support gender-responsive preparedness and recovery).

Reform Area 2: Systems, information and tools for risk management including risk-informed development strengthened

The program will support the approval and implementation of regulatory frameworks, and the design and application of risk management tools in all five program countries and area (pacific area, Kiribati, Samoa, Solomon and Tonga). This will include improved climate and disaster risk information, risk-informed decision-making tools, as well as laws and regulations in relation to spatial planning and building codes. Policy actions aiming to strengthen health emergency management capabilities are expected to include health information and communication system upgrades, standard operating procedures, and protocols for syndromic surveillance and reporting.

Reform Area 3: Risk financing and public financial management to address disaster impact improved

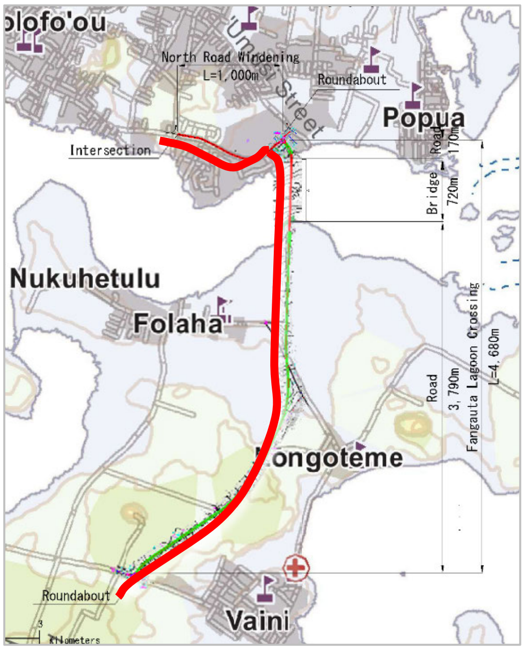
Reforms will increase access to and strategic use of climate and disaster risk financing and the efficient, effective, and transparent management of funds. Policy actions include adoption of disaster risk financing strategies and improved emergency PFM practices.

2) The Fanga'uta Lagoon Crossing Project

To secure a tsunami evacuation route from the low-lying Nuku'alofa district, ADB is considering a bridge and access road project across the Fanga'uta Lagoon to connect it to the Nukuhetulu Folaha district in the south. The project started in 2020, before the HTHH volcanic eruption, and was designed by a Japanese company.

The road length including the access road is 5,680 m, and the length of the bridge portion is 720 m. It is planned to have two lanes, one on each side.

The budget for the bridge is USD 25 mil., but the design plan is being reviewed because there is a large gap with the estimated cost of the design plan.



Source: Project Update (Civil Works for the Fanga'uta Lagoon Crossing Project), ADB, 2021

Figure 2.5.10　Project Location Map

3) Assistance in the field of integrated city resilience

Since 2019, ADB has been supporting the Tongan government under the name of the Integrated Urban Resilience Sector Project. The amount of aid was $21.317 million, of which $18.275 million, or 85.7%, was borne by ADB.

The contents are (1) effective flood risk management infrastructure to the Land Transport Authority (LTD), (2) water supply service in Nukualofa district to the Tonga Water Board (TWB), (3) environment-friendly management to the Waste Management Authority (WAL) and (4) Community-based disaster risk management program with consideration for gender in Nuku'alofa district.

Output 3 supports the TGS in implementing WASH awareness activities and strengthening management of the home hygiene system. As for Output 4, it is carried out by NSPAO as a counterpart organization and it will formulate a gender-sensitive urban development strategy and investment plan resilient to climate change and disasters in Nuku'alofa.　It also promotes urban planning, and guide investment in the urban area to address long-term resilience to the impacts of climate change. It aims to work with NGOs to formulate a community-based disaster risk management (CBDRM) plan, and Tongan government has started recruiting consultants.

(3) United Nation

UN office has shared by 9 UN agencies in Tonga (UNFPA, UNICEF, FAO, IOM, UN Women, etc.). Before the eruption, the staff consisted of 35 people., nutrition, and public relations staff had been increased by 12 or 3 people, but they returned to their home country after their assignments were completed.

Support is provided to the Ministry of Education center on UNICEF, support from WHO to the Ministry of Health, and technical support to the Ministry of Tourism.

The UN is moving toward overall control of the Pacific region, and with the addition of PNG, there are about 15 countries, but they are moving in the direction of dividing them into three groups and administering them (Pacific Cooperation Framework). It will be reviewed in the 5-year plan from FY2023. More projects are being organized in multiple countries.

1) Tongatapu Island Northern Coast Conservation Project

UNDP is providing technical assistance to NEMO in collaboration with other donors as part of the ``Tongatapu Island Northern Coast Conservation Project" by the Global Climate Change Alliance's GCF (Green Climate Fund). The United Nations Development Program, in collaboration with the Asian Development Bank and the Tongan government, is carrying out a seawall project based on the concept of green infrastructure that utilizes mangroves and other plants, mainly in the northeastern residential area of Tongatapu Island.

2) Strengthening Tonga's Resilience and Adaptive Capacity to Disasters – Post HTHH volcano and tsunami (2023-2025)

The UNDP and UNDRR collaboration aim to support the Government of Tonga to identify and prioritize bundles of actions that collectively can strengthen their ability to reduce risk from, prepare and respond effectively to future hazards. This vision of building resilience breaks away from the current tendency to pursue disparate and fragmented disaster risk management measures that frequently trip and fall at unforeseen hurdles. The project aims to support four specific outcomes:

Output 1: Operationalization of DRM through improved system of laws, regulations, policies, and procedures that will complement effective coordination of disaster risk management processes in Tonga.

Output 2: Strengthened DRM governance and institutional arrangements to support community resilience.

Output 3: Investing in disaster resilience initiatives in response to changing risk landscapes through improved national disaster preparedness, response, and recovery.

Output 4: Strengthened early warning and preparedness systems to support early action of affected populations.

(4) USAIDs

USAID is implementing a USD 2.6million support program for humanitarian response to Tonga. The funds will be used to support UN Agencies and NGO partners (MORDI, CRS Catholic Relief Services, Act for Peach, etc.). Preparing a community-level Disaster Response Program. Community-based evacuation support for disabled and elderly people. UNICEF has a cooperative fund with Japan, assistance for agriculture and fisheries through FAO, and coordination functions through UN OCHA.

They are conducting two scientific initiatives. They have been collaborating with Tongan Met Service for many years on early warning systems. This is a system using Iridium's satellite communication system, and the transmitter (Chatty Beetle) is scheduled to be replaced due to failure. With this system, tsunami warnings can be sent outside the island. Chatty Beetle sent a system-wide emergency message 11 minutes after the eruption, but it did not reach Tongatapu. It was delivered to Fiji Met Service.

The other is an earthquake and eruption monitoring system, and Tonga did not have seismic monitoring equipment when the scientists examined it. A set of equipment was sent to New Zealand to monitor active volcanoes.

(5) Australia

AUS$ 18 million was provided in financial support for this disaster.

(6) New Zealand

The New Zealand government has announced assistance of approximately NZ$ 7.55 million as disaster countermeasures. In terms of areas, they are providing support for communication resilience, climate change countermeasures, community resilience, health resilience, and economic resilience.

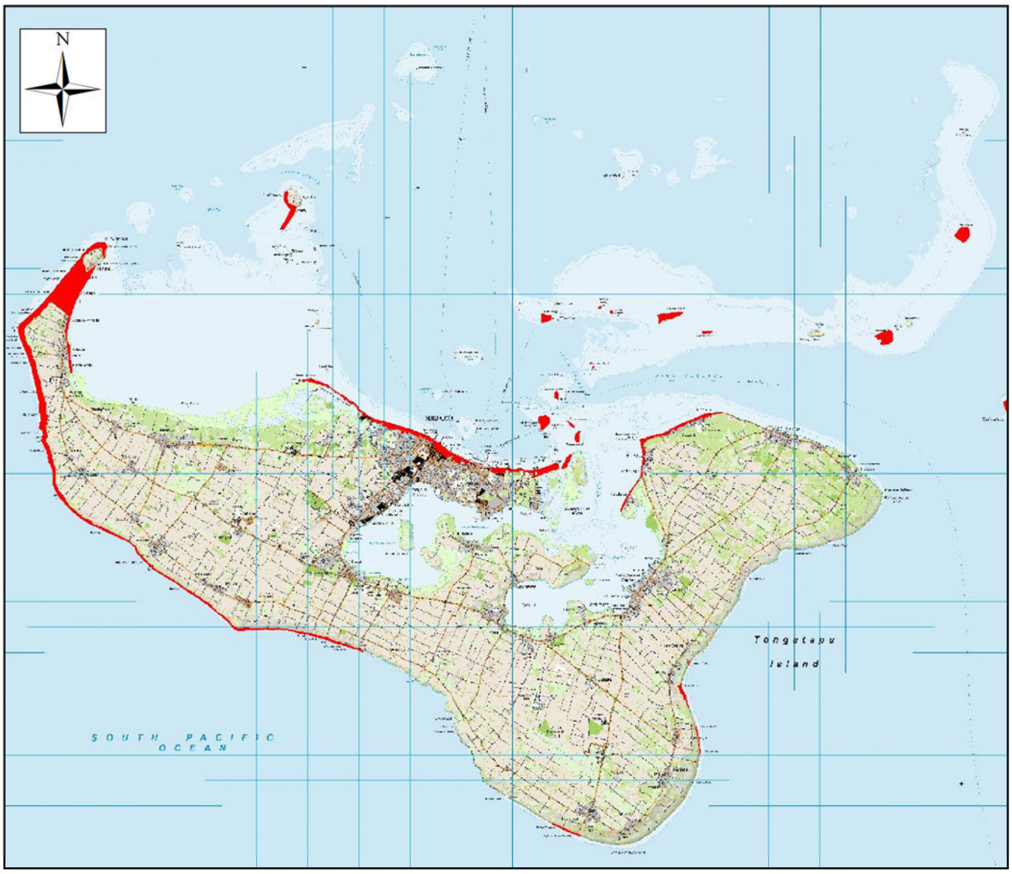
2.6. Information on Disaster Damages

2.6.1. Flooding Areas

The flooding area caused by tsunami due to the large-scale eruption of the submarine volcano HTHH on January 15, 2022 is shown in Figure 2.6.1. The inundation extent was very wide in the northwestern cape area (Kanokpolu and Ha'atafu villages). Inundation also occurred in Nuku’alofa because of its low ground elevation. On the southern coast, the inundation area was very small because of the high ground level.

The Tongan government's maps of the inundation area and the direction of tsunami inundation are shown in Figure 2.6.2 to Figure 2.6.5.

These figures also show that the northern part of the island was inundated to a large extent.



Tsunami Inudation area due to
Hunga Tonga– Hunga Ha'apai submarine volcano explosion in 2022

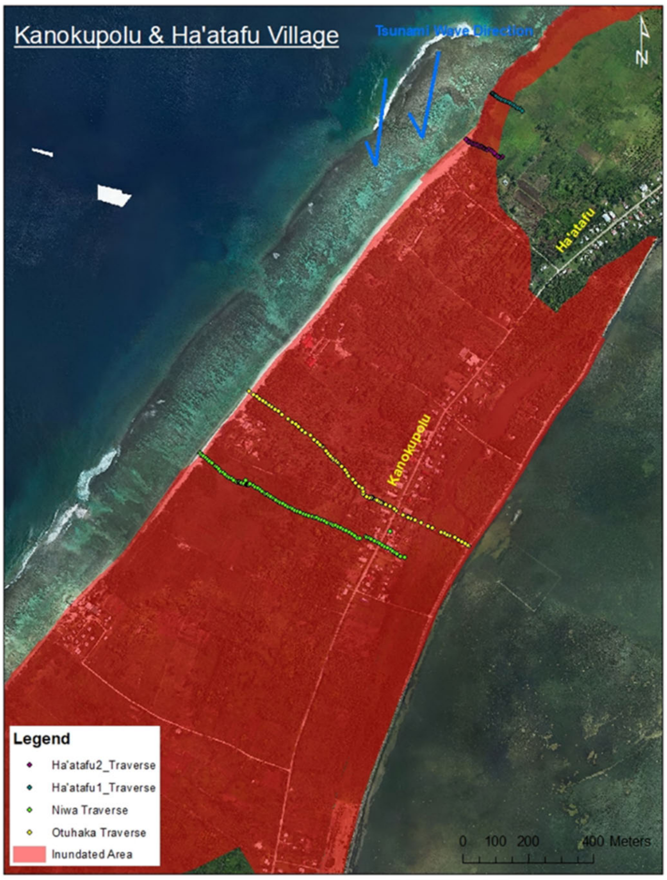
Sourece: Field Survey conducted by Prof.Cronin and Tonga Goverment
Map: Ministry of Lands, Survey, Natural Resources, and Environment

Source: JICA Study Team

Figure 2.6.1 Map Showing Tsunami Inundation Area (due to the 2022 HTHH Volcanic Tsunami)

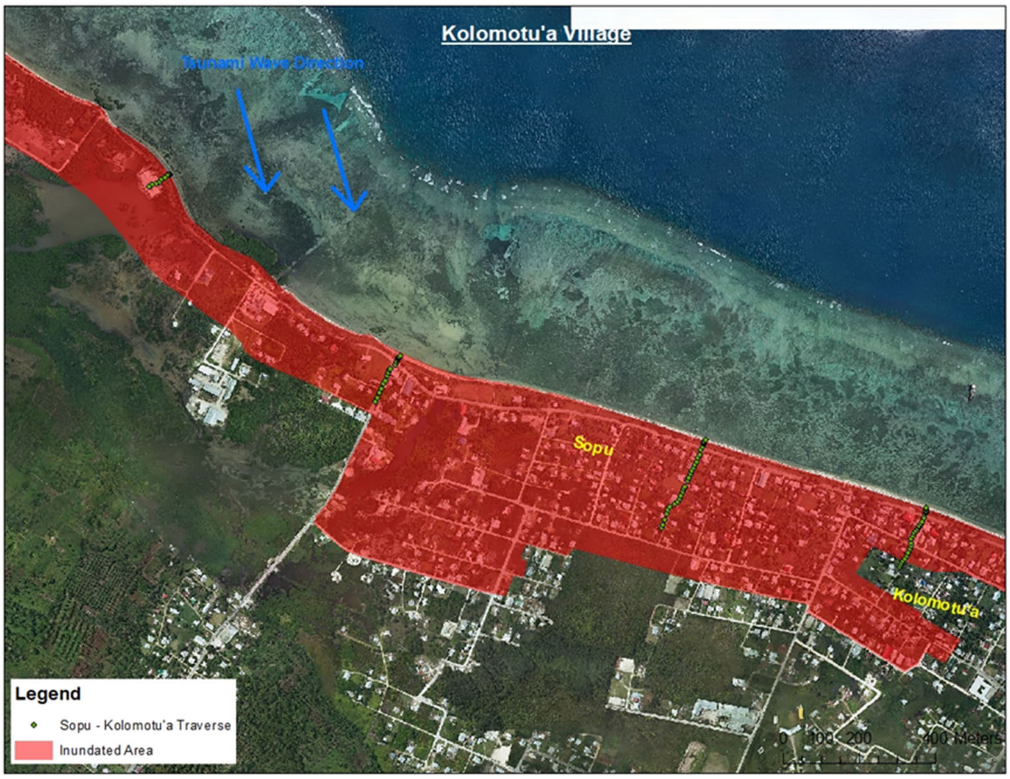
Source: Tonga Geological Services

Figure 2.6.2 Expanded Tsunami Inundation Area (due to the 2022 HTHH Volcanic Tsunami)



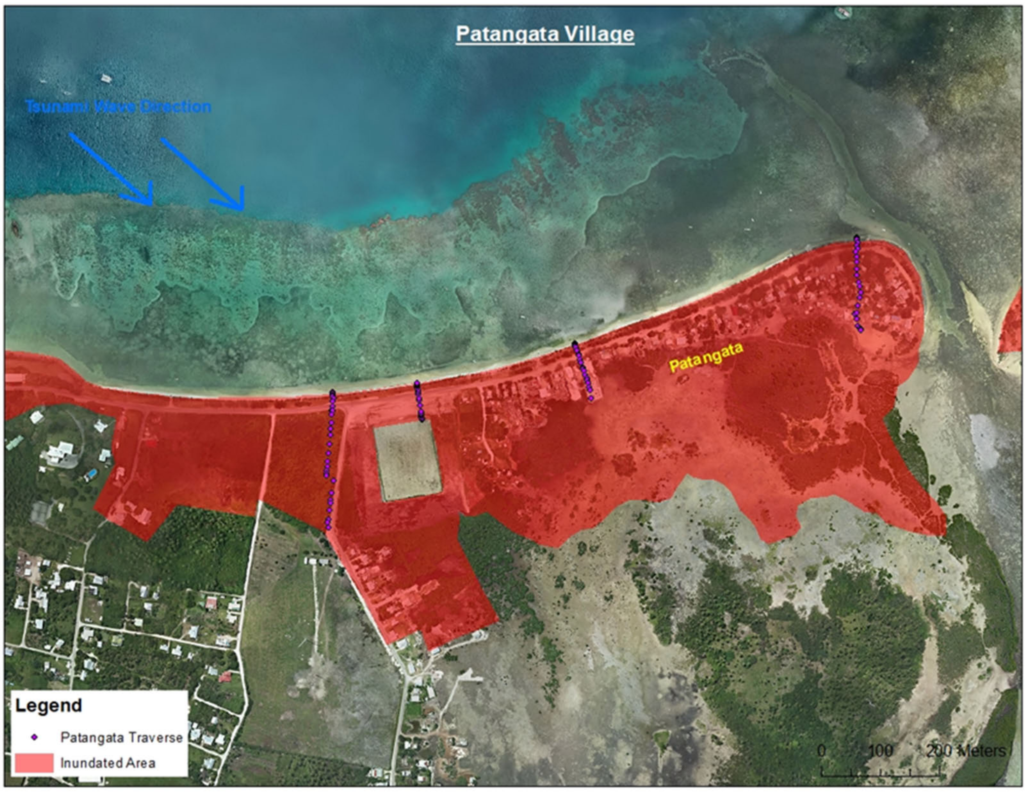
Source: Tonga Geological Services

Figure 2.6.3 Expanded Tsunami Inundation Area 2 (due to the 2022 HTHH Volcanic Tsunami)



Source: Tonga Geological Services

Figure 2.6.4 Expanded Tsunami Inundation Area 3 (due to the 2022 HTHH Volcanic Tsunami)

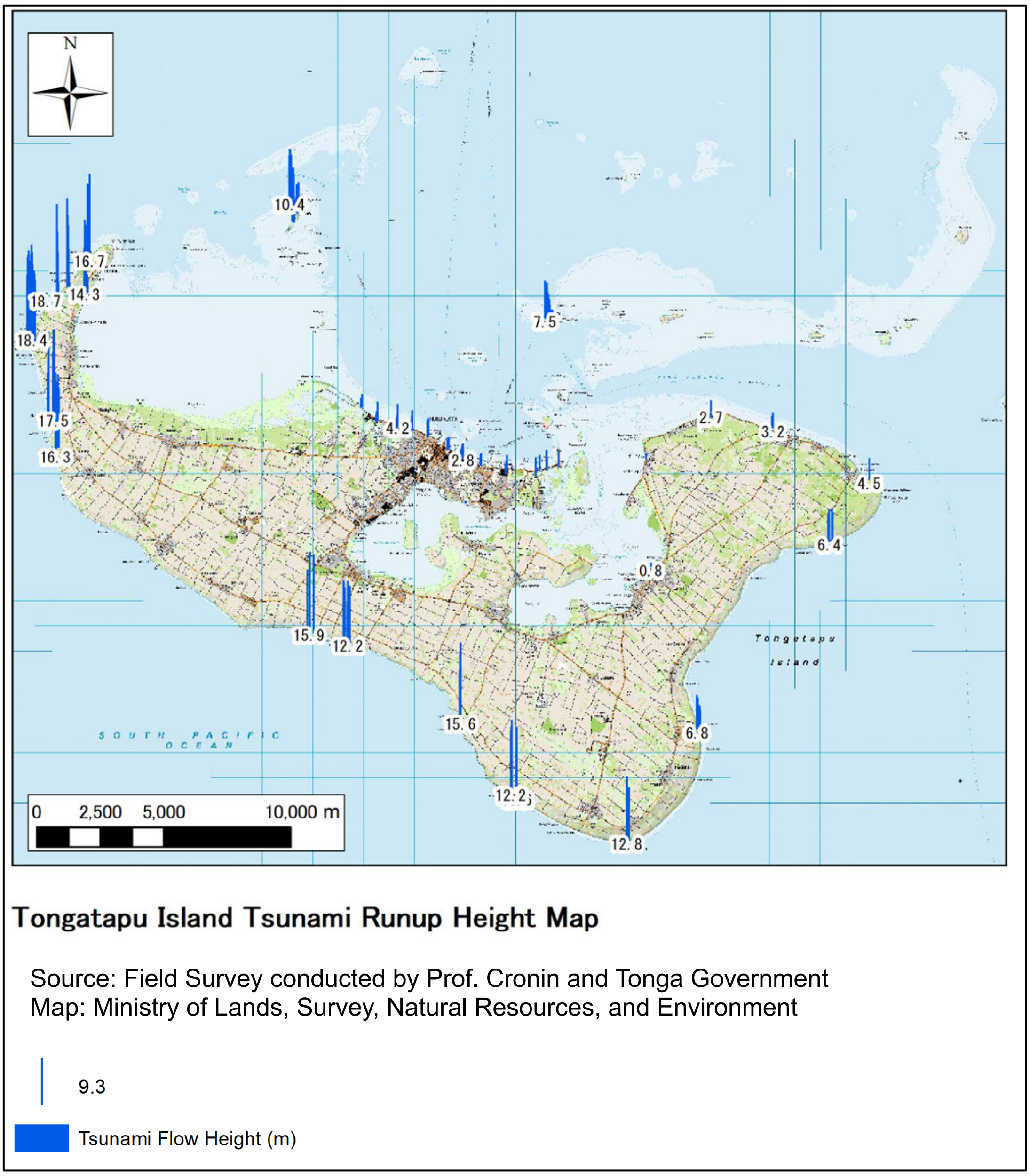


Source: Tonga Geological Services

Figure 2.6.5 Expanded Tsunami Inundation Area 4 (due to the 2022 HTHH Volcanic Tsunami)

2.6.2. Run-up Height of the Tsunami

The run-up data were provided by Tonga government, and these were organized. The results are shown in Figure 2.6.6. The tsunami run-up height in the north-western part of the island was very high, exceeding 15 meters. The tsunami run-up height was also high in the southern part of the island. In Nuku'alofa coast, the tsunami run-up height was small, although the inundation area was large. It is thought that the reason why the tsunami run-up height was the deformation and concentration of tsunamis caused by the cape-like topography and the topography of the shallow-water area.



Sources: Prof. Cronin, Tonga Geological Services; Ministry of Lands, Survey, Natural Resources and Environment; JICA Study Team

Figure 2.6.6 Distribution of Tsunami Run-up Height

2.6.3. Volcanic Ash Damage

The eruption of the HTHH volcano on January 15, 2022, caused ash fall, hence, the surrounding islands were covered with volcanic ash. Tongatapu Island, parts of the Ha'apai Islands, and 'Eua Island were covered with ash and caused prolonged damage, while the islands of Niuas and Vava'u in the north were damaged but it recovered within a year. The thickness of the ash cover ranged from 20 to 60 mm. In particular, the western part of Tongatapu reported to have twice as much ash as the eastern part.

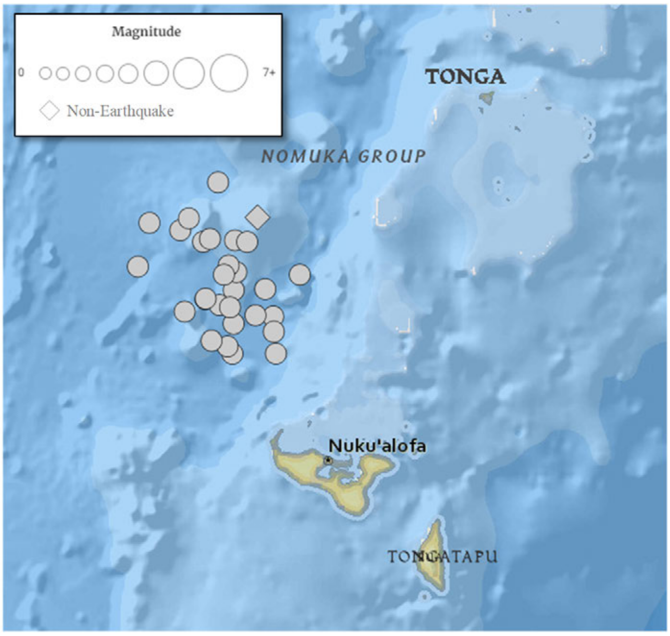
The main impacts and damages of the volcanic ash are as follows:

- The ash had no significant effect on the human body (eyes, nose, throat, and skin).
- Regarding photosynthetic inhibition in crops, there was an effect immediately after the eruption, but the effect became smaller with subsequent rainfall.
- Crop damage on Tongatapu Island ranged from 30% to 95% depending on location. And the vegetables (root crops) and fruit trees grown at the time of the eruption were temporarily affected but have recovered with subsequent rainfall.

There were few direct effects on livestock, but there is concern that future food harvesting may have an impact. As for the effects on airborne ash, water, food and livestock, ash leaching tests were conducted by Massey University in New Zealand and confirmed that the effects were small.

2.6.4. Earthquake Damage

Regarding seismic activity, earthquakes with magnitudes ranging from 4.4 to 4.9 on the Richter scale occurred around the HTHH volcano before and after the eruption, and an earthquake with a magnitude of 5.8 occurred during the volcanic eruption. Since none of the earthquakes were large in magnitude, they were considered to have caused little earthquake damage. The earthquake locations and their magnitudes from January 13, 2022, to January 17, 2022 are shown in Figure 2.6.7. The list of earthquakes is also shown in Table 2.6.1.



Source: USGS https://earthquake.usgs.gov/earthquakes/

Figure 2.6.7 Earthquake Locations and Magnitudes (January 13-17, 2022)

Table 2.6.1 Earthquake Time and Magnitude (January 13-17, 2022)

time	latitude	longitude	depth	mag	type
2022-01-17T20:57:58.159Z	-20.8468	-175.51	10	4.6	earthquake
2022-01-17T20:29:49.092Z	-20.5484	-175.57	10	4.5	earthquake
2022-01-17T18:23:09.595Z	-20.8249	-175.348	10	4.6	earthquake
2022-01-17T16:41:27.784Z	-20.7853	-175.396	10	4.7	earthquake
2022-01-17T15:57:59.917Z	-20.7213	-175.37	10	4.4	earthquake
2022-01-17T14:16:13.738Z	-20.6861	-175.478	10	4.5	earthquake
2022-01-17T13:15:02.936Z	-20.878	-175.342	10	4.5	earthquake
2022-01-17T11:59:26.704Z	-20.8604	-175.469	10	4.4	earthquake
2022-01-17T07:48:48.134Z	-20.5985	-175.515	10	4.6	earthquake
2022-01-17T07:26:07.929Z	-20.5593	-175.673	10	4.5	earthquake
2022-01-16T16:07:43.141Z	-21.4629	-176.195	137.29	4.6	earthquake
2022-01-16T16:02:08.468Z	-20.7446	-175.526	10	4.5	earthquake
2022-01-16T15:50:05.981Z	-20.7658	-175.462	10	4.5	earthquake
2022-01-16T14:50:54.677Z	-20.6663	-175.703	10	4.5	earthquake
2022-01-16T11:42:04.235Z	-20.6055	-175.532	10	4.7	earthquake
2022-01-16T10:45:07.511Z	-20.6635	-175.466	10	4.5	earthquake
2022-01-16T10:00:49.269Z	-20.5775	-175.592	10	4.5	earthquake
2022-01-16T05:46:18.410Z	-20.6059	-175.417	10	4.7	earthquake
2022-01-16T03:55:13.907Z	-20.6021	-175.449	10	4.5	earthquake
2022-01-16T02:24:37.770Z	-20.8784	-175.456	10	4.8	earthquake
2022-01-16T01:22:16.176Z	-20.7603	-175.489	10	4.7	earthquake
2022-01-15T18:11:29.058Z	-20.6798	-175.446	10	4.9	earthquake
2022-01-15T13:43:37.809Z	-20.6861	-175.28	10	4.6	earthquake
2022-01-15T09:51:46.774Z	-20.7882	-175.349	10	4.4	earthquake
2022-01-15T05:30:17.706Z	-20.7459	-175.527	10	4.7	earthquake
2022-01-15T04:40:37.335Z	-20.7239	-175.452	10	4.8	earthquake
2022-01-15T04:14:45.000Z	-20.546	-175.39	0	5.8	volcanic eruption
2022-01-15T04:13:01.763Z	-20.7763	-175.581	10	4.7	earthquake
2022-01-15T04:07:53.837Z	-20.8057	-175.453	10	4.7	earthquake
2022-01-14T21:16:48.952Z	-22.0678	-174.361	10	4.9	earthquake
2022-01-14T01:08:39.043Z	-20.4601	-175.493	10	4.7	earthquake

Source: USGS https://earthquake.usgs.gov/earthquakes/

2.7. Field Survey on Comprehension Damages Caused by the HTHH Eruption Disaster

Since this survey was planned under the condition of COVID-19 pandemic, initially the JICA Study Team planned to visit the two islands: Tongatapu and 'Eua. After the team started the field survey in Tonga, it became clear that it could fly to Ha'apai and Vava'u and so it was decided to visit the two islands. The safety precaution against COVID was very strict, especially in 'Eua, which has a zero-coronavirus policy. The team conducted the survey within the allocated area with the use of a private vehicle (so-called bubble system). Therefore, even though the team did not have enough time to survey each island, at least it was able to visit three islands from Tongatapu base.

The survey implementation schedule for each island other than Tongatapu is shown below.

Table 2.7.1 Schedule of Survey Implementation for Each Island

Date	Island	Attendants	Length of stay	Flight	Remarks
5/28	'EUA	Odake, Feng	6.0 Hrs.	Charter	One-day Trip
6/30	VAVA'U	Odake, Feng, Morimoto	3.5 Hrs.	L812/L815	One-day Trip
7/2	HA'APAI	Odake, Feng, Morimoto	3.0 Hrs.	L8022/L8025	One-day Trip
7/13	'EUA	Morimoto	6.0 Hrs.	L8032/L8037	One-day Trip

Source: JICA Study Team

2.7.1. Damage Status at Tongatapu Island

Tongatapu Island is 35km from east to west and 15km from north to south and has an area of 260km ^{2}, hence the largest island in Tonga. It is fan-shaped with a lagoon in its inland part. The geographic characteristic of Tongatapu is that its central area, where the capital city Nukualofa is located, is along the lagoon. It has much low land and is generally flat; besides the east, the west edge and southern part of the island are hilly. But the island itself seems rather flat because the highest point of Tongatapu is only 70m. Around the island, there are coral reefs at around 500m offshore along the coastline of the northern part of Tongatapu.

It was clarified in this survey that the coral reefs have weakening effect on the power of tsunami. This observation can be grasped when comparing the following photos showing the east, west edge and central part of the island.

The JICA Study Team conducted the field survey at Tongatapu separately in 4 blocks: northwest, Nukualofa City, northeast and eastern part as shown below.

Source: JICA Study Team

Figure 2.7.1 Field Survey Location Map of Tongatapu Island

(1) Northwest of Tongatapu Island

The northwestern part of Tongatapu, facing the HTHH volcano, is the most affected area by the tsunami. In this area, there are many sandy beaches along the coastline, and can enjoy the sunset.

On the southeastern and southwestern coasts of Tongatapu Island, cliffs over 20 m high rose immediately from the coastline. Moreover, hills in the hinterland were not affected by the tsunami. The tsunami runs up the slope and crosses over the peninsula.

Photo 2.7.1 Rocky Area with Sand Washed ashore by Tsunami

Photo 2.7.2 Building Destroyed by Tsunami

Source: JICA Study Team

Photo 2.7.3 Foundation that Remained after a Tsunami

Photo 2.7.4 Completely Destroyed Resort Hotel

Source: JICA Study Team

(2) Nukualofa City

The coast of Nuku'alofa city is a cove-like shallow reef surrounded by peninsulas and islands on the east and west.

Although the tsunami force was attenuated and the tsunami height was low, waves of about 1 meter intrude inland over the existing seawall. The tsunami moved away the stone materials of the existing masonry seawalls.

Photo 2.7.5 Scattered Stones on Masonry Seawall

Photo 2.7.6 Fence Pushed back by Tsunami

Source: JICA Study Team

Photo 2.7.7 The Lower Frame Destroyed by Tsunami

Photo 2.7.8 Damage on the West Side of the Jetty

Photo 2.7.9 Block Wall Destroyed by Tsunami

Photo 2.7.10 House Parts Washed away by Tsunami

Source: JICA Study Team

(3) Tongatapu Island Northeast

Different seawalls were constructed in the northeastern part of Tongatapu Island, including those funded by ADB and constructed by residents. A reef is in front of the seawalls. Although the force of the tsunami weakened, most masonry seawalls and structures along the coast were damaged. In particular, areas maintained by residents where water flowed out from the base of the seawall were destroyed.

Photo 2.7.11 Condition of Masonry Seawall after the Tsunami

Photo 2.7.12 Destroyed Masonry Seawall

Photo 2.7.13 Destroyed Concrete Coating

Photo 2.7.14 Ship Washed Inland by Tsunami

Source: JICA Study Team

(4) Tongatapu Island East

The eastern coast of Tongatapu Island is a topography of high cliffs, with small sandy beaches in between, and hotels and accommodation facilities were developed. Although it was on the opposite side of the HTHH volcano, facilities built on the coast were devastatingly damaged by the tsunami that rolled around.

Photo 2.7.15 Resort Destructed by Tsunami

Photo 2.7.16 Resort Destructed by Tsunami

Source: JICA Study Team

2.7.2. Damage Status at 'Eua Island

The JICA Study Team surveyed the situation at 'Eua Island mainly around Nafanua Port located in the central part of the island.

The Port of 'Eua Island is located on the west coast of the island, and it opens to the northwest. Although there is Tongatapu Island located about 20km away to the northwest of 'Eua, it is under severe conditions that directly receive tsunami waves from the open sea.

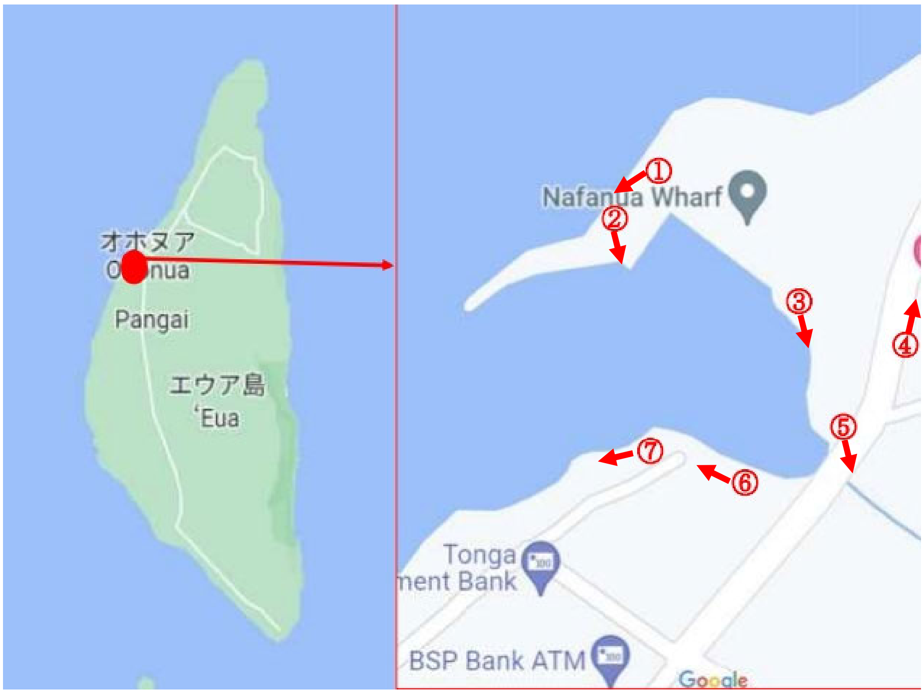
The port facilities are separated into two parts. One is called new port, which is located on the northeast covered by the breakwater protruding towards southwest from the port. It has a ramp, a wharf for small vessels and a terminal building. The other part is called old port, which is located on the southwest surrounded by old breakwater which remains only 50m long of top portion 100m away from shoreline. It has a quay for small vessels.

The new port was built in 1988-89. It suffered damage several times due to tropical cyclones and repair and reinforcement works were carried out by EU and WB each time. The construction work started in January 2020 with assistance from WB (TCRTP) but this was temporarily suspended due to TC Harold in April, just after beginning of work, and was successfully completed in October 2021. However, it was again damaged by the tsunami caused by the HTHH eruption in January 2022. As for the old port, it is not clear when it was constructed and there is no record about it.

According to local interview, the tsunami washed away the area around the port with its direction from south towards north upstream. This is the reason why there are much damage in the new port located on the northeast than in the old port located on the southwest. Due to lack of information on the condition of the old port before the tsunami, a proper assessment cannot be done. It was confirmed that the terminal building at the new port was completely destroyed and, except for the foundation that remained, there is no trace left for a former structure. The sheet pile quay is not damaged, while the masonry seawall and breakwater on the northwest side are severely damaged.

Based on the normal wave conditions, it seems that the location of the old port on the south side is more suitable as a port than the north side, where the coral reefs are closer. Nevertheless, whether the port will be reconstructed on the north, south or both sides, it will depend on how the breakwater outside the port is planned.

The locations surveyed and photos of 'Eua Island are shown in next page.



Source: JICA Study Team

Figure 2.7.2　Location of Survey and Photography on 'Eua Island

 **Photo 2.7.17　Before Disaster (January 2014)**	 **Photo 2.7.18　Masonry Breakwater has Collapsed**
 **Photo 2.7.19　Damage to New Port Apron**	 **Photo 2.7.20　Damage to Small Vessel Wharf**

Source: JICA Study Team

Photo 2.7.21 Tsunami Went up High on the House at the Right

Photo 2.7.22 Damaged Bridge (Culvert)

Photo 2.7.23 Concrete Block Quay of Old Port

Photo 2.7.24 Vast Backyard on the Old Port

Source: JICA Study Team

2.7.3. Damage Status at Ha'apai Island

The port of Ha'apai Island is located on the west coast of the island and the inside of the port is protected by a breakwater installed independently parallel to the land in shallow water about 150m away from the coast. The port facilities comprised of a ferry wharf on the north side, a jetty in the middle, and a ramp and a slipway for small vessels. The port of Ha'apai has been repeatedly repaired by World Bank in 2012-14 and 2018, but it was damaged again by Cyclone Tino in January 2020 and by the HTHH. Concrete structures were damaged, and backfill crushed stones and sediment flowed out at multiple locations.

Based on the assessment of the JICA Study Team from this field survey at site, it seems that the damages of the port are actually concentrated at the northern seawall and on the caisson type mixed breakwater. This is the reason why the effect of breakwater is very important, because this breakwater installed in the sea was not able to protect the quay on the north side.

Although the upper structure has suffered some damage, the sheet pile wharf could surely resist against waves as the foundation.

The structure of the breakwater consists of a masonry seawall and a sheet pile quay with the tip tilted into the bay. But a large part of the masonry has disappeared, and it is unknown how far it was originally extended. When restoring this port, the design plan of the breakwater is most important such as the location and structural design.

Source: JICA Study Team

Figure 2.7.3 Survey Location Map of Ha'apai Island

Source: JICA Study Team

Figure 2.7.4 Location Map of Photography

Photo 2.7.25 ①Masonry seawall of north wharf

Photo 2.7.26 ②Length of seawall is about 130m

Photo 2.7.27 ③Tip of north wharf

Photo 2.7.28 ④Caisson type mixed breakwater

Photo 2.7.29 ⑤Sheet pile wharf can be seen

Photo 2.7.30 ⑥Sheet pile wharf from the ramp

Photo 2.7.31 ⑦View of the jetty from the ramp

Photo 2.7.32 ⑧The edge of the jetty

Photo 2.7.33 ⑨Scouring bottom of the slipway

Photo 2.7.34 ⑩Offshore breakwater

Source: JICA Study Team

2.7.4. Damage Status at Vava'u Island

The port of Vava'u Island is a good natural harbor surrounded by mountains on all sides. Since the waves from the open sea cannot directly enter inside the bay, it seems that the port of Vava'u has almost no damage from tsunami caused by HTHH eruption. Instead of damage status from disaster, the JICA Study Team will report briefly some problems which were pointed out during visit at the site.

The ferry berth for domestic ships has a shallow water depth of 3m and a short berth length of less than 40m (39.8m). First, it will affect the use of international shipping berths (for cargo). On the other hand, berths for international ships can secure a water depth of 10m and can accommodate ferries, passenger ships, and cargo ships of about 10,000 tons, but the berth length is as short as 64.6m, which limits the number of ships that can be accommodated.

Since the hinterland of the port is narrow and there is no mechanical equipment for cargo handling within the port, there are also problems in cargo handling. Since the number of berths that can be docked at the port itself is limited to two, including cargo berths, when there is a large concentration of passengers on the ship, such as when a large-scale meeting is held, the berths will always be crowded. Because there is no room in the anchorage area in the bay, it will cause problems in operation.

Since the land for existing port facilities is narrow, it is sandwiched between military land on the southeast side and land for the fisheries union on the northwest side, leaving no room for horizontal expansion. At the same time, the offshore area is also set up as a route for tankers to oil storage facilities in the inner part of the bay, and there is not enough room for expansion. Because the entrance to the bay is narrow, when large ships such as oil tankers pass through, it will affect the maneuvering of small ships. For this reason, it is being considered to move the port function itself to the outside of the bay mouth.

Source: JICA Study Team

Figure 2.7.5 Survey Location Map of Vava'u Island

Source: JICA Study Team

Figure 2.7.6 Situation Map Around Vava'u Port

 **Photo 2.7.35　Domestic berth**	 **Photo 2.7.36　International berth**
 **Photo 2.7.37　Eastern naval facilities**	 **Photo 2.7.38　View from the yacht anchorage**

Source: JICA Study Team

3. Support for the Formulation of BBB Vision

3.1. Compiling local information after organizing local information after disseminating the BBB vision

(1) BBB Vision Seminar

The Government of Tonga and the JICA jointly held a seminar to set out his BBB vision for the Tongan and present the BBB Concept as a necessary concept when considering future development projects. The contents of BBB Vision is shown in Appendix 3-1.

Its purposes are:

1. to present the BBB Vision for disaster risk reduction in the recovery process
2. to share information on possible future hazards and resulting disasters with all stakeholders involved in recovery, including government officials, donors and NGOs in Tonga.

The conference was held on August 17, 2022, in the presence of HRH Crown Prince and Ambassador of Japan. The seminar was also disseminated to the Japanese side through a Zoom meeting, with participation from JICA's Vice President and other related parties, as well as from the Ministry of Foreign Affairs, the Ministry of Land, Infrastructure, Transport and Tourism, and the Embassy of Tonga in Japan.

(2) Seminar media coverage

Several media representatives including NHK participated in the Zoom meeting. The seminar was reported on NHK World News along with the report on the tsunami damage. Below is the web link for the broadcast.

1. https://www3.nhk.or.jp/nhkworld/en/news/20220817_28/
2. https://www3.nhk.or.jp/news/html/20220817/k10013775971000.html

(3) Reporting to the King

The Crown Prince, who attended the BBB Vision Seminar, reported to the King of Tonga about the content of the BBB Vision Seminar. The king had a strong interest in BBB vision and expressed his opinion to promote nation building using BBB vision.

(4) Diet approval status of BBB vision

Along with holding the BBB Vision Seminar, procedures were taken to obtain the cabinet approval to enact the BBB Vision as a policy of the NSPAO. The Cabinet has been proceeding with the approval process since July 2022, but due to various circumstances, it has not progressed. In 2023, the BBB Vision was submitted to the cabinet again, and the following decisions were made at the cabinet meeting on June 16, 2023.

1. The proposed BBB Vision for Tonga was considered and approved as a government policy under the National Spatial Planning and Management Act 2012.
2. The proposed Tonga BBB Vision was accepted as an extension of the HTHH Volcanic Eruption and Tonga Tsunami Recovery and Resilience Building Plan 2022 - 2025.
3. The Cabinet noted the progress of work on the BBB, which is now in the final stages of planning and the next step will be the "implementation phase of the BBB project".

(5) Incorporation of Roadmap into National Plan

Regarding the positioning of the Roadmap, the government of Tonga has already prepared the HTHH Volcanic Eruption and Tonga Tsunami (HTHH Disaster) Recovery and Resilience Building Plan 2022 - 2025 with the assistance of other donors, and the Tonga National Infrastructure Investment Plan (NIIP) While there is an infrastructure investment plan, even if the Japanese side creates a separate roadmap, it is not effective if it does not have a legal position.

In discussions with the National Planning Division of the Prime Minister's Office, in order to materialize the BBB vision in the long term, the Tongan Strategic Development Framework (TSDF III) is scheduled to be revised from 2023. It was concluded that it would be better to reflect the contents of the report. It is ideal that concrete measures to materialize the BBB vision confirmed by the Tongan government this time will be discussed in the TSDF to be revised in the future. To that end, it is hoped that Japan will provide technical support, leading to the implementation of the BBB. 2022 - 2025

3.2. Implementation of Multi-Hazard Assessment Based on BBB Vision

3.2.1. Hazard Level

The hazards covered by this study are volcanic tsunamis, volcanic ash fall, seismic tsunamis, earthquakes, storm surges or high waves, and cyclones. The intensity and occurrence cycle of hazards in Tonga are identified and evaluated. The hazard level for the disaster management plan and disaster management is measured and identified. Two types of hazard levels, Level 1 and Level 2, will be used for disaster management plans and measures.

Table 3.2.1shows the intensity and frequency of each hazard level and the concept of disaster management plans and countermeasures. It was introduced after Tohoku's great tsunami.

Table 3.2.1 Hazard Level and Frequency

Hazard level	Hazard Intensity and Frequency	Countermeasures
Level 1 (L1)	High intensity and frequency Hazards that occur more frequently than the largest class of hazards Cause significant damage despite low hazard intensity Tens to hundreds of years occurrence cycle	Implement structure measures to protect human life, property, and the economy.
Level 2 (L2)	Largest class hazard Hazards that occur infrequently but can cause devastating damage once they occur hundreds to thousands of years occurrence cycle	Prioritize lifesaving Integrate and implement moderate and comprehensive measures to evacuate residents

Source: Based on Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the “2011 off the Pacific coast of Tohoku Earthquake”, JICA Study Team made

3.2.2. Tsunami Analysis and Storm Surge Analysis

Based on the tsunami caused by HTHH volcanoes in January 2022, numerical methods are utilized to analyze seismic and volcanic tsunamis. In regard to the analysis of storm surges, the storm surges caused by cyclones was examined, given that the area is frequently hit by cyclones. The details of each analysis result are provided in the supplementary reference document Appendix 3-2. Here, an overview is presented.

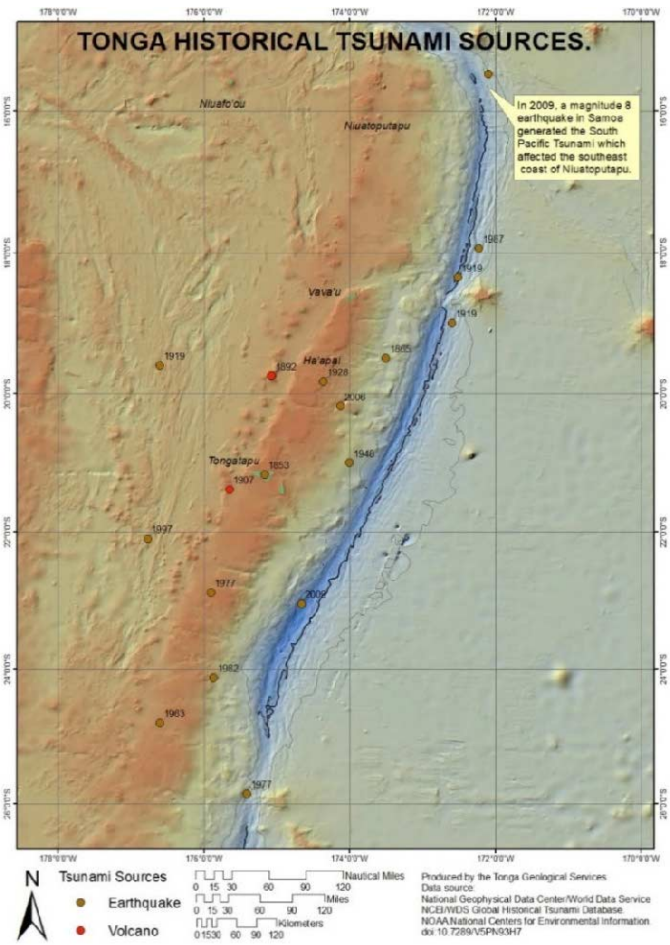
(1) Past Tsunami and Storm Surge Hazard

1) Tsunami Hazard

In Tonga, tsunami hazards are considered to be volcanic tsunamis generated by undersea volcanic eruptions and ruptures, and tsunamis generated by earthquake faulting in the Tonga Trench located in the eastern part of Tonga. The past tsunami wave sources in Tonga are shown in Figure 3.2.1. Two of the 18 wave sources in the figure are volcanic tsunami sources. Adding the case of the 2022 eruption, 84% of the tsunamis since 1853 have been seismic tsunamis, and 16% have been volcanic tsunamis.

Twenty-three tsunamis have been recorded since 1860, but most of them were less than 1 m in height and caused little damage. However, the earthquake in the center of Tongatapu Island in 1919 observed a 2.5-metre tsunami in the Ha’apai Islands, and the 1977 earthquake caused three tsunamis.

In addition, in 2009, Samoa earthquake (Mw 8.1) caused a tsunami that struck the Niautoputapu Islands, 600 km north of Tongatapu Island, killing nine people.

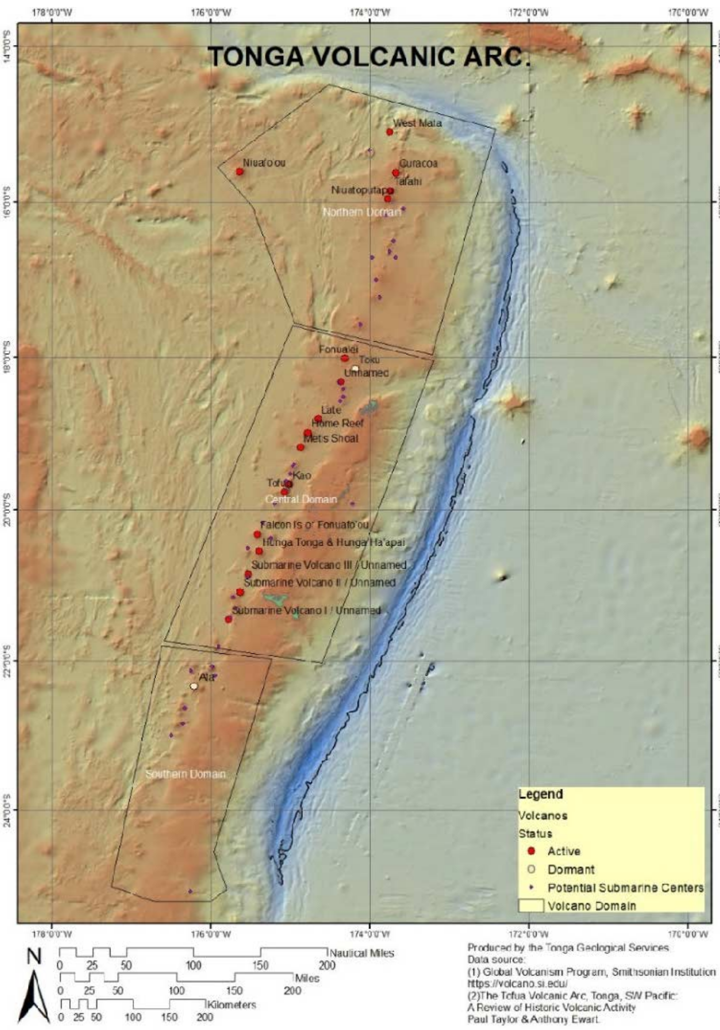


Source: Tonga Geological Services

Figure 3.2.1 Historical Tsunami Wave Sources in Tonga

2) Volcanic Tsunami

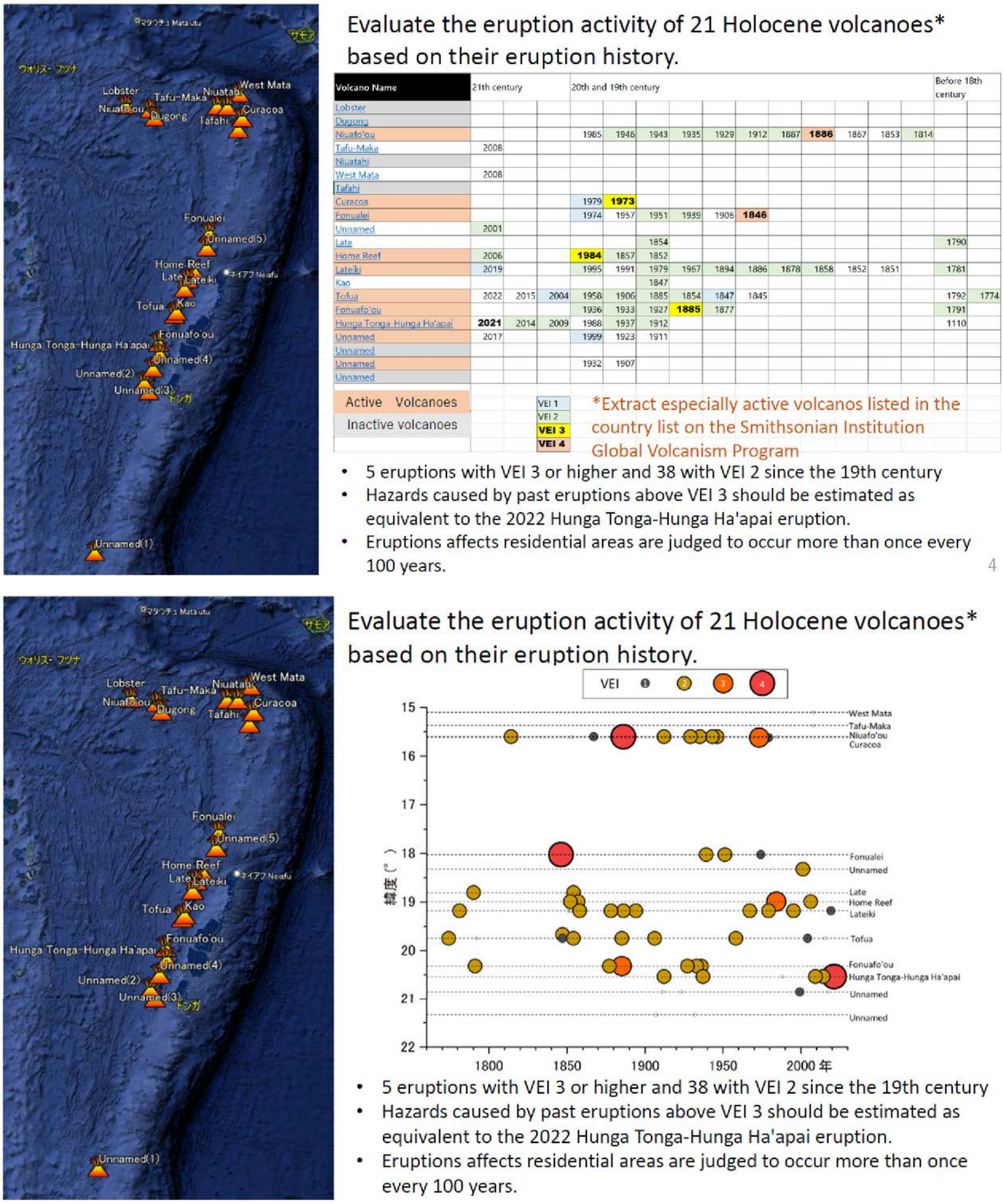
The distribution of volcanoes around Tonga is shown in Figure 3.2.2. Numerous volcanoes are located on the western side of Tonga's islands. Although each volcano erupts infrequently, the possibility of volcanic tsunamis is possible due to the large number of volcanoes.



Source: Tonga Geological Services

Figure 3.2.2 Distribution of volcanoes around Tonga

The frequency and magnitude of past volcanic eruptions have been consolidated by Domestic Support Committee (Figure 3.2.3). According to the result, volcanic eruptions of the same magnitude as the 2022 eruption (VEI 3 or higher) have occurred 5 to 6 times in about 200 years, and a volcanic tsunami of the same magnitude as the recent one may occur once every 30 to 50 years around Tonga. A list of submarine volcanoes is shown in Figure 3.2.4. In this figure, 9 of the 21 volcanoes are submarine volcanoes, which means that volcanic tsunamis cannot be ignored to occur.



Volcano Name	21th century			20th and 19th century											Before 18th century	
Lobster																
Dugong																
Niuafo'ou				1985	1946	1943	1935	1929	1912	1887	**1886**	1867	1853	1814		
Tafu-Maka	2008															
Niuatahi																
West Mata	2008															
Tafahi																
Curacoa				1979	**1973**											
Fonualei				1974	1957	1951	1939	1906	**1846**							
Unnamed	2001															
Late						1854									1790	
Home Reef	2006			**1984**	1857	1852										
Lateiki	2019			1995	1991	1979	1967	1894	1886	1878	1858	1852	1851		1781	
Kao						1847										
Tofua	2022	2015	2004	1958	1906	1885	1854	1847	1845						1792	1774
Fonuafo'ou				1936	1933	1927	**1885**	1877							1791	
Hunga Tonga-Hunga Ha'apai	**2021**	2014	2009	1988	1937	1912									1110	
Unnamed	2017			1999	1923	1911										
Unnamed																
Unnamed				1932	1907											
Unnamed																

Source：Domestic Support Committee

Figure 3.2.3 Summary of frequency of volcanic eruptions around Tonga

Output to Group C:
List of volcanoes in Tonga that can generate tsunamis

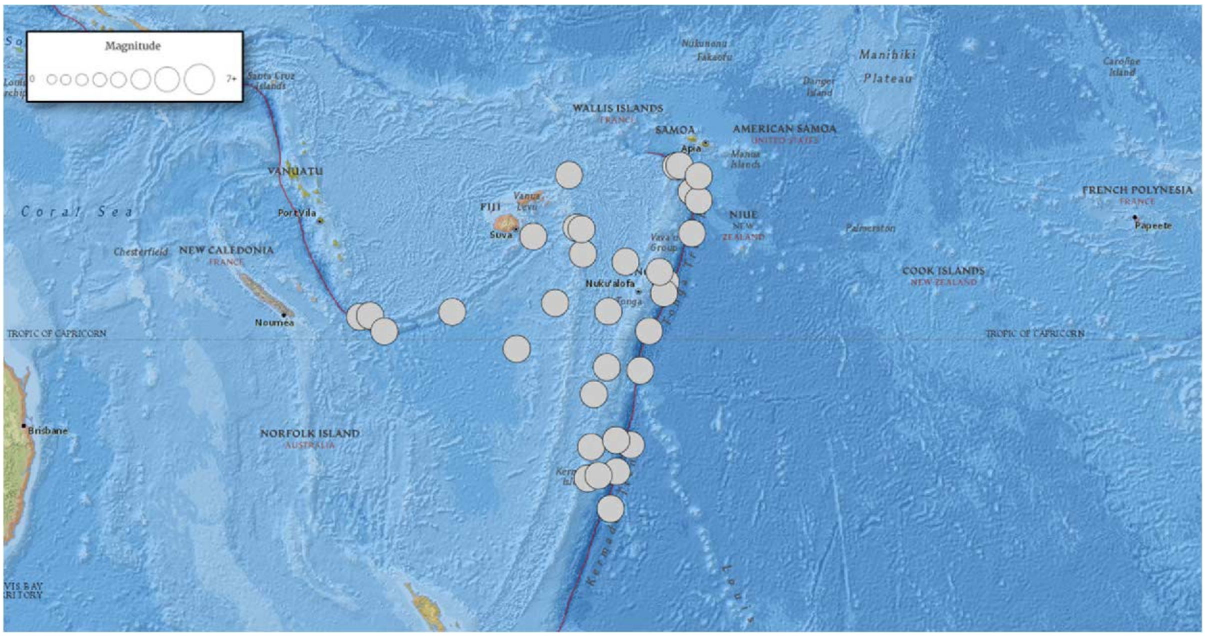
Volcano Name	Location	Last Eruption	Primary Volcano Type	Latitude(°)		Longitude(°)		Elevation (m)
Lobster	Northwest Lau Basin	Unknown - Evidence Uncertain	Submarine	15.333	S	176.283	W	-1500
Dugong	Northwest Lau Basin	Unknown - Evidence Uncertain	Submarine	15.431	S	175.725	W	-1170
Niuafo'ou	Tonga Ridge	1985 CE	Shield	15.6	S	175.63	W	260
Tafu-Maka	Northeast Lau Basin	2008 CE	Submarine	15.37	S	174.23	W	-1400
Niuatahi	Northeast Lau Basin (Tonga)	Unknown - Unrest / Holocene	Caldera	15.379	S	174.003	W	-1270
West Mata	Tonga Ridge	2009 CE	Submarine	15.1	S	173.75	W	-1174
Tafahi	Tonga Ridge	Unknown - Evidence Uncertain	Stratovolcano	15.85	S	173.72	W	560
Curacoa	Tonga Ridge	1979 CE	Submarine	15.62	S	173.67	W	-33
Fonualei	Tonga Ridge	1957 CE	Stratovolcano	18.023	S	174.317	W	188
Unnamed	Tonga Ridge	2001 CE	Submarine	18.325	S	174.365	W	-40
Late	Tonga Ridge	1854 CE	Stratovolcano	18.806	S	174.65	W	540
Home Reef	Tonga Ridge	2006 CE	Submarine	18.992	S	174.775	W	-10
Lateiki	Tonga Ridge	2019 CE	Submarine	19.18	S	174.87	W	43
Kao	Tonga Ridge	1847 CE	Stratovolcano	19.668	S	175.016	W	1009
Tofua	Tonga Ridge	2022 CE	Caldera	19.75	S	175.07	W	515
Fonuafo'ou	Tonga Ridge	1936 CE	Submarine	20.32	S	175.42	W	-17
Hunga Tonga-Hunga Ha'apai	Tonga Ridge	2022 CE	Submarine	20.536	S	175.382	W	114
Unnamed	Tonga Ridge	2017 CE	Submarine	20.852	S	175.55	W	-296
Unnamed	Tonga Ridge	Unknown - Evidence Credible	Submarine	21.15	S	175.75	W	-65
Unnamed	Tonga Ridge	1932 CE	Submarine	21.338	S	175.65	W	-68
Unnamed	Tonga Ridge	Unknown - Unrest / Holocene	Submarine	24.8	S	177.02	W	-385

Source：Domestic Support Committee

Figure 3.2.4 Classification of volcanoes around Tonga

3) Seismic Tsunami

The catalogue of past seismic tsunamis is shown in Figure 3.2.5. According to this catalogue, there are records of numerous earthquakes since 1913. The earthquake of M8.0 or greater, which are considered to cause large tsunamis, have occurred eight times. Therefore, the possibility of seismic tsunami hazard is very high.



Source: USGS https://earthquake.usgs.gov/earthquakes/

Figure 3.2.5 Location and magnitude of earthquakes in and around Tonga (1913-2022)

Table 3.2.2 Time and Magnitude 7.5 or greater of Earthquakes In and Around Tonga (1913-2022)

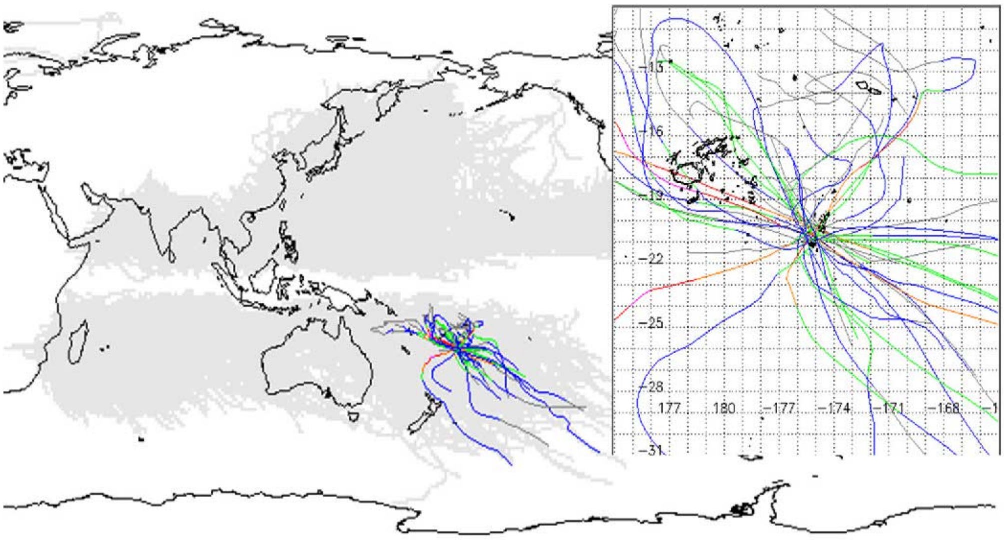
time	latitude	longitude	mag	magType	place	type
1913-06-26T04:57:18.290Z	-20.68	-173.808	7.79	mw	111 km SSE of Pangai, Tonga	earthquake
1917-05-01T18:26:20.360Z	-31.195	-176.653	8.2	mw	Kermadec Islands region	earthquake
1917-06-26T05:49:44.390Z	-14.996	-173.27	8	mw	120 km NNE of Hihifo, Tonga	earthquake
1917-11-16T03:19:35.760Z	-29.849	-177.839	7.5	mw	Kermadec Islands, New Zealand	earthquake
1919-01-01T03:00:34.460Z	-19.318	-178.08	7.8	mw	Fiji region	earthquake
1919-04-30T07:17:16.970Z	-18.322	-172.442	8.1	mw	166 km ENE of Neiafu, Tonga	earthquake
1928-03-16T05:01:05.850Z	-22.36	170.395	7.56	mw	274 km ESE of Tadine, New Caledonia	earthquake
1948-09-08T15:09:14.220Z	-21.222	-173.891	7.5	mw	110 km E of 窶楼honua, Tonga	earthquake
1950-12-14T01:52:54.230Z	-19.705	-175.874	7.8	mw	159 km W of Pangai, Tonga	earthquake
1955-02-27T20:43:27.880Z	-28.336	-175.599	7.52	mw	Kermadec Islands region	earthquake
1956-05-23T20:48:32.710Z	-15.434	-178.803	7.6	mw	144 km SSW of Leava, Wallis and Futuna	earthquake
1963-12-18T00:30:05.470Z	-24.749	-176.844	7.6	mw	south of the Fiji Islands	earthquake
1975-10-11T14:35:15.000Z	-24.894	-175.119	7.8	ms	south of Tonga	earthquake
1975-12-26T15:56:38.700Z	-16.264	-172.467	7.8	ms	146 km ESE of Hihifo, Tonga	earthquake
1976-01-14T16:47:33.500Z	-28.427	-177.657	8	ms	Kermadec Islands region	earthquake
1977-04-02T07:15:22.700Z	-16.696	-172.095	7.6	ms	199 km ESE of Hihifo, Tonga	earthquake
1981-09-01T09:29:31.540Z	-14.96	-173.085	7.7	ms	133 km NE of Hihifo, Tonga	earthquake
1986-10-20T06:46:09.980Z	-28.117	-176.367	7.7	mw	Kermadec Islands region	earthquake
1990-03-03T12:16:27.960Z	-22.122	175.163	7.6	mw	south of the Fiji Islands	earthquake
1994-03-09T23:28:06.780Z	-18.039	-178.413	7.6	mw	240 km E of Levuka, Fiji	earthquake
1997-10-14T09:53:18.150Z	-22.101	-176.772	7.8	mwb	192 km WSW of Haveluloto, Tonga	earthquake
1998-01-04T06:11:58.970Z	-22.301	170.911	7.5	mwc	southeast of the Loyalty Islands	earthquake
2002-08-19T11:01:01.190Z	-21.696	-179.513	7.7	mwc	Fiji region	earthquake
2002-08-19T11:08:24.310Z	-23.884	178.495	7.7	mwc	south of the Fiji Islands	earthquake
2006-05-03T15:26:40.290Z	-20.187	-174.123	8	mwc	47 km SSE of Pangai, Tonga	earthquake
2007-12-09T07:28:20.820Z	-25.996	-177.514	7.8	mwc	south of the Fiji Islands	earthquake
2009-03-19T18:17:40.470Z	-23.043	-174.66	7.6	mwc	191 km S of 窶楼honua, Tonga	earthquake
2009-09-29T17:48:10.990Z	-15.489	-172.095	8.1	mwc	168 km SSW of Matavai, Samoa	earthquake
2011-07-06T19:03:18.260Z	-29.539	-176.34	7.6	mww	Kermadec Islands region	earthquake
2018-08-19T00:19:40.670Z	-18.1125	-178.153	8.2	mww	267 km E of Levuka, Fiji	earthquake
2018-09-06T15:49:18.710Z	-18.4743	179.3502	7.9	mww	45 km S of Levuka, Fiji	earthquake
2021-02-10T13:19:55.530Z	-23.0511	171.6566	7.7	mww	southeast of the Loyalty Islands	earthquake
2021-03-04T19:28:33.178Z	-29.7228	-177.279	8.1	mww	Kermadec Islands, New Zealand	earthquake

Source: USGS https://earthquake.usgs.gov/earthquakes/

4) Storm Surge Hazard

Cyclones strike Tonga every year and storm surges occur with high frequency. According to NOAA's IBTrACS, there have been 7 cyclones of Category[8] 4 or higher, and 17 of Category 3 or higher that have passed around Tongatapu Island since 1947, with a huge cyclone striking the island every 5 years.

[8] Category is a classification of tropical cyclones based on the Saffir-Simpson Hurricane Wind Scale. Category 3 is a tropical cyclone with maximum wind speeds of 50 to 57 m/s, and Category 4 is a tropical cyclone with maximum wind speeds of 58 to 69 m/s that is expected to cause extensive damage.



Source: https://www.ncdc.noaa.gov/ibtracs

Figure 3.2.6 Cyclones that passed Tongatapu Island (1947-2022)

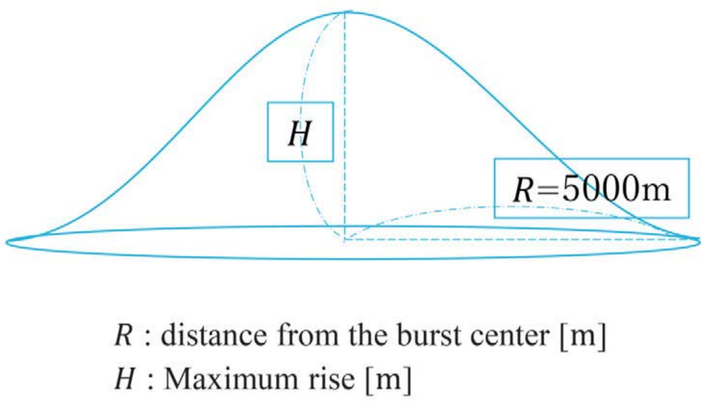
(2) Volcanic Tsunami Analysis

1) Analysis Method

a) Tsunami wave form

- Wave Source Model

A cone-shaped tsunami wave source is modelled as a volcanic tsunami wave source (Figure 3.2.7). Based on the results of the study by the Domestic Support Committee, the shape of the cone is assumed to be a sine curve, and the water level is raised by 5 km to simulate the tsunami height caused by the HTHH volcanic eruption in January 2022. The maximum range of water height is 30 m to 90 m.

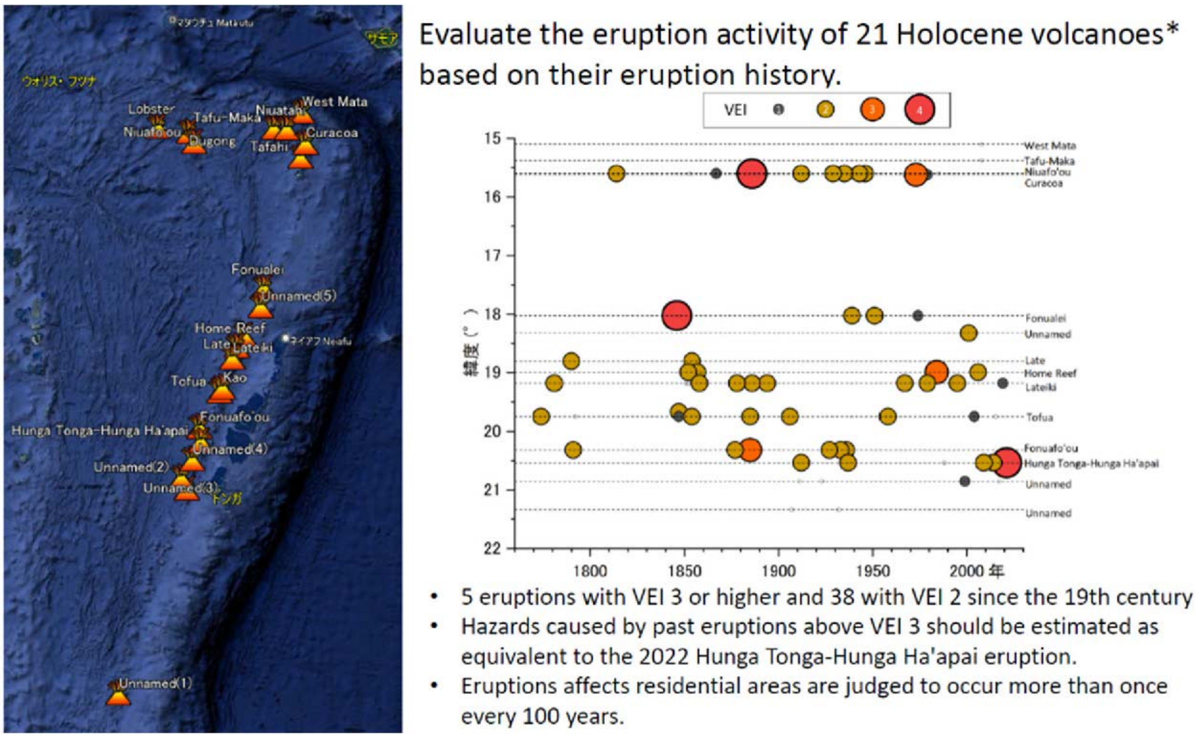


Source: Domestic Support Committee

Figure 3.2.7 Volcanic Tsunami Source Model

- Submarine Volcanoes

The Domestic Support Committee graphed the frequency and scale of past volcanic eruptions (Figure 3.2.8). According to the analysis, six volcanic eruptions (VEI3 or higher), similar to the HTHH eruption, occurred in the past 200 years. Comparable volcanic eruptions may occur in the future.



Source: Domestic Support Committee

Figure 3.2.8 Frequency of Past Volcanic Eruptions around Tonga

Table 3.2.3 shows a list of volcanoes around Turkmenistan. 9 of 21 volcanoes are underwater. Hence, the possibility of volcanic tsunami is not ignored.

The project will analyze 8 volcanoes included in the offshore 15-second-mesh region and considered to have a great impact on Tongatapu Island. Figure 3.2.9 shows the positions of these volcanoes.

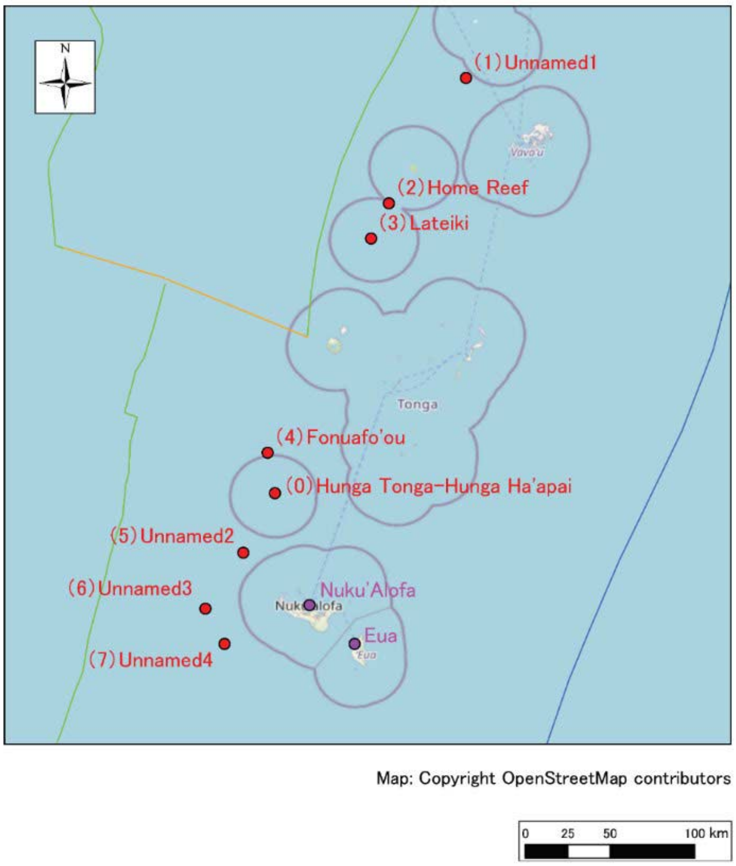
Table 3.2.3 Volcanic activities around Tonga

Name	Location	Last eruption	Type	Longitude (degree)		Latitude (degree)		Height (m)
Lobster	Northwest Lau Basin	Unknown - Evidence Uncertain	Submarine	15.333	S	176.283	W	-1500
Dugong	Northwest Lau Basin	Unknown - Evidence Uncertain	Submarine	15.431	S	175.725	W	-1170
Niuafo'ou	Tonga Ridge	1985 CE	Shield	15.6	S	175.63	W	260
Tafu-Maka	Northwest Lau Basin	2008 CE	Submarine	15.37	S	174.23	W	-1400
Niuatahi	Northwest Lau Basin (Tonga)	Unknown - Unrest / Holocene	Caldera	15.379	S	174.003	W	-1270
West Mata	Tonga Ridge	2009 CE	Submarine	15.1	S	173.75	W	-1174

Name	Location	Last eruption	Type	Longitude (degree)		Latitude (degree)		Height (m)
Tafahi	Tonga Ridge	Unknown - Evidence Uncertain	Stratovolcano	15.85	S	173.72	W	560
Curacoa	Tonga Ridge	1979 CE	Submarine	15.62	S	173.67	W	-33
Fonualei	Tonga Ridge	1957 CE	Stratovolcano	18.023	S	174.317	W	188
Unnamed1	Tonga Ridge	2001 CE	Submarine	18.325	S	174.365	W	-40
Late	Tonga Ridge	1854 CE	Stratovolcano	18.806	S	174.65	W	540
Home Reef	Tonga Ridge	2006 CE	Submarine	18.992	S	174.775	W	-10
Lateiki	Tonga Ridge	2019 CE	Submarine	19.18	S	174.87	W	43
Kao	Tonga Ridge	1847 CE	Stratovolcano	19.668	S	175.016	W	1009
Tofua	Tonga Ridge	2022 CE	Caldera	19.75	S	175.07	W	515
Fonuafo'ou	Tonga Ridge	1936 CE	Submarine	20.32	S	175.42	W	-17
HTHH	Tonga Ridge	2022 CE	Submarine	20.536	S	175.382	W	114
Unnamed2	Tonga Ridge	2017 CE	Submarine	20.852	S	175.55	W	-296
Unnamed3	Tonga Ridge	Unknown - Evidence Uncertain	Submarine	21.15	S	175.75	W	-65
Unnamed4	Tonga Ridge	1932 CE	Submarine	21.338	S	175.65	W	-68
Unnamed5	Tonga Ridge	Unknown - Unrest / Holocene	Submarine	24.8	S	177.02	W	-385

☐ : Marine Volcano, Red letters: volcanoes targeted for calculation

Source: Domestic Support Committee



Source: JICA Study Team

Figure 3.2.9 Location of Volcano

b) Method of Numerical Analysis

An expanded model included 'Eua Island and simulated the tsunami caused by the January 2022 eruption. The STOC[9] model, provided by Chuo University Professor Arikawa of the Domestic Support Committee, was used for basic modelling.

The STOC-ML is a quasi-three-dimensional model using hydrostatic pressure approximation for calculating tsunami-induced fluid motion. Previous studies have shown that the hydrostatic pressure is a good approximation for volcanic tsunamis.

c) Conditions for Numerical Analysis

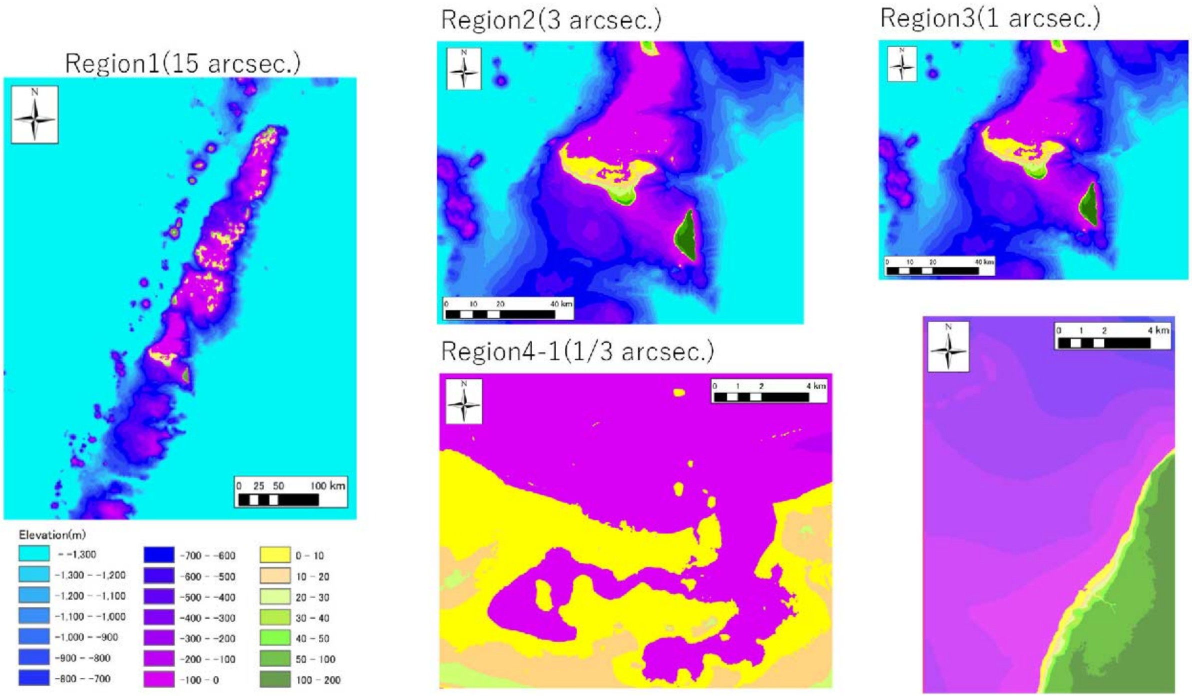
Table 3.2.4 lists the calculation conditions for numerical analysis.

Table 3.2.4 Calculation Conditions

Items	Calculation conditions
Composition of Mesh	Region1 (15sec (around 450m) mesh)：Tonga Trench area
	Region2 (3sec around 90m) mesh)：Tongatapu Island、'Eua Island area
	Region3 (1sec (around 30m) mesh)：Tongatapu Island、'Eua Island area
	Region4 (1/3sec (around10m)mesh)：Tongatapu Island、'Eua Island urban area
Analytical Method	STOC-ML (Tomita and Kakinuma, 2005)
Tsunami	HTHH volcanic eruption in January 15, 2022
Wave source	Chuo University Model
	(Hunga Tonga-Hunga Ha'apai volcanic tsunami wave source with a radius of 5 km and a maximum water level rise of 30 m is set at the volcano.)
Geological conditions	Based on topographical data of Tohoku University, the range of 'Eua Island is added to the 90m mesh area and 30m mesh area.
Water level conditions	M.S.L. (mean sea level) +0m
Time of calculation	After earthquake：5 hours
	Time resolution：minimum 0.01sec
Others	Structure measures：None

Source: JICA Study Team

9 Tomita and Kakinuma: Development of Storm Surge and Tsunami Numerical Simulator STOC Considering 3-Dimensionality of Seawater Flow and Its Application to Tsunami Analysis, Report of Port and Research Institute, Vol.44, No.2, pp.83-98, 2005.



Source: JICA Study Team

Figure 3.2.10 Computational Terrain Model

Source: JICA Study Team

Figure 3.2.11 Existing Seawall

d) Cases for Numerical Calculation Analysis

Table 3.2.5 shows several cases for numerical calculation analysis.

Table 3.2.5 Numerical Calculation Cases

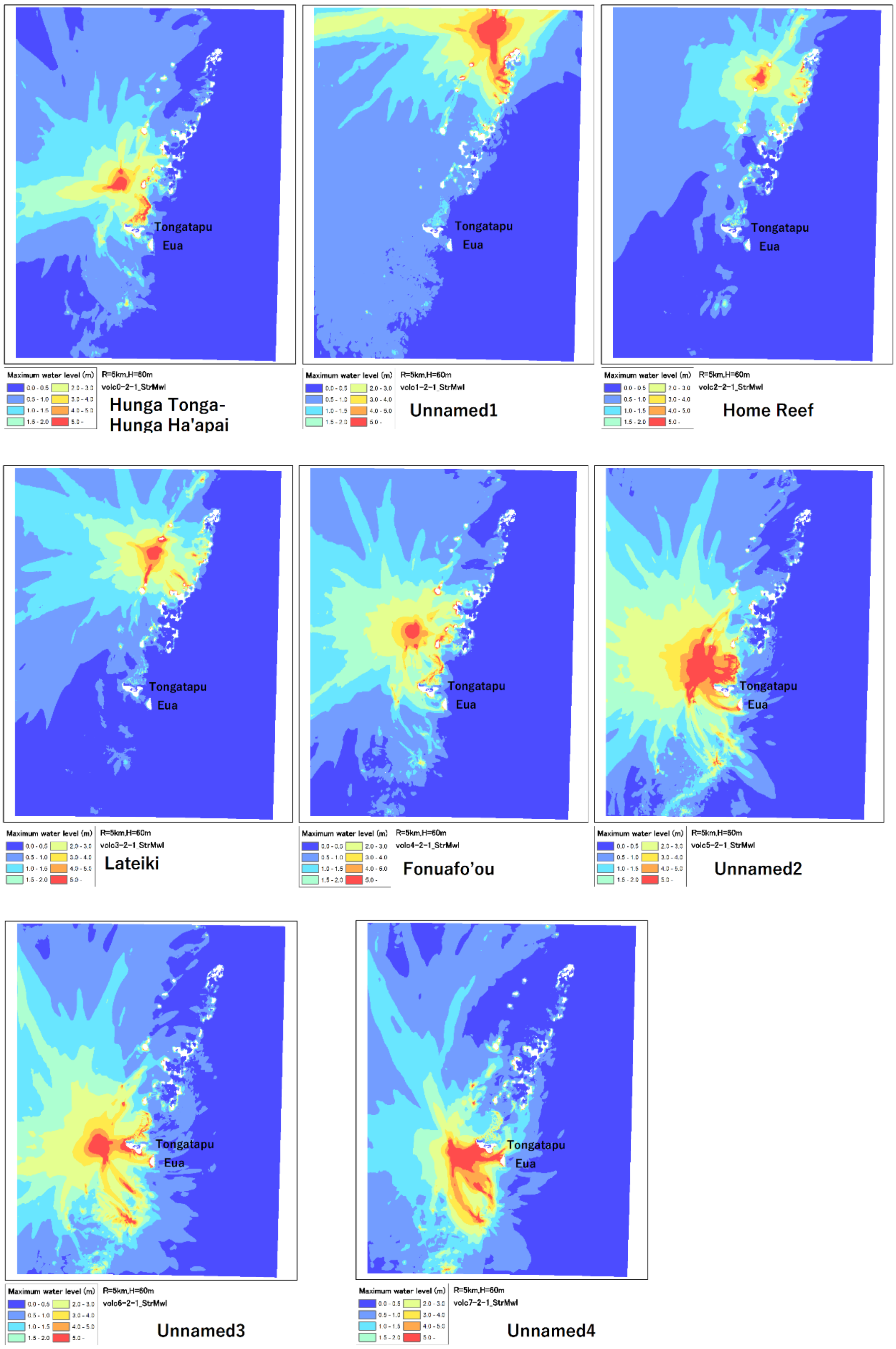
Source	CASE	Volcano name	Tsunami Source	Structure	Minimum Region
Volcanic Tsunami	Volc0-1-1	Hunga Tonga-Hunga Ha'apai	R=5km、H=30m	Exitsting Seawall (Tongatapu Island)	reg4-1(Tongatapu Island 1/3sec grid (10m grid)
	Volc1-1-1	Unnamed1			
	Volc2-1-1	Home Reef			
	Volc3-1-1	Lateiki			
	Volc4-1-1	Fonuafo'ou			
	Volc5-1-1	Unnamed2			
	Volc6-1-1	Unnamed3			
	Volc7-1-1	Unnamed4			
	Volc0-1-2	Hunga Tonga-Hunga Ha'apai		-	reg4-2(Eua Island) 1/3sec grid (10m grid)
	Volc1-1-2	Unnamed1			
	Volc2-1-2	Home Reef			
	Volc3-1-2	Lateiki			
	Volc4-1-2	Fonuafo'ou			
	Volc5-1-2	Unnamed2			
	Volc6-1-2	Unnamed3			
	Volc7-1-2	Unnamed4			
	Volc0-2-1	Hunga Tonga-Hunga Ha'apai	R=5km、H=60m	Exitsting Seawall (Tongatapu Island)	reg4-1(Tongatapu Island 1/3sec grid (10m grid)
	Volc1-2-1	Unnamed1			
	Volc2-2-1	Home Reef			
	Volc3-2-1	Lateiki			
	Volc4-2-1	Fonuafo'ou			
	Volc5-2-1	Unnamed2			
	Volc6-2-1	Unnamed3			
	Volc7-2-1	Unnamed4			
	Volc0-2-2	Hunga Tonga-Hunga Ha'apai		-	reg4-2(Eua Island) 1/3sec grid (10m grid)
	Volc1-2-2	Unnamed1			
	Volc2-2-2	Home Reef			
	Volc3-2-2	Lateiki			
	Volc4-2-2	Fonuafo'ou			
	Volc5-2-2	Unnamed2			
	Volc6-2-2	Unnamed3			
	Volc7-2-2	Unnamed4			
	Volc0-3-1	Hunga Tonga-Hunga Ha'apai	R=5km、H=90m	Exitsting Seawall (Tongatapu Island)	reg4-1(Tongatapu Island 1/3sec grid (10m grid)
	Volc1-3-1	Unnamed1			
	Volc2-3-1	Home Reef			
	Volc3-3-1	Lateiki			
	Volc4-3-1	Fonuafo'ou			
	Volc5-3-1	Unnamed2			
	Volc6-3-1	Unnamed3			
	Volc7-3-1	Unnamed4			
	Volc0-3-2	Hunga Tonga-Hunga Ha'apai		-	reg4-2(Eua Island) 1/3sec grid (10m grid)
	Volc1-3-2	Unnamed1			
	Volc2-3-2	Home Reef			
	Volc3-3-2	Lateiki			
	Volc4-3-2	Fonuafo'ou			
	Volc5-3-2	Unnamed2			
	Volc6-3-2	Unnamed3			
	Volc7-3-2	Unnamed4			

Source: JICA Study Team

2) Results of Analysis

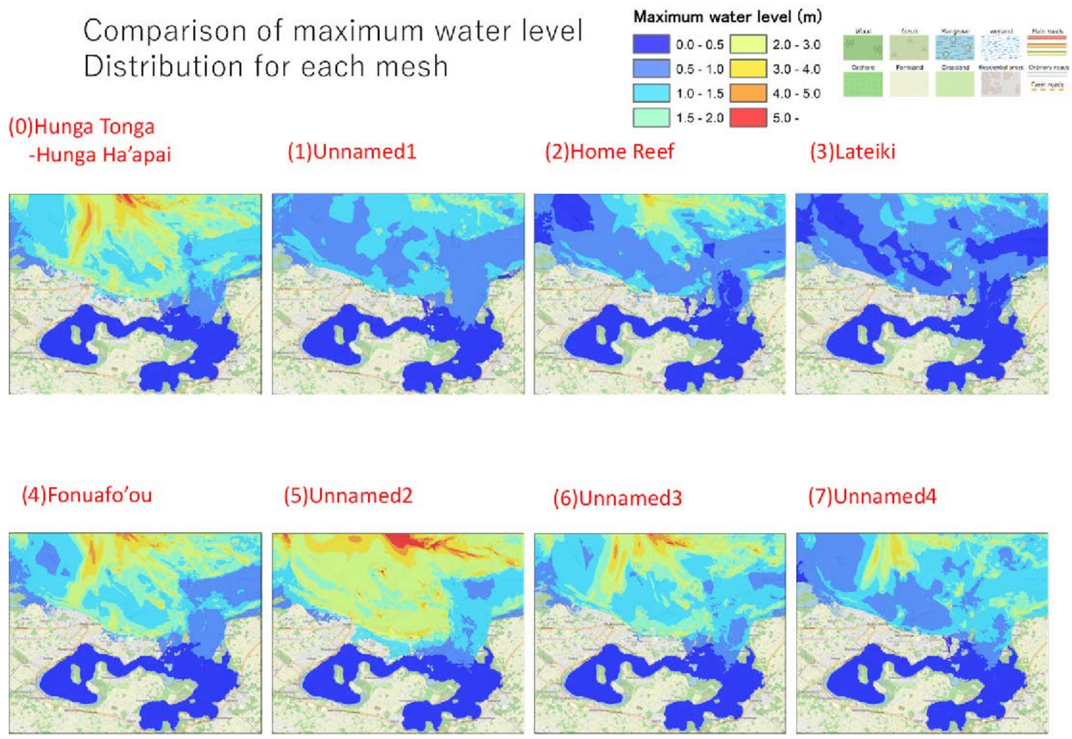
Figure 3.2.12 to Figure 3.2.17 shows an example of results. A separate volume on hazard analysis contains all calculation results.

Figure 3.2.12 shows that volcanic Tsunami waves propagate almost concentrically around the volcano, and therefore, the Tsunami water level is particularly high on the island near the volcano. Figure 3.2.13 and Figure 3.2.14 show that Nukualofa is heavily affected by Tsunami caused by Hunga Tonga-Hunga Ha'apai and Unnamed2 volcanoes, which are located on the northwest side of Tongatapu Island. On the other hand, in Ohonua, 'Eua Island, Tsunami impact by Unnamed3 and Unnamed4 volcanoes located on the west side of 'Eua Island is significant. The impact of Hunga Tonga-Hunga Ha'apai and Unnamed2 volcanoes is smaller in Ohonua, 'Eua Island, because Tongatapu Island blocks the waves.



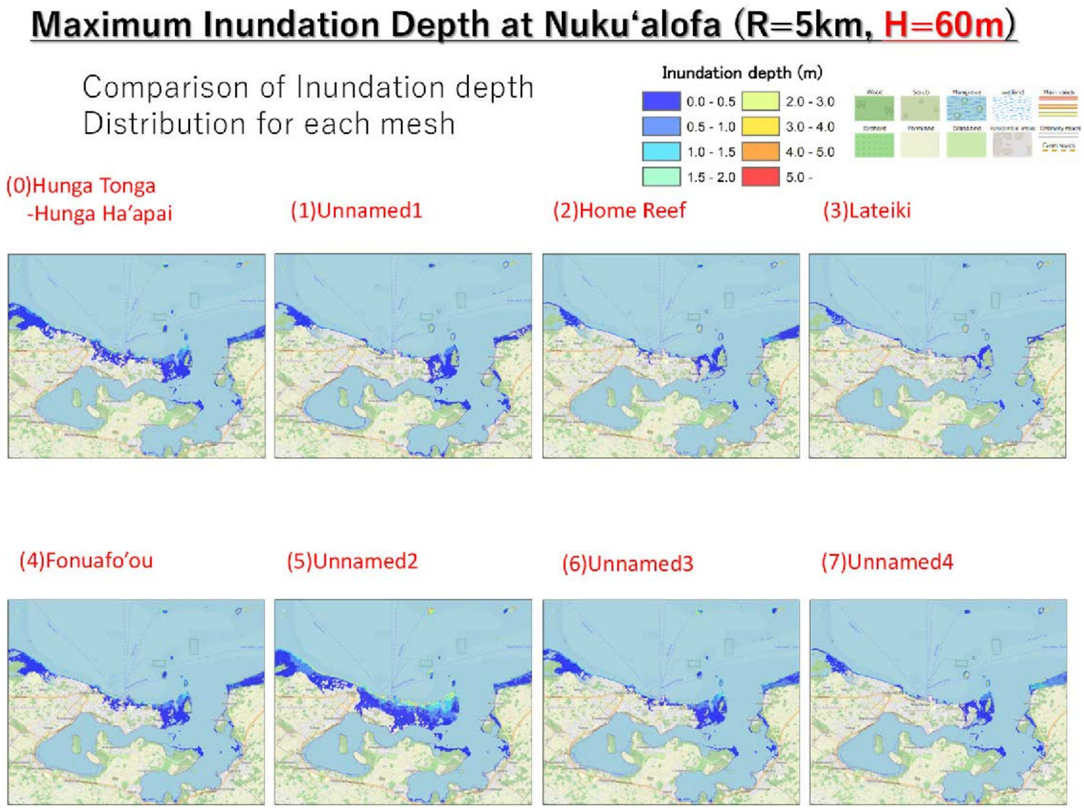
Source: JICA Study Team

Figure 3.2.12 Maximum Water Level Distribution of Volcanoes (R=5km, H=60m)



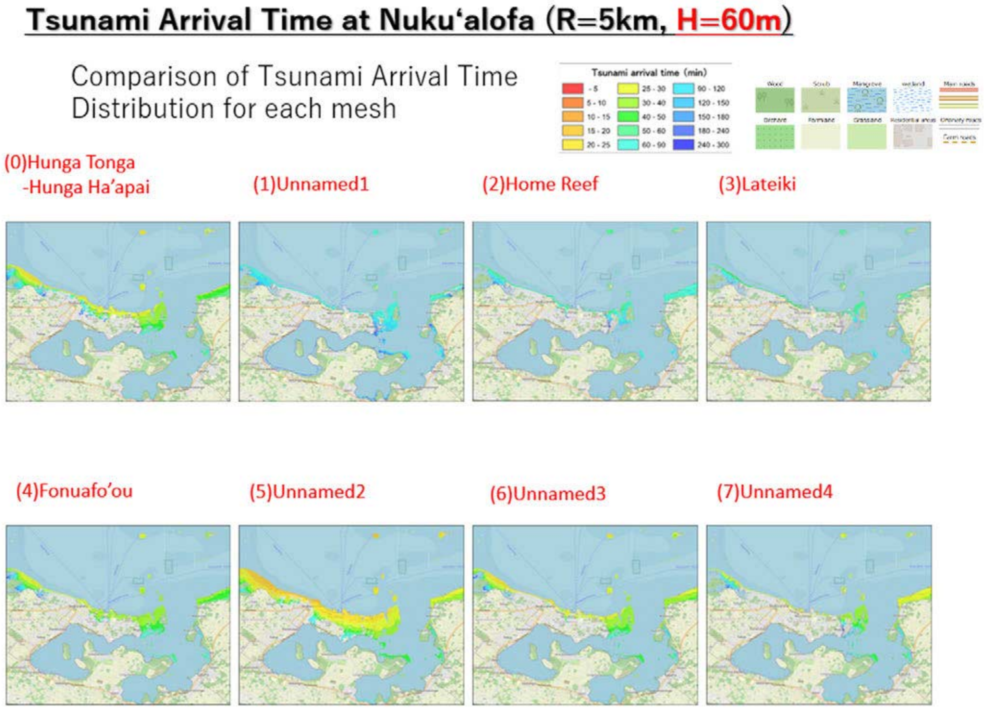
Source: JICA Study Team

Figure 3.2.13 Maximum Water Level Distribution at Nuku'alofa (R=5km, H=60m)



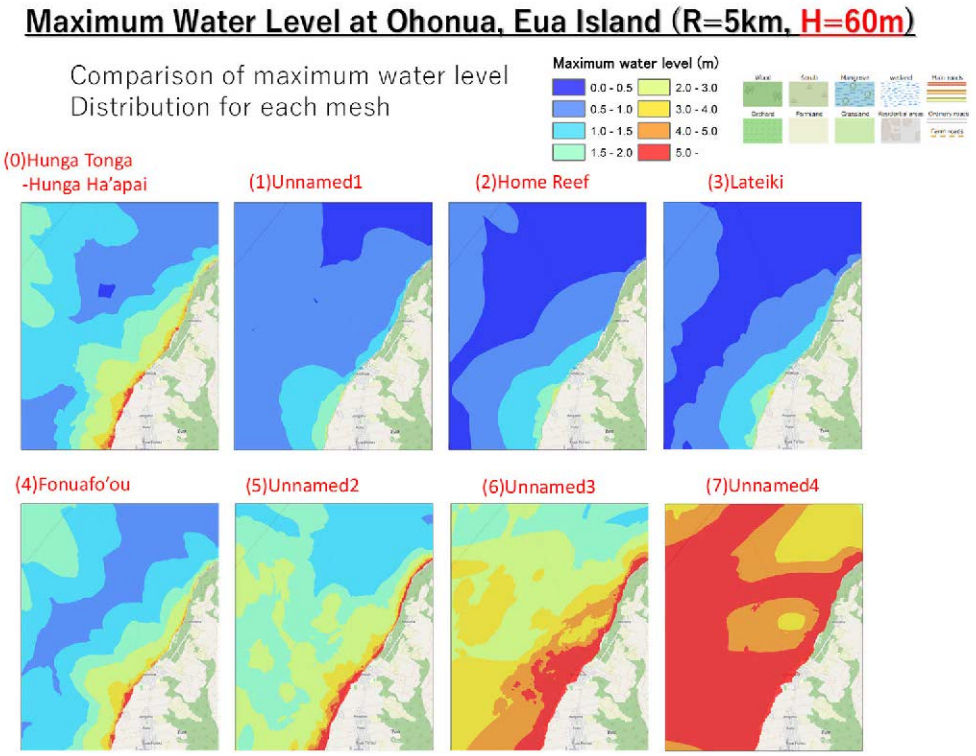
Source: JICA Study Team

Figure 3.2.14 Maximum Water Level Distribution at Nuku'alofa (R=5km, H=60m)



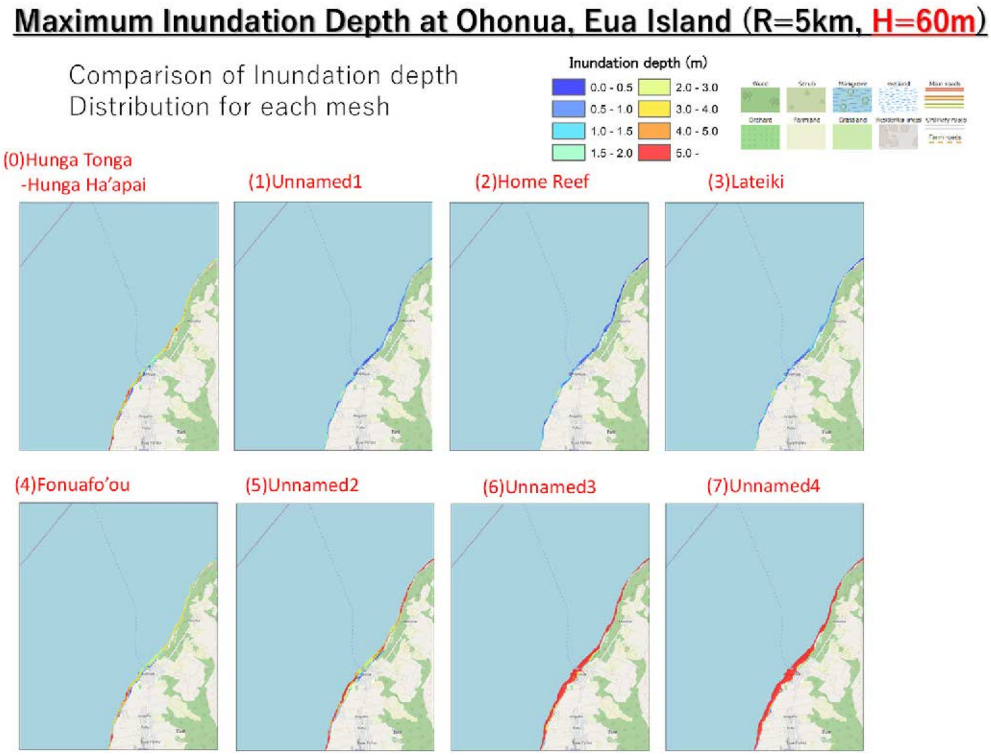
Source: JICA Study Team

Figure 3.2.15 Tsunami Arrival Time at Ohonua (R=5km, H=60m)



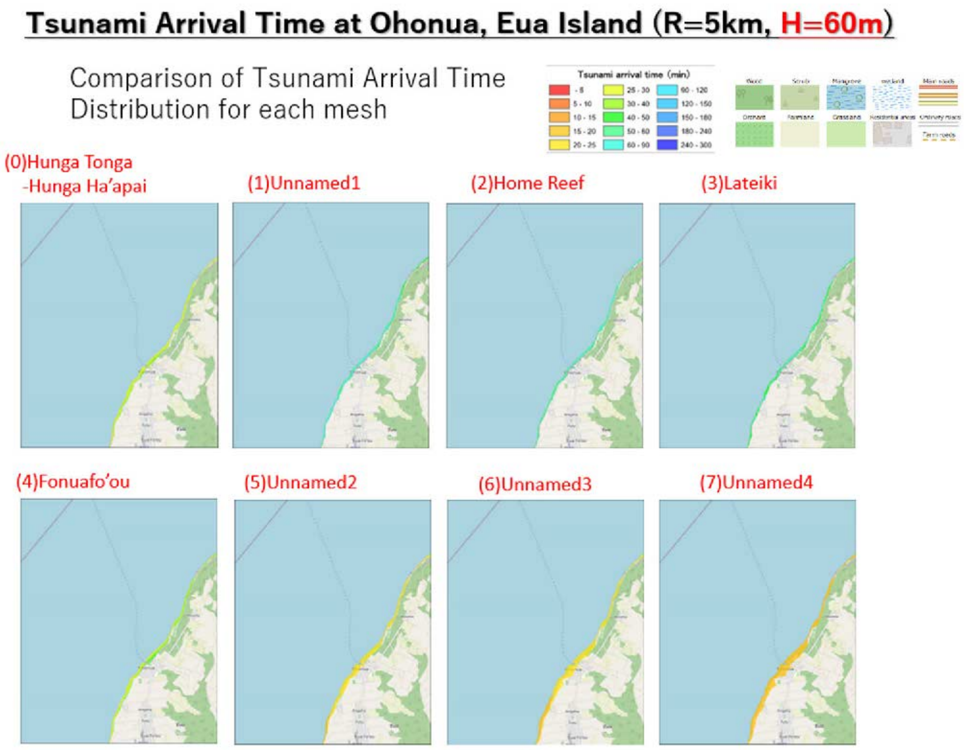
Source: JICA Study Team

Figure 3.2.16 Maximum Water Level Distribution at Ohonua (R=5km, H=60m)



Source: JICA Study Team

Figure 3.2.17 Maximum Inundation Depth at Ohonua (R=5km, H=60m)

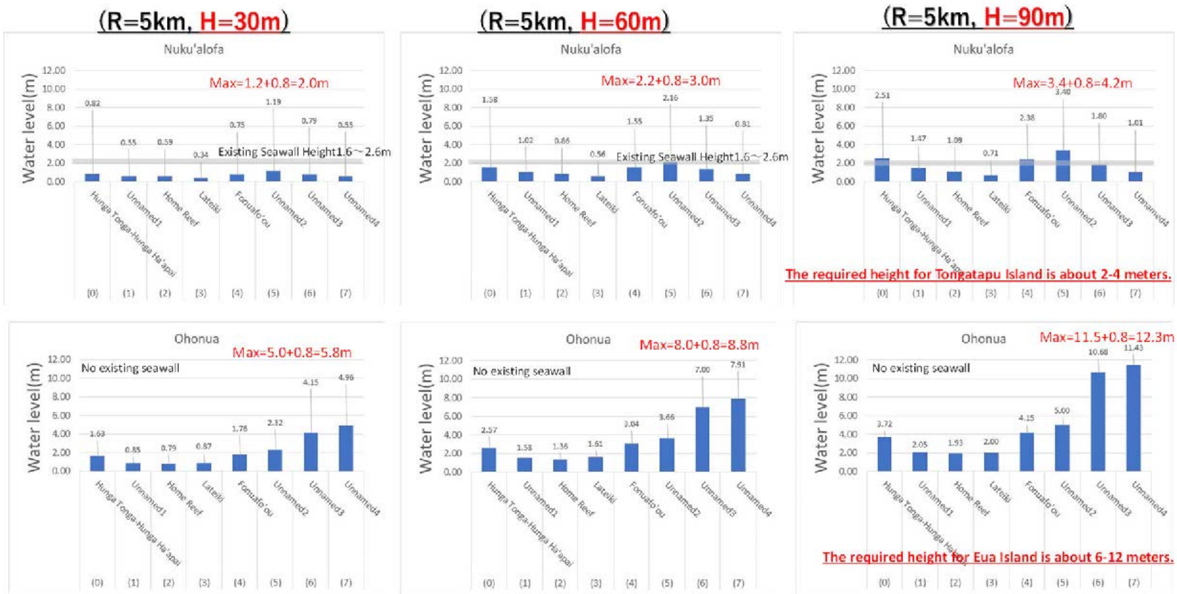


Source: JICA Study Team

Figure 3.2.18 Tsunami Arrival Time at Ohonua (R=5km, H=60m)

3) Examination of the Required Height of a Seawall

The hazard level of tsunamis is examined based on the analysis results of volcanic tsunamis. The required height of the seawall (as shown in Figure 3.2.19) is M.S.L.+4m at Nuku'alofa and M.S.L.+12m at Ohonua, which is significantly higher than the current seawall (M.S.L.+2m).



Source: JICA Study Team

Figure 3.2.19 Height Requirement of Seawall against Volcanic Tsunami

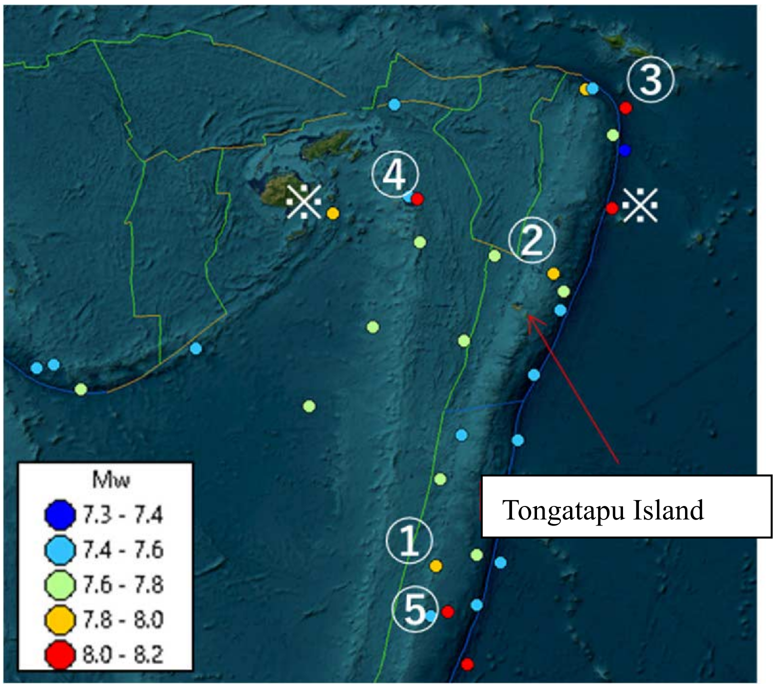
(3) Seismic Tsunami Analysis

1) Analysis Method

a) Assumptions on Tsunami Analysis

The project aims to determine the earthquakes with the highest moment magnitude (Mw) among the earthquakes that occurred after 1913 from the Earthquake Catalog of the USGS. The top 5 earthquakes with the highest moment magnitude are the basis for the fault parameters and tsunami analysis.

Figure 3.2.20 shows the epicenter map of the target earthquake. The study does not consider the earthquakes before 1975 because of limited information, such as the CMT solutions and aftershock distribution. Setting the fault parameters is difficult.



Source: JICA Study Team

Figure 3.2.20 Location of Epicenter

The fault parameters for the target earthquake are defined using a single rectangular model to represent the fault plane of the earthquake.

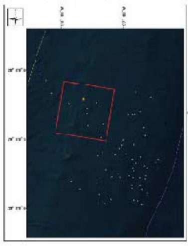
The study utilized the fault model parameters in Figure 3.2.21 and Figure 3.2.22. The USGS Earthquake Catalog[10], the Headquarters for Earthquake Research Promotion's "Strong ground motion prediction method for earthquakes with specified source faults[11]" (March 2020), and the Japan Society of Civil Engineers' Nuclear Power also used the same parameters, which is based on "Tsunami Evaluation Technology for Power Plants 2016[12]" (September 2016).

10 USGS Earthquake Catalog: https://earthquake.usgs.gov/earthquakes/search/
11 Strong ground motion prediction method for earthquakes with specified source faults https://www.jishin.go.jp/main/chousa/20_yosokuchizu/recipe.pdf
12 Tsunami Evaluation Technology for Power Plants 2016：Japan society of civil engineer https://committees.jsce.or.jp/ceofnp/node/84

Fault Model for Tsunami①

1976/1/14 Earthquake (Mw7.9)

Latitude (°)	Lat	-28.29
Longitude (°)	Long	-177.15
Depth at Top (km)	d	23
Length (km)	L	83.496
Width (km)	W	83.5
Strike (°)	strike	189
Angle of Slope (°)	dip	11
Slide Angle (°)	rake	71
Slip Amount (m)	D	2.41
Moment Magnitude	Mw	7.9



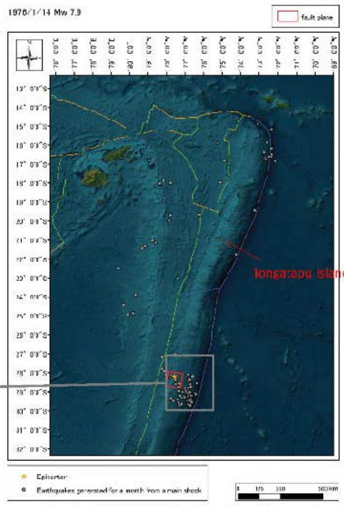


Fig.7 1976/1/14Epicenter location and aftershock distribution of the earthquake

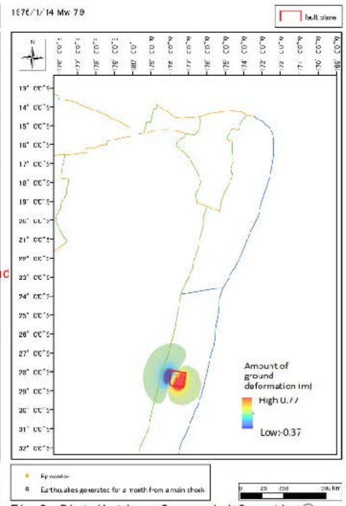


Fig.8 Distribution of ground deformation①
※Calculated by Okada (1985) formula

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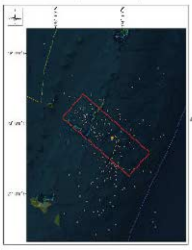
Fault Model for Tsunami②

2006/5/3Earthquakes (Mw8.0)

Latitude (°)	Lat	-20.39
Longitude (°)	Long	-173.56
Depth at Top (km)	d	6.9
Length (km)	L	49.412
Width (km)	W	147.74
Strike (°)	strike	222
Angle of Slope (°)	dip	19
Slide Angle (°)	rake	117
Slip Amount (m)	D	3.45
Moment Magnitude	Mw	8



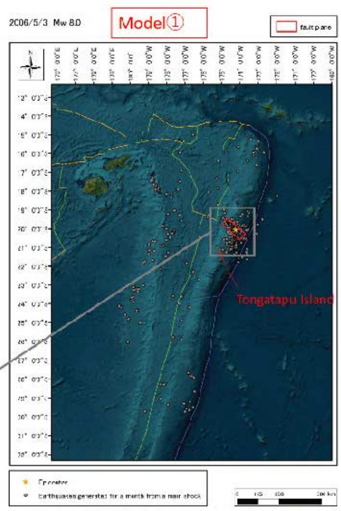


Fig.9 2006/5/3 Epicenter location and aftershock distribution of the earthquake

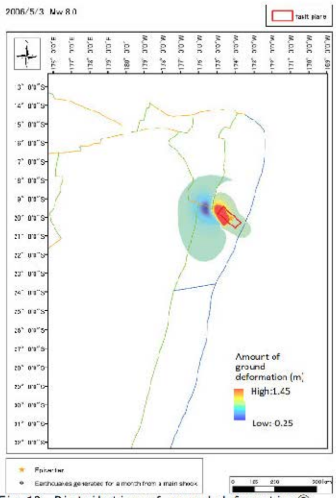


Fig.10 Distribution of ground deformation②
※Calculated by Okada (1985) formula

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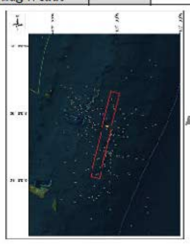
Model②

Fault Model for Tsunami

2006/5/3Earthquakes (Mw8.0)

Latitude (°)	Lat	-20.94
Longitude (°)	Long	-174.37
Depth at Top (km)	d	6.9
Length (km)	L	145.139
Width (km)	W	50.298
Strike (°)	strike	13
Angle of Slope (°)	dip	73
Slide Angle (°)	rake	81
Slip Amount (m)	D	3.45
Moment Magnitude	Mw	8



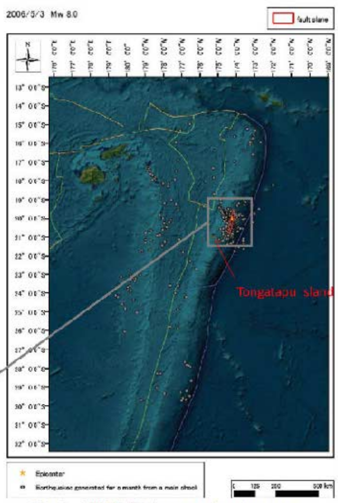


Fig.3 2006/5/3Epicenter location and aftershock distribution of the earthquake

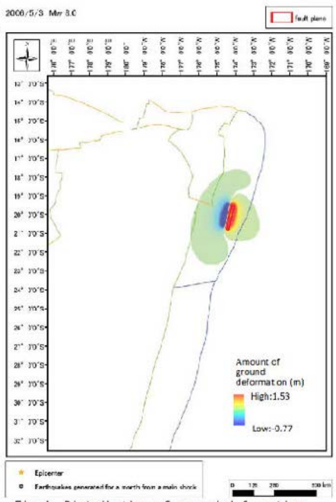
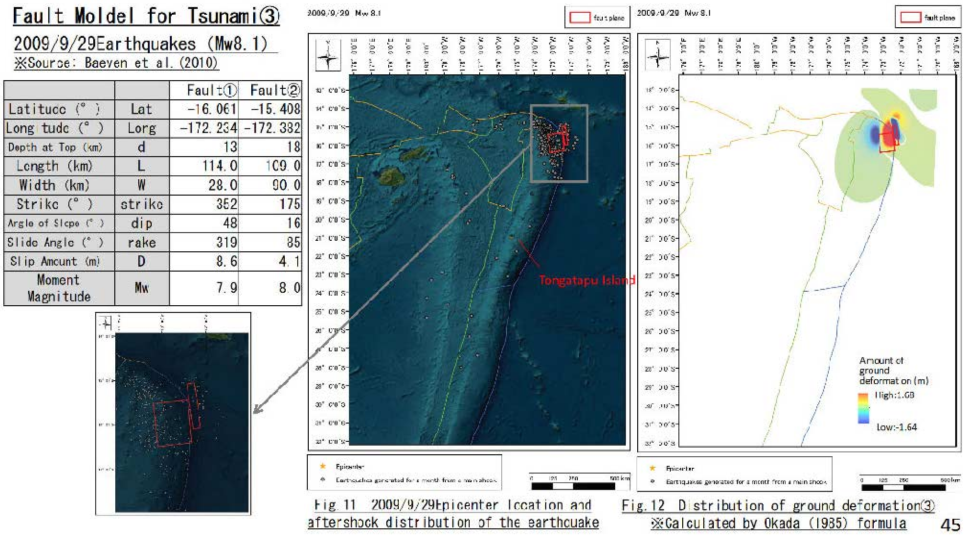


Fig.4 Distribution of ground deformation
※Calculated by Okada (1985) formula

44

Source: JICA Study Team

Figure 3.2.21 Fault Model 1

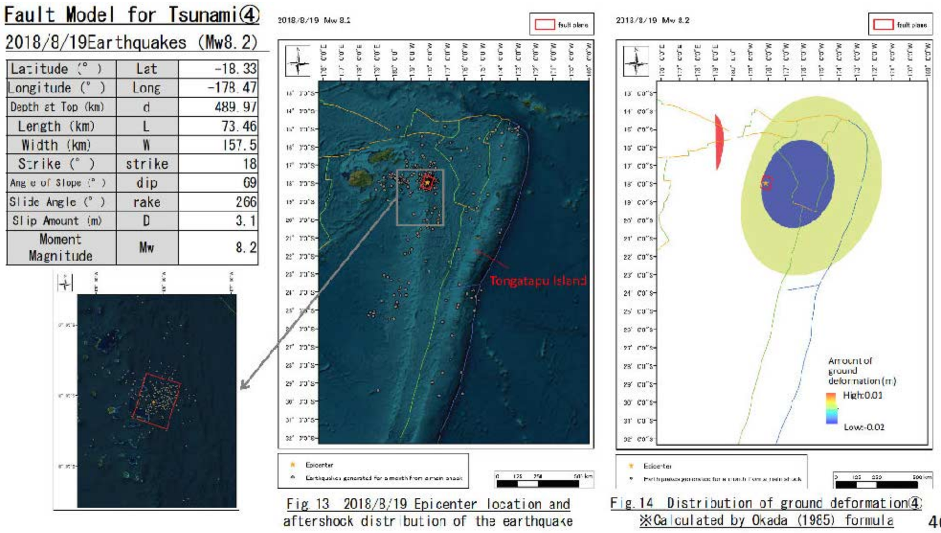


Fault Moldel for Tsunami③

2009/9/29Earthquakes (Mw8.1)

※Source: Baeven et al. (2010)

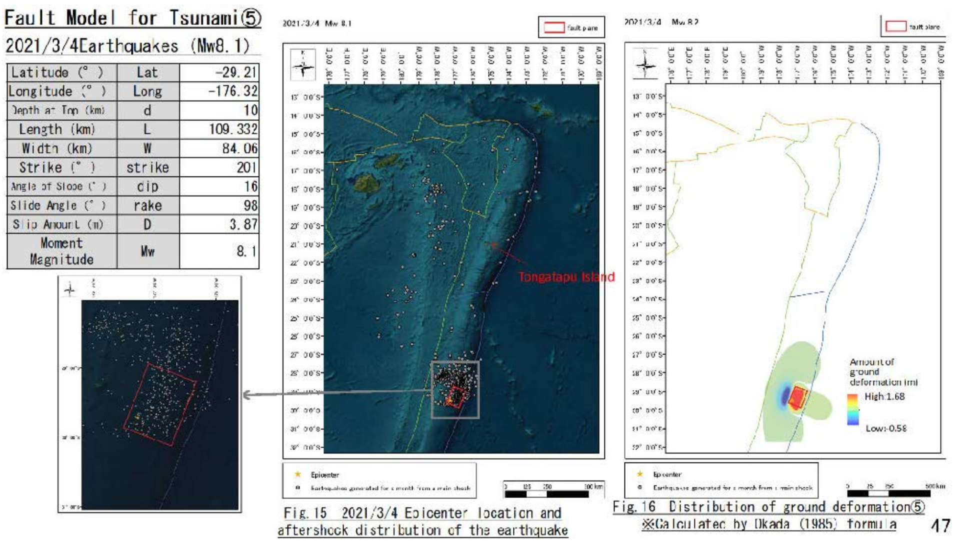
		Fault①	Fault②
Latitude (°)	Lat	-16.061	-15.408
Longitude (°)	Long	-172.234	-172.332
Depth at Top (km)	d	13	18
Length (km)	L	114.0	109.0
Width (km)	W	28.0	90.0
Strike (°)	strike	352	175
Angle of Slope (°)	dip	48	16
Slide Angle (°)	rake	319	85
Slip Amount (m)	D	8.6	4.1
Moment Magnitude	Mw	7.9	8.0



Fault Model for Tsunami④

2018/8/19Earthquakes (Mw8.2)

Latitude (°)	Lat	-18.33
Longitude (°)	Long	-178.47
Depth at Top (km)	d	489.97
Length (km)	L	73.46
Width (km)	W	157.5
Strike (°)	strike	18
Angle of Slope (°)	dip	69
Slide Angle (°)	rake	266
Slip Amount (m)	D	3.1
Moment Magnitude	Mw	8.2



Fault Model for Tsunami⑤

2021/3/4Earthquakes (Mw8.1)

Latitude (°)	Lat	-29.21
Longitude (°)	Long	-176.32
Depth at Top (km)	d	10
Length (km)	L	109.332
Width (km)	W	84.06
Strike (°)	strike	201
Angle of Slope (°)	dip	16
Slide Angle (°)	rake	98
Slip Amount (m)	D	3.87
Moment Magnitude	Mw	8.1

Source: JICA Study Team

Figure 3.2.22 Fault Model 2

b) Numerical Analysis Method

The numerical analysis method for seismic tsunamis is the same as for the volcanic tsunami. However, area expansion is necessary to perform the tsunami simulation for distant earthquake faults.

c) Numerical Analysis Conditions

The numerical analysis conditions for seismic tsunamis are the same as for the volcanic tsunami.

d) Numerical Analysis Cases

Table 3.2.6 lists the cases for the numerical analysis.

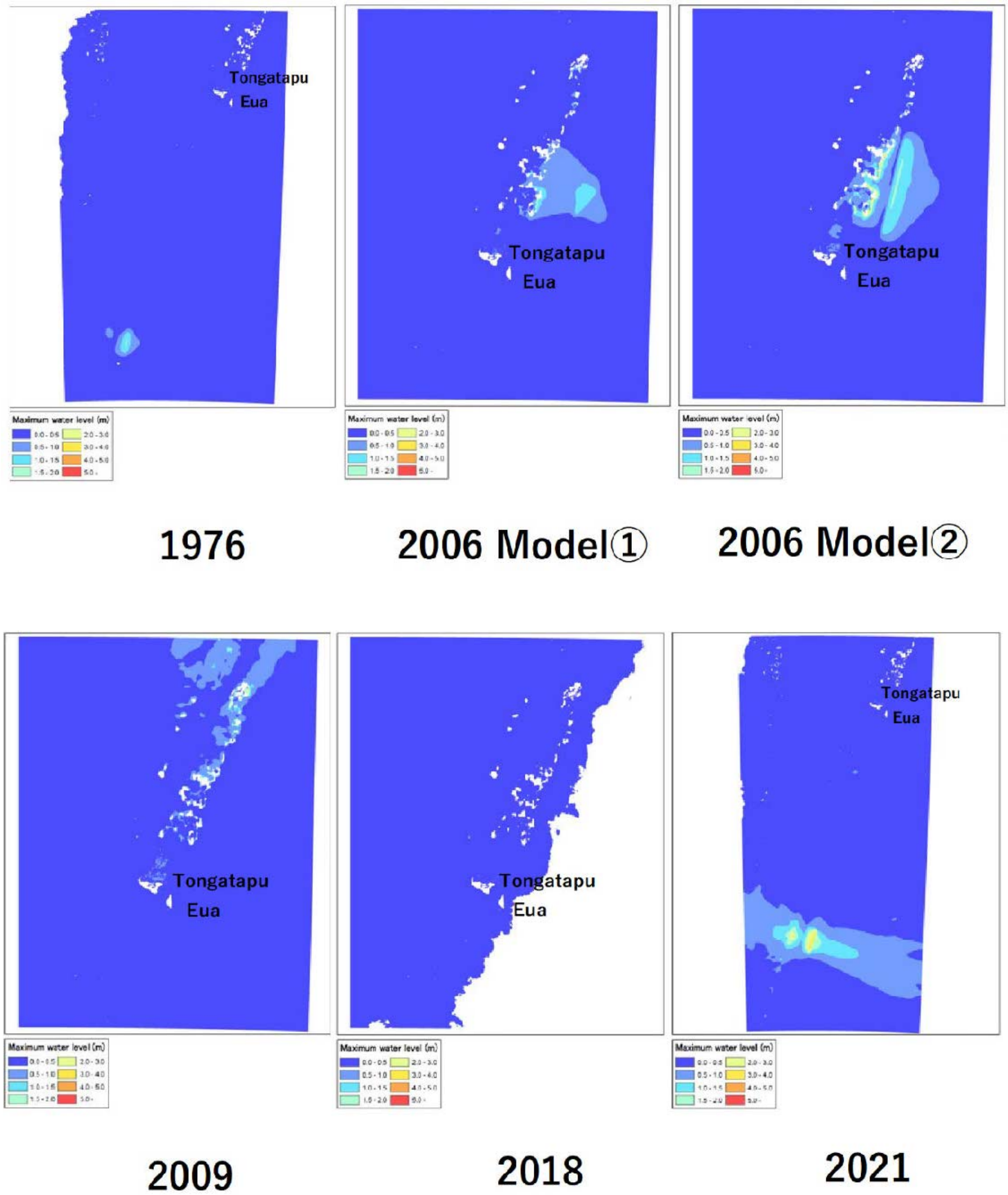
Table 3.2.6 Numerical Analysis Cases

Source	CASE	Volcano name	Tsunami Source	Structure	Minimum Region
Seismic Tsunami	fault1976-1	1976/1/14 Earthquake	Past Seismic Tsunamis	Exitsting Seawall (Tongatapu Island)	reg4-1(Tongatapu Island 1/3sec grid (10m grid)
	fault2006-1	2006/5/3Earthquake(Model①)			
	fault2006-2	2006/5/3Earthquake(Model②)			
	fault2009-1	2009/9/29 Earthquake			
	fault2018-1	2018/8/19 Earthquake			
	fault2021-1	2021/3/4 Earthquake			
	fault1976-2	1976/1/14 Earthquake		-	reg4-2(Eua Island) 1/3sec grid (10m grid)
	fault2006-1	2006/5/3Earthquake(Model①)			
	fault2006-2	2006/5/3Earthquake(Model②)			
	fault2009-2	2009/9/29Earthquake			
	fault2018-2	2018/8/19Earthquake			
	fault2021-2	2021/3/4 Earthquake			

Source: JICA Study Team

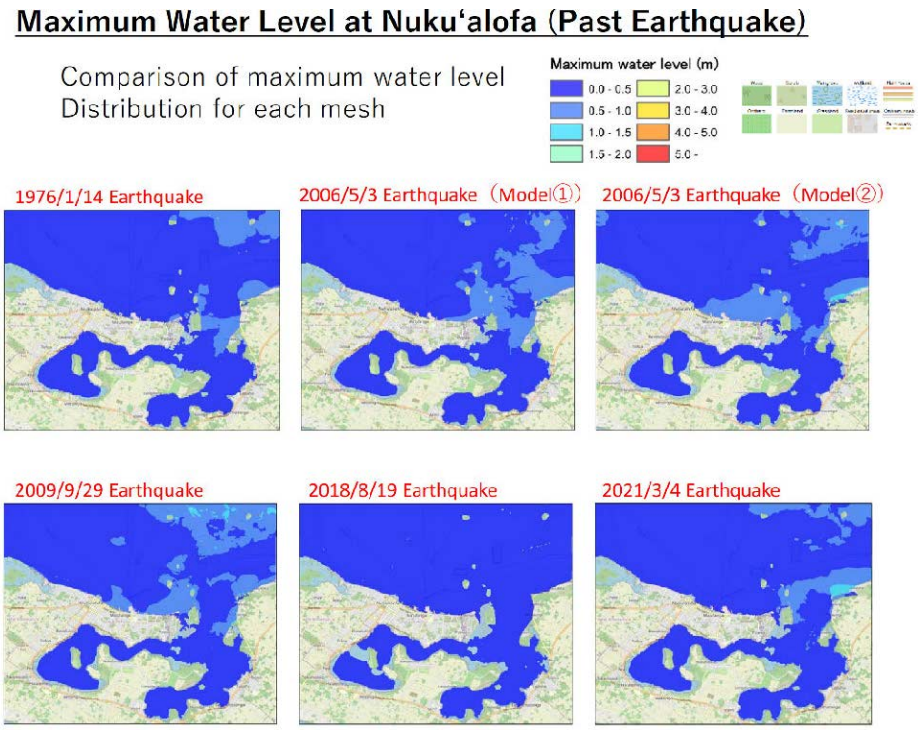
2) Result of Analysis

Figure 3.2.23 shows that the tsunami generated by the earthquake fault model propagates waves mainly from east and west of the earthquake fault, because the fault plane is long from north to south. Figure 3.2.24 and Figure 3.2.25 indicate that tsunamis caused by any earthquake do not cause serious inundation damage to Nuku'alofa. This trend is also similar for Ohonua, 'Eua Island (Figures 3.2.24 and 3.2.25).



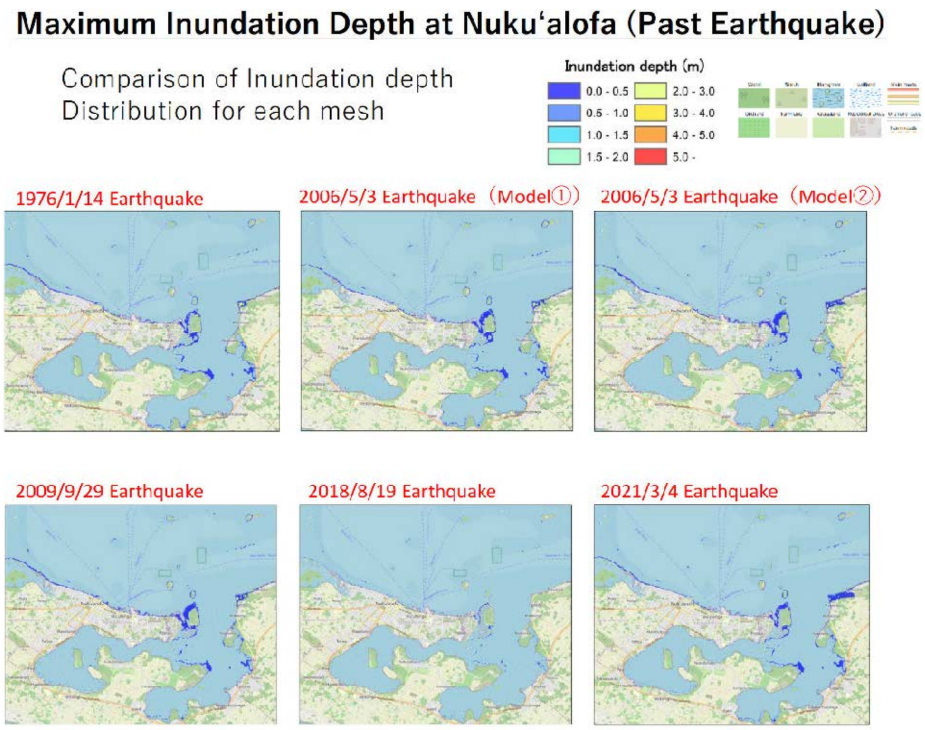
Source: JICA Study Team

Figure 3.2.23 Maximum Water Level Distribution for Each Earthquake Fault (R=5km, H=60m)



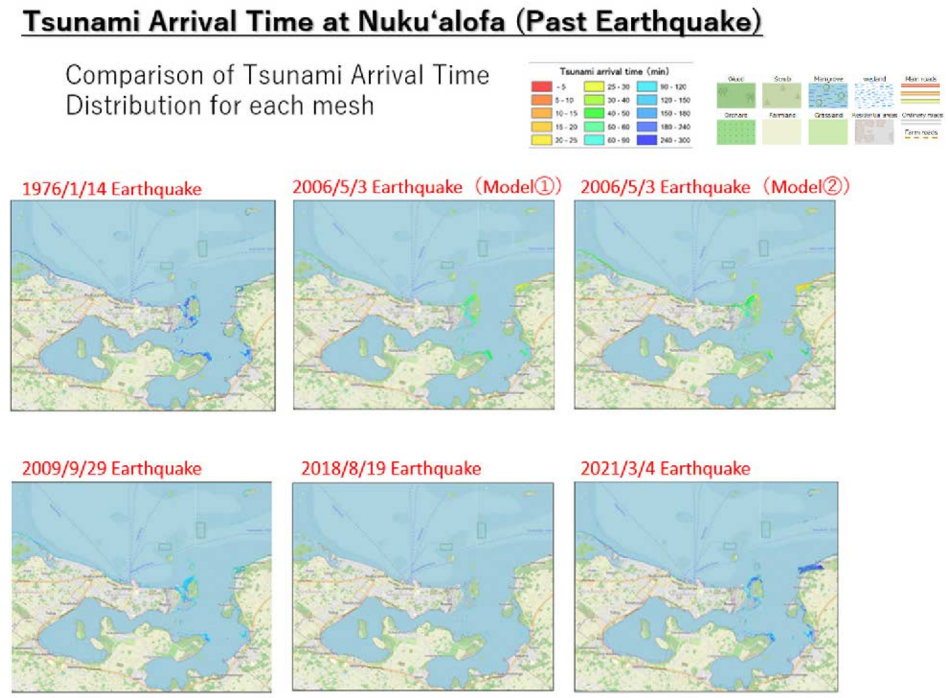
Source: JICA Study Team

Figure 3.2.24　Maximum Water Level Distribution at Nuku'alofa (Fault)



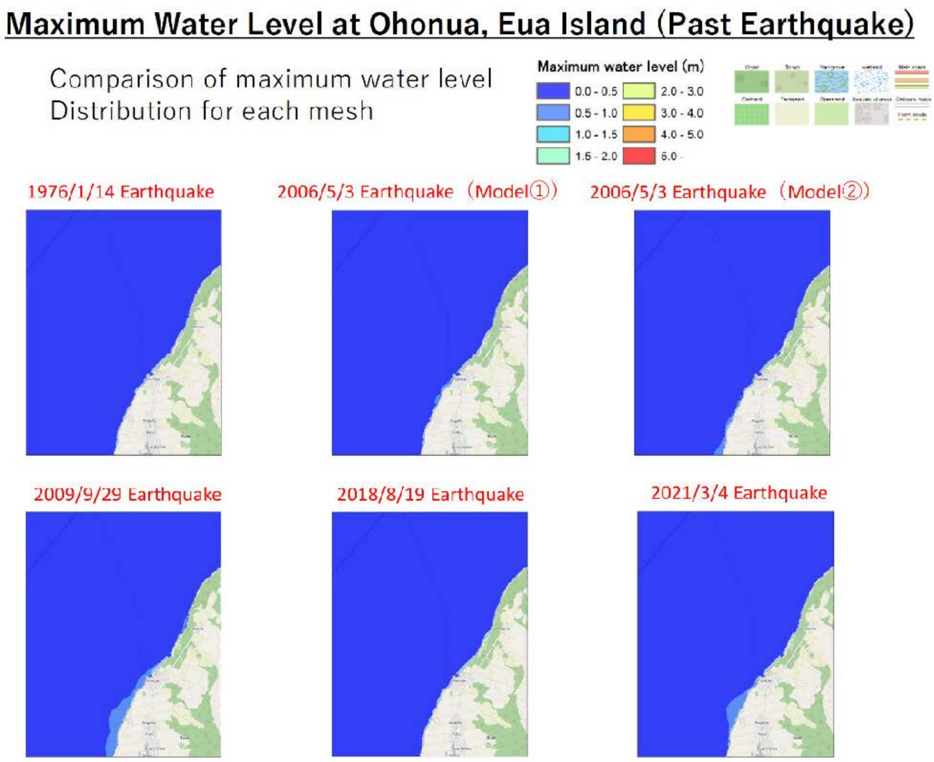
Source: JICA Study Team

Figure 3.2.25　Maximum Inundation Depth at Nuku'alofa (Fault)



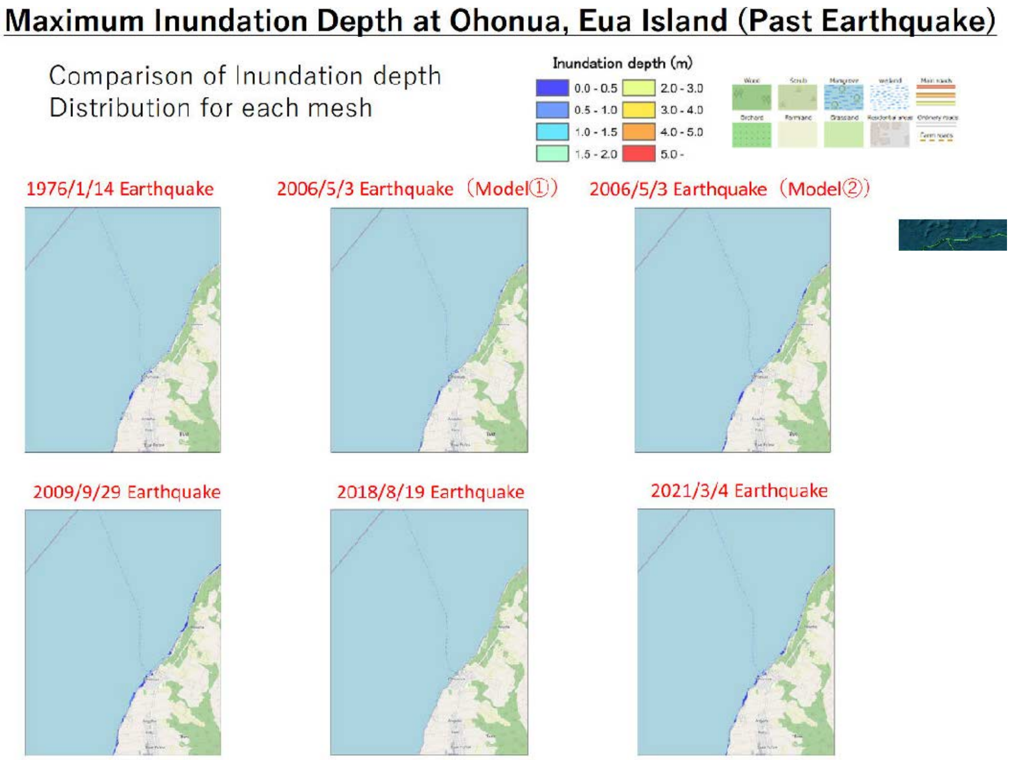
Source: JICA Study Team

Figure 3.2.26 Tsunami Arrival Time at Nuku'alofa (Fault)



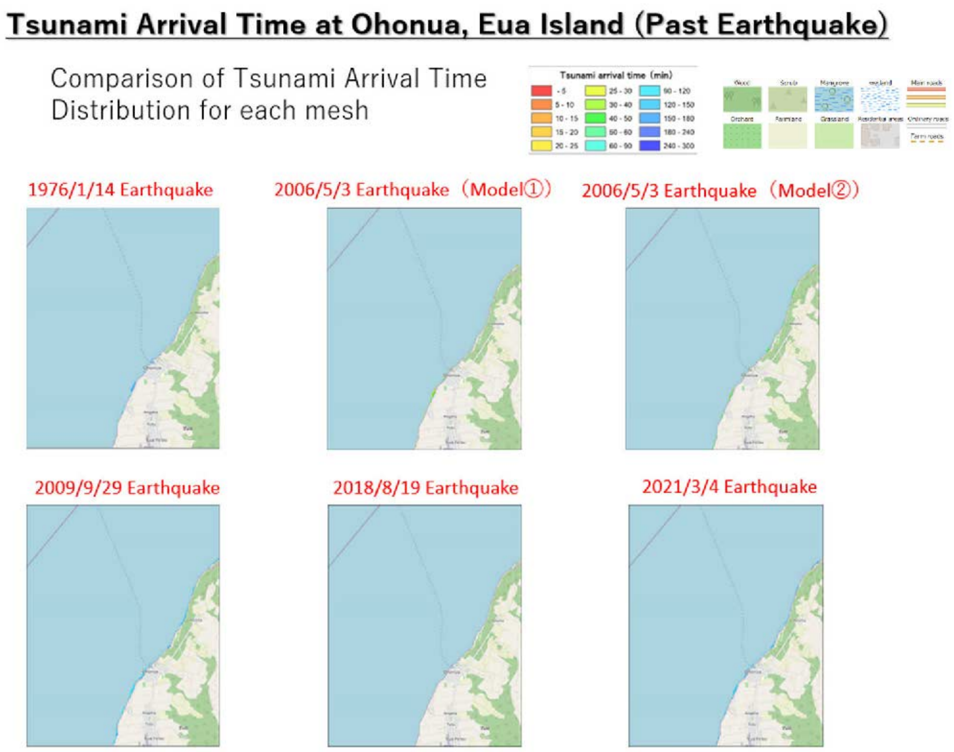
Source: JICA Study Team

Figure 3.2.27 Maximum Water Level at Ohonua (Fault)



Source: JICA Study Team

Figure 3.2.28 Maximum Inundation Depth at Ohonua (Fault)



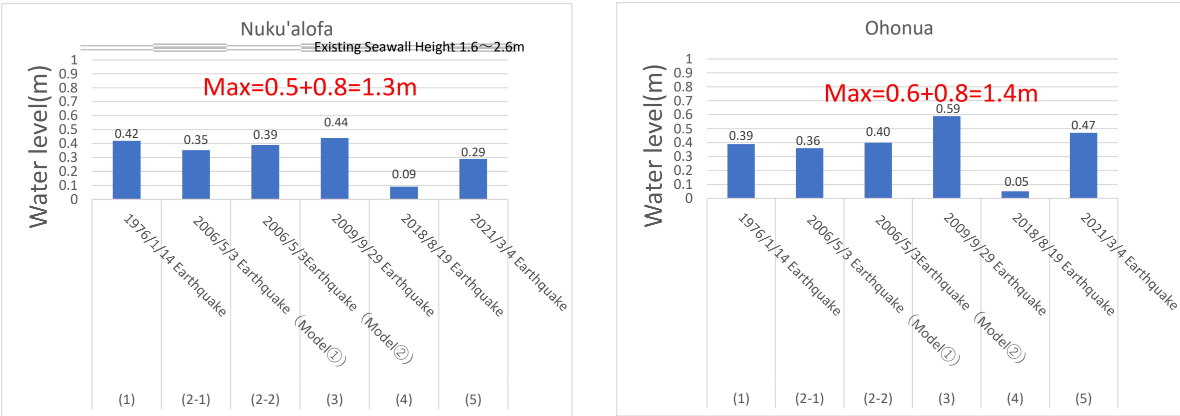
Source: JICA Study Team

Figure 3.2.29 Tsunami Arrival Time at Ohonua (Fault)

3) Examination of the Required Crest Height of Seawall

The height requirement of the seawall is examined based on the analysis results of the seismic tsunami. Seawalls heights against tsunamis of M8 or higher that occurred in the past are shown below.

The required height of the seawall is M.S.L.+1.3m at Nuku'alofa and M.S.L.+1.4m at Ohonua.



Source: JICA Study Team

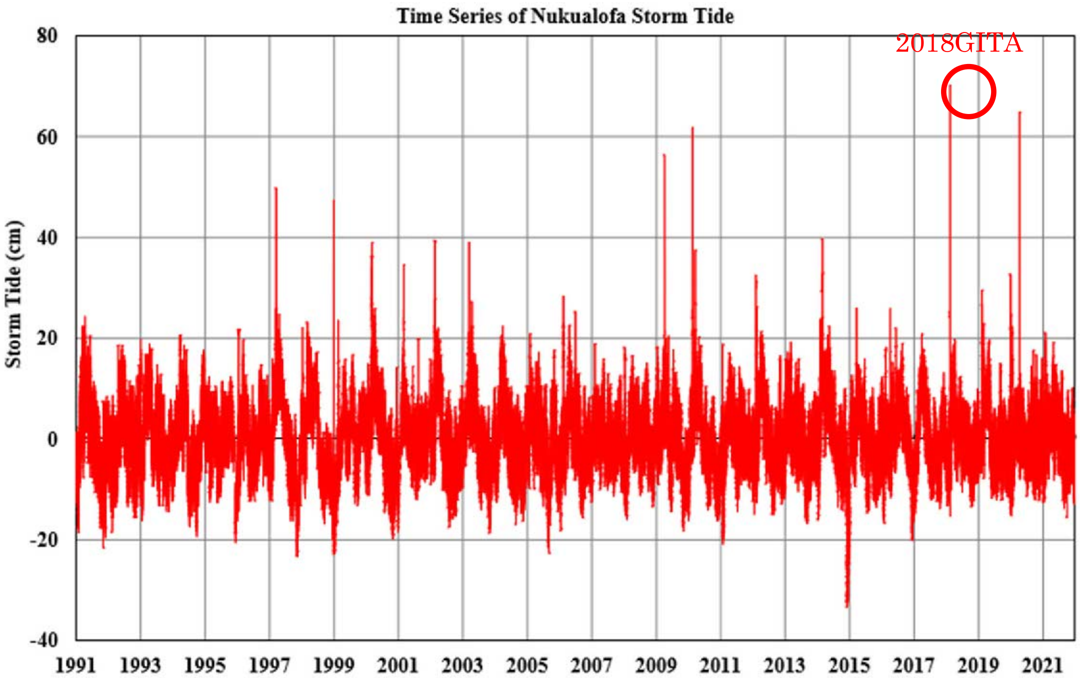
Figure 3.2.30 Required Crest Height of Seawall against Seismic Tsunami

(4) Storm Surge Analysis

1) Analysis of Tidal Deviation

Tide-level observation at Nuku'alofa has been conducted since 1991. Therefore, the astronomical tide is measured by performing harmonic decomposition on the tide level observation data from 1991 to 2021 and calculating the harmonic constant. Moreover, the astronomical tide level is subtracted from the measured tide level to calculate the deviation of the storm surge tide level. Figure 3.2.31 shows the storm surge level deviation. Table 3.2.7 shows the storm surge anomalies due to climate change.

Among the cyclones hit Tonga from 1991 to 2021, Cyclone Gita in February 2018 had the greatest tidal anomalies.



Source: JICA Study Team

Figure 3.2.31 Storm Surge Level Deviation (1991-2021, Nuku'alofa,)

Table 3.2.7 List of Tide Deviations Due to Meteorological Disturbances

Year	Month	Day	Hour	Storm surge deviation:cm	Rank
1997	3	8	15	25.78	
1997	3	10	4	25.78	
1997	3	14	9	25.78	
1997	3	16	8	49.78	5
1998	12	26	2	47.15	6
2000	3	9	9	39.00	10
2000	4	7	21	25.90	
2001	3	2	12	34.59	
2002	2	19	1	39.20	8
2002	2	20	14	27.80	
2003	3	13	5	39.03	9
2003	4	14	14	27.23	
2006	2	13	11	28.36	
2006	6	30	1	25.26	
2009	4	4	23	56.31	4
2010	2	15	9	61.70	3
2010	3	16	20	37.50	
2012	2	5	15	32.42	
2012	2	14	5	26.22	
2014	3	1	15	39.68	7
2015	3	21	18	25.97	
2016	4	5	14	25.93	
2018	2	12	11	70.19	1
2019	2	8	11	29.56	
2019	12	30	18	32.66	
2020	4	8	18	64.82	2

2018 GITA

Note: The top 3 rankings of tidal deviation in descending order are colored in yellow.

Source: JICA Study Team

2) Analysis method

a) Selection and Calculation of Objective Cyclone

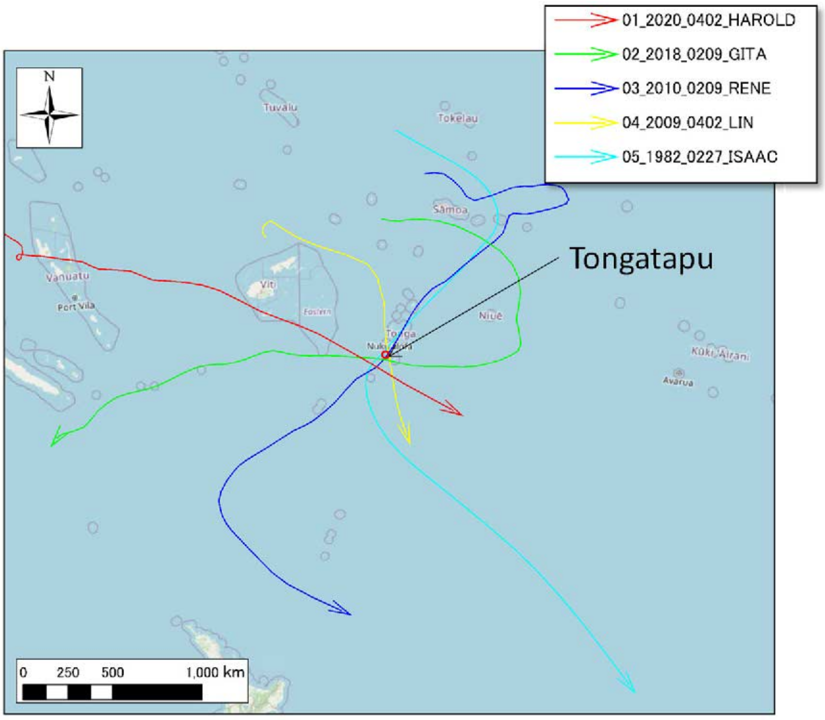
Table 3.2.8 shows the selected results for the simulated calculation based on the analysis results of the storm surge level. The cyclones with large tide level deviations are selected from Table 3.2.8.

Cyclone Isaac of 1982 was selected because of the serious damage it caused Tonga. IBTrACS[13] was used for the course information of the cyclone and the numerical calculation.

Table 3.2.8 Selection of Objective Cyclone

Year	Month	Day	Hour	Storm Surge Deviation (cm)	Rank	Cyclone NAME	Reasons for Selection
2018	2	12	11	70.2	1	Gita	High storm surge deviation
2020	4	8	18	64.8	2	Harold	ditto
2010	2	15	9	61.7	3	Rene	ditto
2009	4	4	23	56.3	4	Lin	ditto
1982	3	3	-	No DATA	–	Isaac	Most Severe Damage

Source: JICA Study Team



Source: JICA Study Team

Figure 3.2.32 Calculation Course of Cyclone

[131] IBTrACS(https://www.ncei.noaa.gov/products/international-best-track-archive)

b) Conditions for Numerical Calculation

The study used the STOC for storm surge and tsunami analysis methods.

c) Numerical Analysis Conditions

Table 3.2.9 lists the calculation conditions. The expanded calculation for the tsunami includes the cyclone course. Figure 3.2.32 shows the topographic model used for storm surge calculation.

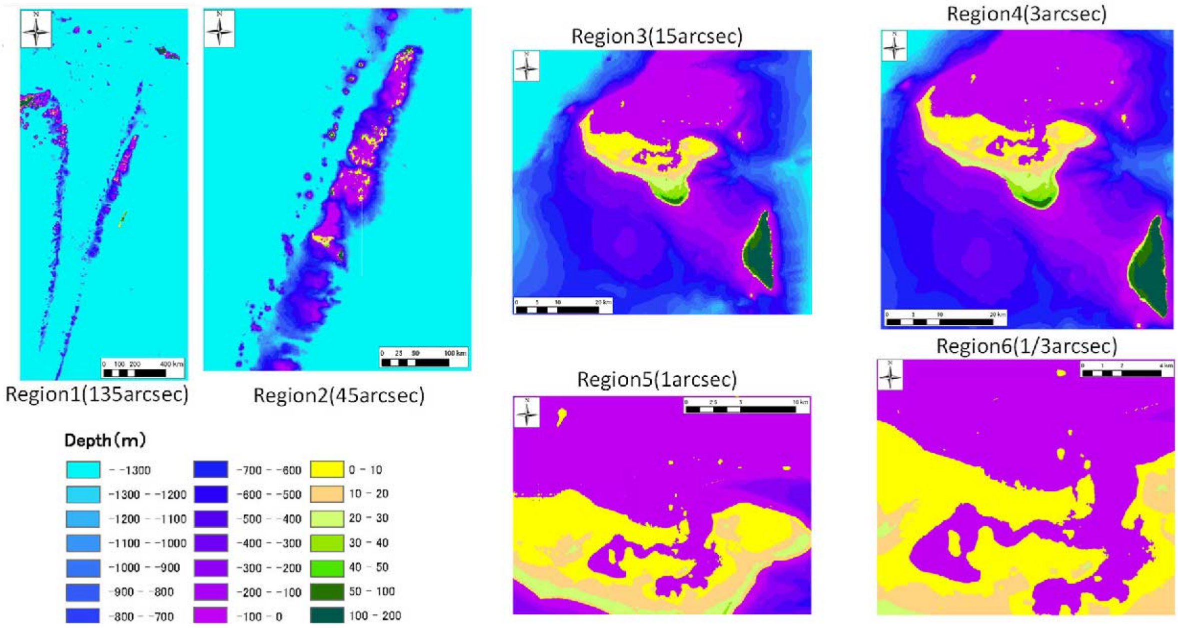
Table 3.2.9 Calculation Conditions for Storm Surge

Items	Calculation conditions
Mesh Composition	Region1 (135sec (around4050m) mesh)：Cyclone Development range
	Region2 (45sec (around 1350m) mesh)：Cyclone Development range
	Region3 (15sec (around 450m) mesh)：Cyclone Development range
	Region4 (3sec (around 90m) mesh)：Tongatapu Island
	Region5 (1sec (around 30m) mesh)：Tongatapu Island
	Region6 (1/3sec (10m) mesh)：Tongatapu Island
Analytical Method	STOC-ML (Tomita and Kakinuma, 2005)
Objective Cyclone	2018 Gita, 2020 Harold, 2010 Rene, 2009 Lin, 1982 Isac
Cyclone Model	Cyclone central pressure・Cyclone course: IBTrACS Cyclone Pressure: Myers (1954)[14] Cyclone Radius: Kato (2005)[15]
Geological Conditions	Based on topographic data from Tohoku University
Tide Level	M.S.L.0m
Calculation Time	Calculated according to the start and end times of each cyclone
	Time Resolution：min 0.01sec
Others	Structure Measures：Existing Level

Source: JICA Study Team

[14] Myers, V.A.(1954): Characteristics of U.S. hurricanes pertinent to levee design for lake Okeechobee, Fla., Hydro metrological. Rep., No. 32, Weather Bureau, U. S. Dept. Commerce, Wash D. C. 106p.

[15] Kato, F (2005); Study on Risk Assessment on Storm Surge Flood, TECHNICAL NOTE of National Institute for Land and Infrastructure Management, No.275



Source: JICA Study Team

Figure 3.2.33 Storm Surge Calculation Results

d) Numerical Analysis Cases

Table 3.2.10 lists the cases for numerical analysis.

Table 3.2.10 Cases for Numerical Analysis

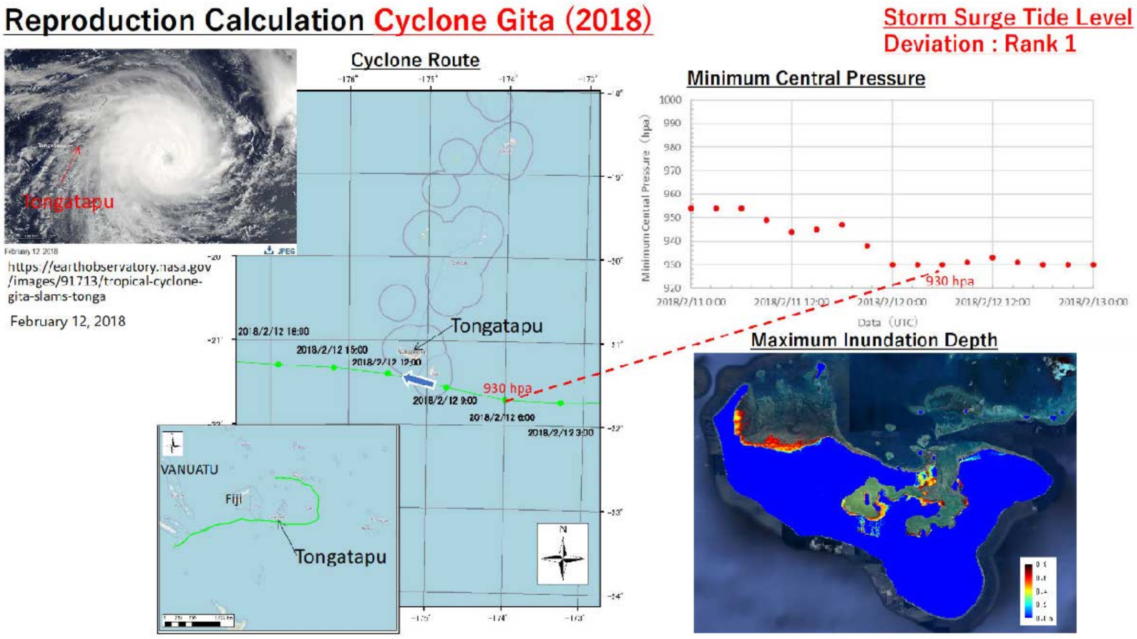
Year	Name	Calculation Period	
		Start	End
2018	Gita	2018/02/11 18:00	2018/02/12 18:00
2020	Harold	2020/04/08 00:00	2020/04/09 00:00
2010	Rene	2010/02/14 18:00	2010/02/15 18:00
2009	Lin	2009/04/04 06:00	2009/04/05 06:00
1982	Isaac	1982/03/02 09:00	1982/03/03 09:00

Source: JICA Study Team

3) Analysis Result

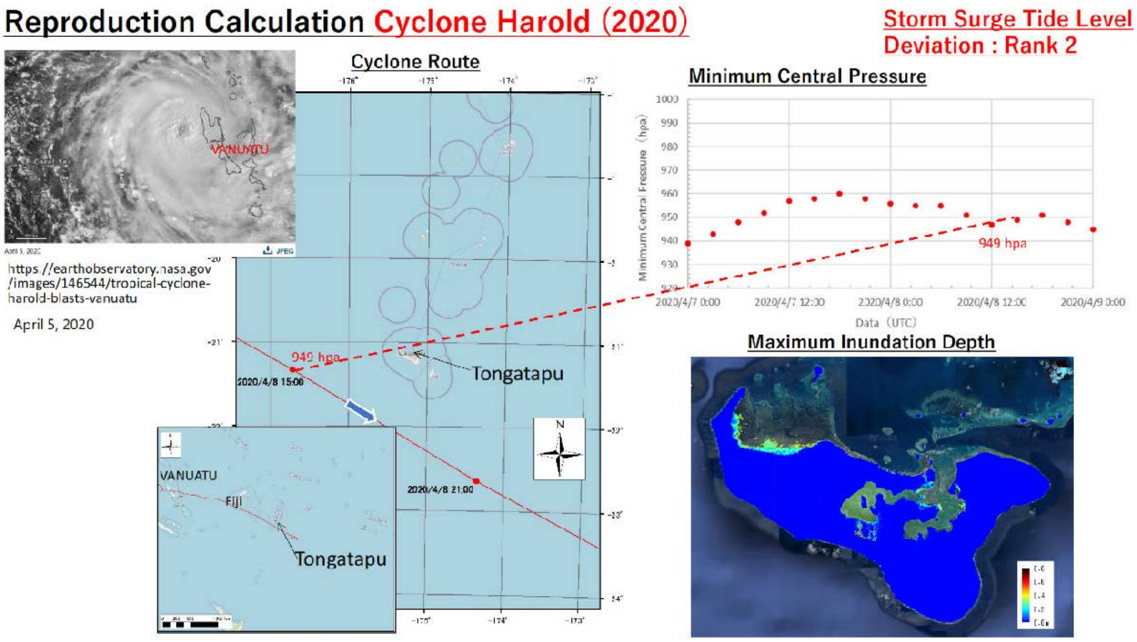
a) Results for Reproduced Cyclone Calculation

Figure 3.2.34 to Figure 3.2.38 provide an overview of the analysis results for each cyclone.



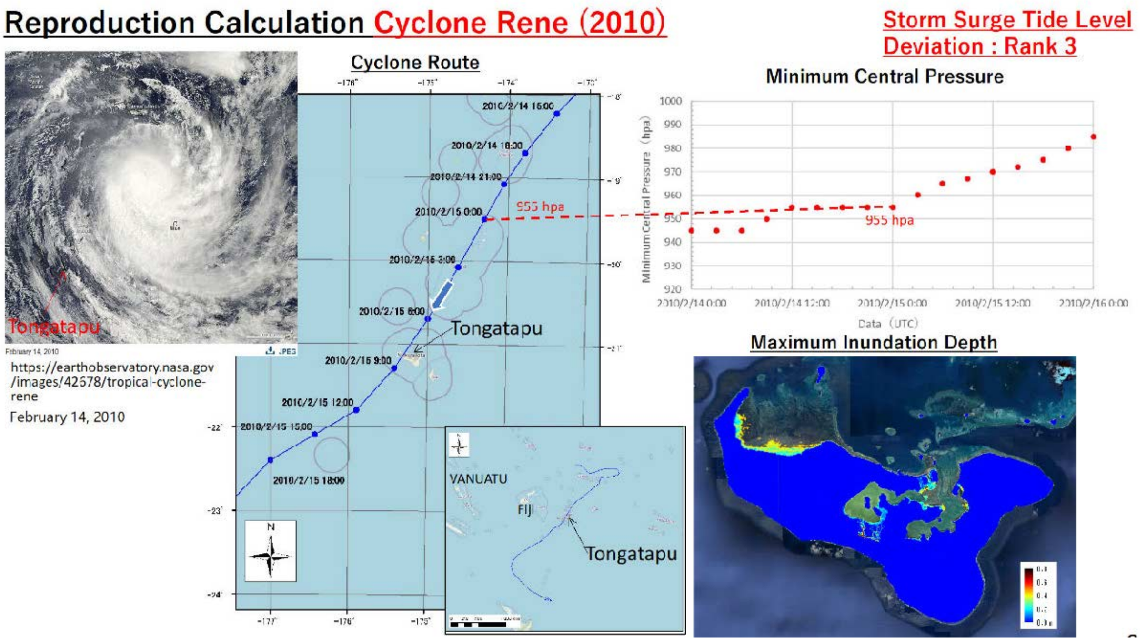
Source: JICA Study Team

Figure 3.2.34　Reproduction Calculation of Cyclone Gita (2018)



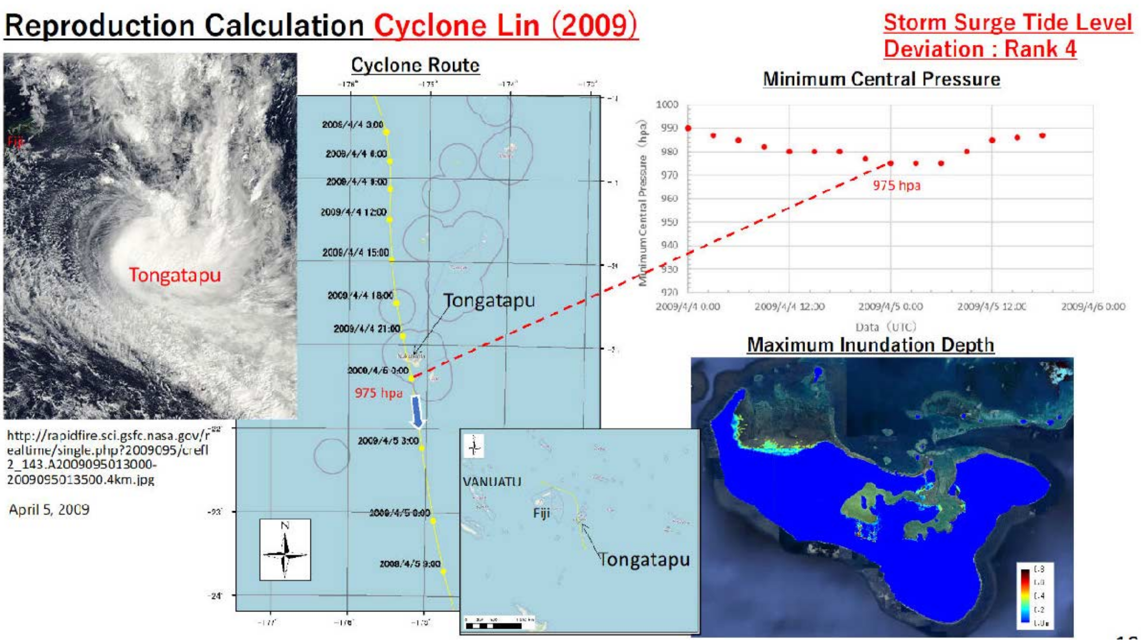
Source: JICA Study Team

Figure 3.2.35　Reproduction Calculation of Cyclone Harold (2020)



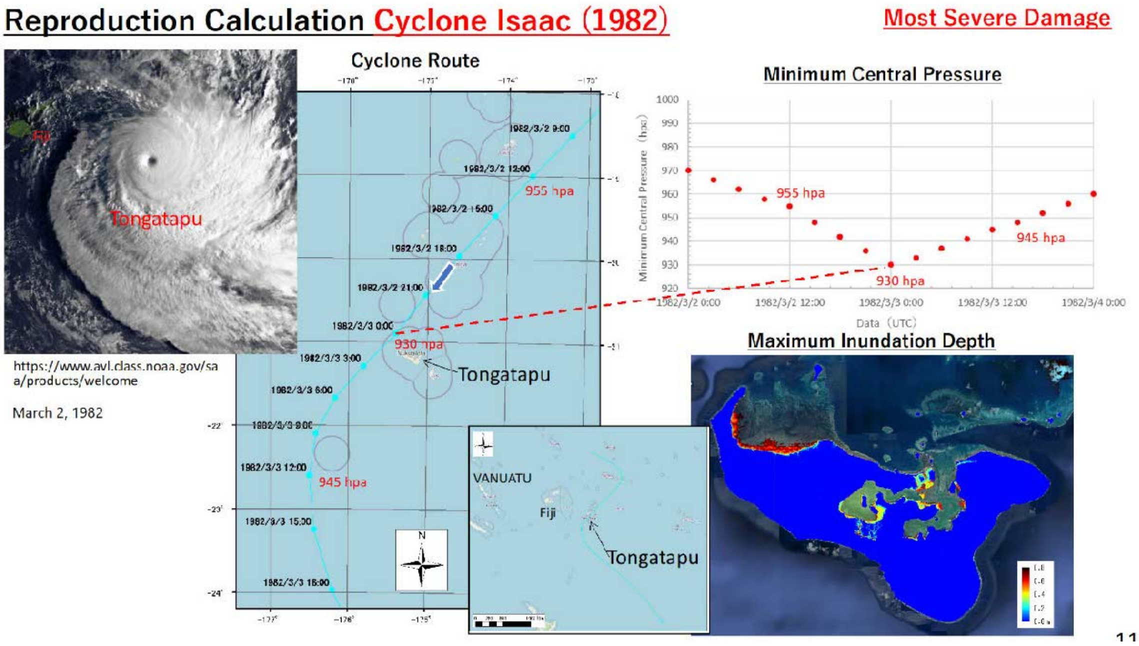
Source: JICA Study Team

Figure 3.2.36 Reproduction Calculation of Cyclone Rene (2010)



Source: JICA Study Team

Figure 3.2.37 Reproduction Calculation of Cyclone Lin (2009)



Source: JICA Study Team

Figure 3.2.38 Reproduction Calculation of Cyclone Isaac (1982)

4) The characteristics of cyclones cause severe conditions in Nuku'alofa.

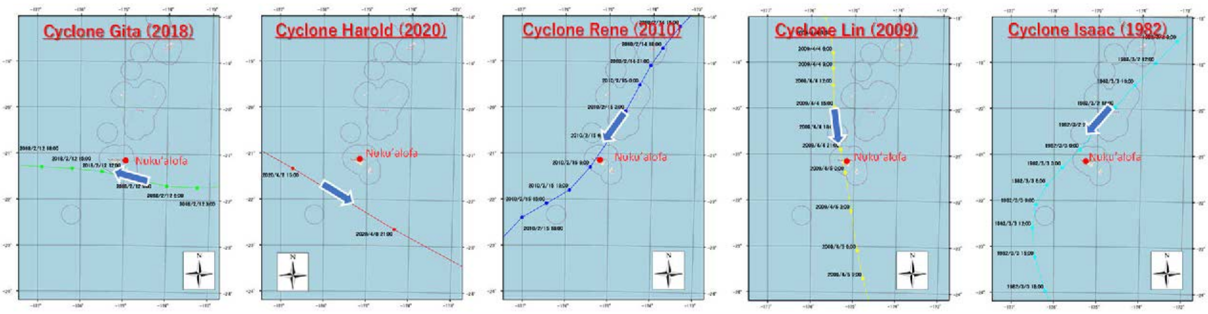
Figure 3.2.39 compares the courses of cyclones that have caused large storm surges in Nuku'alofa.

Generally, storm surges are high when a cyclone passes near Tongatapu Island. The wind in the same direction as the cyclone is strong. Since Tongatapu Island is located on the left side of the cyclone, the wind is strong, and the storm surge is high.

Each cyclone caused remarkable storm surges in locations above or near Tongatapu Island. Moreover, four of five cyclones reproduced themselves.

In contrast, Cyclone Gita (2018) moved in a different direction from other cyclones causing large storm surges. Tongatapu Island is on the right side of the travel direction of the Cyclone Gita. Because the Cyclone Gita was sizeable, with a minimum atmospheric pressure of 930 hPa, it passed slowly over the south side of Tongatapu Island. Strong winds blew from the north to the south of Tongatapu Island for a long time. In the case of Cyclone Harold, winds blew harder, and the storm surge grew higher because of its faster passing.

Cyclone Isaac, which caused enormous damage in 1982, becomes the typical example of the worst course for Tongatapu Island (Nuku'alofa).



Source: JICA Study Team

Figure 3.2.39 Comparison of Cyclone Course

5) Examination of Probable Storm Surge Anomaly

a) Selection of Target Cyclones

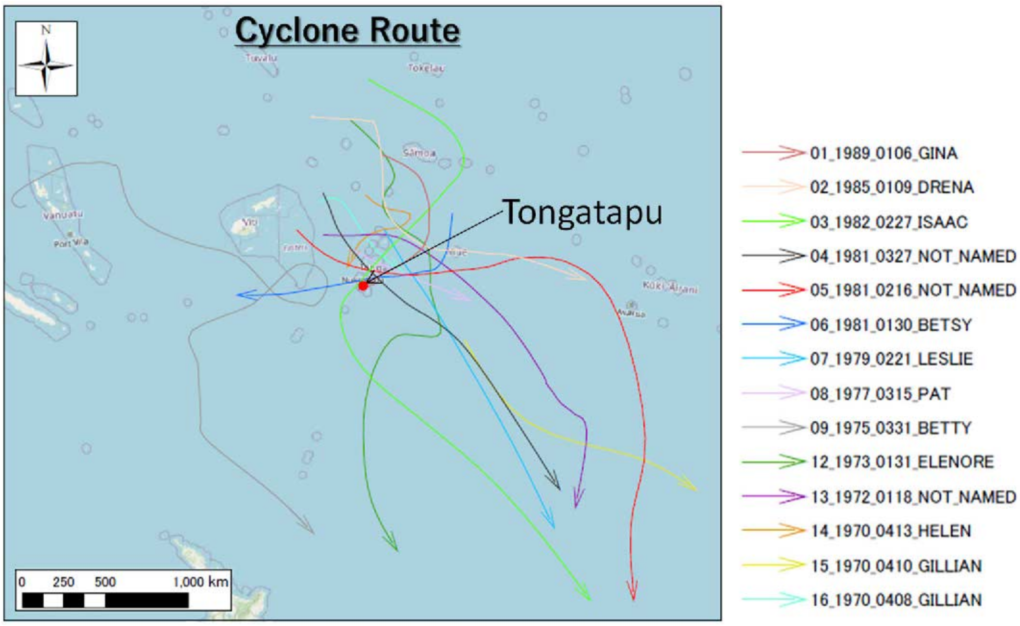
The tide level observation period on Tongatapu Island (Nuku'alofa) has been 30 years since 1991. It is short as statistical period for the calculation of the probability of tide level anomalies. Therefore, cyclones that affected Tongatapu Island before 1991 will be selected, and the data for statistical analysis will be supplemented by calculating the anomalies of storm surge levels.

As for the extraction method, IBTrACS is used to extract cyclones within a 500 km radius of Nuku'alofa on Tongatapu Island. The IBTrACS data is excluded where tide level observations were not conducted in Tonga. Table 3.2.11 and Figure 3.2.40 show the selected cyclones.

Table 3.2.11 Selected Cyclone for Probable Tide Level Deviation Calculation (1947-1990)

Cyclone Name	Central Pressure (hPa)	Cyclone Radius (km)
1989GINA	995	154
1985DRENA	993	151
1982ISAAC	944	78
1981NOT_NAMED_86	997	156
1981NOT_NAMED_47	997	157
1981BETSY	997	157
1979LESLIE	989	144
1977PAT	989	144
1975BETTY	984	136
1973ELENORE	990	145
1972NOT_NAMED	997	157
1970HELEN	997	157
1970GILLIAN_100	980	129
1970GILLIAN_98	987	141

Source: JICA Study Team



Source: JICA Study Team

Figure 3.2.40 Selected Cyclone Course for Probabilistic Tide Level Deviation Calculation (1947-1990)

6) Calculation of Tidal Deviation

Numerical calculations are utilized for the cyclones extracted in the previous section. As for the calculation conditions, the calculation was performed in a large area to obtain only the tide level deviation. Table 3.2.12 and Table 3.2.13 list the calculation conditions and storm surge deviation, respectively.

Table 3.2.12 Calculation Conditions for Probabilistic Tide Level Deviation Calculation

Items	Calculation conditions
Mesh Compositions	Region1 (135 sec (around 4050m)mesh)：Cyclone development area
Analysis Method	STOC-ML (Tomita and Kakinuma, 2005)
Objective Cyclone	1989GINA,1985DRENA, 1982ISAAC, 1981NOT_NAMED_86 ,1981NOT_NAMED_47 1981BETSY, 1979LESLIE, 1977PAT, 1975BETTY, 1973ELENORE, 1972NOT_NAMED 1970HELEN, 1970GILLIAN_100, 1970GILLIAN_98
Cyclone Model	Cyclone central area pressure・Cyclone course: IBTrACS Pressure dis: Myers (1954) Cyclone radius: Kato (2005)
Geological Conditions	Base on Tohoku University data
Tide Conditions	M.S.L.+0m
Calculation Time	Calculated according to the start and end times of each cyclone
	Time Resolution: Minimum 0.01sec
Others	Structure：Existing seawall

Source: JICA Study Team

Table 3.2.13 Calculated Tidal Deviation of Cyclones

Year	Name of Cyclone	Maximum tidal anomaly at Nuku'alofa (m)
1970	Gillian	0.06
1970	Gillian	0.13
1970	Helen	0.09
1972	Not Named	0.06
1973	Elenore	0.08
1975	Betty	0.14
1977	Pat	0.13
1979	Leslie	0.08
1981	Betsy	0.16
1981	Not named	0.12
1981	Not named	0.13
1982	Isaac	0.70
1985	Drena	0.07
1989	Gina	0.16

Source: JICA Study Team

7) Calculation of Probable Storm Surge Anomaly

Probable storm surge anomalies were calculated using the tidal anomalies from 1947 to 1990 calculated in the previous section and the tidal anomalies calculated from the tidal observation data from 1991 to 2021, wherein the latter are considered maximum data values. Table 3.2.14 shows the extreme value data. Table 3.2.15 and Figure 3.2.41 provide the calculation results of probable tide level deviation. The probable tidal anomaly is 80 cm with a probability of 100 years.

Table 3.2.14 Extreme Value Statistics Input

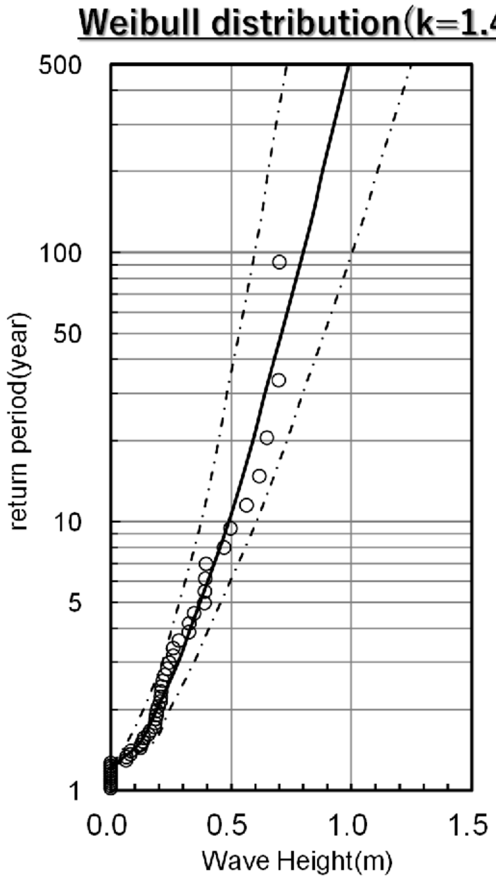
No.	Year	Max Storm surge deviation at Nuku'alofa (m)	No.	Year	Max Storm surge deviation at Nuku'alofa (m)
1	1970	0.13	22	2002	0.39
2	1972	0.06	23	2003	0.39
3	1973	0.08	24	2004	0.23
4	1975	0.14	25	2005	0.21
5	1977	0.13	26	2006	0.28
6	1979	0.08	27	2007	0.19
7	1981	0.16	28	2008	0.18
8	1982	0.70	29	2009	0.56
9	1985	0.07	30	2010	0.62
10	1989	0.16	31	2011	0.19
11	1991	0.24	32	2012	0.32
12	1992	0.19	33	2013	0.19
13	1993	0.20	34	2014	0.40
14	1994	0.21	35	2015	0.26
15	1995	0.12	36	2016	0.26
16	1996	0.22	37	2017	0.21
17	1997	0.50	38	2018	0.70
18	1998	0.47	39	2019	0.33
19	1999	0.23	40	2020	0.65
20	2000	0.39	41	2021	0.21
21	2001	0.35			

Source: JICA Study Team

Table 3.2.15 Probable Storm Surge Level Deviation

Recurrence Period	Probable Storm Surge Anomaly at Nuku'alofa (m)
10 years	0.49
20 years	0.59
30 years	0.64
50 years	0.71
100 years	0.80

Source: JICA Study Team



Source: JICA Study Team

Figure 3.2.41 Extreme Value Statistics Result (probability storm surge tide level deviation)

(5) Hazard Level of Tsunami and Storm Surge

Based on the results of tsunami and storm surge analyses, two types of hazard levels, Level 1 and Level 2, are used to examine hazard levels for disaster management plans and countermeasures. Table 3.2.16 defines each hazard level.

Table 3.2.16 Intensity, Frequency and Countermeasures for Hazard Levels

Hazard Level	Hazard Intensity and Frequency	Countermeasures
Level 1 (L1)	High Intensity and frequency Lower-intensity hazards might cause more damage than larger-classed hazard types because of their frequency Occurrence cycle spans several tens to several hundred years	Implement preventive engineering measures to protect human life, their property, and the local economy.
Level 2 (L2)	Largest-class hazard Hazards might occur infrequently but cause devastating damage Occurrence cycle spans several hundred to several thousand years	Put lifesaving first. Implement comprehensive efforts to evacuate residents by combining all kinds of soft and hard measures.

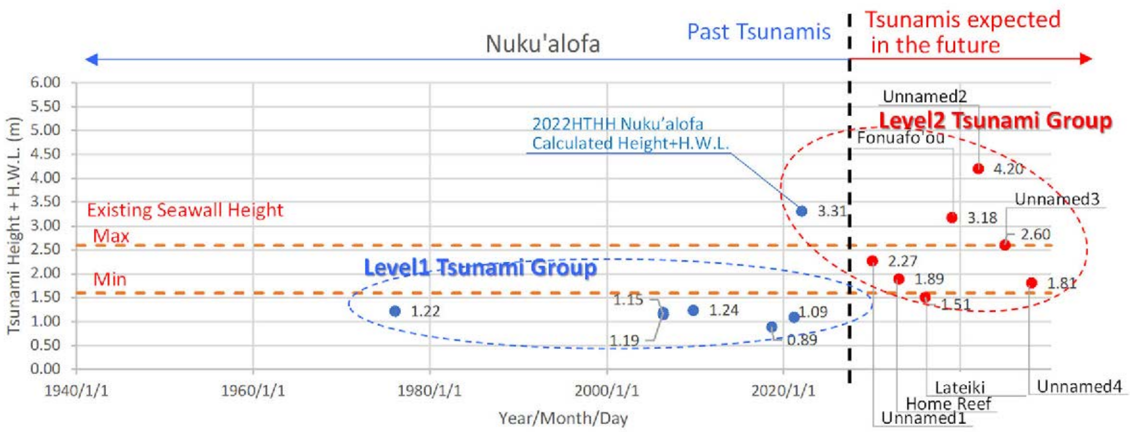
Source: JICA Study Team

1) Tsunami Hazard Levels

Figure 3.2.42 shows the time-series plots of tsunami analyses at Nuku'alofa for both volcanic and seismic tsunamis.

The past Nuku'alofa tsunami was about 1-2 m at H.W.L. (High water level: Mean high water spring tide) Similar-sized tsunamis have a record of recurring several times in the past 100 years. Past seismic tsunamis are most likely hazard level 1 and were dealt with by structure countermeasures.

On the other hand, the projected future volcanic tsunami height at Nuku'alofa is 1.5-4.2 m at H.W.L. If a volcano similar in size to the 2022 HTHH volcano occurs elsewhere, tsunami exceeding 3 m had not happen in the past 100 years, including the 2022 tsunami caused by Hunga Tonga and Hunga Ha'apai volcanoes. Therefore, volcanic tsunamis of the same scale as HTHH volcanoes are hazard level 2 tsunamis, the largest class tsunamis, which necessitate evacuation measures.



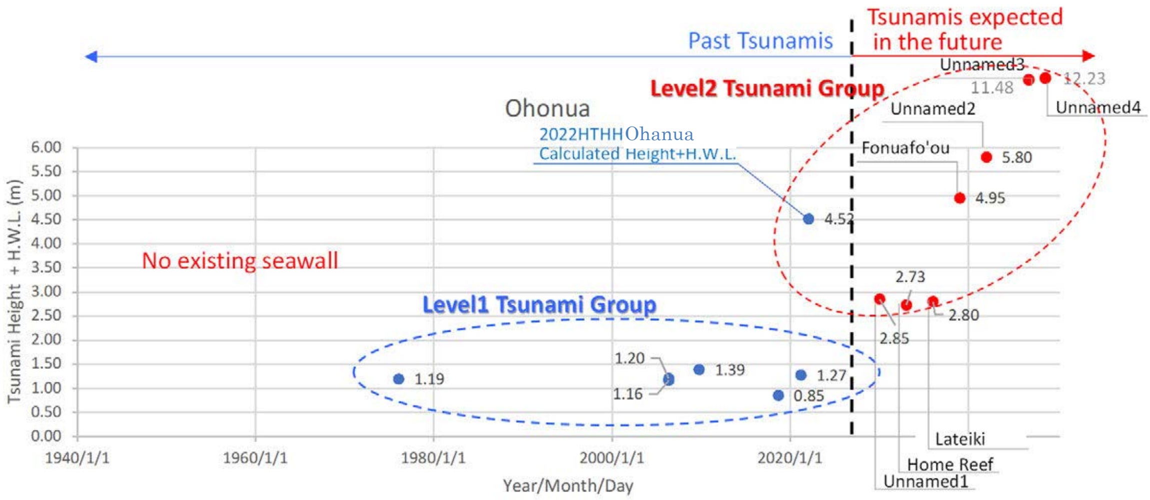
Source: JICA Study Team

Figure 3.2.42 Classification of Tsunami Hazard Levels at Nuku'alofa

The height of past earthquake tsunamis at Ohonua on 'Eua Island was also about 1 to 2 m at H.W.L., with a record of occurring several times in the past 100 years. Therefore, past seismic tsunamis are most likely hazard level 1 tsunamis, dealt with by structural countermeasures.

On the other hand, if an eruption similar in size to HTHH in January 2022 occurs elsewhere, the projected future volcanic tsunami height at Ohonua on Ewa Island is 2.7 to 12 m at H.W.L.

In Ohonua, no tsunami exceeding 3m has been on record in the past 100 years, excludeing the 2022 tsunami caused by the HTHH volcanoes, and an eruption of the same size as the 2022 HTHH event may occur repeatedly in next 100 years. Therefore, volcanic tsunamis of the same scale as HTHH volcanoes are hazard level 2 tsunamis, the largest class, which require evacuation measures.



Source: JICA Study Team

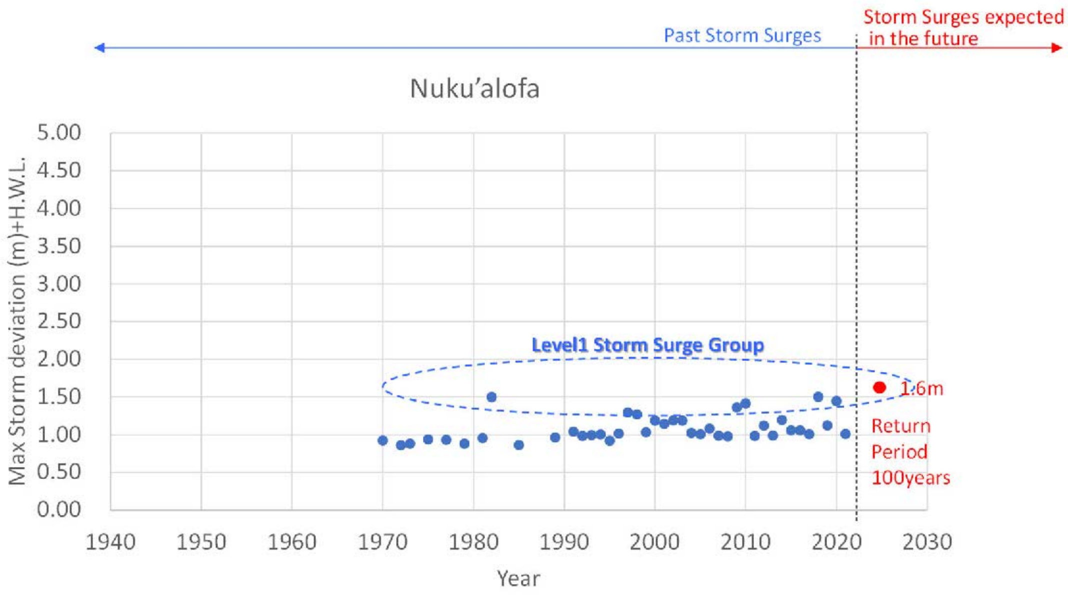
Figure 3.2.43 Classification of Tsunami Hazard Levels at Ohonua

This study examines volcanic tsunamis of the same scale as the ones generated by the HTHH eruption. However, it is worth mentioning that tsunamis caused by volcanoes smaller than HTHH volcanoes may occur several times in 100 years.

2) Hazard Level of Storm Surge

Records from 1991 to 2021 indicate anomaly storm surge levels due to cyclones normalized at about 0.7m. However, the extreme statistical values in storm surge deviations are present in pre-existing 100-year probability results, which consider the H.W.L. Therefore, this study deems it appropriate to set 100-year probability tide level deviations for hazard level 1 storm surges, which are dealt with by structural measures.

The JICA Study Team note that the required height of the embankment must consider not only the tide level but also the wave dimensions.



Source: JICA Study Team

Figure 3.2.44 Classification of Storm Surge Hazard Levels at Nuku'alofa

In this study, "H.W.L." is defined as mean monthly-high water level at the study of the existing seawall expansion plan in 1988. The H.W.L. at that time is astronomical tide level calculated from the harmonic constants of the major four tidal components determined by harmonic analysis based on 15 days and nights of tide level observation records at Nuku'alofa. Since it was determined from the major four tide components calculated from relatively short period observed data, it can be said that it is the approximate mean monthly-high water level. "King Tide" is the high tide that generally occurs several times a year, and it is a predictable astronomical tide that does not include the effects of cyclones and other weather-related storm surges. Therefore, it is the same type of tide level as the approximate mean monthly-high water level used in this study. However, "King Tide" is considered to be larger than the H.W.L. in this study because "King Tide" is affected by local weather patterns and ocean conditions in addition to major four tidal components.

Table 3.2.17 Probable Storm Surge Anomalies at Nuku'alofa During H.W.L.

Recurrence period	Probable Storm Surge Anomaly during H.W.L at Nuku'alofa (m)
10 years	0.49
20 years	0.59
30 years	0.64
50 years	0.71
100 years	0.80

Source: JICA Study Team

3) Comparison Between the Design Tide Level at the Time of Seawall Designing and Projected Hazard Level 1

The height of existing seawall was set by the typhoon Isaac[16] in 1982. He considered wave height, tide levels, and the predicted water elevation on the reef. The outline of the study results is as follows.

Table 3.2.18 Overview of Existing Seawall Design Specifications

Items	Observation values	Remarks
Design figures to accommodate offshore wave height	H0=11.6m	Isaac Wilson estimates from 1982
Design to accommodate offshore wave period	T0=12.6s	—
Offshore wave source	Northeast	—
Wave height before seawall	H1/3=1.7-5.4m	—
Design figures to accommodate tide	H.W.L.+storm surge deviation L.W.L.+1.5+0.2=L.W.L.+1.7m =M.S.L.+1.0m	—
Water level increase on the reef	0.21-0.9m	—
Required seawall height	L.W.L.+2.95-3.00m Example: Design tide level + amount of water level rise on the reef + required height of permissible overtopping flow = 1.7+0.9+0.35=2.95m	Set to satisfy the allowable overtopping flow rate
Design seawall height	L.W.L.+2.3-3.3m (M.S.L.+1.6-2.6m)	—

Source: JICA Study Team

If the L1 storm surge water levels account for 100 years, the existing seawall must feature an additional height of 0.6m. Since the required seawall height is determined based on the overtopping discharge, it is necessary to recalculate it.

(6) Hazard Level 2 Storm Surge and Tsunami Study

1) Hazard Level 2 Tsunami Assessment (Volcanic Tsunami)

The study results up to the previous section indicate that any tsunami caused by an eruption of the same scale as HTHH in January 2022 from another submarine volcano has a Hazard Level 2 classification. This section examines its impact on Tongatapu Island and 'Eua Island. The results are in Table 3.2.19 and Figure 3.2.45.

For the volcanoes shown in Table 3.2.19, the JICA Study Team calculated the inundation area with the tide level as H.W.L. Figure 3.2.46 and Figure 3.2.47 shows the calculation results of the inundation area. Especially in the northwestern part of Tongatapu Island, the inundation depth is large, exceeding 5 meters. Some areas of Nuku'alofa are also inundated to depths of over 2 meters, and significant

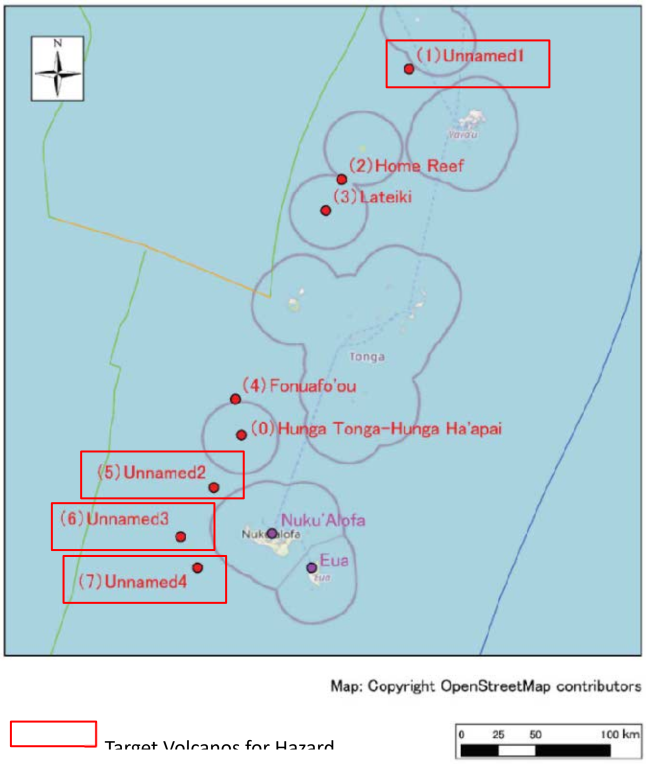
[16] Kingdom of Tonga Report on the Basic Design Study of the Nuku'alofa Seawall Expansion Project, February 1988, Japan International Cooperation Agency

damage is estimated. On 'Eua Island, Ohonua Harbor is inundated to over 5 meters, but the inundation area is limited to low-lying coastal areas.

Table 3.2.19 Depth on Inundation on Tongatapu and 'Eua Islands (volcano name)

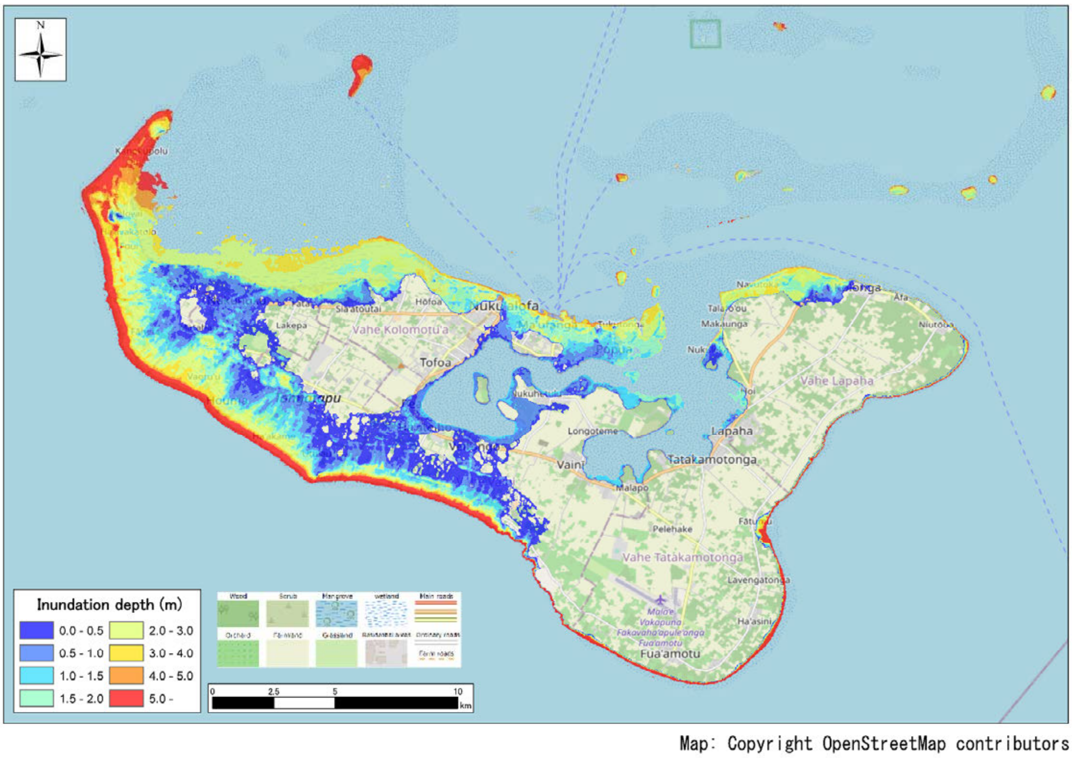
Tongatapu Island	'Eua island
Unnamed1 (H=90m)	Unnamed2 (H=90m)
Unnamed2 (H=90m)	Unnamed3 (H=90m)
Unnamed3 (H=90m)	Unnamed4 (H=90m)
Unnamed4 (H=90m)	−

Source: JICA Study Team



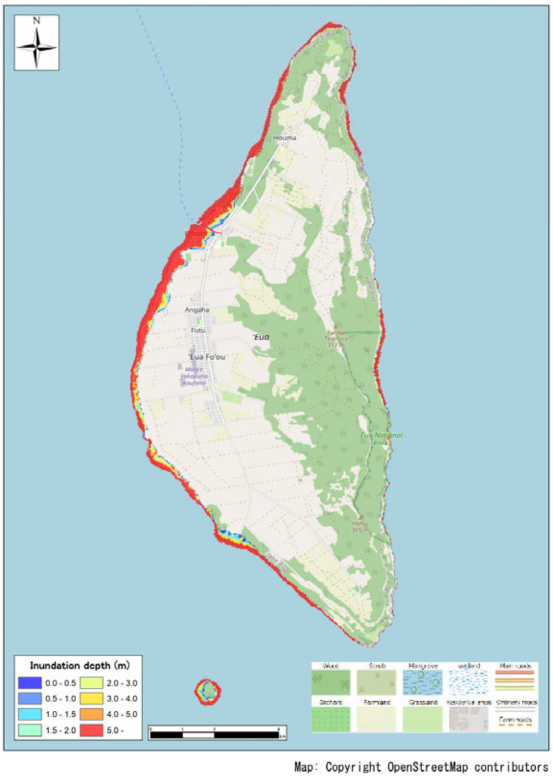
Source: JICA Study Team

Figure 3.2.45 Volcanic Tsunami Impact on Tongatapu and 'Eua Islands



Source: JICA Study Team

Figure 3.2.46　Tongatapu Island Flooding Map (Volcanic Tsunami Hazard Level 2)



Source: JICA Study Team

Figure 3.2.47　'Eua Island Flooding Map (Volcanic Tsunami Hazard Level 2)

2) Examination of Inundation from a Hazard Level 2 Storm Surge and Tsunami

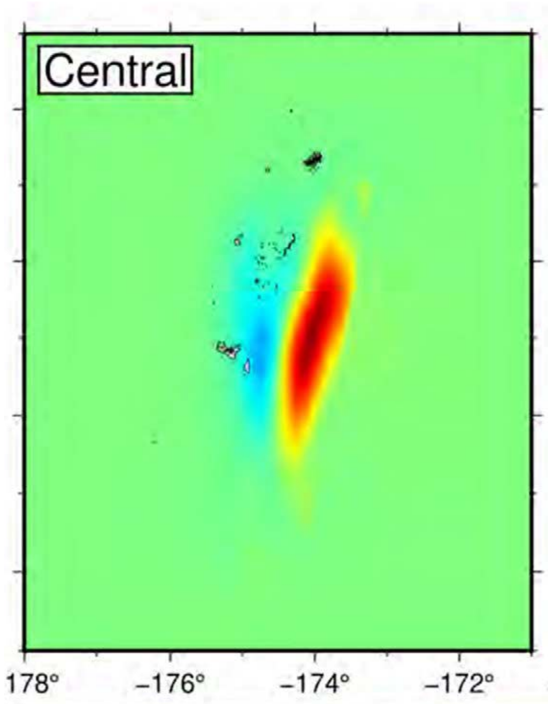
The SOPAC Project produced a tsunami simulation map for Southwest Pacific Tsunami Risk Assessment Capacity Development (Phase 3) developed in 2012. Of the above, the "case of an M8.7 earthquake occurring in the center of the Tonga Trench (east of Tongatapu Island)" adopted in the "The Project for Introduction of Nationwide Early Warning System and Strengthening Disaster Communications" (JICA) will be studied. It will be examined the case where an M8.7 earthquake occurs in the center of the Tonga Trench (east of Tongatapu Island), which is adopted in this study.

The SOPAC seismic fault model indicates no clear information about fault parameters. The initial water level distribution is reproduced and used as the input parameters for the tsunami wave. Figure 3.2.48 shows the initial water level distribution.

With this initial water level distribution as a wave source, the inundation calculation factors the tide level as H.W.L. (M.S.L.+0.8m) and treats it as an adverse condition. The seawall condition refers to its state at the time of this writing.

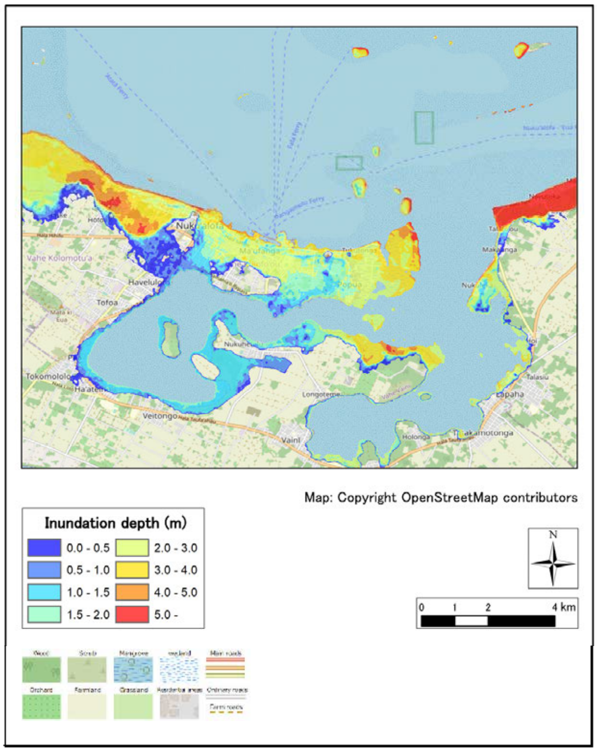
Figure 3.2.49 and Figure 3.2.50 shows the inundation calculation results.

In contrast to volcanic tsunamis, the inundation area and depth are larger on the east side of Tongatapu Island because the fault that is the wave source of the tsunami is located on the east side of the island. In addition, the inundation depth of Nuku'alofa is larger than that of volcanic tsunamis, with some areas inundated to more than 3 m deep.



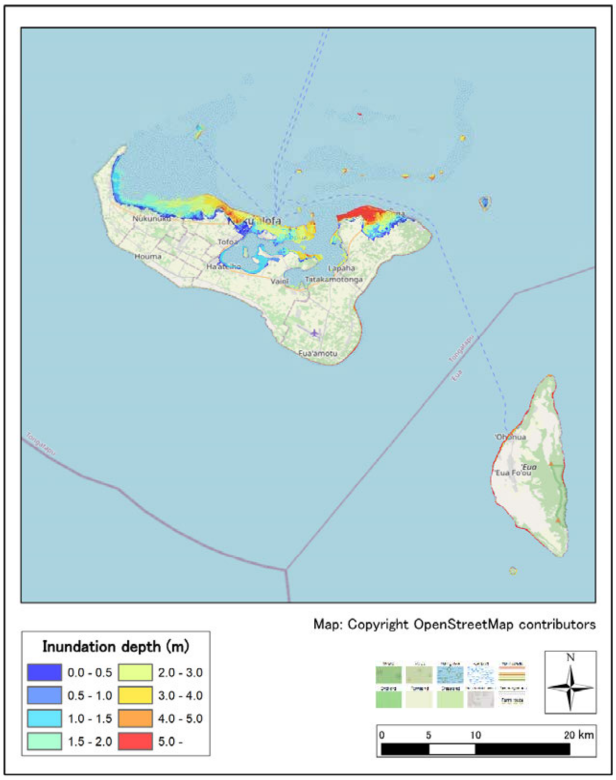
Source: Multi-Hazard Risk Assessment Tongatapu Interim Hazard Assessment Report – Tsunami, Asian Development Bank

Figure 3.2.48 Initial Water Level Distribution (SOPAC M8.7 Earthquake: Center of the Tonga Trench, East of Tongatapu Island))



Source: JICA Study Team

Figure 3.2.49 Tongatapu Island Flooding Map (Earthquake Tsunami Hazard Level 2)



Source: JICA Study Team

Figure 3.2.50 Analysis of a Hazard Level 2 Tsunami

3) Analysis of Tsunami at Hazard Level2

a) Hazard Level 2 Storm Surge Conditions

The JICA Study Team based their Hazard Level 2 storm surge analysis on the 1982 figures from Cyclone Isaac, the most significant local storm surge in the recorded past. It might assume more threatening conditions than rivalling projections.

The analysis assumes a cyclone with a central pressure of 930 hPa, the lowest pressure figure recorded from Cyclone Isaac as it approached Tongatapu Island. The interior pressure figures from this cyclone remains constant at 930 hPa during the calculation period.

Based on the course of Cyclone Isaac, the projected cyclone will shift west from the center of Tongatapu Island by the maximum radius of gyration toward a location where the winds are strongest on Tongatapu Island

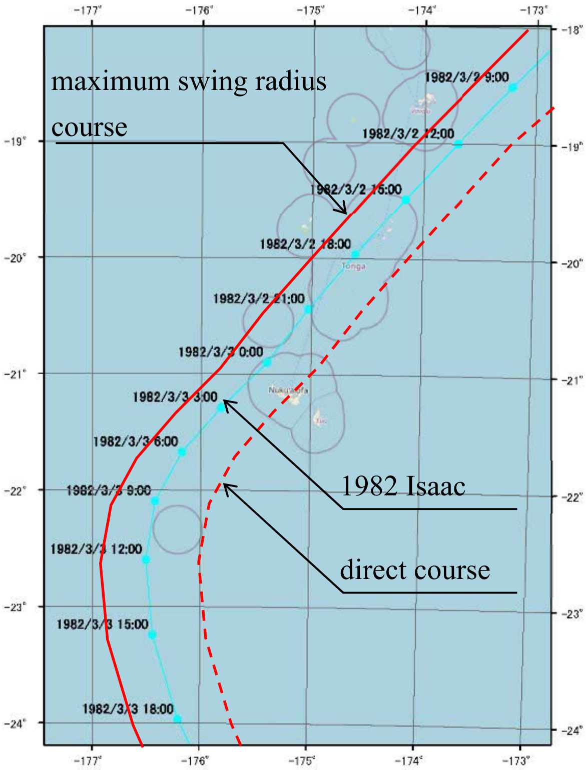
Figure 3.2.51 depicts the course under the assumed maximum radius of gyration.

In the past, cyclones passed close to Tongatapu Island, bringing high tides, like Cyclone Renee in 2010 and Cyclone Rin in 2009. These factors set these cyclones on a course where the centers pass through the Tongatapu Island mainland, as shown in Figure 3.2.51.

If a cyclone speed is high, wind speeds will accelerate with its traveling speed, making storm surges larger, as seen during Cyclone Harold in 2020.

The tide level condition is at H.W.L. (M.S.L.+0.8m), depicting adverse outcomes.

Table 3.2.20 shows the calculation conditions set based on factors above.



Source: JICA Study Team

Figure 3.2.51 Assumed Course of a Cyclone of the Largest Class

Table 3.2.20 Calculation Conditions Under a Hazard Level 2 Storm Surge

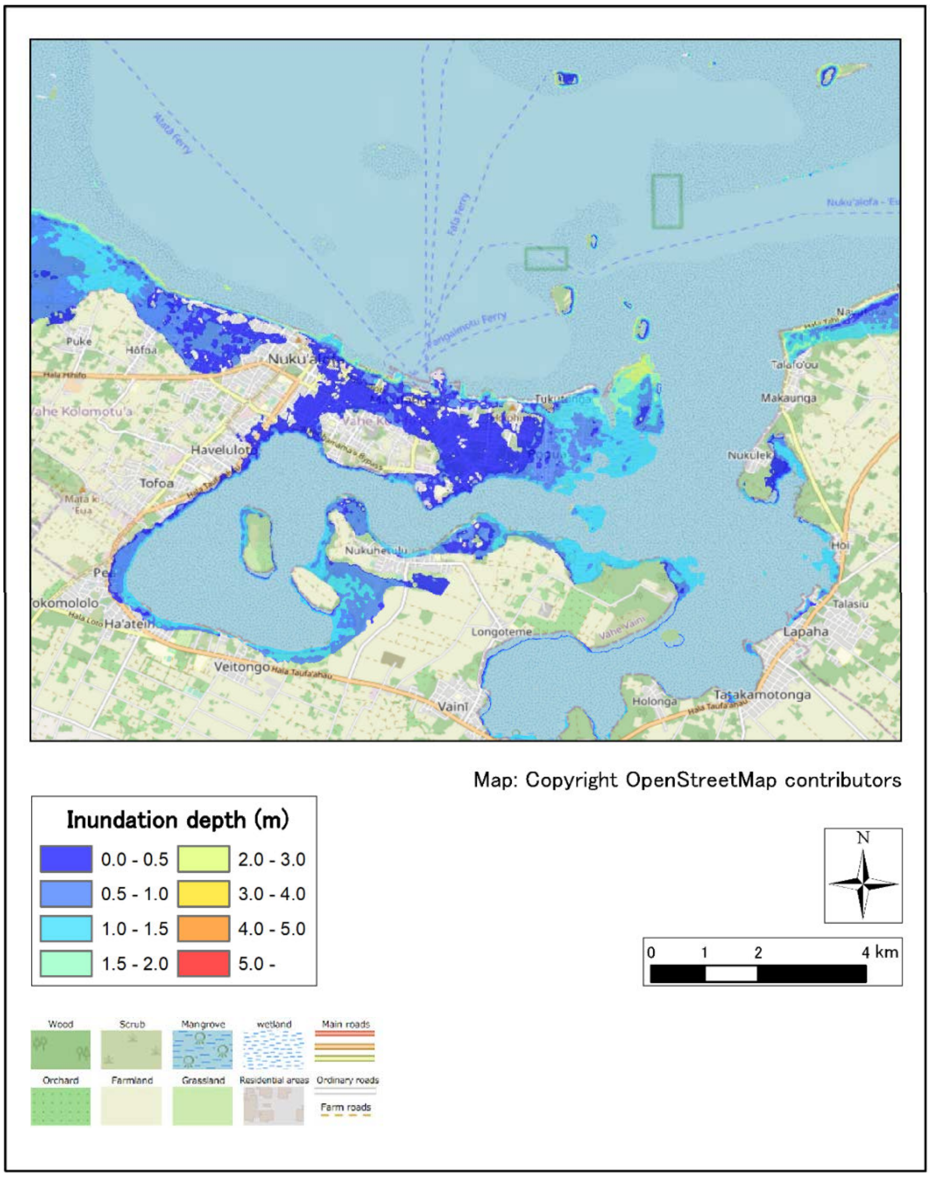
Items	Calculation Conditions
Mesh Compositions	Region1 (135sec (around 4050m) mesh)：Cyclone development range
	Region2 (45sec (around 1350m) mesh)：Cyclone development range
	Region3 (15sec (around 450m) mesh)：Cyclone development range
	Region4 (3sec (around 90m) mesh)：Tongatapu Island
	Region5 (1sec (about 30m) mesh)：Tongatapu Island
	Region6 (1/3sec (about 10m) mesh)：Tongatapu Island
Analytical Method	STOC-ML (Tomita and Kakinuma, 2005)
Objective Cyclone Course	Same course as 1982 Isac but paralleled ・Maximum turning radius course ・Straight course
Cyclone Model	Cyclone central pressure: 930hPa (constant) Cyclone speed: Harold's maximum speed: 56km/h (constant) Pressure distribution: Myers (1954) Cyclone Radius: Kato (2005)
Geological Conditions	Topographic data from Tohoku University
Tide Conditions	M.S.L.+0.8m
Calculation Time	Calculated according to the start and end times of cyclones
	Time Resolution：0.01sec
Others	Structure：Existing Seawall

Source: JICA Study Team

b) Calculation Results from Factors Depicting a Hazard Level 2 Storm Surge

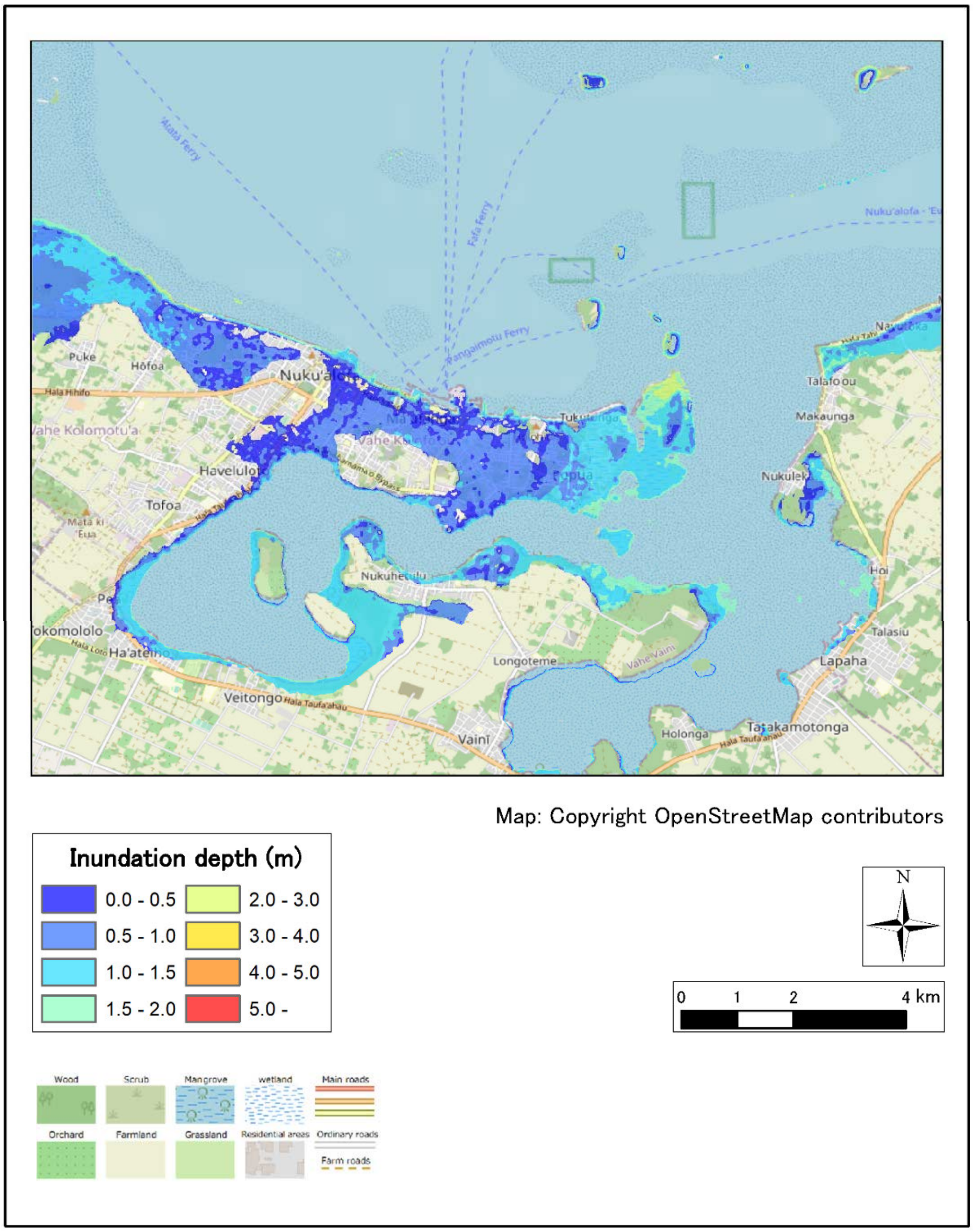
Figure 3.2.52 and Figure 3.2.53 show the storm surge inundation areas calculated with the above settings. In both cases, the areas of inundation are about the same extent. Inundation depths in urban areas are less than 1 m even in large areas, and less than 1.5 m in port areas. The inundation range and depth are noticeably more sizeable in the area directly above its course. Because Tongatapu has a topography that does not feature raised landmasses, the storm surge water level is not likely to rise, similar to, for example, the case of a V-shaped bay.

However, real-world scenarios indicate that cases like these produce storm surges and high waves. It must use caution when setting maximum gyration radius course figures to account for increased wave heights.



Source: JICA Study Team

Figure 3.2.52 Tongatapu Island Flooding Map Under a Hazard Level 2 Storm Surge on a Maximum Swing Radius Course



Source: JICA Study Team

Figure 3.2.53 Tongatapu Island Flooding Map Under a Hazard Level 2 Storm Surge on a Course Directly Above the Island

c) Effects of Climate Change and Sea Level Rise on Inundation

Climate change-induced sea level rise will significantly affect island nations like Tonga through increased flood damage, among other adverse outcomes. Therefore, based on the IPCC Sixth Assessment Report, a Hazard Level 2 scenario based on the sea level rise in Tonga in SSP1-2.6, where temperatures rise below 2°C through sustainable development, is necessary for consideration. A summary of each SSP scenario and the amount of sea level rise for each scenario are shown in Table 3.2.21 and Figure 3.2.54.

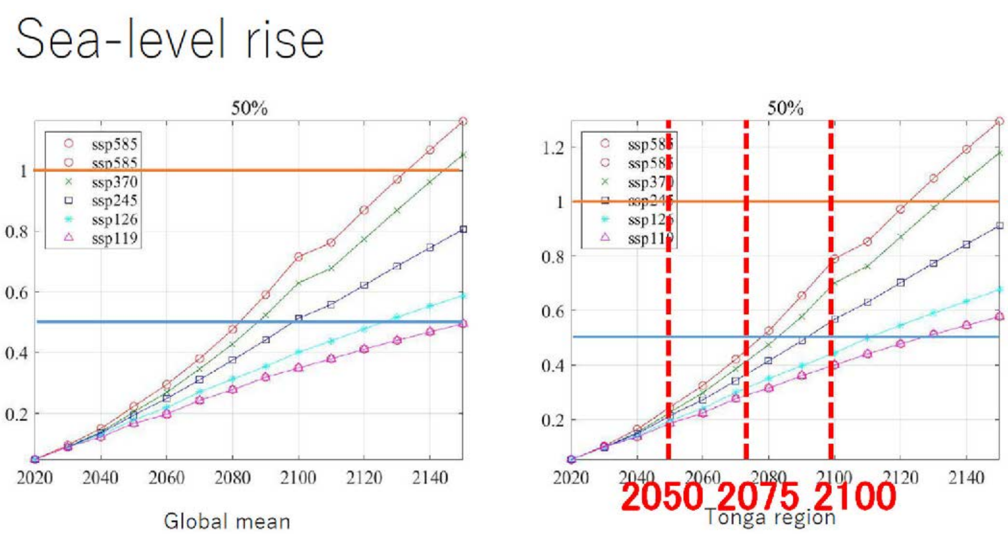
Table 3.2.21 shows the sea level rise in Tonga under the SSP1-2.6 scenario, along with requisite H.W.L. settings. JICA Study Team examined flooding under a Hazard Level 2 storm surge using these presets. The calculation conditions other than the tide level conditions are the same as those in Table 3.2.20.

Figure 3.2.55 and Figure 3.2.56 show the calculation results. Inundation area and depth increased because of the sea level rise.

Table 3.2.21 Summary of SSP Scenario

Scenario	Summary
SSP1-1.9	Scenario for keeping temperature rise below 1.5°C under sustainable development
SSP1-2.6	Scenarios for keeping temperature rise below 2°C under sustainable development
SSP2-4.5	Scenarios for introducing climate policy under a middle way development
SSP3-7.0	Scenarios without climate policy under regionally confrontational development
SSP5-8.5	Scenario of maximum emissions without climate policy under fossil fuel dependent development

Source: Japan Center for Climate Change Actions



Source: Based on Domestic Support Committee, JICA Study Team made

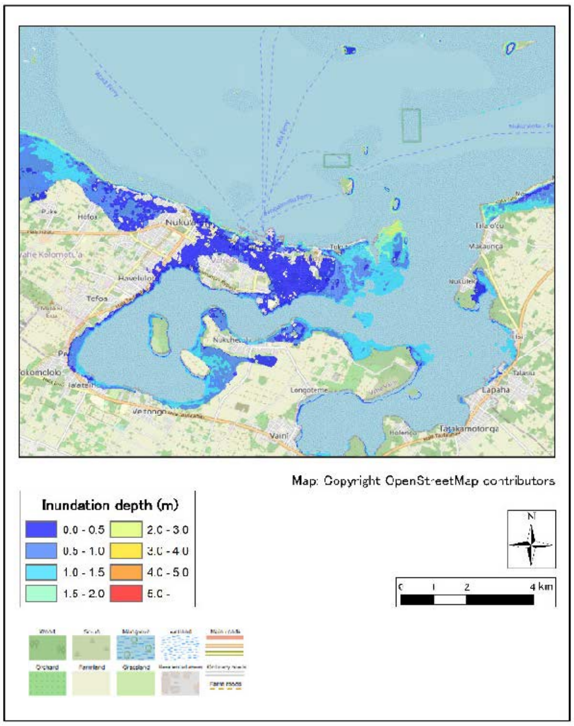
Figure 3.2.54 Sea Level Rise Scenarios

Table 3.2.22 H.W.L. with Rising Sea Levels at Nuku'alofa (SSP1-2.6)

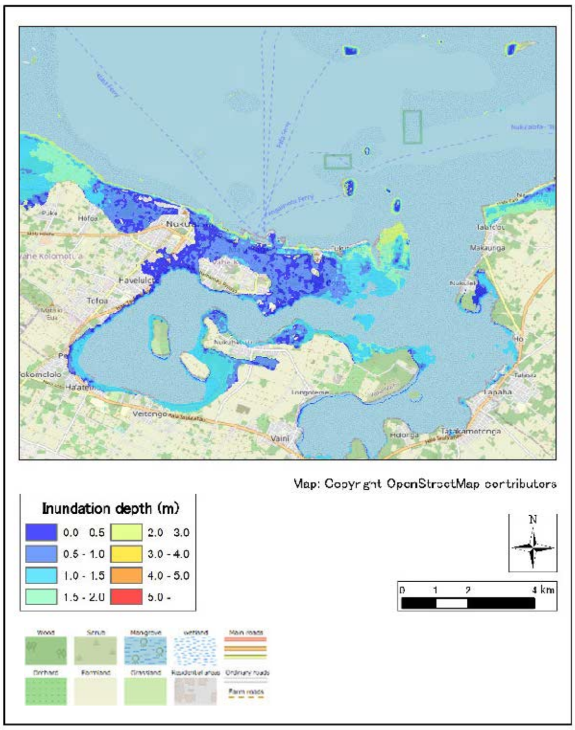
Year	**H.W.L.** (M.S.L.+m)	Sea Level Rise(m)	Calculation Tide Level (M.S.L.+m)
2020	0.8	0.00	0.8
2050	0.8	0.19	0.99
2075	0.8	0.32	1.12
2100	0.8	0.44	1.24

Source: JICA Study Team

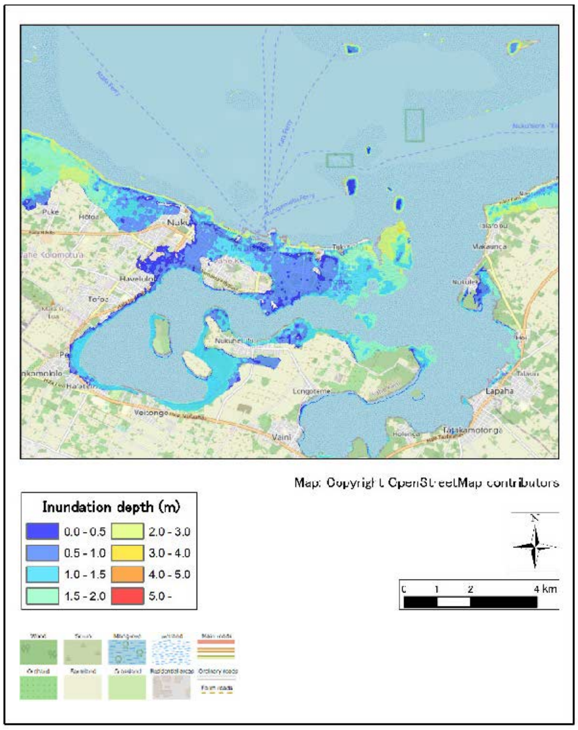
SSP1-2.6（2°C Increase Scenario）



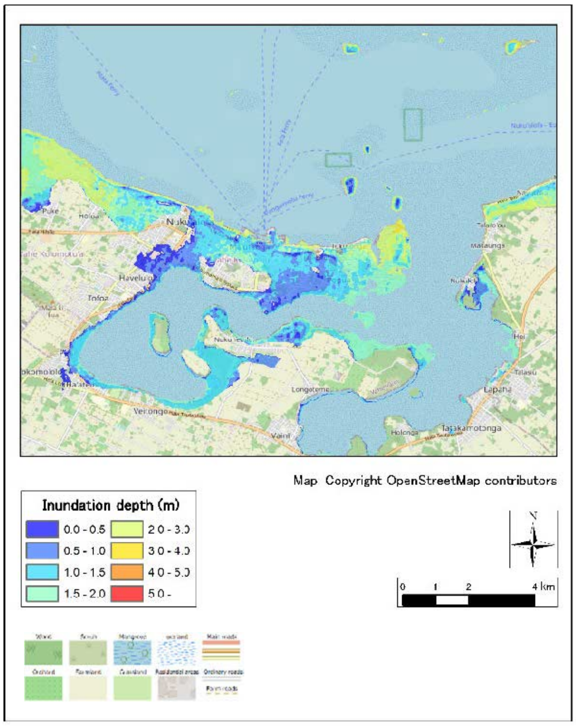
2020 H.W.L. : M.S.L.+0.8m



2050 H.W.L. : M.S.L.+0.99m



2075 H.W.L. : M.S.L.+1.12m

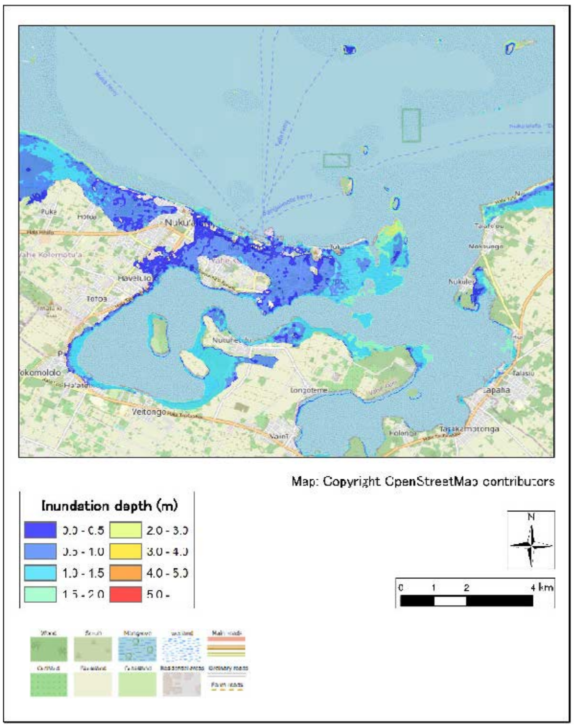


2100 H.W.L. : M.S.L.+1.24m

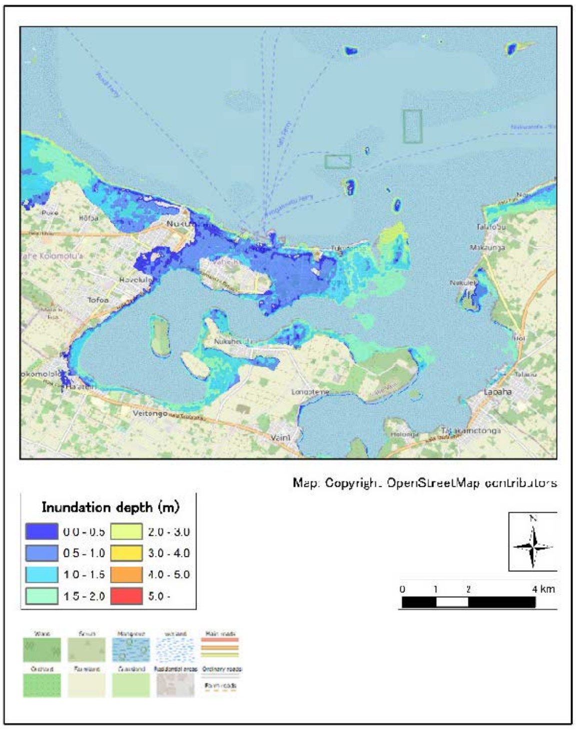
Source: JICA Study Team

Figure 3.2.55 Estimated Inundation from a Hazard Level 2 Storm Surge on a Maximum Swing Radius Course with Projected Sea Level Rise

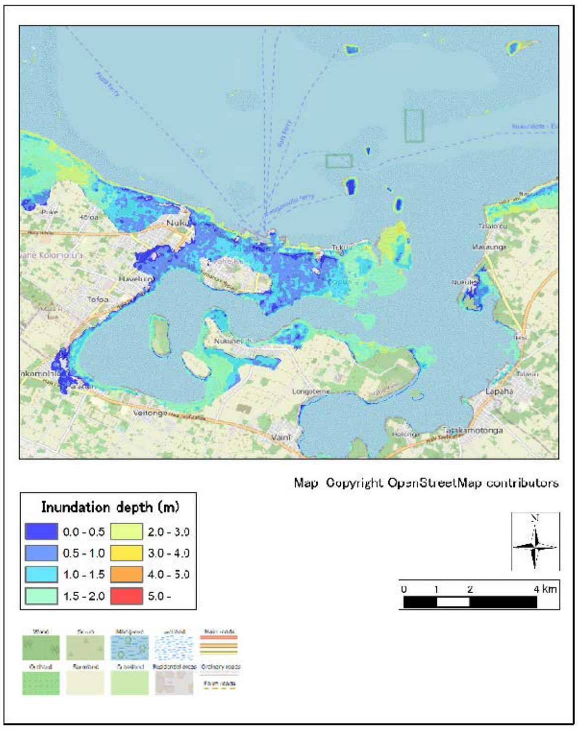
SSP1-2.6（2°C Increase Scenario）



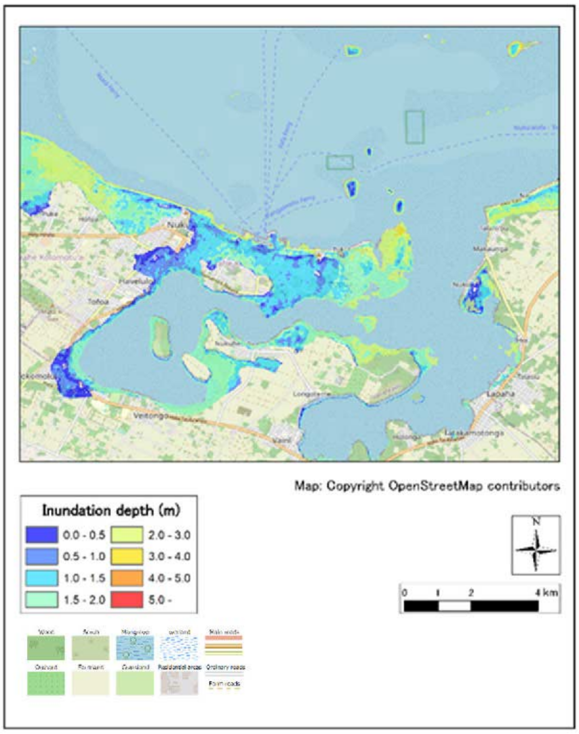
2020 H.W.L. : M.S.L.+0.8m



2050 H.W.L. : M.S.L.+0.99m



2075 H.W.L. : M.S.L.+1.12m



2100 H.W.L. : M.S.L.+1.24m

Source: JICA Study Team

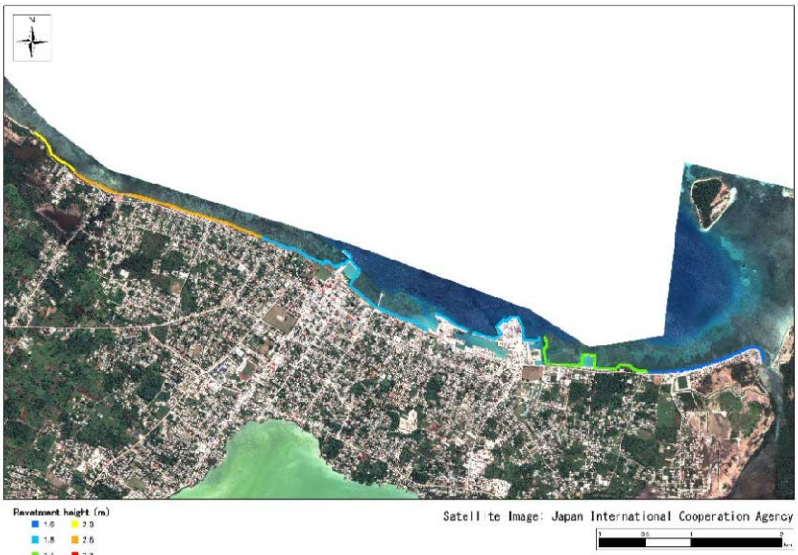
Figure 3.2.56 Estimated Inundation Under Storm Surge Hazard Level 2 on an Overhead Course with Projected Sea Level Rises

4) Analysis of Storm Surge at Hazard Level 2

a) Seawall Conditions

Tongatapu Island has a two-meter-high seawall on its northern coast. Raising its height is most likely to produce the most beneficial effect as a countermeasure against flood damage from tsunamis and storm surges. This section studies the case of raising the seawall.

The height of the seawall has already increased by about 1m from a past construction. It studied a case for potentially improving its height to M.S.L. + 3.0m. Figure 3.2.57 and Figure 3.2.58 depict its current condition. If the seawall in the harbor area is raised, it may interfere with the use of the harbor and future development. Therefore, it will not be raised.



Source: JICA Study Team

Figure 3.2.57 Existing Seawall

Source: JICA Study Team

Figure 3.2.58 Setting of Raised Seawall to M.S.L.+3.0m

b) Examining Calculations for a Higher Seawall

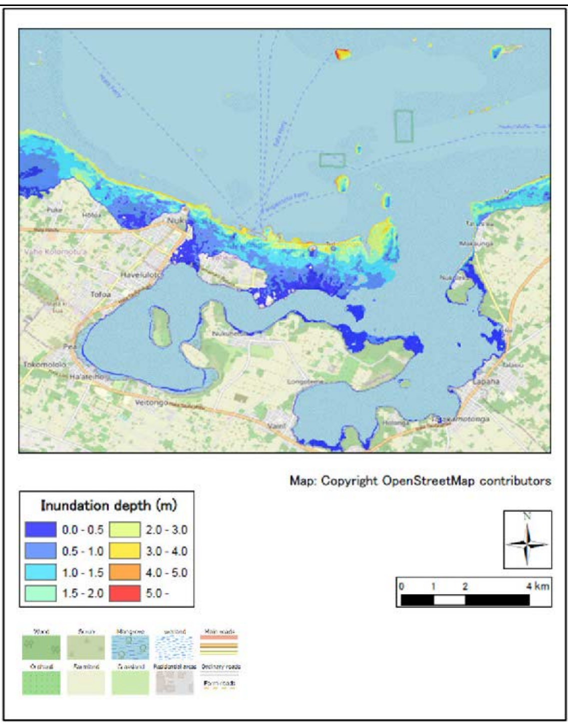
JICA Study Team compare inundation calculations performed while building the existing seawall versus a proposed one.

It compares the results of a case in which a volcanic eruption as the HTHH (H=90m) occurred in Unnamed 2 and Unnamed 3, triggering a volcanic tsunami and creating significant flooding in Nuku'alofa, as shown in Figure 3.2.59, Figure 3.2.60. The other cases are in Appendix 3-2.

In Unnamed 2, Nuku'alofa becomes heavily inundated, showing no notable change in the flooded area between the current and the proposed raised seawall. In the case of Unnamed3, where the inundation is relatively light, the inundation area shows a reduction.

Further raising the level will likely reduce inundation. However, increasing the seawall height by more than 1m might degrade local surroundings, meriting careful consideration.

For storm surge, the difference in inundation area due to seawall height was also studied in the case of Isaac (M.S.L. +0.8m). The results of the study are shown below. In this case, there was no significant difference in the inundation area, but there was a decrease in the inundation area in the center of Nuku'alofa, shown in Figure 3.2.60.

<table>
<tr><th colspan="2">Unnamed2, H=90m</th></tr>
<tr><td>
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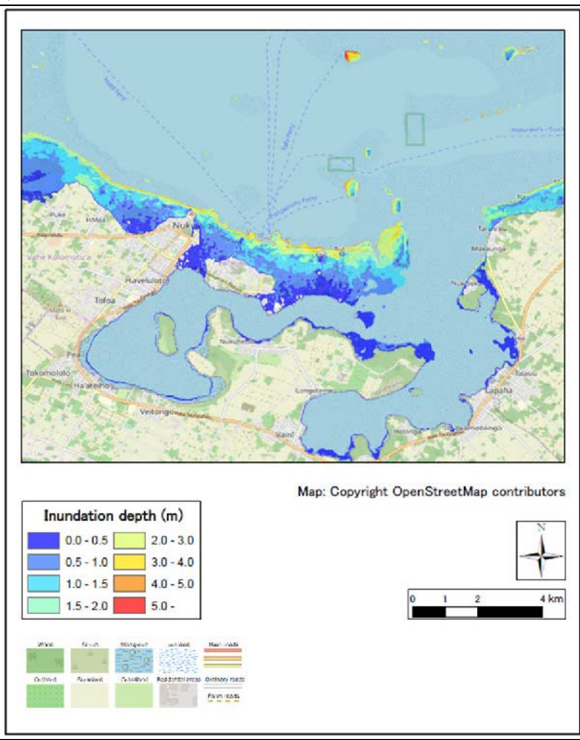
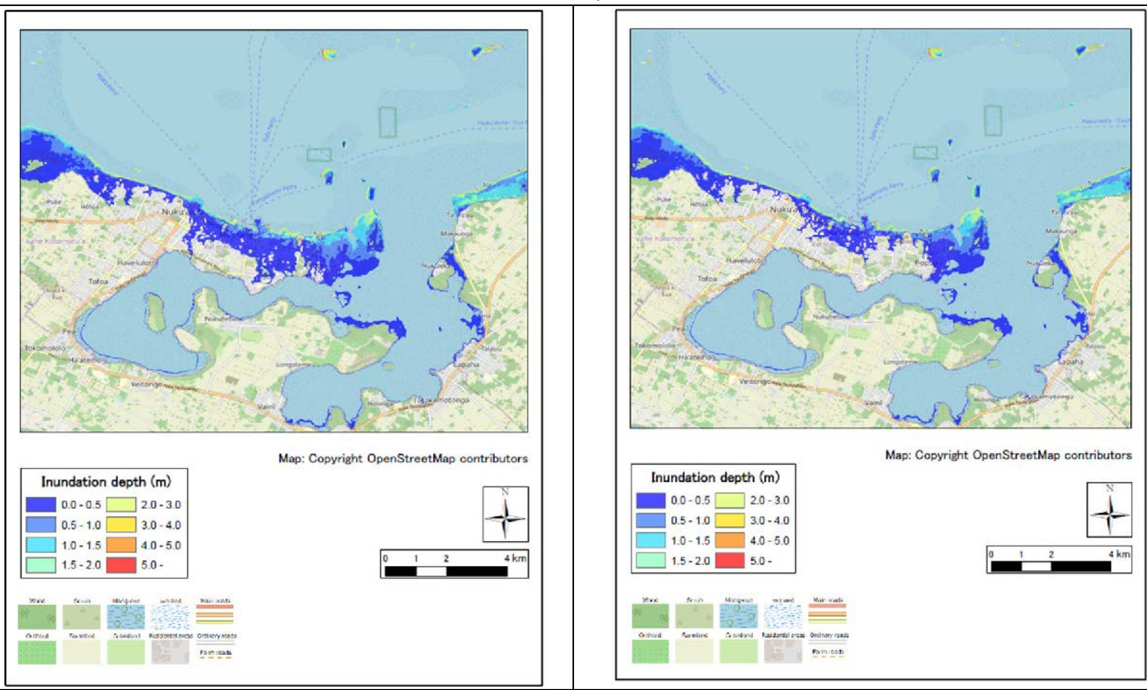
<td>
</td></tr>
<tr><td>Existing seawall : M.S.L.≒2.0m</td><td>Increased seawall : M.S.L.≒3.0m</td></tr>
</table>

Source: JICA Study Team

Figure 3.2.59 Comparison of Seawall Effectiveness (Volcanic Tsunami, Unnamed2, H=90m)

Unnamed3, H=90m

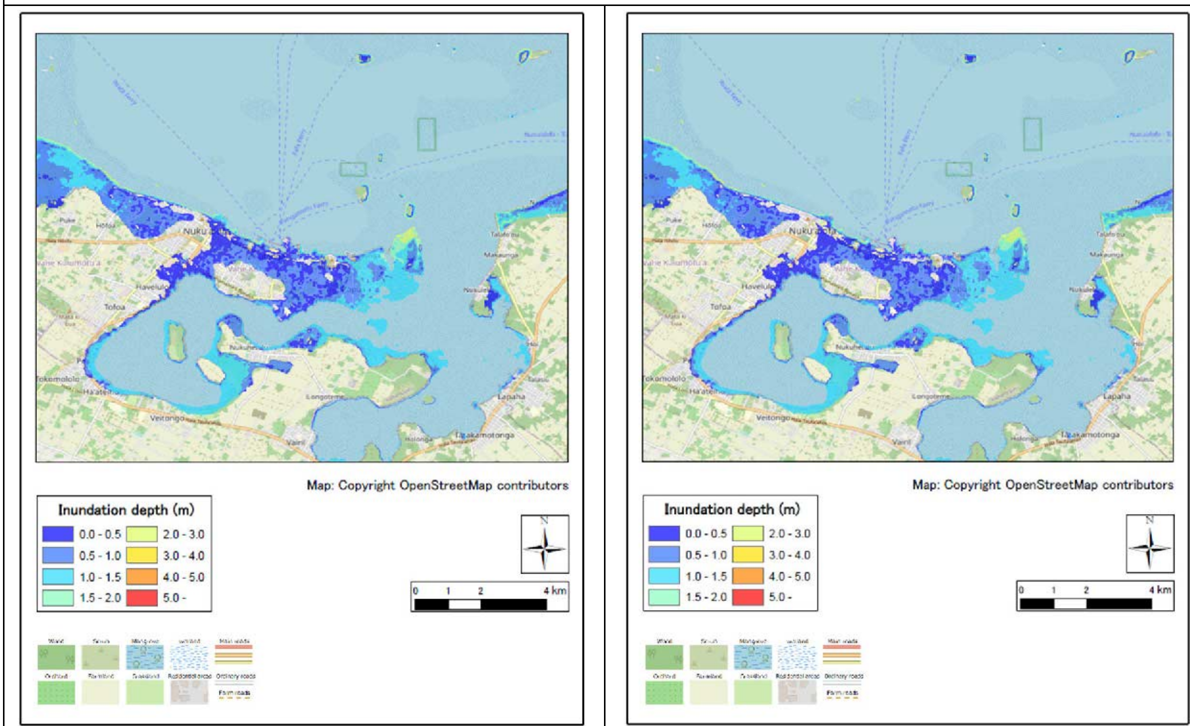


Existing seawall : M.S.L.≒2.0m	Increased seawall : M.S.L.≒3.0m

Source: JICA Study Team

Figure 3.2.60 Comparison of Seawall Effectiveness (Volcanic Tsunami, Unnamed3, H=90m)

Isaac 1982 (M.S.L.+0.8m)



Existing seawall : M.S.L.≒2.0m	**Increased seawall : M.S.L.≒3.0m**

Source: JICA Study Team

Figure 3.2.61 Comparison of Seawall Effectiveness (Isaac 1982, M.S.L.+0.8m)

3.2.3. Creating a Multi-Hazard Map

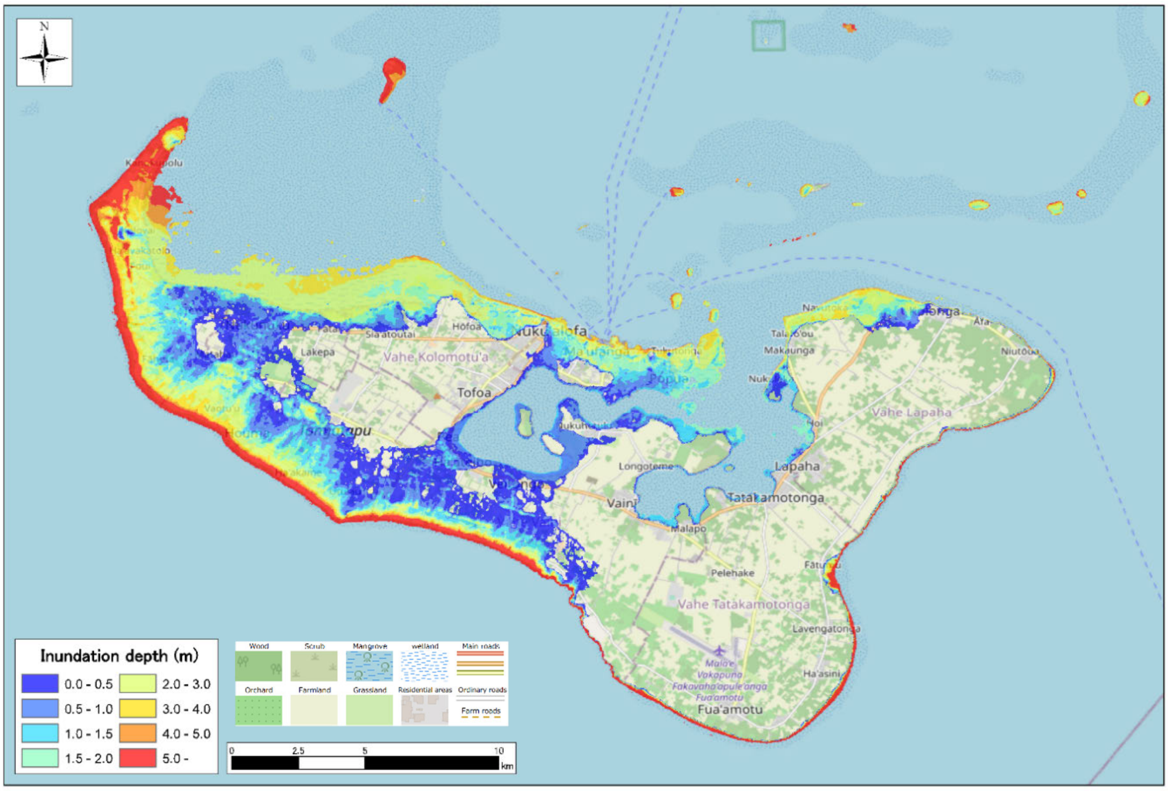
Hazard maps are essential for evacuation, so it must utilize the highest hazard level as relevant factors.

The created an independent hazard map for the tsunami and storm surge hazard examination. The map covers the maximum inundation area and inundation depth.

When the inundation area affects one location differently from another, the maximum inundation range and depth are shown for each case.

(1) Tsunami Hazard Map (Volcanic Tsunami)

Figure 3.2.62 shows a hazard map projecting the largest-class volcanic tsunami examined at Hazard Level 2.



Map: Copyright OpenStreetMap contributors

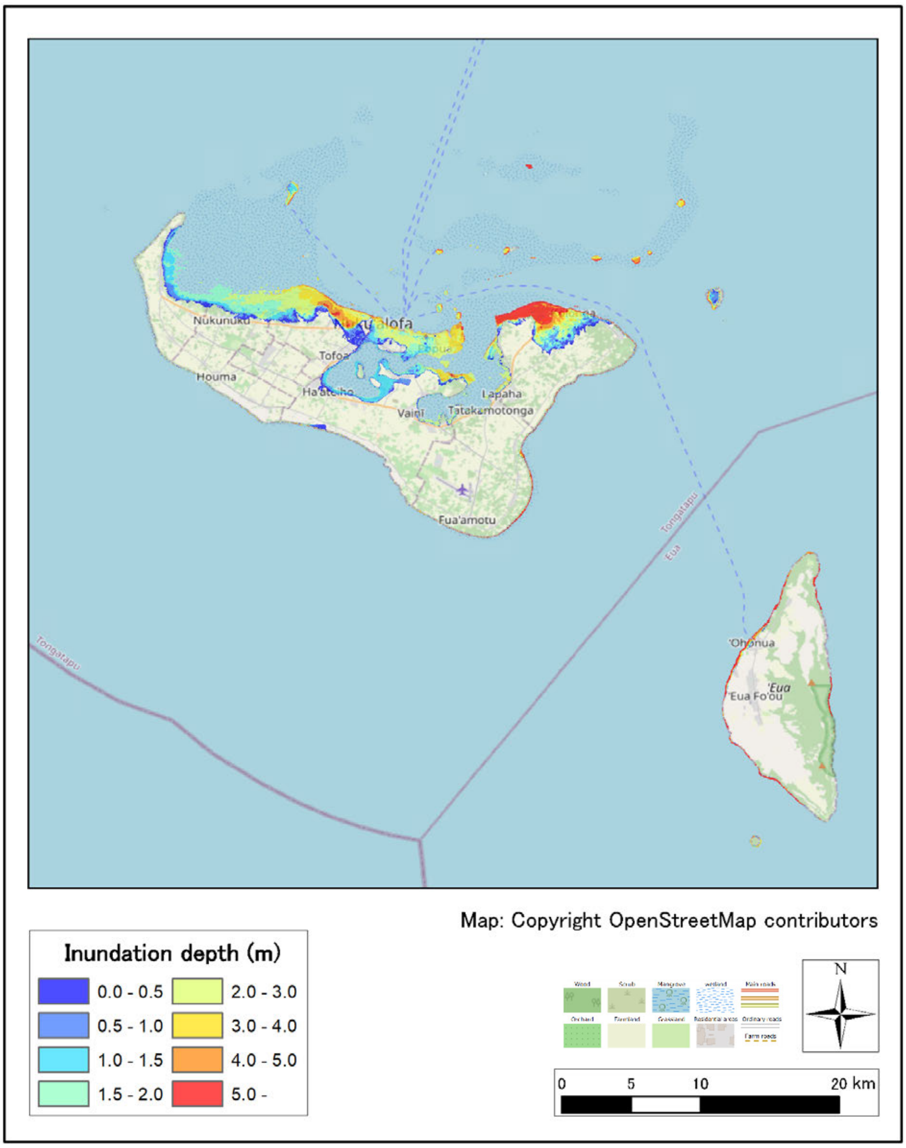
Map: Copyright OpenStreetMap contributors

Source: JICA Study Team

Figure 3.2.62 Volcanic Tsunami Hazard Map

(2) Seismic Tsunami Hazard Map

Figure 3.2.63 shows a hazard map based on the assumption of the largest-class seismic tsunami examined at Hazard Level 2.

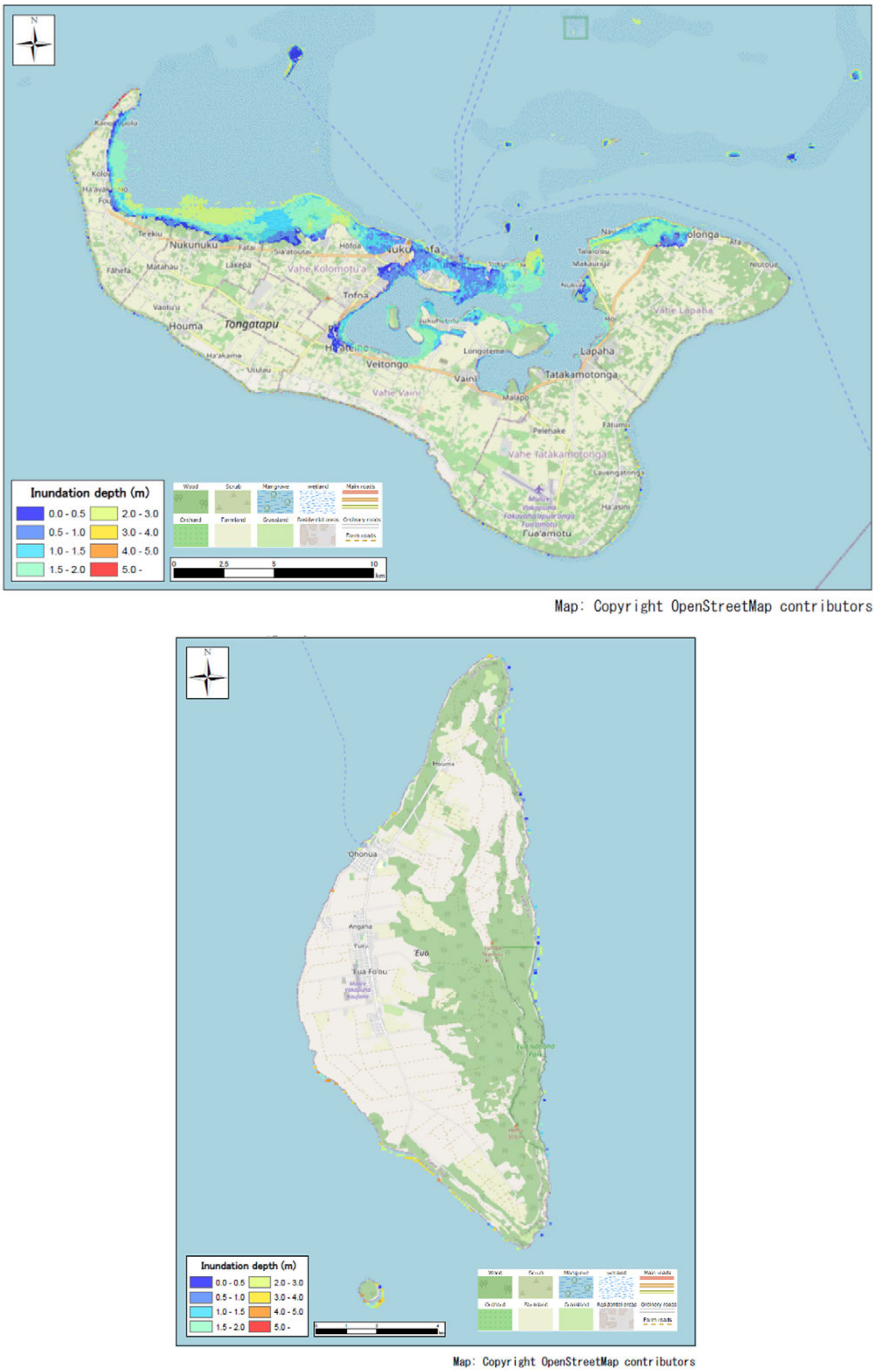


Source: JICA Study Team

Figure 3.2.63 Seismic Tsunami Hazard Map

(3) Storm Surge Hazard Map

Figure 3.2.64 shows a hazard map based on the assumption of the largest-class seismic tsunami examined at Hazard Level 2. The tidal conditions are well projected for 2075, situated in the middle of the significant climate-change-induced sea level rise events, which will occur in 2050, 2075, and 2100.



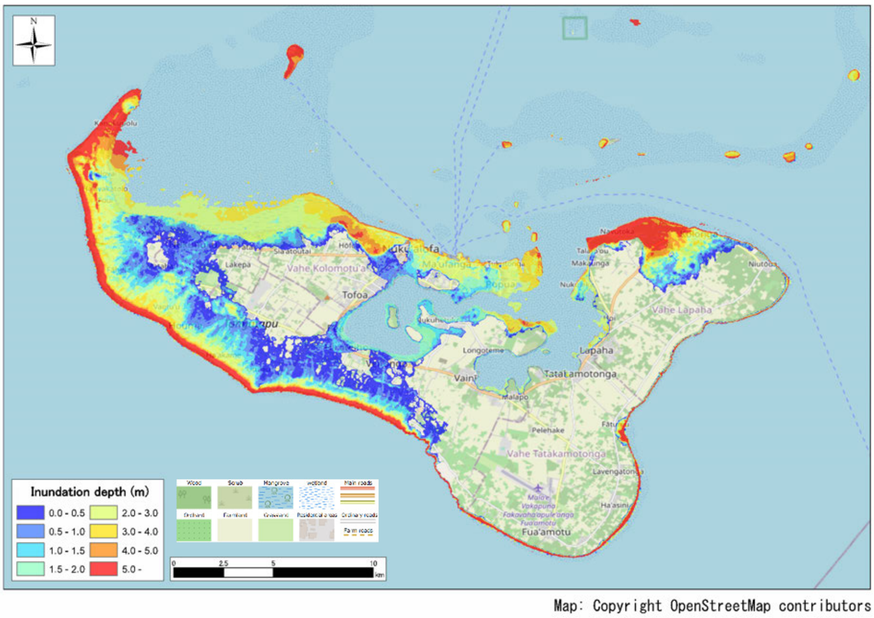
Source: JICA Study Team

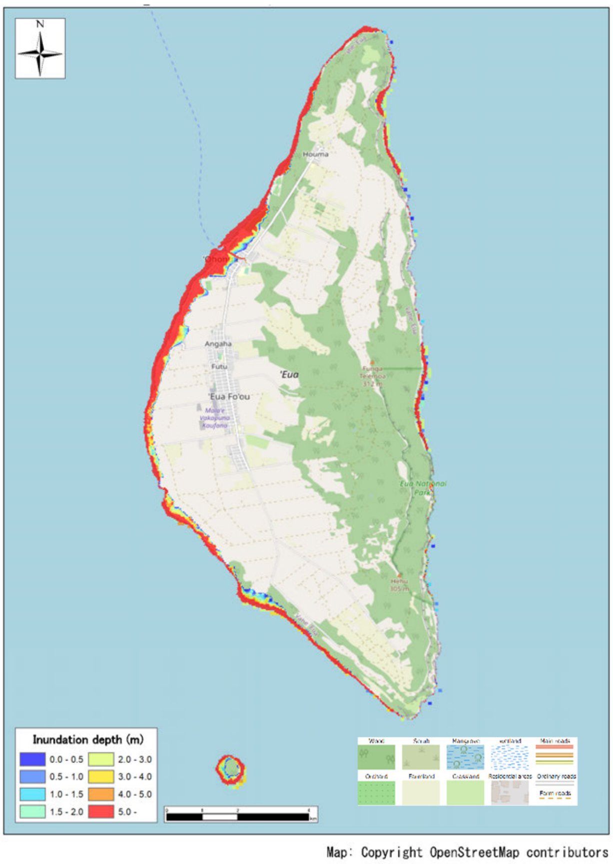
Figure 3.2.64 Storm Surge Hazard Map

(4) Maximum Hazard Map for Tsunami and Storm Surge

The tsunami and storm surge hazard maps were created by overlaying the hazard maps organized in (1) through (3) above.

The results are shown below.





Source: JICA Study Team

Figure 3.2.65 (Seismic/Volcanic) Tsunami and Storm Surge Hazard Map

3.2.4. Disaster Management Direction

Based on the results of hazard analysis, it is recommended to take measures against tsunamis and storm surges in the following directions. The magnitude and return period for each hazard considered in this study are summarized in Table 3.2.24.

Table 3.2.23 Disaster Management Direction

Hazards	Disaster Management Direction
Volcanic Tsunami	➢ For Level 1 scale events (tsunamis caused by small-scale eruptions, such as the 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption), structural measures will be implemented in coordination with earthquake and tsunami surge countermeasures. ➢ For Level 2 scale events (tsunamis caused by volcanic eruptions of the same scale as the 2022 HTHH eruption, but happening in other submarine volcanoes), extensive flooding is anticipated. Therefore, the primary focus will be on enhancing soft measures, such as evacuation, to ensure the protection of lives.
Seismic Tsunami	➢ For Level 1 scale events (frequent tsunamis caused by earthquakes of M8 class), protection can be provided with the current seawalls. Therefore, the existing seawalls will be maintained. ➢ For Level 2 scale events (maximum class of earthquakes in the M8 to M9 range causing tsunamis), extensive flooding is anticipated. Therefore, the primary focus will be on enhancing soft measures, such as evacuation, to ensure the protection of lives.
Storm Surge	➢ For Level 1 scale events, storm surges caused by cyclones that hit once every few years to several decades, measures will be taken by maintaining (including improving) the current seawalls. ➢ For Level 2 scale storm surges caused by cyclones, similar to tsunamis, extensive flooding is anticipated. Therefore, the primary focus will be on enhancing soft measures, such as evacuation, to ensure the protection of lives.

Source: JICA Study Team

Table 3.2.24 L1/L2 external forces and return period of volcanic tsunami, seismic tsunami, and storm surge in this study

Hazard	Hazard Level	Hazard and return period assumed in this study
Volcanic Tsunami	Level 1	Tsunami with high probability of occurrence due to submarine volcanic eruption (VEI 3 or less) on a smaller scale than the 2022 Hunga Tonga-Hunga Ha’apai in the sea area surrounding Tonga*. Hazard return period: unknown (tens to hundreds of years)
	Level 2	Largest tsunami from a submarine volcanic eruption (VEI 4 or greater) of the same magnitude or greater as the 2022 Hunga Tonga-Hunga Ha'apai in the sea area surrounding Tonga Country Hazard return cycle: 200 years to thousands of years or more Supplement: Volcanic eruptions above VEI 4 have occurred in 1846, 1886, and 2022 between the 19th century and the present (40–136-year interval). However, since only the 2022 eruption generated a massive tsunami, the interval between eruptions of massive tsunamis that would have a significant impact on Tongatapu Island is more than 200 years.

Hazard	Hazard Level	Hazard and return period assumed in this study
Seismic Tsunami	Level 1	Tsunamis frequently generated by earthquakes of M8 or greater in the Tonga Trench Hazard return period: several years to several decades
	Level 2	The largest tsunami generated by a M8.7-size earthquake east of Tongatapu Island (SOPAC 2012 assumption) Hazard return period: over a hundred or more decades to thousands of years. Supplement: According to the USGS Earthquake Catalog (1913-2022), 8.7 scale earthquakes have not occurred in the vicinity of Tonga, so a return period of more than a hundred and several decades is assumed.
Storm Surge	Level 1	Frequent storm surges in Tongatapu Island (Nuku'alofa) caused by large cyclones passing through the Tonga Hazard return period: 100 years (storm surges of similar magnitude occur at intervals of several years to several decades)
	Level 2	Maximum storm surge in Tonga when a cyclone with the lowest pressure ever recorded passes over Tongatapu Island (Nuku'alofa) on a worst-case course. In addition, the sea level rise due to the scenario of 2°C rise in future temperature is taken into account. Hazard return period: more than 100 years

Source: JICA Study Team *Level 1 volcanic tsunamis are not studied in this study.

3.3. Collection of domestic and international examples of countermeasures against flood damage such as tsunamis and storm surges, volcanic ash countermeasures, earthquake countermeasures, and storm countermeasures for facilities, etc.

3.3.1. Storm Surge and Tsunami Countermeasures

(1) List of Countermeasures

The list of measures against storm surge and tsunami disasters is shown in Table 3.3.1. Storm surge and tsunami countermeasures include large coastal structures and coastal roads that could become two-line levees.

Table 3.3.1 Storm Surge and Tsunami Countermeasures

Type	Measures	Effect (Objective)
Structure	Levees and seawalls (rivers/coasts)	Prevention of inundation by storm surge and tsunami
	Sluice gates/land locks	ditto
	Breakwaters and other offshore facilities	Prevention of flooding by storm surge and tsunami
	Raised roadway and other dual-use structures	Reduction of water level and current of storm surge and tsunami
Land Use	Usage regulations	Reduce flood damage by regulating land use in areas expected to be inundated
	Building regulations	Regulation of building structures (structure, etc.) in anticipated inundation zones

Type	Measures	Effect (Objective)
Urban Planning	Urban structures	Usage restrictions
	Relocation plans	Disaster prevention collective relocation, etc.
Evacuation Planning	Evacuation plans (timelines)	Reduction of human casualties in flooded areas
	Business Continuity Plan (BCP)	Reduction of damage to business establishments in flooded areas
Warning Systems	Wave Observation System	Wave gauges (GPS wave gauges, seabed-mounted wave gauges, etc.)
	Tidal Observation System	Tide gauges, water level gauges
	Information System	Remote monitoring of observation facilities Remote operation of sluice gates, land locks, etc.
Rescue plan	Ensuring early rescue system Ensure rescue notification system	Protection of human life
Inductive Policies	Promotion of privately owned seawall improvement (Subsidies, grant programs, preferential tax rates)	Promotion of earthquake resistance and repair of privately owned facilities (coastal seawalls, etc.)
	Assistance Programs for Flood Control	Widespread use of flood-resistant construction

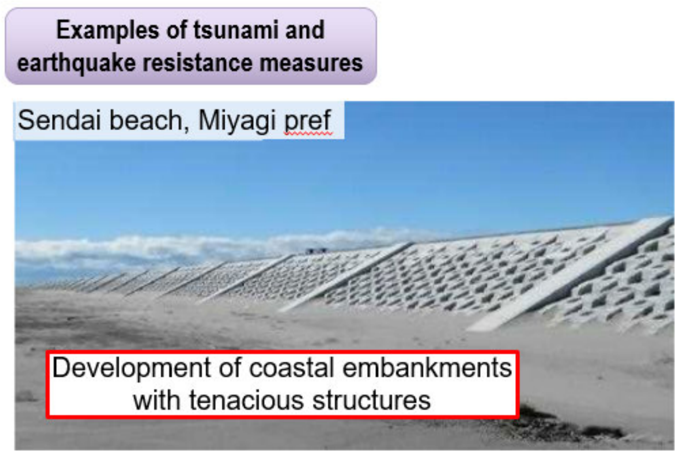
Source: Review of Training Content Related to Comprehensive Disaster Prevention, JICA

(2) Examples of Countermeasures

Examples of countermeasures mainly by structures are shown below.

1) Levees and seawalls (rivers/coasts)

To protect coasts from disasters such as tsunamis and earthquakes, which occur relatively frequently, measures such as the construction and improvement of coastal protection facilities such as levees, seawalls, breakwaters, and tsunami breakwaters are promoted in Japan.



Source: https://www.mlit.go.jp/river/shinngikai_blog/hozen/dai02kai/pdf/doc3.pdf

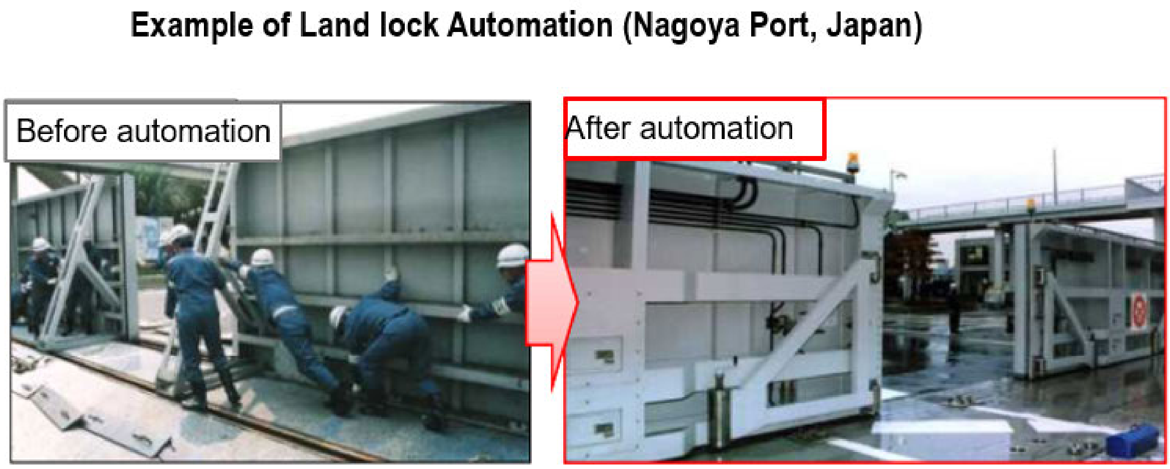
Figure 3.3.1 Levees as tsunami countermeasures

Source: JSCE The International Infrastructure Archives[17]

Figure 3.3.2 Before (left) and after (right) installing a tsunami embankment in the Maldives

2) Sluice gates and land locks

The closure of land locks is being automated in order to close them promptly before a tsunami strikes.



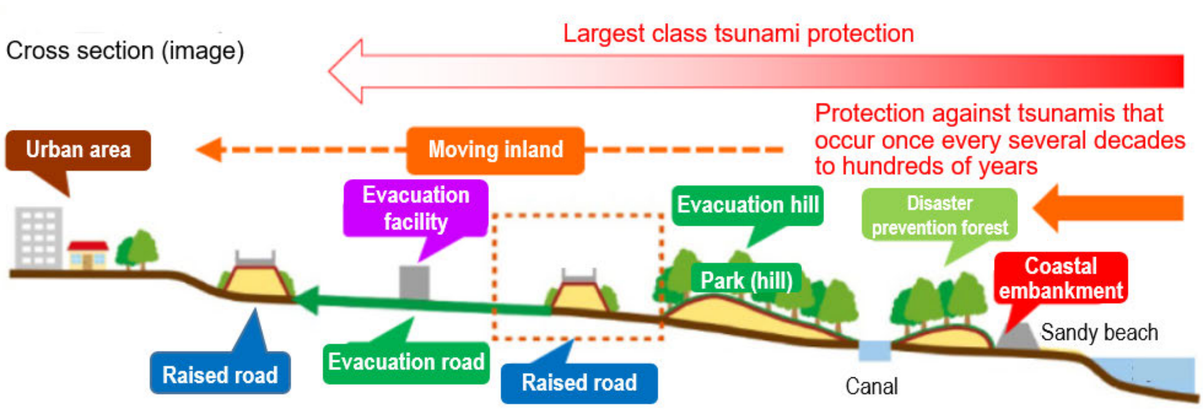
Source: https://www.mlit.go.jp/river/shinngikai_blog/hozen/dai02kai/pdf/doc3.pdf

Figure 3.3.3 Example of automated land lock

3) Raised roadway and other dual-use structures

The road is raised to provide multiple protection by adding a levee function. An example of the development of a road as a two-line embankment is shown in Figure 3.3.4.

[17] https://www.jsce.or.jp/e/archive/project/pj14.html



Source: https://sendai-resilience.jp/efforts/government/development/elevated_road.html

Figure 3.3.4 Example of raised roadway

3.3.2. Earthquake Countermeasures

(1) List of Countermeasures

As earthquake countermeasure, it is first important that seismic design standards for various buildings, infrastructure facilities, and lifeline facilities be developed and properly operated. Moreover, it is necessary to implement seismic reinforcement of buildings and facilities with low seismic resistance, as well as countermeasures against liquefaction and earthquake fires.

Table 3.3.2 List of Earthquake Countermeasures

Type	Measures	Effect (Objective)
Structure	Seismic retrofitting of buildings, infrastructure, lifelines, and other structures (seismic retrofitting and reconstruction)	Mitigation of damage to buildings, infrastructure, lifelines, and other structures; mitigation of human suffering and functional disruption due to structural damage
	Liquefaction countermeasures for buildings, infrastructure, lifelines, etc. (ensuring flexible foundations and piping* of structures)	Mitigation of damage to buildings, infrastructure, lifelines, etc. caused by liquefaction and other ground deformation
	Ground improvement work	Mitigation of damage to structures due to liquefaction and other ground deformation
	Fire-resistant construction of buildings, etc.	Preventing the spread of earthquake fires
Urban Planning/ Land Use	Building regulations (development and application of seismic design standards)	Mitigation of damage caused by earthquake-proofing of buildings; prevention of human casualties due to damage in buildings
	Formulation and application of seismic design standards for civil engineering structures, infra facilities, and lifeline facilities	Mitigation of physical damage and functional disruption to civil engineering structures, infrastructure, and lifeline facilities
	Disaster-resistant urban planning, redevelopment planning with disaster prevention in mind	Improvement of local disaster prevention capacity through reconstruction of buildings to make them earthquake resistant and construction of evacuation routes, etc.
	Elimination of densely built-up areas, development of open spaces such as parks and green spaces	Preventing the spread of earthquake fires
	Regulation of uses/building regulations in the vicinity of active faults	Avoidance and mitigation of structural damage directly above and near faults
Warning Systems	Early earthquake warning	Mitigation of secondary damage by ensuring protective posture and emergency shutdown of equipment and facilities
Rescue plan	Ensuring early rescue system Ensure rescue notification system	Protection of human life
Inductive Policies	Promotion of earthquake resistance of structures (subsidies and subsidy programs)	Mitigation of physical damage and functional disruption to civil engineering structures, infrastructure, and lifeline facilities
	Indication and certification systems (Housing Performance Indication System, Seismic Performance Certification System, etc.)	Improvement of local disaster prevention capacity through reconstruction of buildings to make them earthquake resistant and construction of evacuation routes, etc.

*Note: Flexible piping: General term for flexible pipe, flexible joint, flexible hose, and flexible piping for earthquake countermeasure.

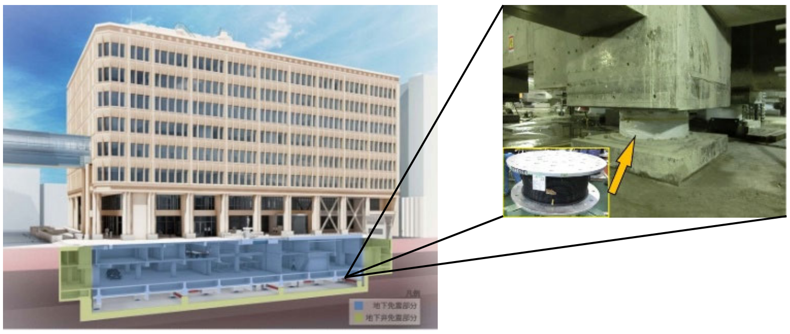
Source: Review of Training Content Related to Comprehensive Disaster Prevention, JICA.

(2) Examples of Countermeasures

Examples of countermeasures, which are mainly structural, are shown below.

1) Seismic isolation of buildings (public facilities)

Shinjuku City Hall Main Office: Earthquake-free construction to ensure that the building can continue to function as a disaster prevention center and continue to be useful after an earthquake, seismic isolation and construction to strengthen disaster prevention functions were conducted (Figure 3.3.5).



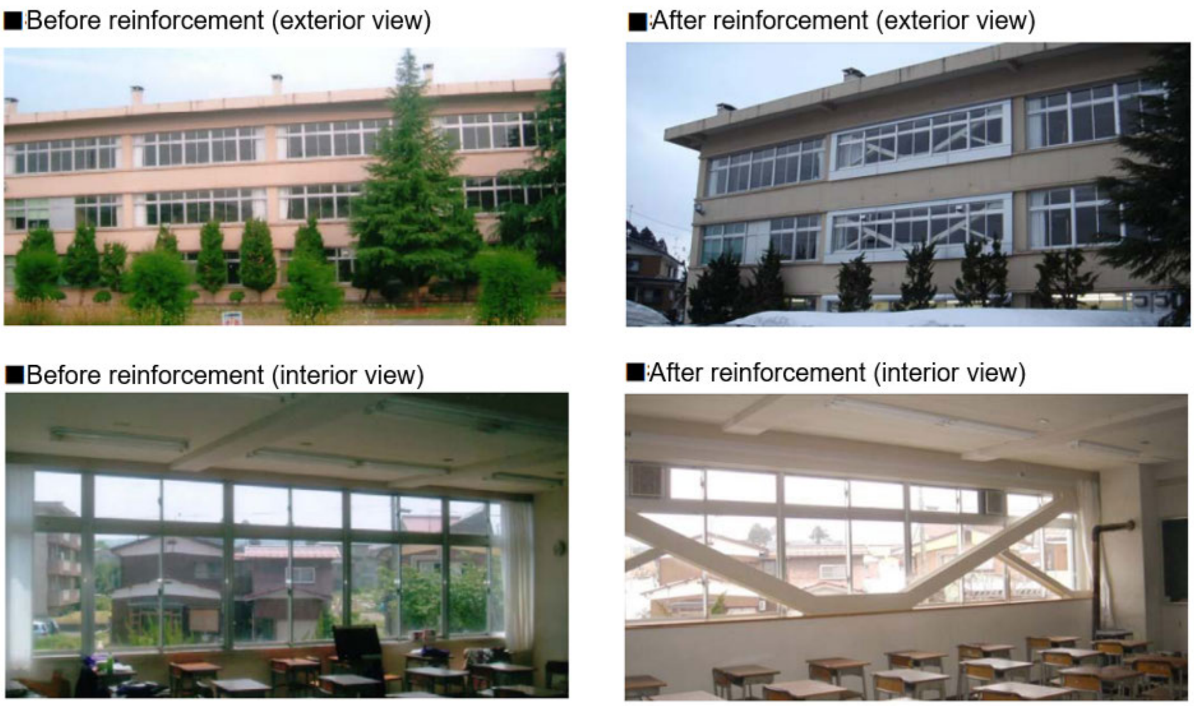
Source：https://www.city.shinjuku.lg.jp/kusei/soumu01_001026.html

Figure 3.3.5 Example of seismic isolation of public facilities

2) Earthquake-proofing of schools

Niigata Prefectural To-ka machi Sogo High School: Earthquake-Resistant Construction

The extremely brittle columns of the existing school building were eliminated by adding sleeve walls and closing the openings. In addition, the building's lack of bearing capacity was reinforced with new steel braces and earthquake-resistant walls (Figure 3.3.6).



Source: https://www.mext.go.jp/component/a_menu/education/detail/__icsFiles/afieldfile/2015/12/11/1237614_001.pdf

Figure 3.3.6 Example of Seismic Reinforcement of School Facilities

3.3.3. Volcanic Ash Countermeasures

(1) List of Countermeasures

Countermeasures for volcanic ash fall can be divided into three stages: preparation, during ash fall, and post-incident response. The measures to be taken at each stage are listed below (

Table 3.3.3).

Table 3.3.3 Volcanic Ash Control

Type	Measures	Effect (Objective)
Preliminary preparation	Preparation of equipment • Dust masks, protective goggles • Preparation of drinking water and preserved food • Cleaning tools (brooms, vacuum cleaners, filters, shovels)	Facilitate post-incident response in the event of ash fall.
	Household measures • Close doors and windows. • Seal gaps with tape, etc. • Cover fragile electrical appliances. • If you use a rainwater collection facility for water supply, remove the collection facility, tank, and pipes	• Prevent ash from entering houses. • Prevent ash from entering electrical appliances and machinery to prevent malfunctions.
	Improvements to the house (make windows, doors, and other openings more airtight)	Make the structure difficult for ash to enter the building.
	Improve the layout and form of roofs, gutters, and gardens, and select finishes and other structures, and shapes that prevent the accumulation of ashes.	Make the structure and shape of the building difficult for ash to accumulate.
During ash fall	- Stay indoors. - If outside, evacuate to a shelter. - Gather information.	• Prevent the effects of ash. • Collect information for post-incident response, etc.
Post-incident response	Outdoor clean-up - Road sweeper - Spray trucks	• Prevent floating of volcanic ash • Removal of ash from residential areas
	Indoor clean-up	• Prevent breakdown of electronic equipment • Prevention of mechanical failure
Others	Ash fall forecast	• Forecasts allow people to prepare for eruptions and volcanic ash.
	Volcanic eruption warnings / forecasts	Volcano monitoring

Source: JICA Study Team

(2) Examples of Countermeasures

1) Volcanic ash removal

Roads should be cleaned by road sweepers or water spray trucks. Example of volcanic ash clean-up is shown in Figure 3.3.7 and Figure 3.3.8.

Source: Kagoshima City

Figure 3.3.7 Road Sweeper (collects volcanic ash from roads)

Source: Kagoshima City

Figure 3.3.8 Water Sprinkler Truck (sprinkling water to prevent volcanic ash dispersion)

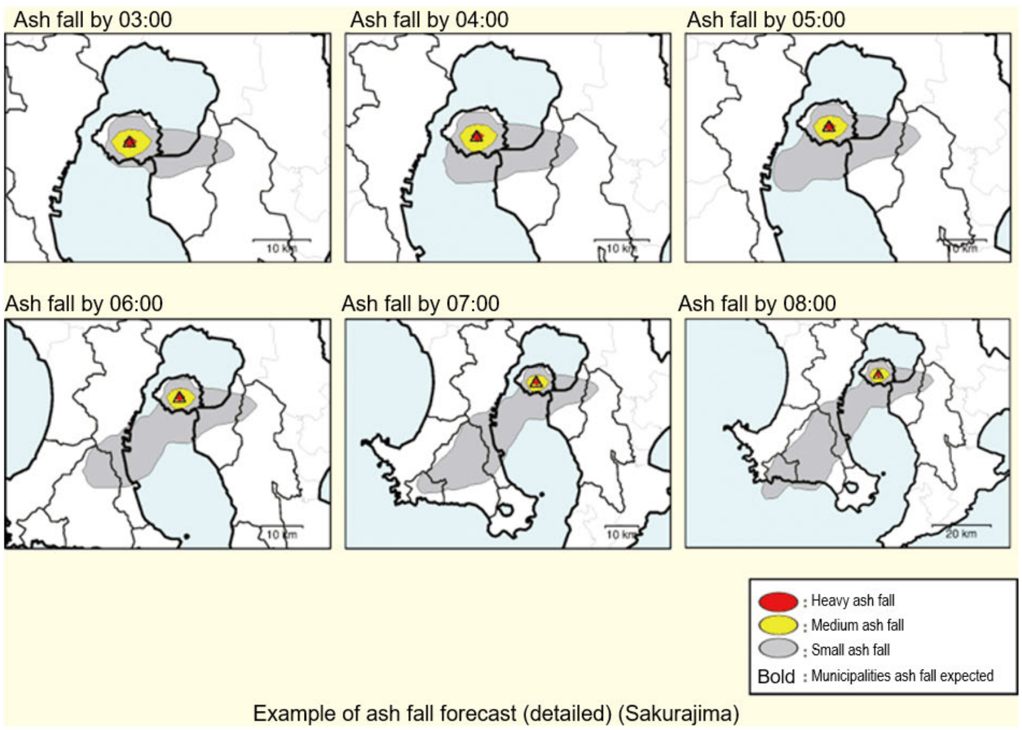
For residential areas, citizens collect ash using ash bags, etc., which are distributed free of charge to citizens, and collect and accumulate the ash at designated ash collection stations.

Source: Kagoshima City

Figure 3.3.9 Ash station (volcanic ash accumulation site)

2) Ash fall Forecasting

In March 2008, the Japan Meteorological Agency (JMA) began operating an ash fall forecast to provide information on areas where ash fall is expected approximately six hours in advance in the event of a volcanic eruption of a certain magnitude of volcanic eruption in Japan. When it first started, this forecast only provided information on the area, but later research made it possible to predict the amount of ash fall as well. In March 2015, a new ash fall forecast was launched to provide more detailed information by upgrading the previous one.



Source：https://www8.cao.go.jp/koutu/taisaku/r03kou_haku/zenbun/genkyo/topics/topic_05.html

Figure 3.3.10 Ash fall forecast

3.3.4. Wind Storm Countermeasures

(1) List of Countermeasures

Cyclones produce storm surges and windstorms. The list of storm and high wind countermeasures is shown in Table 3.3.4.

Table 3.3.4 List of Storm and High Wind Countermeasures

Type	Measures	Effect (Objective)
Structure	Strong Wind Protection for Roofs Connecting roofing tiles and other roofing materials Improvement of roofing material fixing methods	Prevent roofs from being damaged by strong winds.
	Countermeasures against strong winds for glass window Installation of storm doors and shutters Attachment of shatterproof film	Preventing glass and other materials from being damaged by strong winds
	Fixing of equipment	Prevention of scattering of equipment
	Wind-resistant construction of buildings, etc.	Fixing of items that may be scattered by storms Household goods Containers Containers, ships, etc.
Inductive Policies	Change of building notification standards (Reinforcement of measures against strong winds)	Reinforcement of measures against strong winds in new buildings
	Subsidy system for strong wind measures Wind Resistance Diagnosis of Roof Establishment of a subsidy program for wind retrofit work Application of renovation promotion projects	Reinforcement of high wind protection for existing buildings

Source: JICA Study Team

3.4. Examination of Environmental Vulnerabilities in Tonga

3.4.1. Examination of Facilities, Buildings, Land Use and Development Plans

Disaster risk accounts for the potential loss of life, injury, or property loss. It also calculates the loss to a system, society, or community over time in the future, determined probabilistically as a function of hazard, exposure, and vulnerabilities to adverse events.

This study finds no detailed planar distribution information for hazards other than tsunamis and storm surges. So, it exclusively evaluated disaster risk data for tsunami and storm surge hazards.

(1) Exposure and Vulnerability Information of Population, Facilities, Buildings, etc.

Chapter 2.4.4 contains exposure and vulnerability figures for the local population, facilities, buildings, and other variables. This section examines exposure and vulnerability information for essential infrastructure, especially power supply facilities.

(2) Tsunami Disaster Risk

Tsunami disaster risk adversely affects population in its potential areas of inundation. However, data from the number of flooded buildings and power supply facilities is also essential. Regarding tsunami hazards, it covers the maximum enveloping range of volcanic tsunamis and the risks it creates.

1) Tsunami-Affected Populations

Figure 3.4.1 and Figure 3.4.2 show the population distribution among the potential inundation areas of tsunamis. The presence, absence, and efficacy of evacuation plans strongly correlate to the potential for human damage.

Human damage might not immediately occur or become measurable after a tsunami.

The tsunami-affected population of 'Eua Island is about 460 people, which is merely 10% of the population. From the data, it concluded that Tongatapu Island has a higher risk of human damage from tsunami-caused flooding than 'Eua Island.

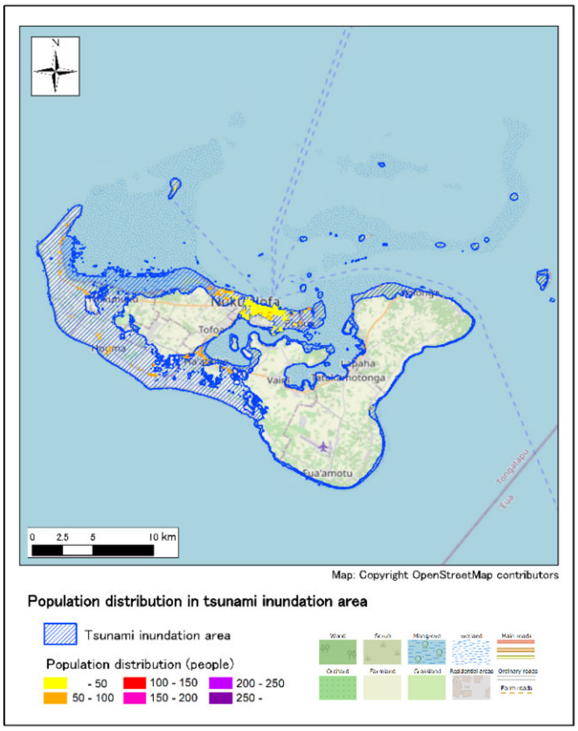


Figure 3.4.1 Population Distribution within the Flooded Area in Tongatapu Island

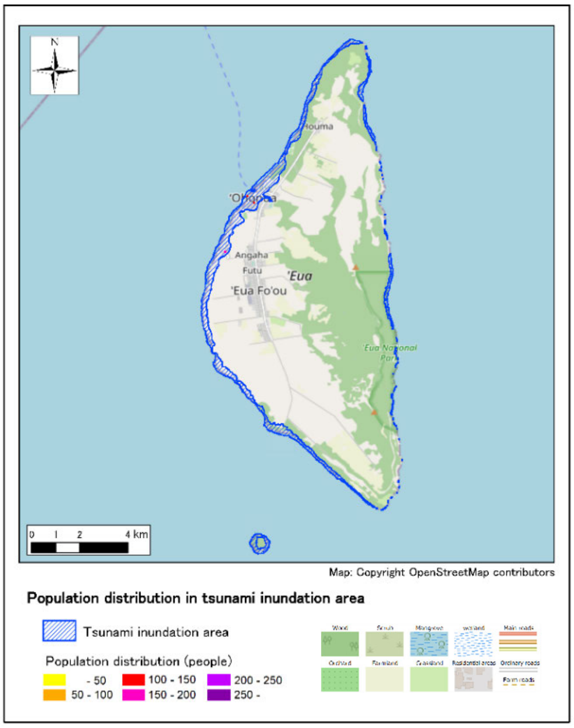


Figure 3.4.2 Population Distribution within the Flooded Area in 'Eua Island

Source: JICA Study Team

2) Inundated Buildings

Figure 3.4.3 and Figure 3.4.4 show the building distribution and inundation areas in Tongatapu and 'Eua Islands. The number of flooded buildings is about 11,400 on Tongatapu Island, accounting for about 49% of the total buildings inland and covering a more significant swath of the population. On the other hand, the number of flooded buildings on 'Eua Island is about 440 or 20% of all standing structures. Tongatapu Island faces a greater risk of flood damage to its buildings compared to 'Eua Island.

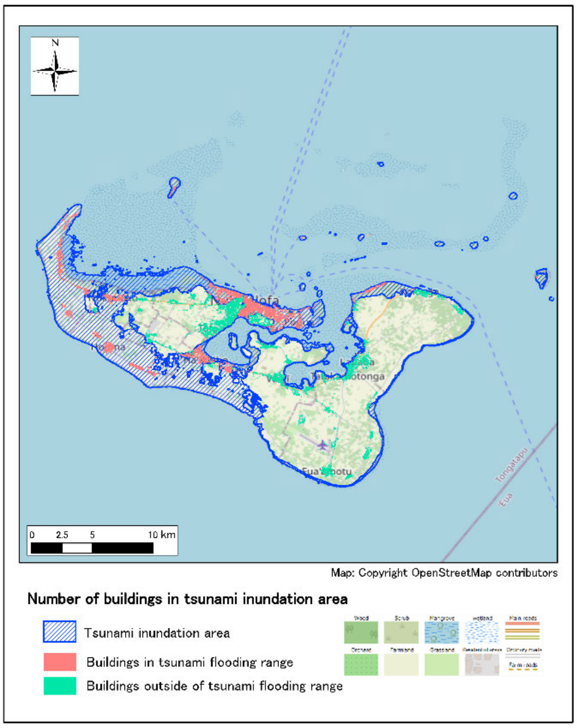


Figure 3.4.3 Building Distribution within the Flooded Area in Tongatapu Island

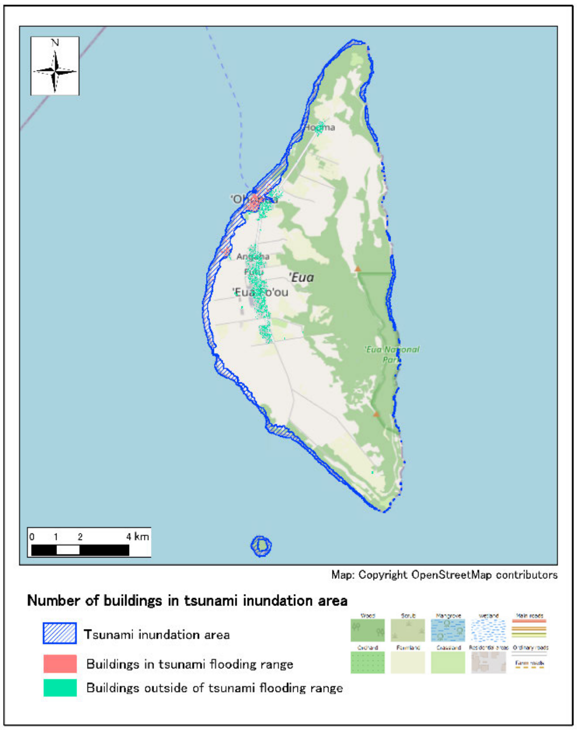
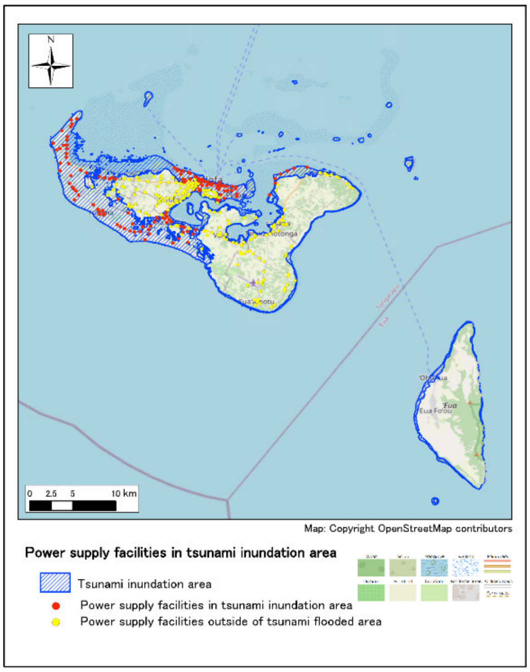


Figure 3.4.4 Building Distribution within the Flooded Area in 'Eua Island

Source: JICA Study Team

3) Inundated Power Supply Facilities

Figure 3.4.5 shows a superimposed diagram of power supply facilities and flooded areas as essential facilities vulnerable to flooding. While not all affected facilities will be unusable immediately, countermeasures are required as they enable critical services for protection.



Source: JICA Study Team

Figure 3.4.5 Electric Power Facilities in Flooded Areas in Tongatapu Island and 'Eua Island

(3) Storm Surge Disaster Risk

The JICA Study Team also examined risks associated with storm surges and considered the population segments affected within flooded areas. They also statistically accounted for potentially flooded buildings and power supply facilities. The variables for computing the storm surge hazard originate from the tidal conditions were assumed for 2075 (M.S.L.+1.22m) under a Hazard Level 2 tidal event.

1) Population Affected by a Storm Surge

Figure 3.4.6 and Figure 3.4.7 illustrate a map overlaying the population distribution and flood range on Tongatapu and 'Eua Islands.

The JICA Study Team estimates the population affected by the storm surge on Tongatapu Island to be approximately 31,600, accounting for 35% of the island's inhabitants. On the other hand, the tidal-affected population on 'Eua Island is likely zero. Therefore, like the case with tsunamis, Tongatapu Island displays a higher risk of flood disaster due to tidal surges compared to 'Eua Island.

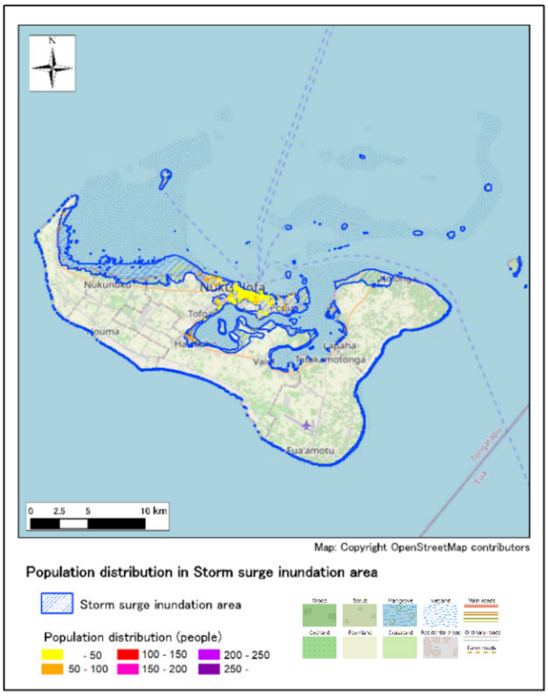


Figure 3.4.6 Population Distribution within the Storm Surge Flooded Area in Tongatapu Island

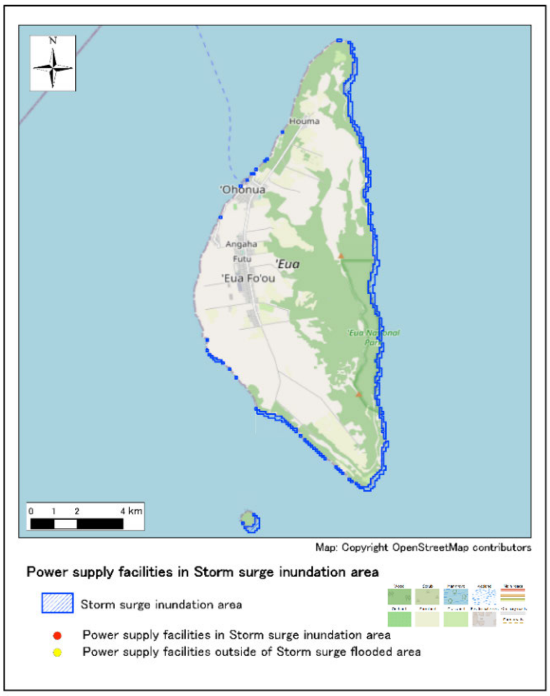


Figure 3.4.7 Population Distribution within the Storm Surge Flooded Area in 'Eua Island

Source: JICA Study Team

2) Building Affected by Storm Surges

Figure 3.4.8 and Figure 3.4.9 show a map overlaying the building distribution and flood range in Tongatapu and 'Eua Islands. The number of potentially flooded buildings on Tongatapu Island will be approximately 7,600, accounting for about 32% of all inland structures. On the other hand, the number of at-risk buildings on 'Eua Island is about 2.

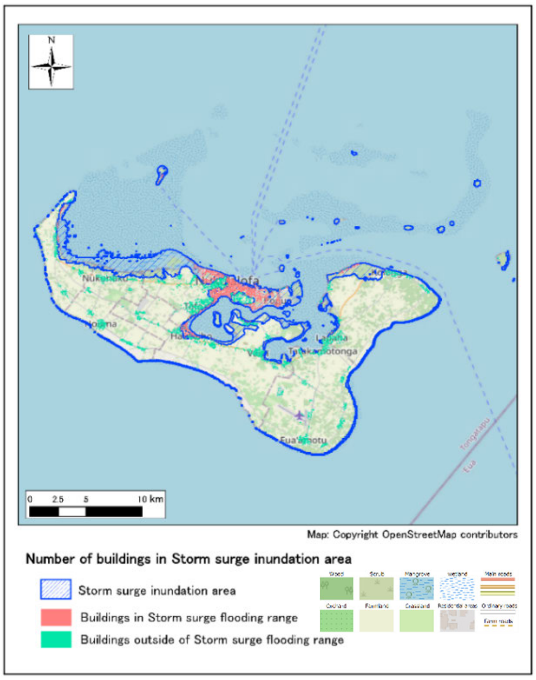


Figure 3.4.8 Building Distribution within the Storm Surge Flooded Area in Tongatapu Island

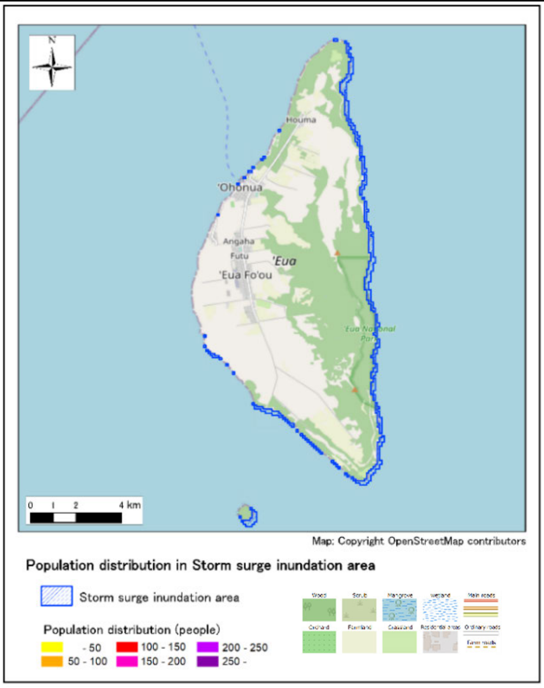


Figure 3.4.9 Building Distribution within the Storm Surge Flooded Area in 'Eua Island

Source: JICA Study Team

3) Storm-Surge-Affected Power Supply Facilities

Figure 3.4.10 and Figure 3.4.11 show a map overlaying the local flood zones and power supply facilities, which are critical structures extremely vulnerable to flooding. Although not all power supply facilities become unusable immediately, they are essential for the continuity of local emergency and other functions, meriting extraordinary measures for protection.

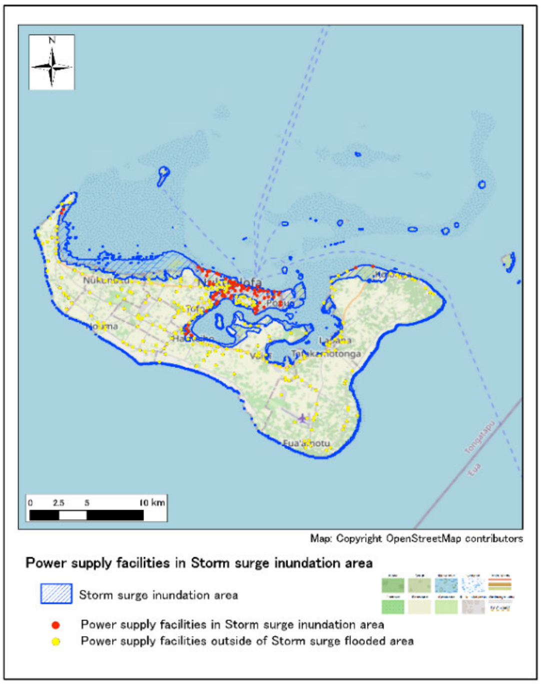


Figure 3.4.10 Power Supply Facility Distribution within the Storm Surge Flooded in Tongatapu Island

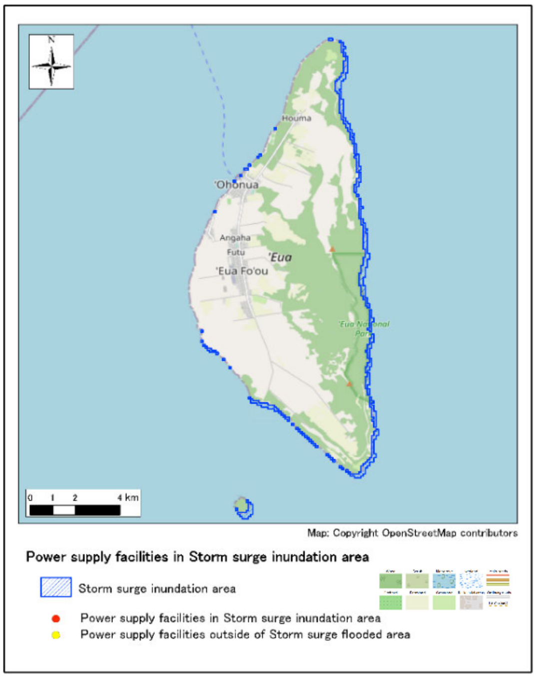


Figure 3.4.11 Power Supply Facility Distribution within the Storm Surge Flooded Area in 'Eua Island

Source: JICA Study Team

3.4.2. Organizing and Analyzing Information About Disaster Prevention Laws and Regulations

(1) Disaster Management Laws and Regulations

1) National Spatial Planning and Management Act 2012

a) Summary

The National Spatial Planning and Management Act 2012 aims to regulate the spatial development of Tonga and, in particular, to provide for fair, orderly, economical, and sustainable land use, development and management, including the protection of natural and man-made resources and the up keeping of existing ecological processes.

The National Spatial Planning Authority appoints the Minister of Land and Infrastructure as its governing head. The organization facilitates the preparation and approval of sustainable management plans and to conducts development assessments. It also promotes strategic planning and enacts concerted efforts that ensure the sustainable use of land.

This law governs spatial plans that guide the utilization of national, regional, district, village or site-specific lands, instituting a governmental consent system for all development unless an existing regulation specifies otherwise. In select circumstances, authorities may require an applicant to submit a development plan. It will evaluate then this plan for strategic land use and development and see it through implementation. The application must include an environmental impact assessment, as applicable environmental laws require. The agency may track on any terms it deems appropriate in giving its consent.

b) Chapter Components

Part 1: Previous Chapter

Part 2: National Spatial Planning Agency
This section defines the purpose and functions of the National Spatial Planning Agency.

Part 3: Spatial Planning
This section stipulates the definition and content of spatial plans, procedures essential to formulating plans and approving plans, and more.

Part 4: Planning and Development Evaluation
This section outlines the development of land content subject to agency permission.

Part 5: Plan Judgment
This section outlines provisions for appealing to the Planning Court regarding development permits.

Part 6: Enforcement and Legal Proceedings
This section contains provisions related to legal enforcement.

Part 7: Miscellaneous

2) Emergency Management Act 2016

Disaster management laws and regulations in Tonga are based on the Emergency Management Act enacted in 2007. Revisions were made in 2014 and 2016, and the members of the organization necessary for conducting disaster management administration were specified in these revisions. The law provides a framework for implementing disaster management administration in Tonga. It stipulates the establishment of the National Emergency Management Office (NEMO) as the organization that carries out disaster management administration in Tonga, with the support of three major committees in the implementation aspect. At the same time, the law stipulated the formulation of a disaster management plan and a declaration of a state of emergency. However, the law focuses on emergency response with little attention to disaster risk management and other aspects of disaster management in general.

The law also stipulates the submission and content of annual disaster-related reports in Tonga, including information on annual emergency response status and disaster risk reduction priorities.

3) Disaster Risk Management Bill 2021

The Disaster Risk Management Bill 2021 focuses mainly on pre-disaster emergency response with reference to the current Emergency Management Act (2007), but deals with all disaster situations according to the disaster management cycle. It has been modified to allow what the disaster risk management law in 2007 covers and go beyond to include man-made disasters and epidemics. However, it excludes wars, nuclear disasters, cyberattacks, industrial disputes and riots.

The law was submitted to the Diet in July 2021, but as of August 2022, it has not yet been enacted. The law has received comments from related ministries and agencies, and there is no prospect of it being enacted. However, while the current law emphasizes emergency response, this law deals with disaster management as a whole, so it is absolutely necessary to promote disaster management administration in Tonga.

4) Building Code

The Building Control and Standards Act was enacted and enforced in 2002 as the basis of building administration in Tonga. This law stipulated the organizational structure for building administration, building permit procedures, and building standards. The Building Control and Standards Regulations were enacted in 2004, and the National Building Code of the Tonga is in operation with the enforcement of the Building Code Regulations in 2007.

Building codes in Tonga are basically based on the standards of Australia and New Zealand. Also, in many articles, Australian and New Zealand standards are used as they are, but in the 2007 Building Code Regulations, seismic design should follow either the California Building Code 1998 or the Australian and New Zealand Seismic Codes. The building standards regulations enacted in 2007 were later revised in 2018, incorporating performance design methods and other factors.

5) Earthquake and wind load in Tonga

The design horizontal seismic coefficient stipulated in the 2018 Building Standards is a combination of building importance (levels 1 to 4) and service life (25, 50, 100 years), and the standard horizontal seismic coefficient Z (=0.7g, annual exceed probability 1/500) and the return period factor R (Z*R). The return period coefficients and corresponding design horizontal seismic coefficients are shown in the table below. Also, the return period coefficient R for Tonga is slightly different from that for New Zealand. For reference, the return period coefficients for New Zealand are also shown in the Table 3.4.1.

Table 3.4.1 Annual Probability of Exceedance for Buildings Importance Levels

Annual Probability of Exceedance	Return Period Factor R	Design Horizontal Seismic Coefficient Z*R (g)	R in NZS1170.5
1/2500	2.0	1.4	1.8
1/2000	1.8	1.26	1.7
1/1000	1.4	0.98	1.3
1/500	1.0	0.7	1.0
1/250	0.75	0.525	0.75
1/100	0.50	0.35	0.5
1/50	0.40	0.28	0.35
1/25	0.30	0.21	0.25
1/20	0.25	0.175	0.2

Source: National Building Code of the Kingdom of Tonga

The annual exceedance probability and corresponding design wind speed and horizontal seismic intensity are shown in Table 3.4.2.

Table 3.4.2 Summary of wind speed and horizontal seismic intensity for building design

Importance Level	Wind (wind speed, m/s)			Earthquake (horizontal seismic coefficient, g)		
Design Life (Years)	<25	50	100	<25	50	100
Importance Level 1	-	60	66	0.28	0.35	0.525
Importance Level 2	60	66	70	0.525	0.7	0.98
Importance Level 3	66	70	76	0.7	0.98	1.4
Importance Level 4	70	76	*	0.98	1.4	*
* Importance Level 4 buildings with a design life of 100 years require a special study.						

*) A separate survey is required for buildings with a design life of 100 years among the importance level 4

Source: National Building Code of the Kingdom of Tonga

The design horizontal seismic coefficient in Tonga is 0.7g for general buildings, 0.98g for important buildings used by an unspecified number of people, and 1.4g for important buildings for disaster management in the case of 50-year service life. In the case of a service life of 100 years, it is 0.98g for general buildings and 1.4g for important buildings used by an unspecified number of people. Japan's level 2 design horizontal seismic coefficient is 1.0g, and the importance coefficient is 1.5 for Category I (emergency response government facilities, disaster base hospitals, public evacuation facilities, etc.) and Category II (government facilities, general hospitals, schools, etc.). is 1.25), and Class III (general buildings) is 1.0. Comparing the horizontal seismic intensity of Tonga and Japan, general buildings with a service life of 50 years are smaller than Japan, but important buildings with a service life of 50 years and 100 years are considered to be about the same as Japan.

Building codes in Tonga are based on Australian or New Zealand standards. In the structural design, the parts other than changing the regional hazards for Tonga are applied as they are. New Zealand has a high seismic hazard, and the first seismic standards date back to 1935, giving it a long history of seismic design. The 2004 version of New Zealand's seismic code is the latest version.

In the 2018 revision, the standard horizontal seismic coefficient Z was increased from 0.4g to 0.7g, and the return period coefficient R was introduced. It is also necessary to examine the handling of buildings built according to the 2007 version (seismic diagnosis and seismic reinforcement).

In Tonga, the history of building regulations is short, so it is necessary to build a system for compliance with building regulations and building standards, strengthen the capacity of organizations and human resources involved in building administration, especially to develop technical human resources who understand new design standards and are involved in seismic design and quality control. Capacity building is considered an issue in Tonga.

(2) Disaster Management Organization

1) Ministry of Meteorology, Information, Disaster Management, Environment, Climate Change and Communications (MEIDECCC)

MEIDECCC currently consists of 10 departments: (1) Leadership, (2) Corporate Services, (3) Weather, (4) Energy, (5) Information, (6) Disaster management, (7) Environment, (8) Climate Change, (9) Telecommunications, (10) CERT/E-Government), and has 211 staff in 2018/19. The annual budget is $111.3 (million). There are many departments related to disaster management within the Ministry such as NEMO and TMS.

2) National Emergency Management Office（NEMO）

NEMO is a major organization dealing with disaster management administration and is currently under MEIDECCC. It reviews and monitors the National Emergency Management Plan as part of its role as support and advisory body to the three committees, including the Emergency Response Committee. Furthermore, it is supposed to implement the policies and decisions of the National Emergency Management Committee. NEMO also plays an important role in coordinating emergency management activities. Due to repeated disasters since then, the need for measures to reduce disaster risk and prepare for disasters has been recognized, and the "Disaster Risk Management Bill 2021" was submitted to the Cabinet in 2021 to expand the role of the organization. However, it was not approved at that time, but in June 2023, when the emergency response to the HTHH eruption had calmed down, it was approved by the Cabinet as the "Disaster Risk Management Act," and NEMO became the National Disaster Risk Management Office (NDRMO). To avoid confusion, both names will be used together for one year after approval.

(In this report, descriptions will be unified by NEMO.)

3) Tonga Meteorological Service (TMS)

TMS is an organization under MEIDECCC and is mainly responsible for meteorological observations. It observes weather in Tonga, monitors tsunamis and issues tsunami warnings based on tsunami warning standards. Its office is at the domestic terminal of Fa'amotu International Airport on Tongatapu Island.

Recently, the meteorological equipment of TMS was updated through the cooperation with New Zealand. Fully automated observation systems have been installed in 21 locations throughout Tonga. These are 8 locations on Tongatapu Island, 5 locations on Vava'u, 4 locations on the Ha’apai Islands, and the rest have already been installed on other islands. These observation systems generate data that are aggregated at the TMS headquarters via mobile phones.

4) Tonga Geology Service (TGS)

TGS is an organization under the Ministry of Lands and Natural Resources. TGS conducts seismic observations and responsible for observing submarine volcanoes. TGS currently has 8 sets of seismometers, of which 6 have already been installed. In addition, TGS plans to purchase eight more sets of seismometers through cooperation with World Bank.

In addition, the large-scale eruption of the submarine volcanoes Hunga Tonga-Hunga Ha'apai on January 15, 2022, triggered the introduction of volcano observation equipment. With the support of the USGS, TGS already received one set of infrasound arrays for observing submarine volcanoes. This will be operated at the observation facility in the airport of TMS, but the installation location has not yet been determined. TGS hopes to get support from the USGS for another set, which will be installed at Vava'u.

5) Ministry of Infrastructure (MoI)

The Ministry of Infrastructure is mainly in charge of infrastructure development in Tonga. The MoI has five departments (Civil Aviation, Land Transport, Maritime Transport and Ports, Building Regulations, and Other Infrastructure). The Ministry currently has 107 staff members.

6) National Disaster Council (NDC)

NDC is at the highest level among organization with functions related to disasters management in Tonga. NDC is established in the Cabinet, chaired by the Prime Minister, and organized by ministers. Under the NDC, three committees have been organized, with NEMO serving as the Secretariat. These committees are the National Emergency Management Committee, National Emergency Operation Committee, and National Emergency Recovery Committee

7) National Emergency Management Committee (NEMC)

There are three national committees for disaster in Tonga, but NEMC has the overall jurisdiction over emergency management. The three committees are currently chaired by the Minister of the MEIDECCC.

NEMC formulates policy on emergency management, and is responsible for approving national disaster management plans, implementing the plans, and coordinating with other countries under times of emergency.

8) National Emergency Operation Committee (NEOC)

This committee responds to emergency situations that have occurred, are occurring, or are likely to occur in Tonga. Emergency management will be carried out mainly by this committee.

9) National Emergency Recovery Committee (NERC)

This committee is established to coordinate post-disaster restoration and reconstruction. The members are the main government offices of the Tongan government.

10) District Emergency Management Committee (DEMC)

District level emergency management committees have been established in the following regions of Tonga: Ha'apai, Vava'u, Niuatoputapu, Niuafo’ou, and 'Eua.

District emergency management committees formulate district emergency management plans. They implement disaster management at the local level according to the policies of the National Emergency Management Committee and implement disaster risk reduction activities according to its recommendations. District disaster management committees play a central role in promoting disaster management activities in the region.

11) Village Emergency Management Committee (VEMC)

Each village organizes a Village Emergency Management Committee with the village chief as chairman. This committee is responsible for emergency management and disaster risk reduction at the village level as requested by the National Emergency Management Committee.

The Village Emergency Management Committee carries out educational activities for residents according to the disaster cycle. It also prepares and submit annual reports at the village level.

(3) Disaster Management Related Plan

1) National Emergency Management Plan (NEMP)

The National Emergency Management Committee (NEMC) will be formulating a National Emergency Management Plan with the following contents:

- Mitigation, preparedness, emergency response and recovery/reconstruction in accordance with the process of disaster risk management and special events
- Roles and responsibilities of related agencies
- Prioritization of disaster risk reduction
- Support from other countries and donors
- Supporting and coordinating district emergency management committees

Similarly, each region is obliged to formulate a local emergency management plan. These plans are also open to the public.

3.5. Proposal for DRR Plans for Tongatapu and 'Eua, and a Roadmap for the Implementation of BBB Vision

3.5.1. Examination of Structural Measures with Appropriate DRR Infrastructure According to Defense Level for Each Hazard

(1) Defense Level for each hazard

The hazard analysis was performed about following three types of hazards and the results are also shown in Table 3.5.1.

Table 3.5.1 Analysis results according to defense level for each hazard

Target Area	Defense Level	Seismic Tsunami	Volcanic Tsunami	Storm Surge (Cyclone)
Tongatapu Island	L1	H=1m-2m	N/A	H=3.0m
	L2	H=1m-4m	H=1m-4m	
'Eua Island	L1	H=1m-2m	N/A	
	L2	H=3m-12m	H=3m-12m	

*All dimensions are based on MSL+
Source: JICA Study Team

(2) Examination of Structural Measures by DRR Infrastructure

1) Tongatapu Island

- For seismic tsunami L1: Since the current height of Nuku'alofa seawall is 2m on average, no special measures are required.
- For storm surge (Cyclone) L1: It is necessary to raise the existing seawall height up to 3m.
- For seismic and volcanic tsunami L2: Because the tsunami will invade urban area where is expected inundation area overtopping the seawall which raised up under the countermeasure for L1 mentioned above, several substantial measures are required, such as construction of tsunami evacuation tower, relocation of residents to higher land, raise up the elevation of the coastal road and surrounding lands.

2) 'Eua Island

- For Seismic tsunami L1: Since no big damage is expected same as Tongatapu, no special measures are required.
- For seismic & volcanic tsunami L2: The structures located on land lower than the estimated tsunami height of 12m to be considered to relocate to as high location as possible.

3.5.2. Examination of Resilience of Important Structures according to Defense Level for Each Hazard

(1) Tongatapu Island

For seismic & volcanic tsunami L2: First of all, the elevation of existing port facilities should be checked and listed into the hazard map to analyze their soundness. For the countermeasure against 4m tsunami, several measures are required such as construction of raised flooring type house, registration of the evacuation building including the vertical evacuation of the important facilities such as electric room, etc. from ground floor.

(2) 'Eua Island

For seismic & volcanic tsunami L2: In order to protect the existing Nafanua port and related facilities in the coastal area of Ohonua District, which is below 12m above sea level, from tsunami, it is technically possible to construct the breakwater in front offing the port about 1km length to cover the whole area of the port as shown in the figure below.

Source: JICA Study Team

Figure 3.5.1 'Eua Island Breakwater Plan

3.5.3. Land use and evacuation plan

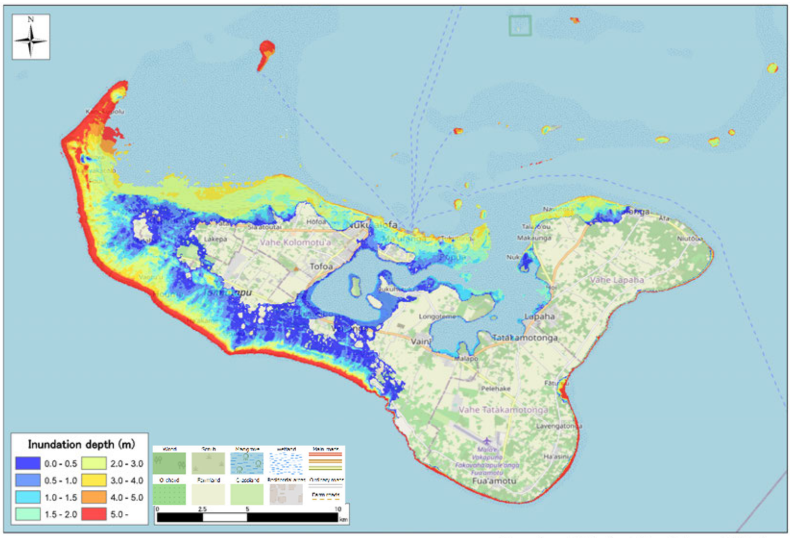
(1) Land use planning

There is no land use plan in Tonga. Therefore, it is difficult to restrict buildings by land use regulations, but it would be possible to divide the land according to the depth of tsunami inundation map, and to request support for each division when applying for a building.

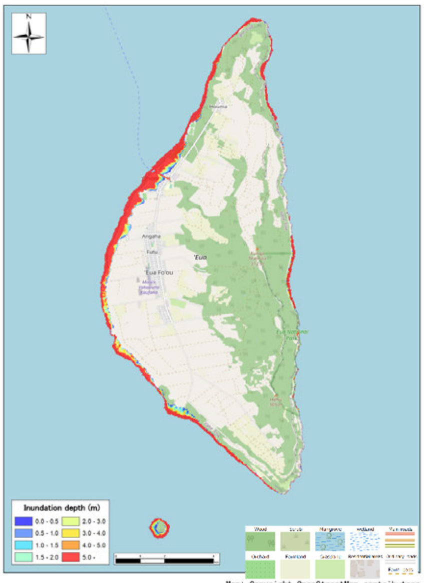
(2) Evacuation Plan

According to the hazard analysis results of this survey, it was confirmed that volcanic tsunami is the hazard that requires evacuation on Tongatapu Island and 'Eua Island. In Nuku'alofa City on Tongatapu Island, which has the largest population, a seismic tsunami can be prevented by existing defense facilities. Also, although the height of the tsunami on 'Eua Island will be high, it is thought that the tsunami will only cause limited damage because few people live in the coastal areas. However, in some areas, people also live in coastal areas, so it will be necessary to protect these residents by structural measures or promote their relocation to other areas through land use regulations.

In terms of volcanic tsunamis, while high tsunami attacks are expected for both Tongatapu and 'Eua Islands, it has been pointed out that the frequency of occurrence is low. Below is a map of the area affected by a volcanic tsunami.



Map: Copyright OpenStreetMap contributors



Map: Copyright OpenStreetMap contributors

Source: JICA Study Team

Figure 3.5.2 Inundation area of L2 level

This figure shows that the tsunami and cyclone come from different directions. In the future, when formulating an evacuation plan in Tonga, the hazard map prepared by the project should be used as a reference to formulate an evacuation plan as soon as possible.

When formulating an evacuation plan, it is necessary to pay attention to the following points.

1) Development of evacuation plan

The development of an evacuation plan is already stipulated in the current Disaster Prevention Law. The government's emergency response system, procedures, division of roles among governments, and the establishment of an initial response system are relatively well-developed.

2) Judgment and transmission of evacuation orders

The TMS monitors meteorological disasters as well as tsunamis. However, seismic observations are carried out by the TGS, which includes observations of submarine volcanoes. Since TMS is conducting 24-hour observations, it will issue an evacuation warning to public. It has become possible to issue warnings through sirens installed with assistance from JICA. After that, evacuation orders were issued in each village, and they were to evacuate.

According to the interviews at TMS, the issuance of warnings is the role of TMS, but it seems that the criteria are not clear. Currently, it seems to issue a tsunami warning for earthquakes with a magnitude of 7.3 or higher. It should have a more detailed warning to the residence for evacuation.

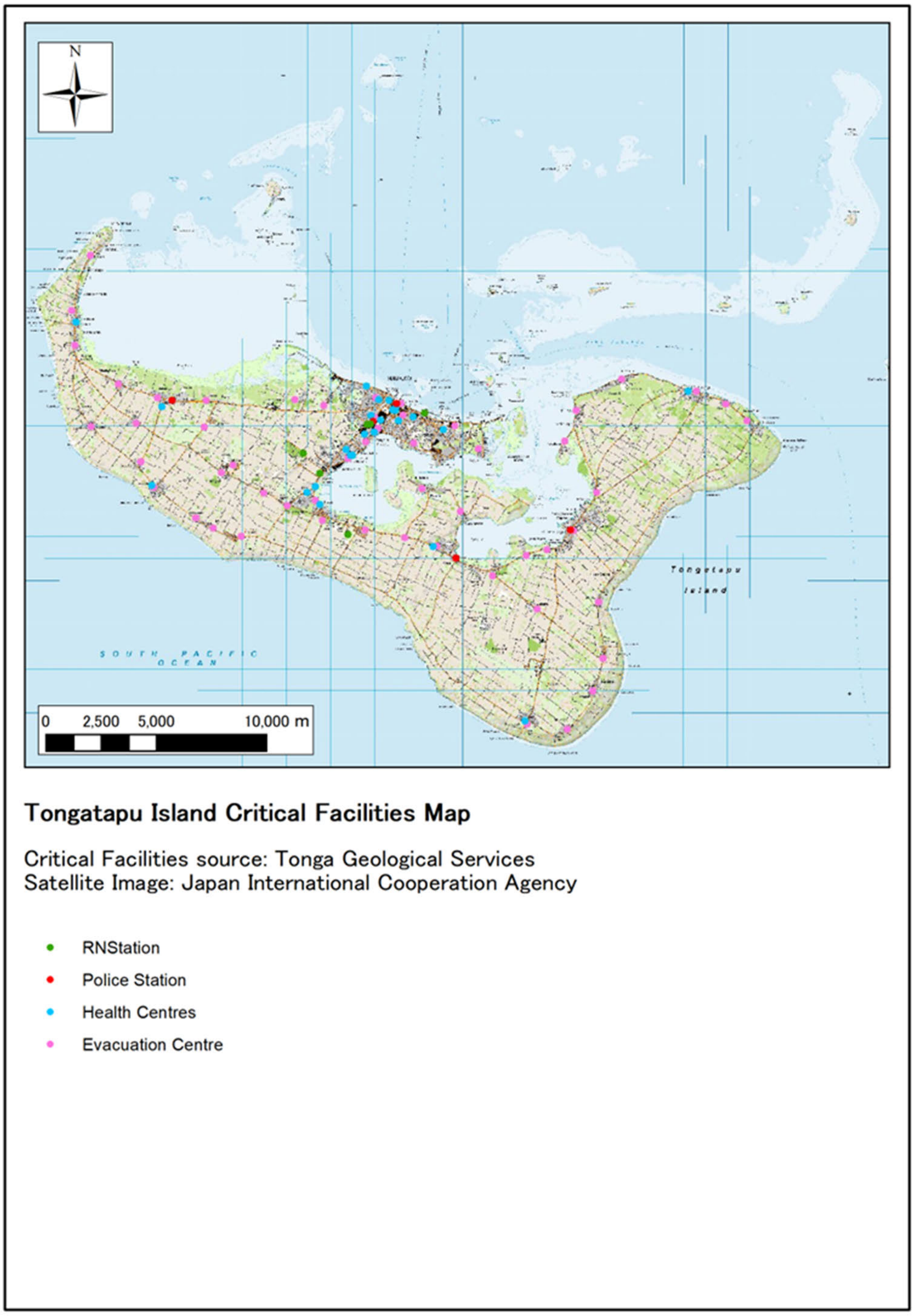
3) Evacuation guidance

The M.7.6 earthquake that occurred on May 11, 2023, triggered a siren warning issued by TMS and some citizens were evacuated. Many residents evacuated by private car, but it is pointed out that evacuation guidance was not sufficient and traffic jams occurred frequently. Evacuation guidance is the role of the police, but they should cooperate other organizations to evacuation guidance.

4) Designation, establishment, and operation of shelters

Designation of evacuation centers is the role of NEMO, since the hazard map was newly prepared in this study, it is necessary to refer to it and review the previous one. In addition, it is necessary to make arrangements in advance regarding management and other matters.

Shows the location of the shelter that can be confirmed now.



Source: JICA Study Team

Figure 3.5.3 Location Map of Evacuation Centers, etc.

The hazard map (Figure 3.5.2) and Tsunami arrival time distribution map (Figure 3.2.15) shows that volcanic tsunamis will strike Tongatapu Island from the northwest to the southeast. Due to the considerable height of the tsunami, many parts of Tongatapu may also be destroyed. Also, since the arrival time of the tsunami is 18 minutes, which is relatively short, efficient evacuation is necessary. It is necessary to devise ways to evacuate in a short time by incorporating the concept of vertical evacuation, such as designating tsunami buildings.

5) Ensuring the safety of persons requiring special care

It is also necessary to make advance arrangements regarding the evacuation of people requiring special care, and to clarify in advance how many people in each village need special care in order to ensure their safety.

3.5.4. Points to note for each project.

(1) Tongatapu Island

1) Raising Nuku'alofa Seawall

When raising the seawall, there is a risk that the height of seawall might be too high depending on the location and the sea cannot be seen from the coastal road. Therefore, it is necessary to make an invention that the residents can easily access to the beach, such as the promenade on top of seawall with stairs or slopes provided at certain distance.

2) Tsunami Evacuation Tower, Relocation of private housing and Raised Flooring Type House

For the Tsunami evacuation tower, it is necessary to consider that there is no climbing facility other than stairs for an elderly person and person with a physical disability.
Sufficient planning is also required for basic infrastructure, such as roads, water supply and electricity.

3) Raise the ground level including the road

It is necessary to develop a drainage channel from low land to avoid the seawater that has overtopped the seawall and entered into the inland area will not be able to return to the sea and remain inland due to the elevated elevation of the coastal road and part of the land.

(2) 'Eua Island

1) Relocation of Important Facilities below H=12m to higher ground

Sufficient planning is also required for basic infrastructure, such as roads, water supply and electricity.

2) Construction of Breakwater

A question remains because of the construction cost is extremely high compare to its effectiveness.

3.5.5. Facility Plan/Cost Estimate

(1) Tongatapu Island

1) Raising Nuku'alofa Seawall

Details of this item will be described later in the Section 4.1.2.

2) Tsunami Evacuation Tower, Relocation of private housing and Raised Flooring Type House

- For the Tsunami Evacuation Tower, there is the result of 200 million yen for the height of around 10m in Japan.
- For the Relocation of private housing, the government of Tonga (MOI) has a plan to build up the Tsunami Evacuation House consisted of 2-20feet container (2x 15m2=30m2) combined one with value of 90,000 TOP.
- For the Raise Flooring Type House, there is a proposal that with the same condition as above (30m2) its cost is 2,200 top/m2 x 30m2 = 66,000 TOP.

3) Raise the ground level including the road

Construction cost for a typical 2-lane road is around 1 million yen per m in Japan.

(2) 'Eua Island

1) Relocation of Important Facilities below H=12m to higher ground

The relocation plan of the existing bridge at Ohonua will be described later in Section 4.2.2.

2) Construction of Breakwater

Construction costs depend on conditions of the area, but there are cases of 50 million yen/m2 depending on the conditions[18].

3.6. Advice on BBB/disaster prevention considerations for recovery and reconstruction projects supported by Tonga and Japan

3.6.1. Hazard understanding and infrastructure construction

The Tonga created The Tonga National Infrastructure Investment Plan, 2021-2030 (NIIP3) to promote infrastructure development and was approved by the Cabinet in August 2021. Due to the spread of COVID-19, the tsunami caused by the HTHH eruption on January 15, 2022, and the damage caused by volcanic ash fall, etc., NIIP3 has been revised and re-issued after these events. Added a new project to solve the problem. 47 projects have been added, of which 21 are directly and 7 are partially involved in the HTHH eruption. These newly added projects and original projects will be published as NIIP3 in April 2023.

In NIIP3, to determine priority projects, each project is scored according to five indicators and the order of priority is determined. One of the indicators is natural resources and environment, and disaster

[18] Ministry of Land, Infrastructure, Transport and Tourism Kinki Regional Development Bureau "Shibayama Port Shibayama District Evacuation Port Development Project"

prevention is also taken into consideration. Since NIIP3 is expected to implement from 2021 to 2030, the following points should be taken into consideration when implementing projects.

(1) Dissemination of disaster management in the tourism industry

The tsunami caused by the recent eruption of HTHH also caused severe damage to the tourism industry. In particular, tourist facilities located on the eastern side of Tongatapu Island were almost completely destroyed. The tourism industry in Tonga is one of important sectors in Tonga, and it is important to fully disseminate the concept of disaster management in the tourism industry. In particular, the volcanic tsunami clarified in this analysis will be high on the south side of the island, so sufficient countermeasures are necessary. In addition, it is necessary to carry out evacuation drills on a regular basis and determine in evacuation routes and procedures after a disaster, as well as guidance for foreign tourists.

(2) Link with land use

It is necessary to utilize the hazard map (Figure 3.5.2), include hazard information in land use, and indicate the structure of buildings. In addition, it is necessary to confirm the dangers of residents living in tsunami-prone areas and, if possible, encourage their relocation.

(3) Formulation of evacuation plans and implementation of evacuation drills

In Nuku'alofa, a bank protection facility has been constructed with assistance from Germany and Japan. The current protection facilities are lower than they were at the time of construction and may be hit by tsunamis and storm surges. Furthermore, in this analysis, the volcanic tsunami will strike from the southeast side of Tongatapu Island, so evacuation plan for volcanic tsunami is required. Evacuation sites are currently being designated, but they need to be reviewed based on the results of hazard analysis. In the evacuation behavior so far, there are many problems such as how to think about the use of cars and how to evacuate to people who need support. Evacuation should be carried out efficiently by effectively utilizing vertical evacuation such as tsunami towers and tsunami evacuation buildings.

The tsunami will reach the south coast of Tongatapu Island directly and quickly and will be damaged by the tsunami. There is a possibility of normal training may not assume situations occur. Designated evacuation places in level 1 tsunami may not be used. Structural measures are constructed for tsunamis of level 1, but in the case of Tongatapu Island, constructed at level 1 tsunami structure is not or a little impact on level 2 tsunami from the southern side.

Evacuation drills will also be required. It is recommended that the international tsunami day or some disaster event day can be used for the tsunami evacuation drill.

3.6.2. Survey on Water Facilities

The Ministry of Health, Labor, and Welfare commissioned project, 'Guidance for the creation of Water Project Plan for 2023 (First Phase), Water Supply Recovery Support Plan, Kingdom of Tonga, March 2023', has conducted an analysis, including water facilities damaged by the HTHH eruption. As the project is shaped with an understanding of the BBB Vision, its early implementation is desired. In addition, the water facility project is also highlighted in the NIIP3, compiled by Tonga, and can be said to align with the wishes of the country."

4. Consideration of Coastal DRR Projects

4.1. Nukualofa Seawall Restoration Project

4.1.1. Damage Status of Nukualofa Seawall

Source: JICA Study Team

Figure 4.1.1 Overall Layout of Nukualofa Seawall

Along the coastal road located on the north side of Nukualofa, the capital of Tonga, the seawall is installed as protection against tidal wave and tsunami. This structure mainly consists of masonry and partially reinforced with concrete.

The total length of the seawall is about 8.2km and it is divided into three areas as shown below.

1. Japanese grant aid: The masonry seawall was constructed in two phases in 1988-89. Excluding the urban area of the city, the west side is 2.7km, and the east side is 2.5km.

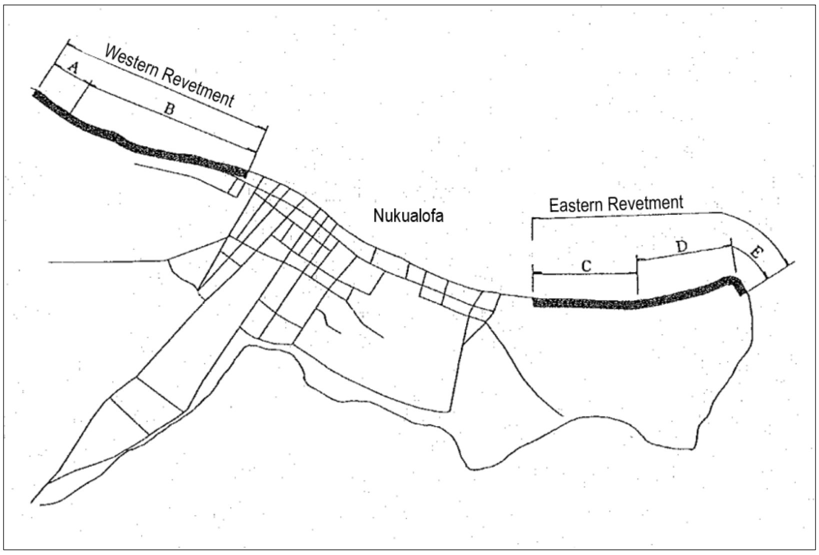
2. Germany's grant aid: Although the date of construction is unknown, there is a seawall provided by Germany's grant aid that existed before the Japanese grant aid project was implemented. The structure at the time of construction is unknown, but it is currently covered with concrete on the masonry. The seawall is located across the Vuna Wharf, the left side is 1km and the left side is also 1km, and total length is about 2km.

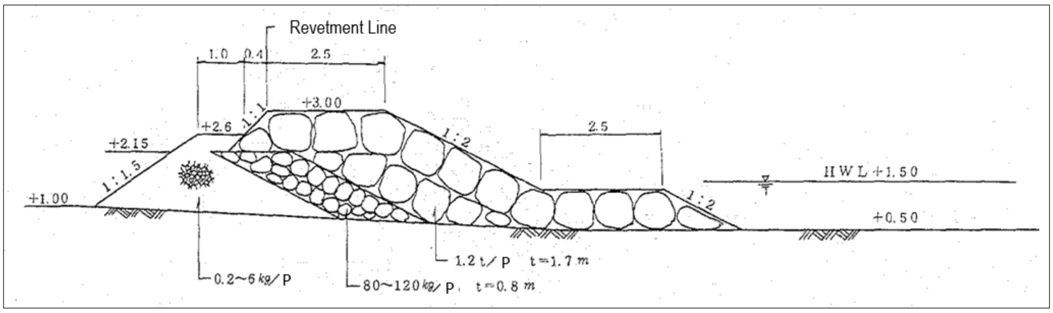
3. Outside the above two seawalls area-Since it is located behind the existing port facilities, it is not required to install the seawall along the coastal road. The length of this area is about 1km.

(1) Damage Status of Japanese Grant-Aid Seawall with Its Typical Cross Section

The construction area is divided into 5 parts depending on the height of the seawall. The heights (H.W.L.+1.60m, etc.) shown in the Typical Cross-Sectional Drawings are indicated by the high tide water level (H.W.L) determined by tide level observation at the time of construction. The report at that time states that this H.W.L was determined by tide level observation as mean water level (M.S.L.) +0.7m. However, the exact relationship between the M.S.L. at this time and current M.S.L. is unknown. Also, photos of the current state of the seawalls constructed in each range attached together.

1) Cross-section A





Source: JICA Basic Design Study Report on the Project for Extension of Nuku'alofa Foreshore Protection, 1988

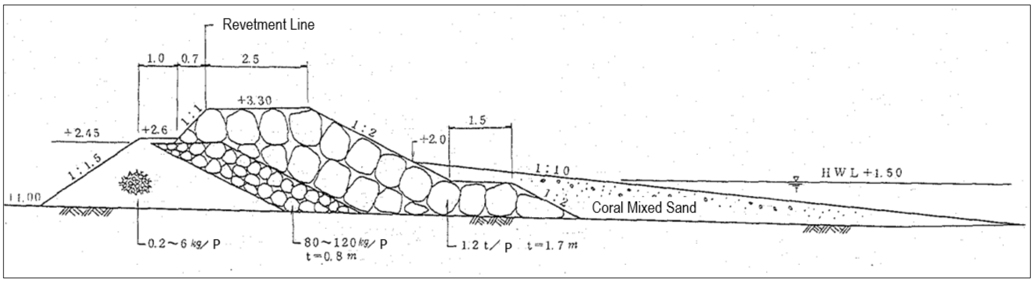
Photo 4.1.1 The beginning point of west side

Photo 4.1.2 Damaged masonry seawall by tsunami

Source: JICA Study Team

Figure 4.1.2 Design Section Division Diagram and Cross Section A (H=3.00)

2) Crass-section B



Source: JICA Basic Design Study Report on the Project for Extension of Nuku'alofa Foreshore Protection, 1988

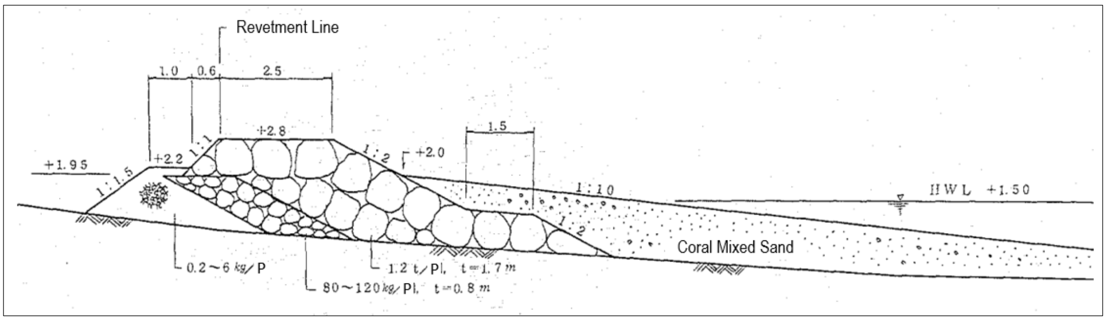
Photo 4.1.3 Restoration by casually piling up stones

Photo 4.1.4 The height of seawall is lower

Source: JICA Study Team

Figure 4.1.3 Cross Section B (H=3.30)

3) Cross Section-C



Source: JICA Basic Design Study Report on the Project for Extension of Nuku'alofa Foreshore Protection, 1988

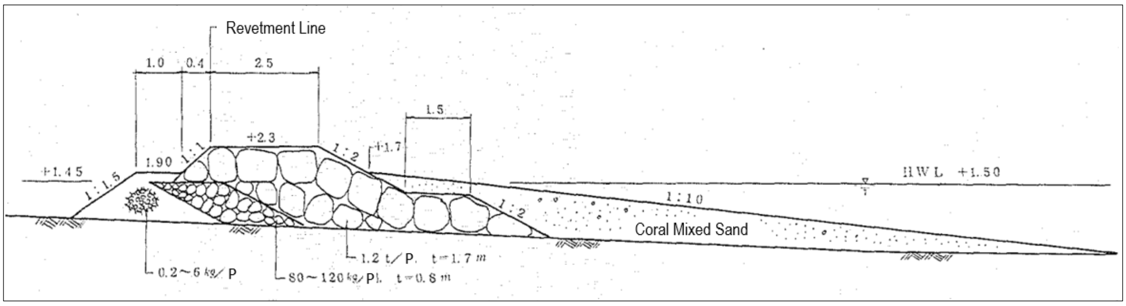
Figure 4.1.4 Cross Section C (H=2.80)

Photo 4.1.5 East side is low and inconspicuous

Photo 4.1.6 It becomes gentle hills

Source: JICA Study Team

4) Cross Section-D



Source: JICA Basic Design Study Report on the Project for Extension of Nuku'alofa Foreshore Protection, 1988

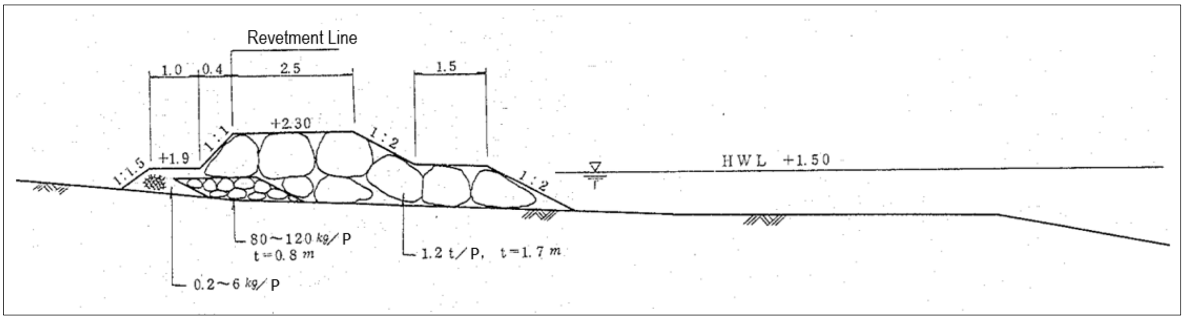
Figure 4.1.5 Cross Section D (2.30)

Photo 4.1.7 Rocks are still scattered.

Photo 4.1.8 This can no longer be called a seawall.

Source: JICA Study Team

5) Cross Section-E



Source: JICA Basic Design Study Report on the Project for Extension of Nuku'alofa Foreshore Protection, 1988

Figure 4.1.6 Cross Section D (H=2.30)

	
Photo 4.1.9 View facing east coast at the end of the coastal road	**Photo 4.1.10 This area has almost no damage by tsunami.**

Source: JICA Study Team

(2) Damage Status of Germany's Grant-Aid Seawall

Regarding this section, it was reported that MOI had no records such as drawings and reports at the time of second survey of this mission.

Source：JICA Study Team

Figure 4.1.7 Location Map of Photography

 **Photo 4.1.11 Seawall collapsed at Vuna Wharf**	 **Photo 4.1.12 The seawall is partially maintained.**
 **Photo 4.1.13 Damaged part from here**	 **Photo 4.1.14 Collapsed part about 60m from left photo**
 **Photo 4.1.15 Collapsed part about 45m from here**	 **Photo 4.1.16 In front of domestic terminal fence**

Source: JICA Study Team

4.1.2. Examination of the Plan and Confirmation of the Public Opinion

When considering the plan for the restoration of Nuku'alofa seawall, based on the concept of the BBB vision, the height of each hazard was examined in Section 3.6 above. In order to cope with tsunami and storm surge, instead of using only original materials of stone masonry, RC structure and CSG method (Cemented Sand and Gravel method) considered as stronger structures The comparison of three methods of construction of seawall is shown in this section.

(1) CSG construction method

The brief overview of the new CSG construction method proposed to adopt in the construction of the seawall is described below.

- CSG is an abbreviation for Cemented Sand and Gravel and is a material obtained by mixing locally generated materials (soil and stone), cement, and water with its definition of strength, test methods and quality control methods. In order to secure the strength of mixing material, the exclusive mixing plants are developed and patented by some companies and corporation (Which is now 8 parties).
- Since this construction method is assured its necessary strength, it has been applied to the dam body which is the one of the most important permanent structures. But since this method is originally manufactured as a material for temporary roads during dam construction, it can be utilized as the small embankment like this time with sufficient results of temporary roads.

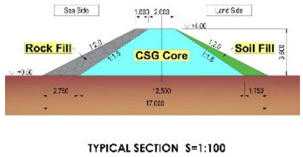
<u>Feature and merits of the construction method</u>

- Rationalization of materials and environmental conservation
  The local materials can be effectively utilized only with minimum treatment such as removal of oversize and crushing without classification, particle size adjustment and washing.
- Rationalization of the construction, short construction period and low cost
  It is not necessary to set up large-scale aggregate plant. With the mechanized construction using locally produced materials and ordinary construction equipment, the short construction period and low cost will be realized.
- Applicable to structures other than dam, such as check dam and seawalls
  It is possible to effectively utilize soil generated on site as a raw material.

(2) Comparison of Stone Masonry Seawall, RC Seawall and CSG Method

A comparison table of Stone Masonry Seawall, Reinforced Concrete Seawall and CSG Method is shown below.

Table 4.1.1 Comparison Table of Seawall Construction Method

Type of Seawall	Stone Masonry	Reinforced Concrete	CSG Method
Image Figure			
Pros and Cons	[Pros] - Materials (lime stone and wood) are easily obtain locally - Simple construction and recover, use ordinary equipment [Cons] -Easy destroy by overtopping tsunami due to lack of core for seawall	[Pros] - With the strong concrete core of seawall, highly reliable in quality and resilient against overtopping tsunami [Cons] - Except stone and wood, other materials to be imported - In order to keep quality, need proper quality control	[Pros] - Excavated soil at site can be utilized as CSG materials - Except cement, other materials are locally available - CSG core can be resilient against overtopping tsunami [Cons] - Due to patent, special plant to be imported and need some treatment to be prepared
*Unit Cost per linear m	¥290,000/m	¥1,000,000/m	¥780,000/m
Evaluation	○	△	◎

*Direct Cost Base

Source: JICA Study Team

(3) Confirmation of the Public Opinion

During the 4th field survey (From May 9, 2023, to May 25, 2023), the officials from the local government of Tonga were invited and held a BBB Vision Workshop. In the Workshop, it was shared that some opinions from participants about the improvement of the existing seawall at Nuku'alofa. The summary of the opinions is introduced below.

1) Summary of Workshop Opinion

In the Workshop, the participants were divided into the following three groups for discussion and the opinions of each group were summarized as follows.

Table 4.1.2 List of Public Opinions at BBB Vision Workshop

Group No.	Group Member	Summary of Opinion
Group 1	Tonga Meteorological Service (TMS) University of South Pacific (USP)	Conditionally agree with the average height (MSL+3.0m) of seawall Conditions; Topography aspects, Rise in sea level, Several months front-loaded prediction of seismic tsunami, 4m wall affect planning
Group 2	Ministry of Infrastructure (MOI)	Agree with the average height of seawall with similar conditions of the group 1
Group 3	Tupou Tertiary Institute (TTI) Tonga Police Force	Although to use of land to avoid tsunami, they agree with the average height. When deciding height of seawall, they need to consider the future of Tonga. The police noted that people need to know how to prevent the damage due to the fact the eastern volcanic eruption cause bigger damages than the previous one.

Source: JICA Study Team

2) Future course of action

As a result of this Workshop, people understood that it was necessary to raise the seawall up to certain level. Therefore, a proper height (MSL+ around 3.0m) was proposed based on technical background not too high about 4m in which level people cannot see the sea.

4.1.3. Survey and Investigation for the Facilities Design

When considering the plan for the restoration of Nuku'alofa seawall, it is a normal procedure to conduct the topographic survey and the soil investigation along the northern coast of Nuku'alofa. But this time, since JICA Study Team are not going to make any actual detail design, in order to roughly grasp the current state of the existing seawall, first of all, a cross-sectional survey of the seawall and a simple in-situ soil test (DCP test: Dynamic Cone Penetration test) were conducted.

For the 'Eua Island, a situation survey of existing subsidence bridge which is a composite type of existing causeway and box culvert and a longitudinal profile survey of the candidate site for the construction of a new bridge which is proposed to move from the location of the subsidence bridge toward mountain side were conducted respectively. Both surveys work at Nuku'alofa and 'Eua were performed from November to December 2022.

(1) Cross-Sectional Survey and DPC Test for Nuku'alofa Seawall

Source: JICA Study Team

Figure 4.1.8 Location of Cross-Sectional survey and DCP Test at Nuku'alofa

As shown in the figure above, cross-sectional survey was carried out at intervals approximately 1 km on the 7.2 km long seawall. Specifically,1,2,3,4,5 cross sections from the west of the Japan grant aid portion, and the German grant aid portion is 6,7,8,9. The east side of Japan grant aid portion is surveyed at 10,11,12,13. Total survey points are 13.

For the DCP Test, a total of 8 locations were implemented including 2 from Japan west, 2 from German west, 2 from German east and 2 from Japan east respectively.

1) Cross-Sectional Survey

The cross-sectional survey is performed under Global Navigation Satellite System using Real-time kinematic (RTK) method and total station. And the reference for elevation in Tongatapu is the benchmark Ton1 (MSL+1.119m).

While since there is no benchmarks in 'Eua, the RTK value is applied Directly.

2) DCP Test

As the condition of construction for the CSG Method, which is considered as a pillar of this restoration plan, the ground of construction site should have its standard penetration value (N-value) more than 15. Basically, Tongatapu Island itself is formed by coral and since the location of the planned seawall has its history that the stone masonry seawall made of coral stone has long been installed, it seems that there is no problem about the strength of the ground. Therefore, using a simple Dynamic Cone Penetration (DCP) Test which data (Nd) can generally be converted to Nd=1.5N, the Nd value was measured at the position of MSL-0.2m (LWL+0.5m) on the assumed construction base of CSG Method. The test equipment conforms to ASTM D6951 and consisted of 20mm diameter, 1m long rod with 60° cone tip and an 8kg hammer. The cross-section results are shown in Appendix 4-1

(2) Cross-Sectional Survey Results

During the cross-sectional survey this time, in order to emphasis on the positional relationship between the seawall and the coastal road running parallel to the shoreline, the range of the cross-sectional survey was measured from the edge of land side of the existing road to the shoreline and the results are, of course, differ depends on the location.

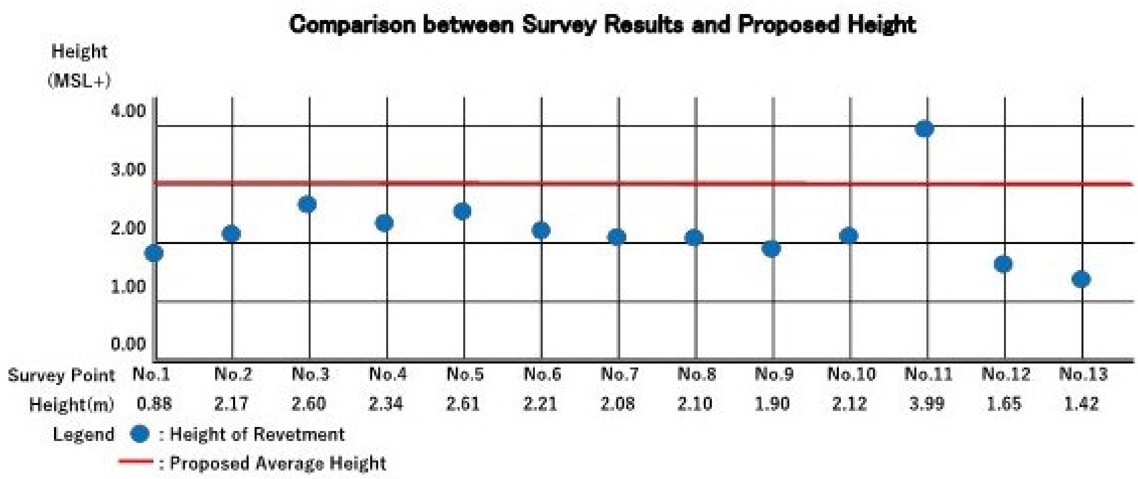
Below is a list of seawall heights and existing road heights for each measurement point.

Also, the drawing comparing the existing seawall height and the proposed raised height M.S.L.+3.0m as a countermeasure against the storm surge L1 is shown below.

Table 4.1.3 List of Results of Cross-Sectional Survey at Nuku'alofa Seawall

Point No..	Distance	Seawall Height	Road Height	Remarks
No.1	0.00	0.88	0.05	MSL+
No.2	202.28	2.17	1.31	MSL+
No.3	907.31	2.60	1.74	MSL+
No.4	1,949.61	2.34	2.23	MSL+
No.5	2,657.82	2.61	2.59	MSL+
No.6	3,082.96	2.21	2.3	MSL+
No.7	3,315.10	2.08	2.17	MSL+
No.8	3,896.94	2.10	1.88	MSL+
No.9	4,859.08	1.90	1.62	MSL+
No.10	6,301.74	2.12	2.20	MSL+
No.11	7,324.13	3.99	2.00	MSL+
No.12	7,913.00	1.65	1.09	MSL+
No.13	8,574.76	1.42	1.22	MSL+
Average		2.20	1.72	MSL+

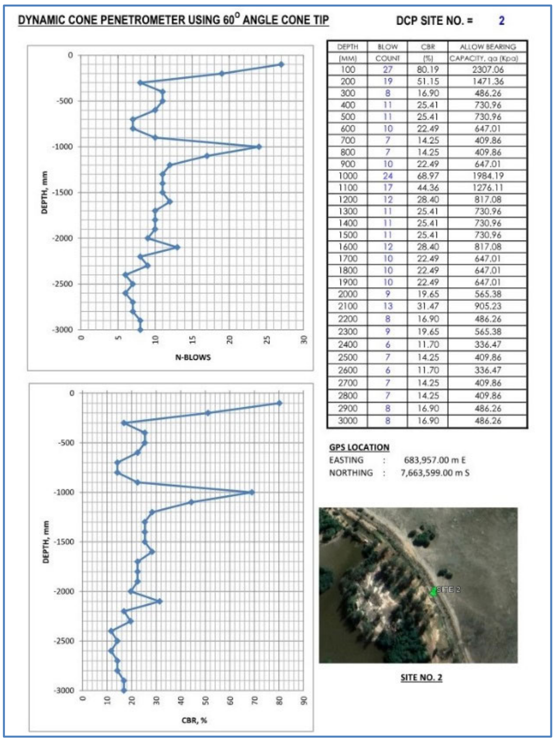
Source: JICA Study Team



Source: JICA Study Team

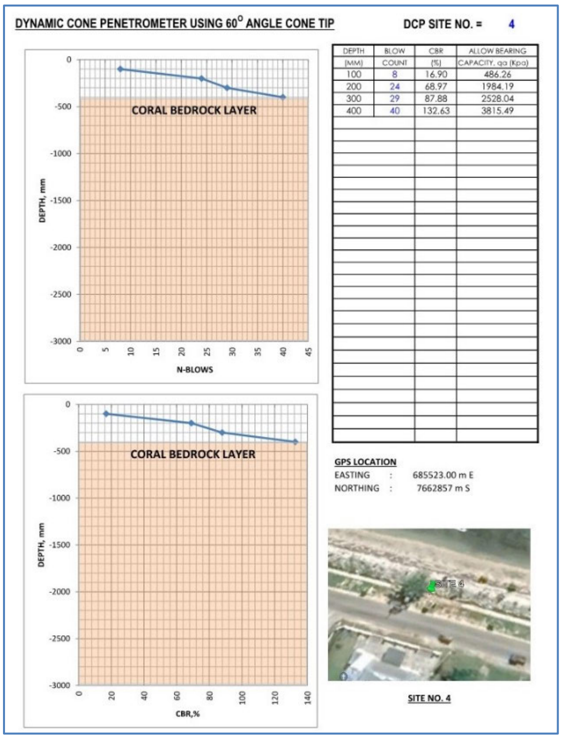
Figure 4.1.9 Survey Results and M.S.L.+3.0m for storm surge L1

(3) DCP Test Results



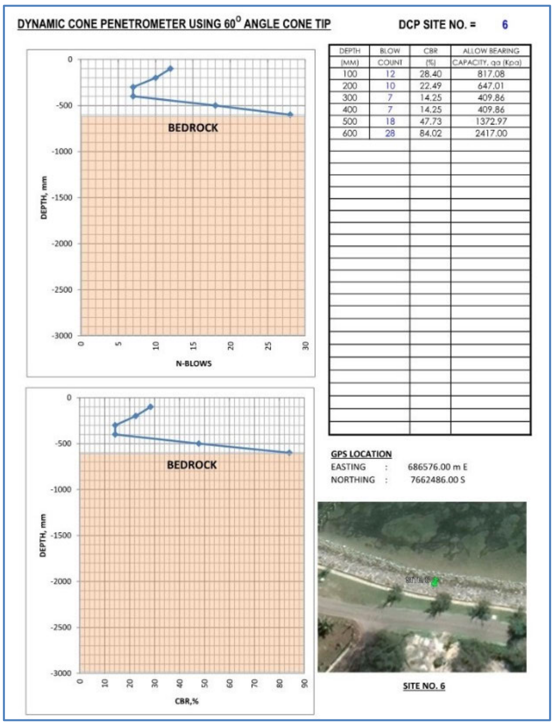
DEPTH (MM)	BLOW COUNT	CBR (%)	ALLOW BEARING CAPACITY, qa (Kpa)
100	27	80.19	2307.06
200	19	51.15	1471.36
300	8	16.90	486.26
400	11	25.41	730.96
500	11	25.41	730.96
600	10	22.49	647.01
700	7	14.25	409.86
800	7	14.25	409.86
900	10	22.49	647.01
1000	24	68.97	1984.19
1100	17	44.36	1276.11
1200	12	28.40	817.08
1300	11	25.41	730.96
1400	11	25.41	730.96
1500	11	25.41	730.96
1600	12	28.40	817.08
1700	10	22.49	647.01
1800	10	22.49	647.01
1900	10	22.49	647.01
2000	9	19.65	565.38
2100	13	31.47	905.23
2200	8	16.90	486.26
2300	9	19.65	565.38
2400	6	11.70	336.47
2500	7	14.25	409.86
2600	6	11.70	336.47
2700	7	14.25	409.86
2800	7	14.25	409.86
2900	8	16.90	486.26
3000	8	16.90	486.26

Figure 4.1.10 DCP No.2



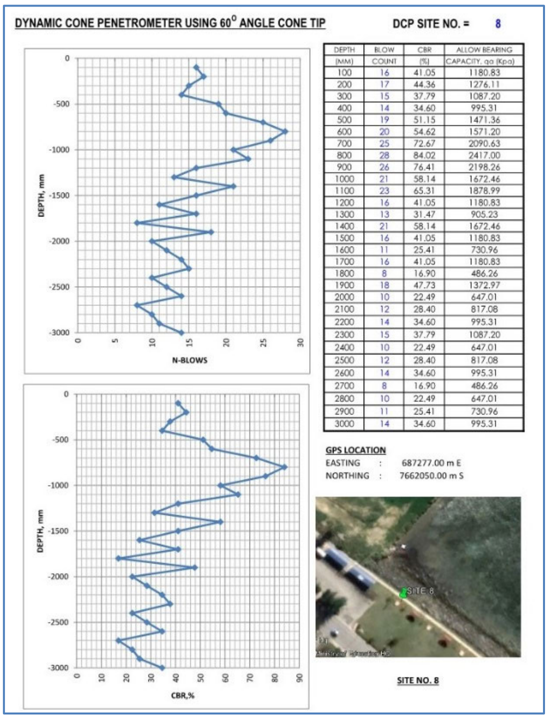
DEPTH (MM)	BLOW COUNT	CBR (%)	ALLOW BEARING CAPACITY, qa (Kpa)
100	8	16.90	486.26
200	24	68.97	1984.19
300	29	87.88	2528.04
400	40	132.63	3815.49

Figure 4.1.11 DCP No.4



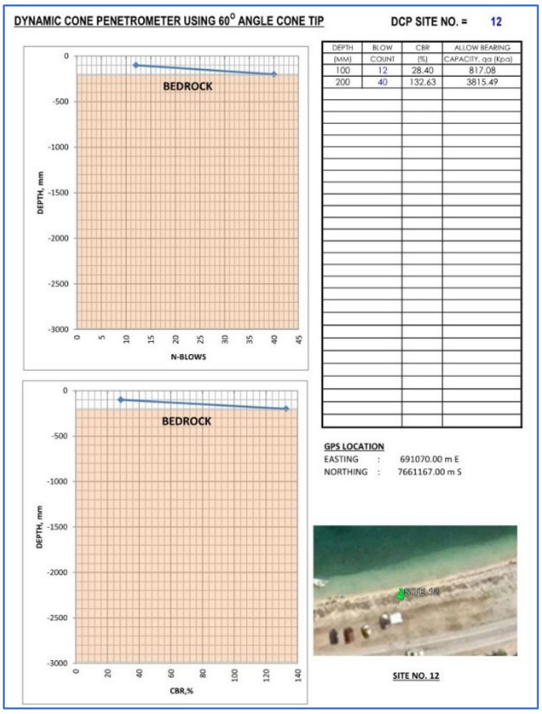
DEPTH (MM)	BLOW COUNT	CBR (%)	ALLOW BEARING CAPACITY, qa (Kpa)
100	12	28.40	817.08
200	10	22.49	647.01
300	7	14.25	409.86
400	7	14.25	409.86
500	18	47.73	1372.97
600	28	84.02	2417.00

Figure 4.1.12 DCP No.6



DEPTH (MM)	BLOW COUNT	CBR (%)	ALLOW BEARING CAPACITY, qa (Kpa)
100	16	41.05	1180.83
200	17	44.36	1276.11
300	15	37.79	1087.20
400	14	34.60	995.31
500	19	51.15	1471.36
600	20	54.62	1571.20
700	25	72.67	2090.63
800	28	84.02	2417.00
900	26	76.41	2198.26
1000	21	58.14	1672.46
1100	23	65.31	1878.99
1200	16	41.05	1180.83
1300	13	31.47	905.23
1400	21	58.14	1672.46
1500	16	41.05	1180.83
1600	11	25.41	730.96
1700	16	41.05	1180.83
1800	8	16.90	486.26
1900	18	47.73	1372.97
2000	10	22.49	647.01
2100	12	28.40	817.08
2200	14	34.60	995.31
2300	15	37.79	1087.20
2400	10	22.49	647.01
2500	12	28.40	817.08
2600	14	34.60	995.31
2700	8	16.90	486.26
2800	10	22.49	647.01
2900	11	25.41	730.96
3000	14	34.60	995.31

Figure 4.1.13 DCP No.8



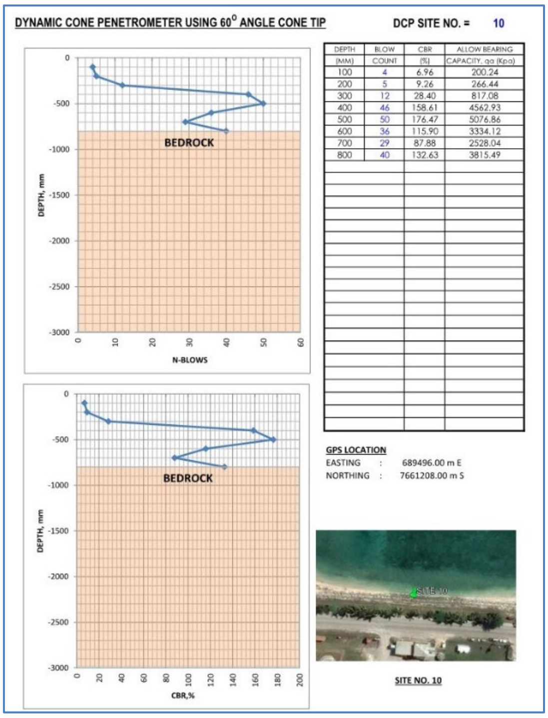


Figure 4.1.14 DCP No.10	**Figure 4.1.15 DCP No.12**

Source: JICA Study Team

As a result of the DCP test, the value of the Nd and the converted N value at the CSG Method construction base surface are shown in the table below. The NP in the table indicates that the rod cannot penetrate (No Penetration) and the parenthesis shows the height of the NP position.

Table 4.1.4 List of DCP Test Results

Point No.	Ground Level (MSL+)	Depth to the Construction Base (m)	Nd/N
2	1.59	1.79	10/7
4	2.10	2.30	NP(MSL+1.60)
6	1.85	2.05	NP(MSL+1.15)
8	1.52	1.72	16/11
10	1.59	1.79	NP(MSL+0.69)
12	1.15	1.35	NP(MSL+0.85)

Source: JICA Study Team

Contrary to expectation, since point 2 and 8 did not reach the coral layer, it is necessary to confirm the support layer with a more accurate investigation paying attention to the surrounding of these two points.

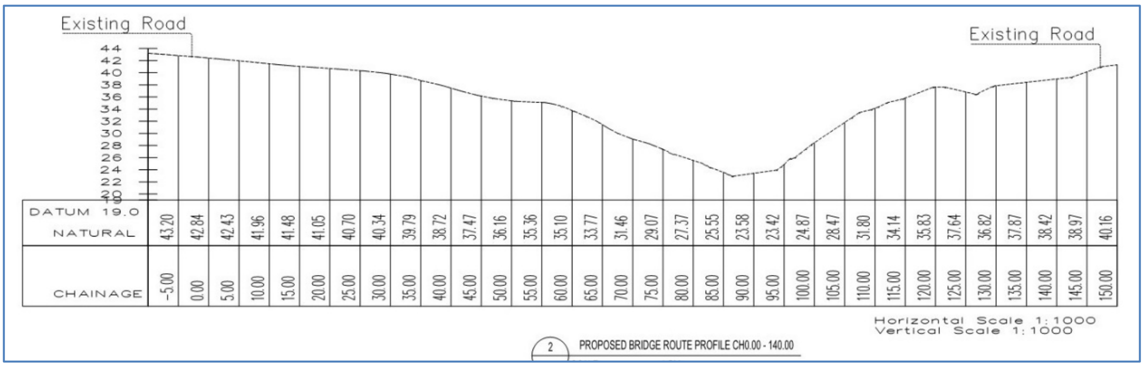
(4) Survey Result of 'Eua Island

The candidate site for the new bridge in Ohonua district of 'Eua Island is located about 520m upstream from existing bridge near the port, between the Hango Agricultural Research Institute and the Ministry of Infrastructure Office. This new bridge will connect the north and south road, which are separated by the river, by crossing river for about 150m. The location is shown in the figure below.

Source: JICA Study Team

Figure 4.1.16 Location Map of Candidate Site for New Bridge in Ohonua on 'Eua Island

The result of longitudinal survey is shown in the figure below.



Source: JICA Study Team

Figure 4.1.17 Result of Longitudinal Survey of Candidate Site for New Bridge in Ohonua

4.2. Causeway Restoration Plan in 'Eua Island

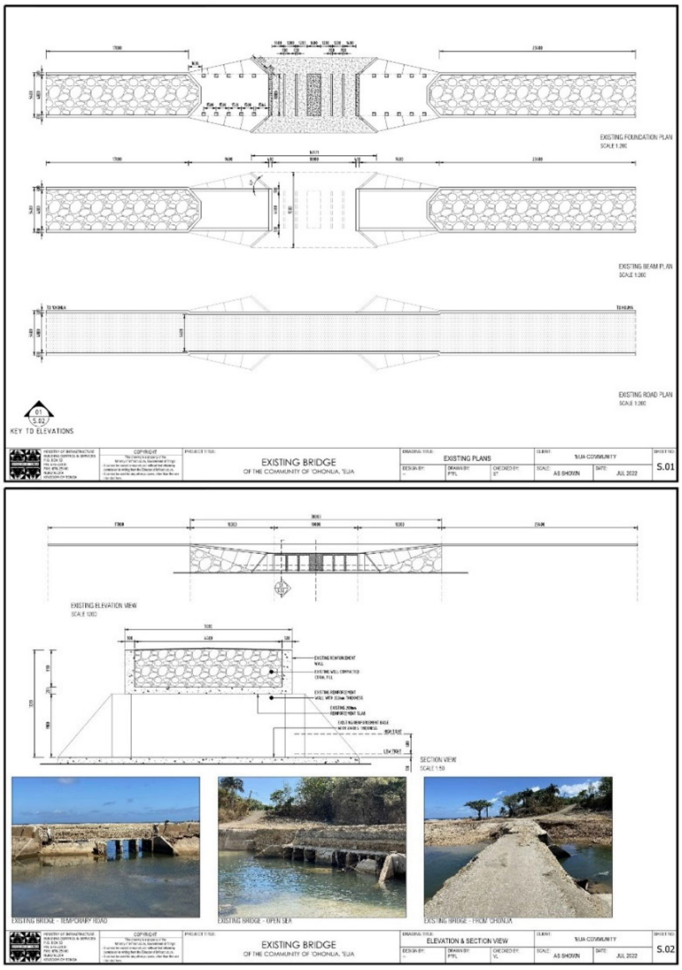
In this survey, it was found that the causeway on 'Eua Island is an existing bridge (box culvert), but the damage situation of this bridge has already been reported as the “'Eua Island Damage Status”.

In a survey conducted in August of 2022, the issue of replacing this bridge surfaced separately, but it seems that there have been no concrete developments since then.

4.2.1. Damage survey

The only existing bridge connecting north and south of 'Eua Island is located near the estuary on the east side of Nafanua Harbor in the Ohonua district. The structure of this bridge is consisted of 2 parts against the 30m width of river, one is at the center part of RC Box Culvert with 10m width and the other is both sides of stone causeway connecting to existing road with width 10m each. The survey report of the damage of this bridge by HTHH disaster was already reported in the Section 2.10.2 of this report together with the situation report of Nafanua port surveyed on July 13th, 2022.

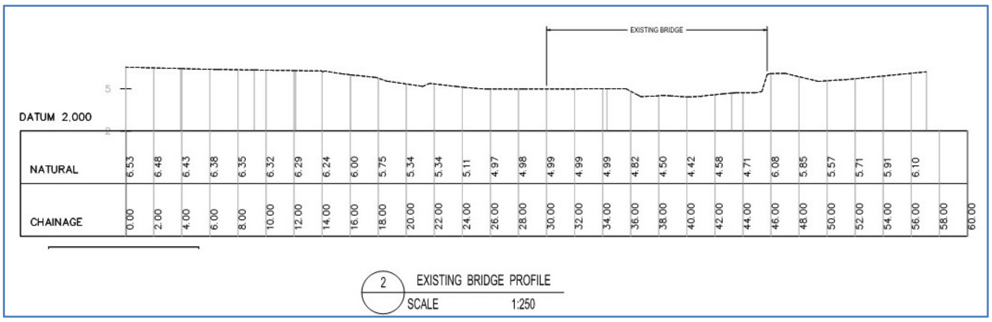
Therefore, it attached the diagram of MOI survey conducted in July 2022. At that time the bridge was already repaired temporary, but no elevation data described.



Source: Ministry of Infrastructure

Figure 4.2.1 Current Status of Ohonua (July 2022)

As you can see from this drawing and photo, the box area is clearly lower than the existing roads on both sides. The results of measuring the height are shown below.



Source: JICA Study Team

Figure 4.2.2 Longitudinal Survey Result of Ohonua Existing Bridge

4.2.2. Examination of Recovery Plan

Based on the survey results described so far, 2 plans were shown. One is the restoration at the original location and the other is the restoration at the new location, as follows.

(1) Restoration at the original location

Looking at the above-mentioned Longitudinal Survey Results (Figure 4.2.2), there is 1 m difference between the Box part (MSL+4.5m) and existing road (MSL+5.5m) at both sides. Even though this bridge is originally designed as the subsidence bridge, it is necessary to examine that using the Box Culvert as big size as possible raising the elevation up to same level of existing road to avoid the damage by the wood, gravel etc. which are drifted by the downstream from upper portion during heavy rain and cyclone due to small area of the Box Culvert. Although including this kind of technical examination, this plan can be operated by the local contractor and the cost of construction is around 0.5 million TOP (30 million yen.).

(2) Restoration at New Location

Similarly, according to the survey results (Figure 4.1.17), the height difference between the existing roads on both sides of valley and the bottom of the valley is so deep around 15m and the width of the bottom also so narrow, so that it is not possible to install the pier at the center of the valley and the span length of the bridge in the middle section will be as long as 45m, and it will be necessary to adopt a steel bridge. Therefore, as a proposal, it is assumed the construction cost under the following conditions.

*Bridge type (Bridge length): RC Girder Bridge (15m) + Steal Arch Bridge (45m)
+ RC Bridge (15m) = 75m
*Approach Passage: Left Side= 50m, Right Side= 25m
*Bridge Width: 2 Lanes (3.5m x 2) + Shoulder (1.5m x 2) = 10m
The estimated cost under these conditions is assumed to be 2.1 billion yen

4.3. Review and Recommendations for Meteorological Events, Earthquake, and Tsunami Monitoring Plans, Including Warning Systems

In Tonga, the development of meteorological disaster and earthquake observation systems is already in-progress. However, issues as the interpretation of the warning system, what criteria to use for issuing warnings, and whether residents can correctly understand the meaning of warnings plague its development. Residents must comprehend warnings so they can make correct decision.

Going forward, it will be necessary for NEMO to take the lead in implementing evacuation plans that guide residents to safe locations after issuing warnings, from the perspective of disaster prevention, and to execute those plans.

5. Consideration of Supporting Projects for On-going or Completed Projects and Building New Projects

5.1. Examination of BBB needs for public facilities and lifeline infrastructure, such as sewage, waste management systems, electrical grids, ports, roads, airports, metered water supply facilities, assembly facilities, public housing, relocation subsidies, etc.

The revised version of NIIP3, created in Tonga, has been updated to include reconstruction needs after the HTHH eruption.

Below is a breakdown of the infrastructure sectors based on the National Infrastructure Investment Plan (NIIP). The 'Other Buildings' category includes a range of projects, such as structures for government agencies, fire departments, police, and defense facilities. Maritime transport infrastructure is crucial for Tonga, making up 14% of all projects.

Table 5.1.1 List of Projects by Sector

Infrastructure Sector Category	G1	G2	G3	Total	G1	G2	G3	Total
Roads	4	5	0	9	207,500	17,835	0	225,335
Aviation	2	2	1	5	3,100	11,800	103,100	118,000
Maritime	3	6	5	14	51,642	162,003	172,080	385,725
Waterways	1	3	4	8	3,000	43,000	56,660	102,660
Water and sanitation	5	1	0	6	133,801	3,000	0	136,801
Energy	4	1	0	5	21,165	4,000	0	25,165
Telecommunications	4	0	0	4	46,127	-	0	46,127
Education and training	2	3	0	5	16,000	7,000	0	23,000
Health	4	1	0	5	60,500	5,500	0	66,000
Other buildings	8	13	6	27	62,211	65,458	39,100	166,769
Urban development	5	5	2	12	31,600	33,972	10,215	75,787
Total	**42**	**40**	**18**	**100**	**636,646**	**353,568**	**381,155**	**1,371,369**

Note)
Unit of numbers in the figure it 1,000 Pa'anga (the national currency of Tonga)

1. The ranking includes projects based on the National Infrastructure Investment Plan 2021-2030 (NIIP3) and projects based on the revised NIIP3, including the Tongan government's response to the HTHH eruption. The ranking in both versions is based on multi-criteria analysis, adjusted to the final decision of the Tongan government cabinet.
2. The infrastructure sectors category was not present in NIIP3. They will now act as components of the existing NIIP3 projects that remain on the list for consistency. The projects presented here have a 2030 implementation date. Their implementation phases must confirm to the BBB vision approved by the Tongan government.

Source: Tonga National Infrastructure Investment Plan 2021-2030、April 2023

5.2. Indirect Support for On-going and Completed Projects

5.2.1. Collecting Information for Realizing of the BBB Vision by Expanding the Scope of Ongoing Projects and Following Up on Implemented Ones

The projects appear as follows, following previous instructions.

Table 5.2.1 Ongoing Projects in Tonga

Project	Period	Project Type	Summary	Proposal for the realization of the BBB vision
Project for Capacity Development of ICU Using Telemedicine under COVID-19 Pandemic	From 7/2021 to 9/2022	Technical cooperation	Given the confirmed needs for Tonga to improve its medical systems on remote islands, it is considering expanding existing components. JICA Study Team also plan to affirm the need for necessary infrastructure under the country’s present circumstances, such as an ICT framework.	Conducting drills to ensure functionality in the event of a disaster and establish satellite internet capabilities.
Project for Introduction of Clean Energy by Solar Home System	From 3/2010	Grant aid	In response to the residents' desire to return to their homes, it is addressed the complete restoration of household solar power systems on severely damaged islands like Atata island by expanding the components of existing cooperation.	Further support for widespread use of emergency power source in times of disaster.
Project for Introduction of Hybrid Power Generation System in the Pacific Island Countries	From 3/2017 to 6/2022	Technical cooperation	Advice regarding damage to electrical facilities necessitates reconstruction plans. Tonga's participation in technical training commenced on March 2022	Construction in areas with lower-risk areas, as indicated on hazard maps.
Promotion of Regional Initiative on Solid Waste Management in Pacific Island Countries Phase 2 （J-PRISM2）	From 2/2017 to 2/2022	Technical cooperation	Experts in Samoa consider supporting the creation of a disaster waste management plan. A request for the provision of heavy machinery to improve the efficiency of disposal sites has been in place since before the disaster. Technical advice on waste collection and landfill operations is complete, and support for fuels for waste collection is already commenced.	Support for formulating business continuity plans for each type of disaster, especially when the disaster waste disposal site sustains damage.
Improving the Livelihood and Health of Residents Through the Effective Use of Breadfruit (BF) and the Development of New Processed Products	From 3/2017 to 2/2023	Technical cooperation	Support through a broader range of agricultural techniques, such as guidance on cultivation in volcanic ash soil, construction of seedling facilities, and supplying seedlings, is currently being considered, based on local needs	Restrengthening the structural integrity of the damaged seedling facilities and reevaluating the types of crops to be grown based on the new hazard map.

Source: JICA Study Team

5.3. Examination of New Support Projects

In addition to the new support project proposals formed in this survey, the proposals also include projects formed under the separate Ministry of Health, Labor and Welfare contract ‘Project for the Creation of Water Project Plans for 2024 (Phase 1) - Water Reconstruction Support Plan for the Kingdom of Tonga'. The project profiles are shown in Appendix 5-1 and Appendix 5-2.

Table 5.3.1 List of Grant-Aid Projects

No.	Project	Outline	Estimate Cost (mil yen)	Ministry
1	Reconstruction of Seawall	Rehabilitation of existing seawall facilities. Distance of seawall facilities: Approximately 8.2 kilometers including the city center Structure: Adopting the CSG (Cemented Sand and Gravel) construction method (see attached 3 CSG construction method), sand and gravel that are easily available locally are mixed with water and cement to create the core of the cut-off wall, and the sea.	2100	MOI, MLNR
2	Construction of Bridge in 'Eua Island	Since the road network around the port of 'Eua Island is fragile, a bridge will be constructed as the missing link of the central road on the hill, which is the main residential area.	2100	MOI
3	New port construction of Vava’u	Since the existing port is too small, it is difficult to transport and store goods in an emergency situation. It is not functioning sufficiently as the center of the northern islands. Momentum for construction is increasing in the wake of this disaster.	5200	MOI. MLNR, PAT
4	Construction of slipway for ship inspection and maintenance	To shorten the time required for maintenance in other countries, this project is proposed to enable the conduct of inspections and maintenance of ships in Tonga.	3000	MOI, PAT
5	Resilience of water supply systems against natural disasters (Part 1) (Development of new water sources and related water supply facilities	Diversify water supply by developing new water sources and improving connecting pipes to drainage ponds.	2820	TWB
6	Measures against sea water intrusion to water sources due to climate change (Part 1).	Water source investigations will be conducted, installed groundwater observation wells, and undertaken other new water source development activities to counteract groundwater salinization due to climate-change-induced sea level rise.	1420	TWB

Source: JICA Study Team, No.5 and 6 are from Project for the Creation of Water Project Plans for 2024 (Phase 1) - Water Reconstruction Support Plan for the Kingdom of Tonga

5.3.1. Proposed Small-Scale Grant-Aid Projects

The following is a list of proposals for small-scale grant-aid projects.

Table 5.3.2 List of Small-Scale Grant-Aid Projects

No	Project	Outline	Estimated Cost (mil yen)	Ministry
7	Disaster Management Information Center	Build facilities that consistently collect, manage, and utilize disaster information. This information will be used to promote disaster prevention education and disaster prevention research. NEMO plans to set up an information center with PREP support. It is necessary to clarify the differentiation of functions.	200-400	MLNR/TGSM EIDECCC /MET
8	Construction of Tsunami Tower	A tsunami tower will be constructed to secure a vertical evacuation route in Nuku'alofa City. Including the use in normal times, ensure the relationship with the evacuation plan.	200	MOI、MLNR, MEIDECCC
9	Improvement of Water quality Management	Development of a water quality testing lab and provision of equipment for water quality testing devices that examine everyday items such as turbidity, pH, residual chlorine, and office automation equipment for recording and analysis. Guidance on water quality management (water quality testing, data analysis, manual preparation, etc.) will be conducted.	40	TWB Tongatapu Headquarters and Various Island Branches
10	Support to enhance emergency recovery	To restore the water supply pipes damaged by volcanic eruptions and tsunamis to aim to develop workshops, provide necessary materials and equipment, and foster abilities related to emergency recovery.	100	TWB Tongatapu Headquarters and Various Island Branches
11	Measures against sea water intrusion to water sources due to climate change (Part 2).	For countermeasures against groundwater salinization of groundwater due to sea level rise in climate change, water source investigations will be conducted, installed groundwater observation wells, and undertaken other new water source development activities.	310	TWB Lifuka Island

Source: JICA Study Team, No. 9, 10, 11 are from Project for the Creation of Water Project Plans for 2024 (Phase 1) - Water Reconstruction Support Plan for the Kingdom of Tonga

5.3.2. Proposed Technical Cooperation Projects

The draft list of technical cooperation projects is shown below.

Table 5.3.3 List of Technical Cooperation Projects

No	Project	Outline	Estimated Cost (M/M)	Ministry
12	The Project for strengthening Administrative Capacity for Disaster Risk Reduction to Realization of BBB Vision in Tonga	In order to implement the BBB vision introduced by Tonga, the necessary guidelines and manuals will be created, and the project will be implemented in line with the BBB vision without confusion. It is important to support the improvement of laws and regulations that are lacking (earthquake/eruption observation, bank protection standards, disaster prevention plan formulation, etc.). It is important to support the inclusion of disaster prevention and mitigation roadmaps in TSDF III.	85	MEIDECCC/ NEMO, NSPAO, MLNR
13	The project for Human Resource Development in the observation and monitoring of hazard in Tonga	The recent eruption reminded us once again of the importance of a hazard observation system. This project will develop human resources for observation of earthquakes, tsunamis, meteorological aspects, volcanic eruptions, etc. It is also important for effective use of the warning system to support the creation of a database for quickly judging whether or not a tsunami will occur based on the location, depth, and scale of an earthquake. Human resource development for earthquake and eruption observation will be carried out in line with the establishment of the Disaster Information Center . Inoue Sensei's WB procurement and adjustment required.	30	MEIDECCC/ MET/ NEMOM/ LNR/ TGS
14	The project for Tourism Development based on BBB Vision	Tourism industry is Tonga's most important economic sector, but the recent tsunami has severely damaged tourism facilities in the eastern part of the country. Consider tourism development while dealing with disasters is part of the BBB vision. Establish a system for approving tourism development plans, including disaster prevention and evacuation plans. A plan in which the fire department is to evaluate and provide guidance on evacuation drills, as in Japan, is expecting.	40	MoT

Source: JICA Study Team

Appendix to Chapter 2

Appendix 2-1 29 Outcomes of TSDFII

Appendix 2-2 Recovery plan’s budget by cluster

Appendix 2-1
29 Outcomes of TSDFII

29 Outcomes of TSDFII

Pillar1: Economic Institutions

1.1: Improved macroeconomic management and stability with the development of a stronger, deeper, more inclusive financial system to ensure sound macro-economic environment within which inclusive and sustainable business and social opportunities can be developed and pursued.
1.2: Closer, more effective public/private partnerships with business, consumers and other community groups across the Kingdom to help better identify and address constraints to more inclusive, sustainable and resilient economic growth.
1.3: Strengthened enabling environment for business, encouraging broad-based investment and more sustainable and inclusive employment and profits, while protecting the rights of the consumer and being sensitive to the environment.
1.4: Improved public enterprise performance to generate appropriate returns on government investment while supporting inclusive, sustainable development and the growth of businesses and communities.
1.5: Better access to economic opportunities overseas including trade, employment, (short and long term and in a wider range of skill areas) and foreign investment to expand the range of income-earning opportunities across the Kingdom and beyond.

Pillar 2: Social Institutions.

2.1: Improved collaboration with, and support to, social and civil society organisations promoting the development of groups which encourage greater involvement by all members of the society, a wider range of community activities, social and sporting events, healthy lifestyle and viable livelihoods in more inclusive and effective ways.
2.2: Closer partnership between government, churches and other stakeholders providing services to communities and support to community development to help promote stronger communities, better inclusion of all groups and human development.
2.3: More appropriate social and cultural practices which help maintain the positive aspects of the Tongan identity while also helping to promote those changes needed for further development of democracy in the country and for more sustainable and inclusive institutions better able to interact with the opportunities and threats presented by the wider world.
2.4: Improved education and training which encourage life-long learning of both academic and vocational knowledge by all people, so better equipping us to make active use of the opportunities in the community, the domestic economy, and overseas
2.5: Improved, country-wide, healthcare systems which better address the medical conditions becoming more prevalent in Tonga so hastening recovery and limiting pain and suffering.
2.6: A stronger and more integrated approach by all parts of society, to address communicable and noncommunicable diseases, significantly cutting the rate of these diseases and the burden they place upon communities and the economy.
2.7: Better care and support for vulnerable people that ensure the elderly, the young, disabled and others with particular needs continue to be supported and protected despite shrinking extended families and other changing social institutions.
2.8: Improved collaboration between Tongans in the Kingdom, and the Tongan diaspora to help develop the social and economic quality of life of both groups.

Pillar 3: Political Institutions.

3.1: A more efficient, effective, affordable, honest and transparent public service, with a clear focus on priority needs, working both in the capital and across the rest of the country, with a strong commitment to improved performance and better able to deliver the required outputs of government to all people.
3.2: Strengthened implementation and enforcement of law and order in a more inclusive, fair and transparent manner which helps resolve disputes, more effectively punishes and rehabilitates those who have broken the law, while supporting the population to go about their legitimate daily business without fear or favor from government.

3.3: Appropriate decentralisation of government administration and services at all levels providing better scope for active, participatory and inclusive engagement with the wider public, so that local needs can be addressed more quickly and efficiently both in urban and rural areas.
3.4: Modern and appropriate constitution, laws and regulations, reflecting international standards of democratic processes and procedures for political institutions, providing an efficient and effective legal structure that provides inclusive access, human rights and the protections required for a higher quality of life, as well as supporting the development of the appropriate institutions required for a progressive Tonga in a peaceful, constructive and effective manner.
3.5: Improved working relations and coordination between the Privy Council, Executive, Legislative and Judicial wings of government so that they work effectively together in support of the Tongan vision.
3.6: Improved collaboration and dialogue with development partners to ensure that their support is consistent with the needs of the Tongan people and in line with the international standards set out in various international Declarations and Accords.
3.7: Improved political and defense engagement within the Pacific and the rest of the world, including better engagement with other governments and international organisations, to ensure that Tongans are effective members of the international community, able to participate more effectively in the support to other countries and consistent advancement of Tongans' international interests, security and sovereignty.

Pillar 4: Infrastructure and Technology Inputs

4.1: More reliable, safe, affordable and widely available energy services built on an appropriate energy mix moving towards increased use of renewable energy.
4.2: More reliable, safe and affordable transport services on each island, connecting islands and connecting the Kingdom with the rest of the world by sea and air, to improve the movement of people and goods.
4.3: More reliable, safe and affordable information and communications technology (ICT) used in more innovative and inclusive ways, linking people across the Kingdom and with the rest of the world, delivering key services by government and business and drawing communities more closely together.
4.4: More reliable, safe and affordable buildings and other structures, taking greater account of local conditions, helping to lower construction, maintenance and operating costs, increase resilience to disasters, improve the quality of services provided and facilitate increased access.
4.5: Improved use of relevant research and development that focus on the Tongans' priority needs drawing on improved foresight, helping to solve technical and other constraints to facilitate more rapid improvements to institutions and better use of resources and environment so that Tongans 2may progress more rapidly and be more resilient in face of future risks.

Pillar 5: Natural Resources and Environment Inputs

5.1: Improved land use planning, management and administration with stronger and appropriate enforcement which ensures the better provision of public spaces as well as private spaces, ensures more appropriate placement of infrastructure, better protects the environment, and limits risk, so as to improve safety conditions both for communities and business, working in harmony with a better application of the traditional land management system.
5.2: More equitable, inclusive, sustainable and appropriate management of the use of renewable and non-renewable natural resources to maintain a steady long-term flow of benefits rather than booms followed by bust and long-term recovery periods.
5.3: Cleaner environment and less pollution from household and business activities building on improved waste management, minimization and recycling, making conditions safer, healthier and more pleasant for residents and visitors.
5.4: Improved national and community resilience to the potential disruption and damage to well-being, growth and development from extreme natural events and climate change, including extreme weather, climate and ocean events, with a particular focus on the likely increase in such events with climate change.

Appendix 2-2
Recovery plan's budget by cluster

Recovery plan's budget by cluster

No.	Cluster	Cluster Lead	Objectives	Supporting Agencies	Allocated cost (TOP$)	Requested Budget (TOP$)
1	HNWASH	Ministry of Health	● Provided effective leadership and oversight, for a coordinated and effective HNWASH response. ● Restore water, sanitation and hygiene services to affected communities, schools and health care facilities. ● Minimize negative impacts on human healthy by ensuring accessible healthcare services. ● Provided emergency medical assistance to affected areas of Tonga. ● Strengthen capacity to prevent, detect, investigate and respond to disease outbreaks and other public health events. ● Provided nutrition support to treat and prevent deterioration of nutritional status of people especially children, elderly people, pregnant and lactating women. ● Provide information on health, nutrition and WASH through developing and disseminating information, education and communication (IEC) materials through appropriate channels.	TNYC/ CARITAS/ MEIDECC-Environment/ MLSNR-Geology/ All cluster members and Development Partners	$ 1.0 million	$ 1,000,000
2	Emergency Shelter and Non-Food Items	NEMO (Emergency)	Provide emergency shelter and NFIs items (hygiene kit, shelter kit, solar lantern, collapsible water tanks, blankets, kitchen sets) to affected households	TRC/ TNYC/ CARITAS/ MORDI/ Development Partners	Under coordination & Logistic budget	Under coordination & Logistic bugdet
3	Shelter and Protection	MIA	● Ensure that most vulnerability people affected by HTHH Volcanic eruption have	Tonga Family Health, Civil	$ 2.1 million	$ 2,100,000

			access to basic necessities and essential services. Ensure that most vulnerability people have access to Health Support Services, emotional advices, and trauma counselling for households that were serely affected by the Volcanic eruption. ● Security and Protection monitoring and providing measures for referrals and support services. ● Increase support services for Sexual Reproductive Health including support for pregnant and lactating mother in affected.	Society Forum of Tonga/ NATA/ All cluster members and Development Partners		
4	Food Security and Livelihood	MAFF Ministry of Fisheries	Households ● Provide emergency food ration to the people/households impacted by Tsunami and Volcanic ash deposition. Fisheries ● Empowerment of the Tuna and Deep-Water Snapper fisheries; ● Chemical testing of reef seafood; ● Rehabilitation of Aquaculture trial farms; ● Fixing of electrical damages at the Ministry of Fisheries and the Tu'imatamoana fish market. ● Cleaning up for the Ministry of Fisheries and the Tu'imatamoana fish market.	MORDI/ Fisheries / Development Partners	$ 700,000	$ 700,000
5	Logistic and Coordination	NEMO	● Coordinate the logistic support effectively and as required to ensure immediate relief are reaching timely to the neediest ones.	Tonga Police HMAF	$ 5 million	$ 546,100 $ 1,422,763
			● Clearance of Debris deposited by Tsunami web and ash falls from volcanic eruption. ● Emergency Response Coordination at National level.	TFES NEMO		$ 600,000 $ 2,850,000

			● Institutional Readiness with equipment and capacity.			
6	Emergency Communication	Communications/ MEIDECC	● Restore the telecommunication system in and across Tonga. ● Restore and strengthen the emergency communication system. ● Restore the international internet connectivity of Tonga. ● Improve monitoring system and equipment for Tonga Meteorological Service.	Development Partners	$ 1 million	$ 1,000,000
7	Essential Services	Ministry of Public Enterprises	● Restore the supply and services of electricity impacted by the tsunami. ● Rapid re-establishment of water services. Rapid re-establishment of telecommunications. ● Re-establishment and ensure stable radio and TV services. ● Replace damaged discharge pipeline for gas and upgrade storage. ● Proper waste management. ● Restore air and ser transport services. ● Repair and Maintenance of infrastructure at Tonga Port of Authority damaged by the Tsunami.	TPL/ TWB/ MEIDECC/ TPA/ Development Partners	2.1 million	$ 10,211,072
8	Education	Ministry of Education and Training	● Repair and maintenance of school infrastructure damaged by Tsunami ● Cleaning of volcanic ash and debris from the class rooms and school compound and cleaning of drinking water facilities. ● Relocation of schools from Tsunami hit area ● Assistance to the children for ‘going back to school’.	All cluster members and Development Partners	$ 400,000	$ 2,940,000
9	Economic and Social Recovery	Ministry of Finance	● Provide economic and social early recovery to TC Harold impacted households and communities including businesses.	Development Partners	$ 2 million	$ 2,000,000

10	Shelter (Reconstruction)	Ministry of Infrastructure	• Clearance of debris in the affected areas immediately after disaster. • Transition from emergency to recovery shelter needs for severely damaged and totally destroyed households Reconstruction of damaged critical infrustructures in affected areas through the principles of Building Back Better/Safer		$ 700,000	$ 700,000
	Total				$ 14 milion	$ 26,069,935

Appendix to Chapter 3

Appendix 3-1 BBB Vision

1 BBB Vision for Tonga

Appendix 3-2 Appendix Report

(Tsunami and Storm Surge Analysis)

Appendix 3-3 Tsunami Waveforms

Appendix 3-1
BBB Vision

Government of the Kingdom of Tonga

Build Back Better Vision for Tonga

2022.05.12

1. Introduction: On Build Back Better Vision

Government of Japan has proposed the Build Back Better (BBB) concept to Sendai Frame Work. Simple reconstruction work results in the vulnerability resurrection, which is not acceptable.
In contrast, Build Back Better increases the resilience of nations and communities through integrating disaster risk reduction (DRR) measures.

Concept (16 Jan. 2016, Japanese Delegate)
According to the definition of UNISDR, "recovery" after a disaster is "the restoration, and improvement, where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors" (UNISDR, 2009).
The "Build Back Better" concept is generally understand disasters to utilize disasters as an opportunity to create more resilient nations and societies than before them through the implementation of well-balanced disaster risk reduction measures, including physical restoration of infrastructure, revitalization of livelihood and economy/industry, and the restoration of local culture and environment.

BBB stands for utilizing disasters as an occasion to achieve a better social recovery, which requires efforts in all development issues and fields, including DRR. It improves and strengthens the infrastructure and the governmental functionalities damaged during disasters triggered by natural hazards, to accelerate implementation of national development and DRR plan in parallel with humanitarian issues and to remodel the target societies sufficiently resilient against the next disaster. It focuses mainly on structural measures: DRR infrastructure and Critical infrastructure. However, it considers also on non-structural measures: Early Warning System, evacuation plan, land use planning, construction technologies, seismic and wind code, etc.

DRR infrastructure protects "critical infrastructure" shown below and assures its functionalities by suppressing the impact of natural phenomena. This is included in the critical one, too. For example, seawall against storm surge and tsunami. For example, seawall against storm surge and tsunami.
Critical infrastructure bears the national economy, industry, governance and the essential functionalities of the public services to the citizens, both governmental and non-governmental. For example, state office buildings, facilities for: communication; EWS; transport (roads, bridges, wharfs, ports, airports etc.); lifeline (water supply, electricity, waste disposal plants, etc.); hospitals and health service; and Education. Volcanic ash fall cannot have DRR infrastructure and shall be coped by each critical infrastructure.

2. How to Cope With Low Frequent – Highly Severe Disasters

It is necessary to consider multi-purpose measures for low-frequent highly severe disasters, combining with those for high-frequent normal disasters and with ordinary measures to maintain social functions, which have many parts in common among them. Otherwise, by the time the next big one strikes, facilities may be deteriorated, systems and organizations may be obsolete or forgotten, and may not function properly at the time of emergency. For example, it is difficult to find any reason to separate the measures for Tsunami from those for Storm Surge in Tonga case. These measures should be a basis for solving development issues at the same time.

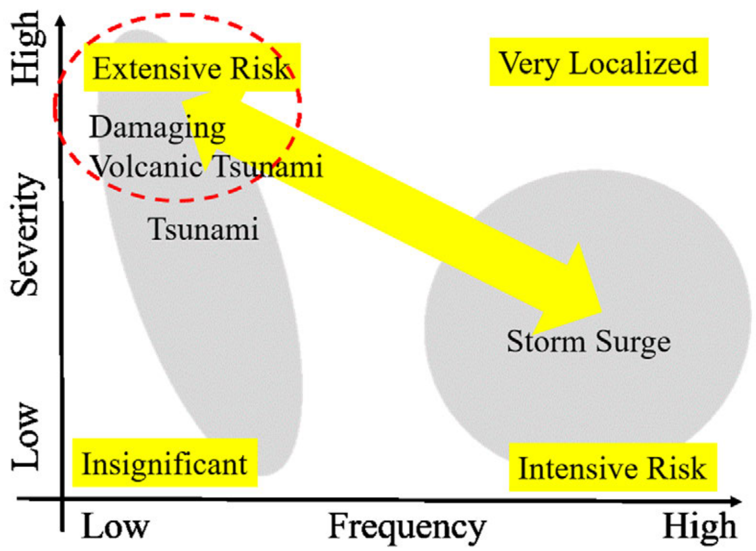


Figure 1. Low Frequent – Highly Severe Disaster and High frequent normal disaster

3. Considerable Natural Phenomena to Tonga

Due to its unique tectonic condition, Tonga is threatened by volcanic eruption from the west, by earthquakes from the subduction zone located east side and by cyclones with much frequency from all directions. These give the direct impact of Storm Surge, Strong Wind, Strong Ground Motion, Tsunami and Volcanic Ash Fall, to the coastal infrastructure, housing, buildings and livelihood.

For the effective DRR, we need to understand the natural phenomena to know their hazards, and to monitor them in combination with Early Warning System. The former is the base of the pre-disaster investment and the latter that of Immediate Response.

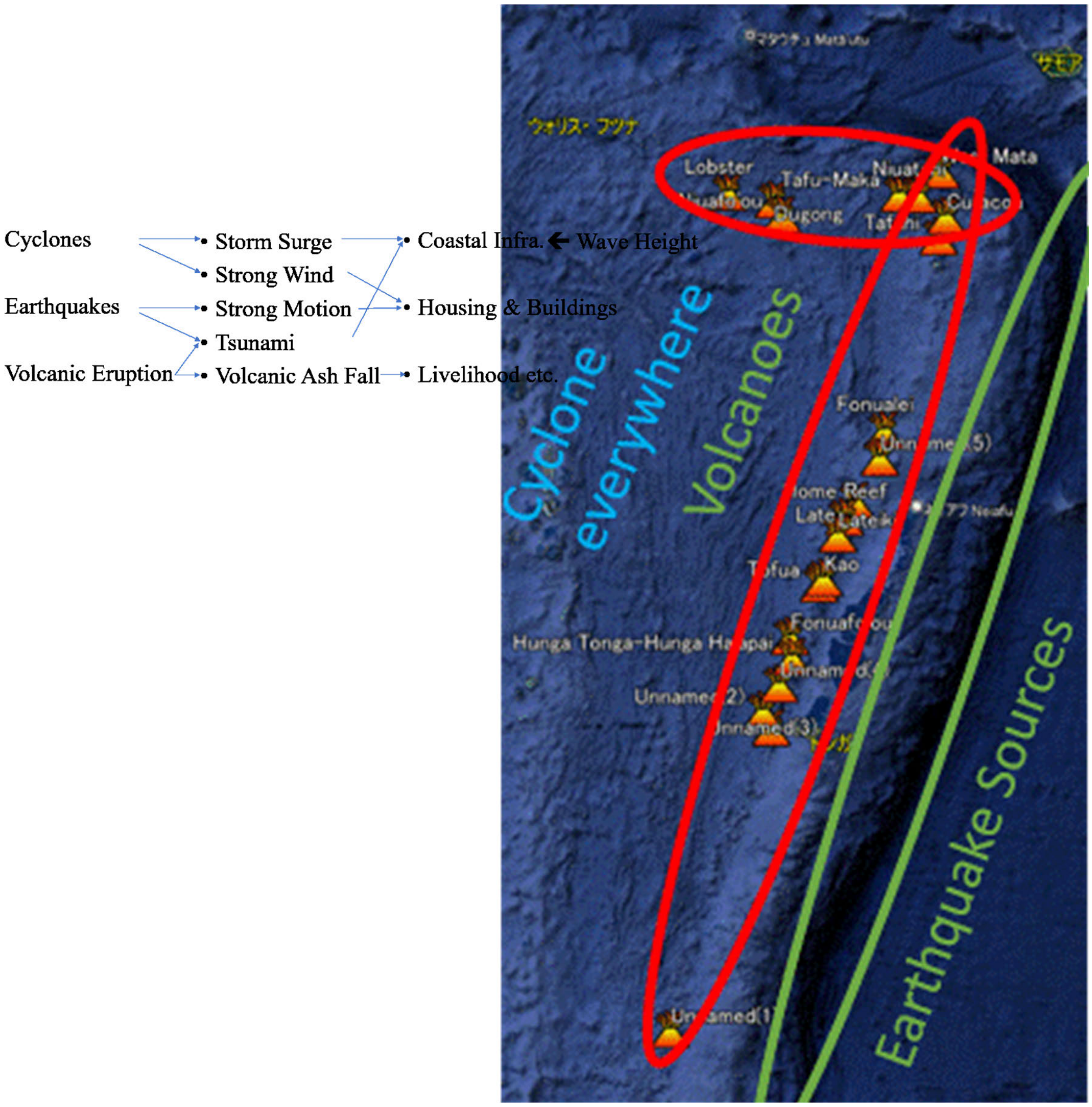


Figure 2 Natural Phenomena and their Impacts to Tonga

[3]

4. Build Back Better Vision

The 2022 HT-HH volcanic tsunami revealed the vulnerable fields of Tonga. Monitoring of hazardous natural phenomena; the capital city; tourism; remote villages including isolated islands; aerial, maritime and land transport; international and domestic communication; and some livelihood issues like water supply etc.

The following explains some examples of the BBB concept based on the needs in Tonga. It is necessary to correct the description by further survey and discussion.

It is most important to estimate the hazards with scientific correctness and to implement measures based on them.

Table 1. Ten items of BBB Vision. The order does not imply priority.

#	items
1	**Understanding** the history and mechanism of natural phenomena for middle and long term estimate of hazard, risk and disaster, and **Monitoring** Combined with Early Warning System.
2	**Protecting the Capital:** Multi-purpose structural measures by pre-disaster investment including multi-protection and resilience of livelihood.
3	**Tourism** (Hotels and Resorts):
4	**Villages at high risk or on Washed Out Islands:**
5	**Measures for Volcanic Ash Fall:**
6	**Immediate Response System:** Strengthening and Capacity development (Training in site and recommendations by experts (NEMO, TGS, TMD etc.)
7	**Disaster Management Planning:**
8	**Transport and Communication:**
9	**Housing:** Residential and non-residential
10	**Livelihood:** Lifeline, Food Safety etc.

4.1 Understanding and Monitoring Natural Phenomena

It is necessary to understand the history and mechanisms of natural phenomena for assessing hazards, risks, and disasters in the medium to long term, and for setting criteria for pre-disaster investment. To monitor natural phenomena and their consequences in combination with early warning systems that also include forecasting of phenomena.

These figures show the example of volcanic disasters. The similar apply to those of earthquakes and cyclones.

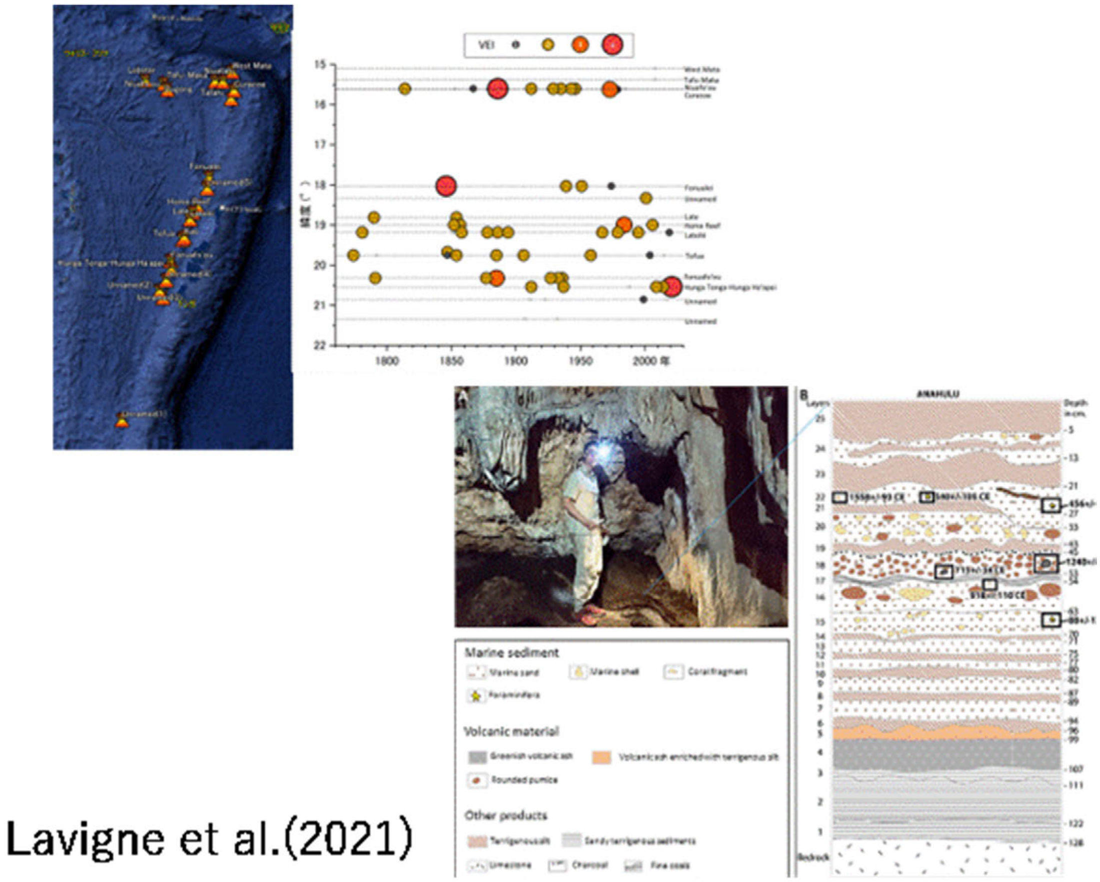


Figure 4. Image of research and survey for understanding

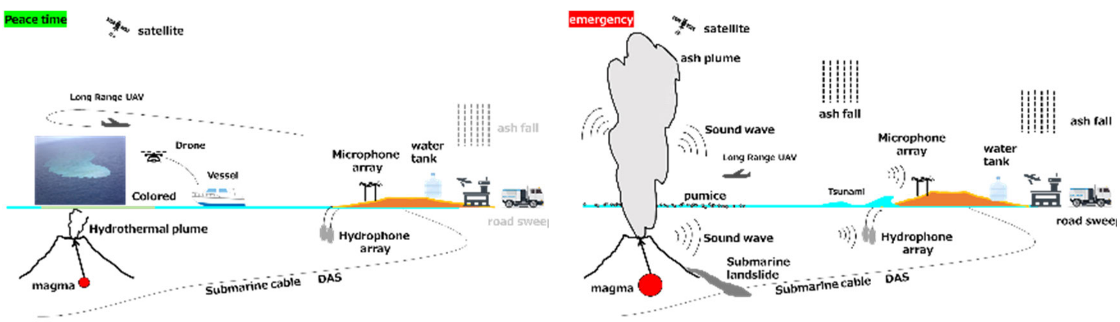


Figure 5. Exampled of monitoring system. Left) ordinary time, right) emergency time.

4.2. Protecting the Capital City from Tsunami and Storm Surge

In the BBB concept, the objective is not to return to the state as it was a few days before the disaster, but to start running toward a favorable future of a safe, resilient, and attractive capital city. Therefore, it is necessary to implement structural measures by pre-disaster investment including multi-protection and resilience of livelihood

In Japan, the following concept sets the base for the design of DRR and critical infrastructure with two wave height levels of Tsunami.

> *# Level-1 highlighted blue in Figure 6 is likely to occur during the service period of the facility, i.e., once per few tens or one hundred years, and used to establish tsunami protection facilities, i.e., structural measure to stop securely tsunami invasion, from the perspectives of protecting human lives and property, stabilizing regional economic activities, and securing industrial bases.*
>
> *# Level-2 highlighted yellow or red in Figure 6 is extremely rare to occur but possible, i.e., once per few hundreds or one thousand years. In other words, maximum class for consideration. Naturally Level-2 exceeds much Level-1. Tsunami protection facilities designed for Level-1 reduces inundation area and depth by a tsunami of Level-2, therefore damages, and makes easier the non-structural measures, mainly evacuation.*

A lesson learnt from the 2011 Tsunami at East Japan is that natural phenomena can occur in its scale beyond our imagination. It is necessary to develop an evacuation plan with sufficient leeway and implement the construction of necessary evacuation routes and tsunami evacuation facilities. For Tongan case, it is still in discussion whether the 2022 HTHH tsunami can be regarded as Level-1 or not. It will be determined whether the main concern is tsunami by volcanic eruption or storm surge by cyclone.

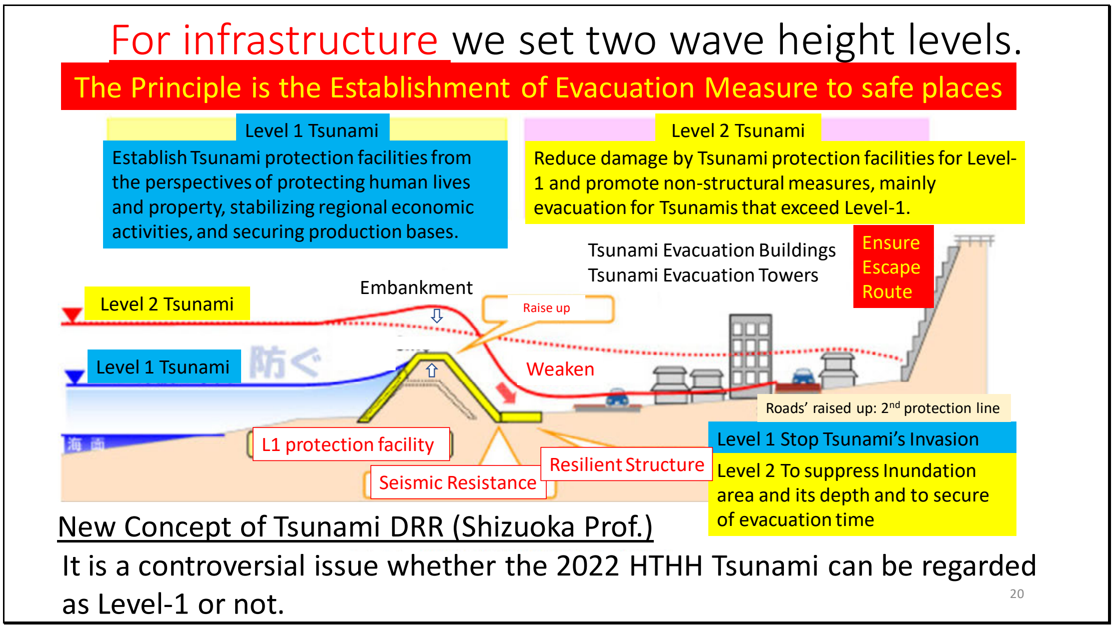


Figure 6. Schematic illustration of two tsunami height for designing infrastructures.

Table 2 shows the summary of the outputs from the experts' discussion on the frequency and severity of Tsunami in 2022 and in future.

Group A concluded "The eruption history of HTHH volcano showed that although the current activity may not be completely over, eruptions such as the January 2022 eruption are unlikely to recur on a 100-year time scale."
Group B "Eruptions (from various volcanoes) affects residential areas in Tonga are judged to occur more than once every 100 years."
Group C's numerical simulation of Tsunami with precise DEM and the digital bathymetry provided by Tonga side is ongoing.
Group D's on going simulation of Storm Surge considers the influence of the climate change, too.
We expect their scientific results for Level-1 Tsunami to set the main concern, Tsunami or Storm Surge.

Table 2.Summary of Experts' Discussion

Group	Member	Topics	Outputs	Remarks
A	Dr. Nakada, Prof. O'minato, Prof. Ichihara, Prof. Maeno (obs)	Mechanisms of 2022HTHH Eruption and the accompanied phenomena	Detail time series of eruptions (especially the first 30 minutes) and an eruption model considering landslide and gravity current.	**The eruption history of HTHH volcano showed that although the current activity may not be completely over, eruptions such as the January 2022 eruption are unlikely to recur on a 100-year time scale.**
B	Prof. Iguchi, Dr. Inoue, Prof. Nogami, Dr. Fujii	Reproducibility of the disasters (ash fall, pyroclastic flow, volcanic blocks, lava flow, gas, mud flow, etc.) caused by eruptions and countermeasure menu and direction for those disasters.	Necessary countermeasures are proposed from the perspective of BBB against various disasters such as ash fall and tsunami, in accordance with the assumption of eruptions that can affect residential areas in Tonga will occur multiple times in 100 years. All Volcanic Disaster Factors must be	**Eruptions affects residential areas in Tonga are judged to occur more than once every 100 years.**

			considered for Niuafo'ou (inhabited island).	
C	Prof. Imamura, Prof. Arikawa, Dr. Inoue, Dr. Kamigaichi, Prof. Chikasada, Prof. Mori	2022HTHH volcanic tsunami and its influence as tsunami height and its run-up height, its recurrence period and tsunami input level for design structures.	Numerical Simulation of HTHH Volcanic Tsunami. Understanding the actual situation, Preparation of run-up simulation, Parametric study about the tsunami source activated by HTHH volcanic eruption.	**Simulation is ongoing with precise DEM and the digital bathymetry provided by Tonga side.**
D	Prof. Mori, Prof. Arikawa, Prof. Imamura	Storm Surge by Cyclone under the influence of Global Climate Change.	Numerical Simulation of historical storm surges. Preparation of storm surge inundation simulation, Numerical simulation of storm Surges to reproduce the events in the recent 60 years. The effect of climate change will be considered from IPCC6 Assessment Report.	**Simulation is ongoing with precise DEM and the digital bathymetry provided by Tonga side.**

Based on the tsunami inundation assessment in 2011 (Damlamian et al., 2011), and in 2021 (Borrero et al., 2021), the capital can be zoned as roughly sketched in Figure 7. This, however, shows just a schematic image that should be finalized by future survey and discussion. Deeply inundated Red Zone, the next Yellow Zone, non-inundated Green zone, and Blue zone that seems safer than Green zone. The separation of Yellow Zone from Red Zone is just a speculation to explain the image, and should be defined by future analysis, too.

There are two island-shaped Green zones which altitude seems not so much higher than the surroundings. Therefore, potentially risky. For example, the smaller west one can shrink or disappear in case of big tsunami if sea level rises due to the climate change.

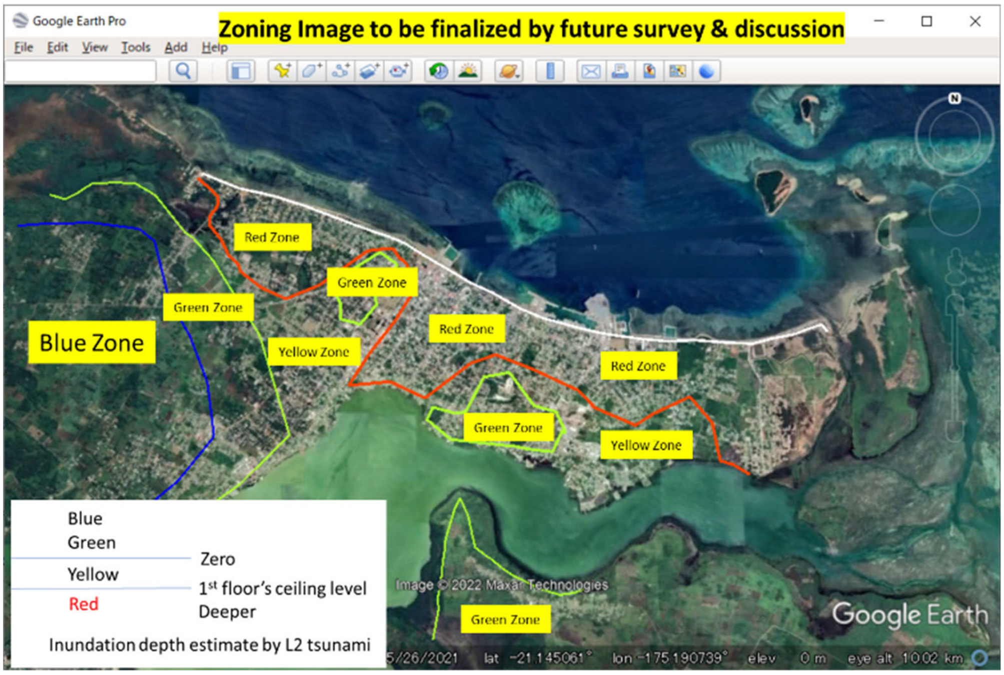


Figure 7. Schematic image of zoning based on inundation assessment

Figure 8 shows a schematic image of DRR structural measures combined with evacuation plan. Being a rough sketch, this should be corrected and finalized by discussion to accommodate with the existing plans.

The white curve along the coast shows the existing seawall. The effect of strengthening this existing seawall and/or additional road embankments as the second protection line shown by thick Green curve may narrow Red and Yellow zones. Possible measures of multi-protection are the followings in case waves pass over the seawall and road embankment.

+ Red zone: Land use control (Only Commercial, Industrial, and Governmental Uses that work as the DRR bases) plus Tsunami evacuation buildings and towers, Road embankment. Relocation of private residences to Green or Blue zones.

+ Yellow zone: Land use control similar to Red zone but with those of Essential Uses (Schools, Hospitals, etc.). Restriction/ recommendation of structure type for private houses (RC or RCB on poles (Piloti structure) or high foundation/ mound).

+ Island-shape Green zones: These should be connected to “Green and Blue Zone” by escape routes with elevated roads or bridge over low land or water to ensure evacuation. It is not a good idea to stay in a confined area to prepare for an attack of titan waves.

+ Green and Blue Zones: Candidate places for destination of relocated residences etc.

Besides DRR consideration, we pay attention to the transport axe (red allows). The east one connecting International Airport to Ferry Terminal, and the west one the city center to a Blue Zone at southwest. These together with road embankment may provide safer evacuation route.

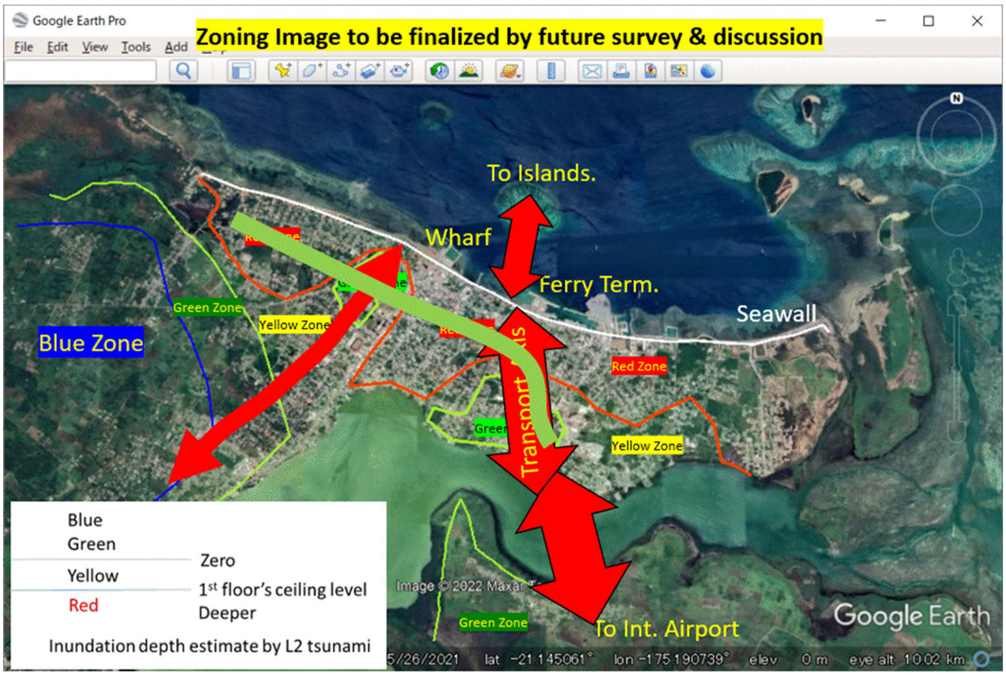


Figure 8. Schematic image of DRR structural measures

Besides DRR, we can list up the following purposes and benefits for development. This shows multi-purpose feature of the image.

+ Securing main evacuation routes from island-shape Green zones with viaducts, road embankment or bridge, etc.

+ Connecting the two main evacuation routes with road embankment (Green curve, i.e., the second protection line) to ensure the safety of evacuation from the center of the capital.

+ The southern shore of the lagoon can be a favorable resettlement site for inhabitants and companies, with access to the center of the capital and the airport.

+ Securing a transportation axe connecting the international airport and the ferry terminal, both in ordinary times and in times of disaster, to enable to activate trading and tourism through relieving traffic congestion in the center of the capital.

+ Integrated renewal of seawall, coastal roads, public open spaces for citizen's amenity, and urban areas through Green infrastructure on land and shore.

+ Control of construction styles in the Yellow zone: to prevent complete destruction of housing and to facilitate recovery of livelihood in terms of resilient housing.

The concept of Green Infrastructure may make the future direction toward an attractive capital city.

Green Infrastructure: Infrastructure and land use planning that contributes to sustainable social and economic development through the wise use of nature's diverse functions

> *(Green Infrastructure Association, Japan).*
> *When the features of nature are understood and harnessed appropriately as infrastructure for the benefit of society and the economy, the costs of developing and maintaining Green infrastructure are lower than those of conventional infrastructure although higher comfort.*

Different approaches may be necessary for cities, suburbs and rural area like isolated islands. The capital city is an extreme and an isolated island another extreme but at opposite side. The reality of each towns and villages are scattered in between them.
In the capital, the government can lead DRR and development directly by pre-disaster investment for structural measures to where capital and industries are concentrated and accumulated. The capital city can support whole country including rural area through investment to the bases of the public assistance, i.e., transport, communication, science, technology, education, medical and health care, human resource development etc., and can contribute to national economy through investment for promotion of commerce, agro-fish-food and information industries, and trading.
In rural area, self-help and mutual assistance within communities are the main for DRR. The public assistance should support them. Self-sustainable Development there should be connected to national economy. Due to the scattered distribution of population, however, structural measures of big scale may not be realistic. Then, investment should be done on selected common key measures, which can support the activities of communities for transport, communication, education, medical and health care etc. Transport and Communication are identified as the target of BBB Vision in this context.

4.3. Tourism (Hotels and Resorts)

Tourism is important for the national economy. The facilities tend to locate close to coast in a scattered way by necessity and difficult to relocate.
Safety measures for every premises should be implemented primarily by the responsibility of owners, for example, tsunami evacuation route/ tower/ mound, selection of construction type (for example, Reinforced Concrete, Reinforced Concrete Block Masonry etc. on mound/ high foundation/ Piloti structure), stockpiles etc. Control of construction type should be applied, by finding realistic solutions.
Because of difficulty to apply structural measures of big size, the concept of the green infrastructure should be considered to suppress the tsunami/ storm surge impact, to conserve and cultivate coral reefs, landscape and environment, and to attract more tourists.
Loan programs differentiated by the grade of disaster preparedness aimed to give a financial benefit for the owners who implement disaster preparedness may promote the preparedness in

tourism industry.

> *Coral reefs can provide comparable wave attenuation benefits to artificial defenses such as breakwaters, and reef defenses can be enhanced cost effectively (Ferrario et al. 2014, Nature Communication))*

4.4. Villages at high risk or on Washed Out Islands

In rural area such as villages at high risk or on washed out islands, different approaches are necessary due to a wide variation of local conditions to be considered.

For those, especially Niuafo'ou island at the rim of a volcanic caldera, the safest way may be resettlement to a safe place in main islands. Temporary settlement is necessary for evacuated people in the case.

However, if inhabitants wish to stay in original risky place, it is necessary for the government to prepare for their preventive evacuation based on information of EWS. This highlights the importance of monitoring.

If enough space for all inhabitants cannot be found in safe place, inhabitants may need shelters for emergency.

For the purpose of easier recovery with resilient housing, restriction or recommendation of structure type for residence (for example, Reinforced Concrete, Reinforced Concrete Block Masonry etc. on mound/ high foundation/ Piloti structure), finding realistic solutions.

Because of difficulty to apply structural measures of big size in rural area, the concept of Green infrastructure should be considered to suppress the tsunami/ storm surge impact, to conserve and cultivate coral reefs, landscape and environment for better quality of life of inhabitants.

In BBB Vision, transport and communication are pointed out as the basis of rural development issues that are mainly livelihood issues.

4.5. Measures for Volcanic Ash Fall

Plans as parts of waste management are necessary for cleaning up, disposing/ reusing/ recycling volcanic ash and debris as well as equipment like machinery and plants, for example, of recycling aggregate. These should be served for ordinary use for waste management.

Although not fatal, volcanic ash can harm the functionalities of lifelines, for example, water supply, Sewage, Wired Electricity or Renewable Energy. Estimate of influence and strengthening measures may be needed as well as those on Agriculture, Fisheries, Transport, Communication and Environment etc.

For example, real time ash fall forecast based on monitoring and numerical simulation may be helpful for various activities of immediate response.

4.6. Immediate Response System

Immediate Response System worked well in the case of the 2022 HTHH eruption. However, it can be bettered by introducing quick simulation for forecasting or estimating ash fall, tsunami etc. Use of Satellite, airplane and aerial drone may help quick damage survey. These should be used ordinary for being maintained in operable condition and for the training of officers, not only for vigilance of volcanos but also that for maritime security, weather forecast etc. Thus, with training in site and recommendation by experts for government officers of NEMO, TGS, TMS etc.

4.7. Disaster Management Planning, Drill and Education

For middle and long term measures as well as immediate response, national disaster management plan is needed as well as that of local level, i.e., district, city, town, village, including stockpile plan and relief plan. At both levels, financial aspect should be considered.

In parallel, every public and private entities should have disaster management work plan, which includes Business Continuity Plan, Business Contingency Plan, and Evacuation Drill etc.

Government should promote to have disaster management work plan or survival plan to owners of small-scale business, sole proprietors and individuals. Education on Science and Technology that comprise DRR, too.

4.8. Transport and Communication

Planning and implementation for resilient transport system is essential for ensuring access to damaged area in emergency and abundant logistics in ordinary time, by strengthening critical facilities of the followings.

+ aerial transport: safe airports with seismic resistance, meteorological monitoring/ observation and EWS. In addition to weather forecast, preventive information of volcanic eruption may contribute to safe aviation.

+ maritime transport: safe wharf and ferry terminal with resistance against earthquakes and tsunami/ storm surge, oceanographic monitoring/ observation and EWS. Preventive information of volcanic eruption may contribute to safe navigation as well as weather forecast.

+ land transport: roads and bridges with seismic resistance, geotechnical monitoring/ observation and EWS.

Planning and implementation for resilient communication and information system is crucial for both of disaster management and sustainable development.

Due to long distances among island groups and from Tonga to neighboring countries, resilient system via submarine cables are indispensable with redundancy, in parallel with the preparedness

to switch immediately to satellite communication from cable based one.
It is necessary to ensure communication among individuals by strengthening of base stations of Cellular and Smart phones.
As recognized well, ICT-based communication can support Digital Transform of society, for example, education and medical care on remote provided by core organizations like USP or Vaiola Hospital. Moreover, e-government, e-commerce, e-learning etc.
The disadvantages of scattered territories will be overcome in this context.

4.9. Housing: Residential and Non-residential Buildings:

As the seismic hazard estimate is high in Tonga and strong wind recur frequently in addition to Tsunami/ Strom surge hazard, it is better to control construction activities by land use control based on hazard assessment, by leading people, especially constructors to follow the seismic and wind codes, and the recommendation about inundation resilient way of housing. Persistent efforts will be required, because it takes time.
Non-residential buildings of essential uses under governmental administration should be more resilient against considered disasters. For example, schools, hospitals etc. should follow stricter standards than ordinary housing for major safety and keeping their functionalities. Governmental offices, transport terminals etc. should have enough resilience to be bases of disaster management in emergency.

4.10. Livelihood

We have overviewed the targets of BBB Vison to ensure the safety against severe disaster. Moreover, measures useful to accelerate various development issues that already have been or newly recognized should be considered, too.
For example:
Lifeline:
- Energy supply: Resilient power plant, Renewable energy
- Water supply: Groundwater management, Purification technology
- Waste and Sewage management

Health and Hygiene:
- Programs for Improvement of Nutrition, Health and Welfare
    - Communicable and Non-communicable diseases (Diabetes etc.).

Support to Agriculture, Fishery, Industry, and Trading, of small scale:
- Development and dissemination of technologies appropriate for Tonga
    - Processing Seafood, agricultural and livestock products
- Loan and insurance programs against natural disaster for financial safety of livelihood.

Linkage with Health problem: Vegetable farming.

Tsunami Waveforms

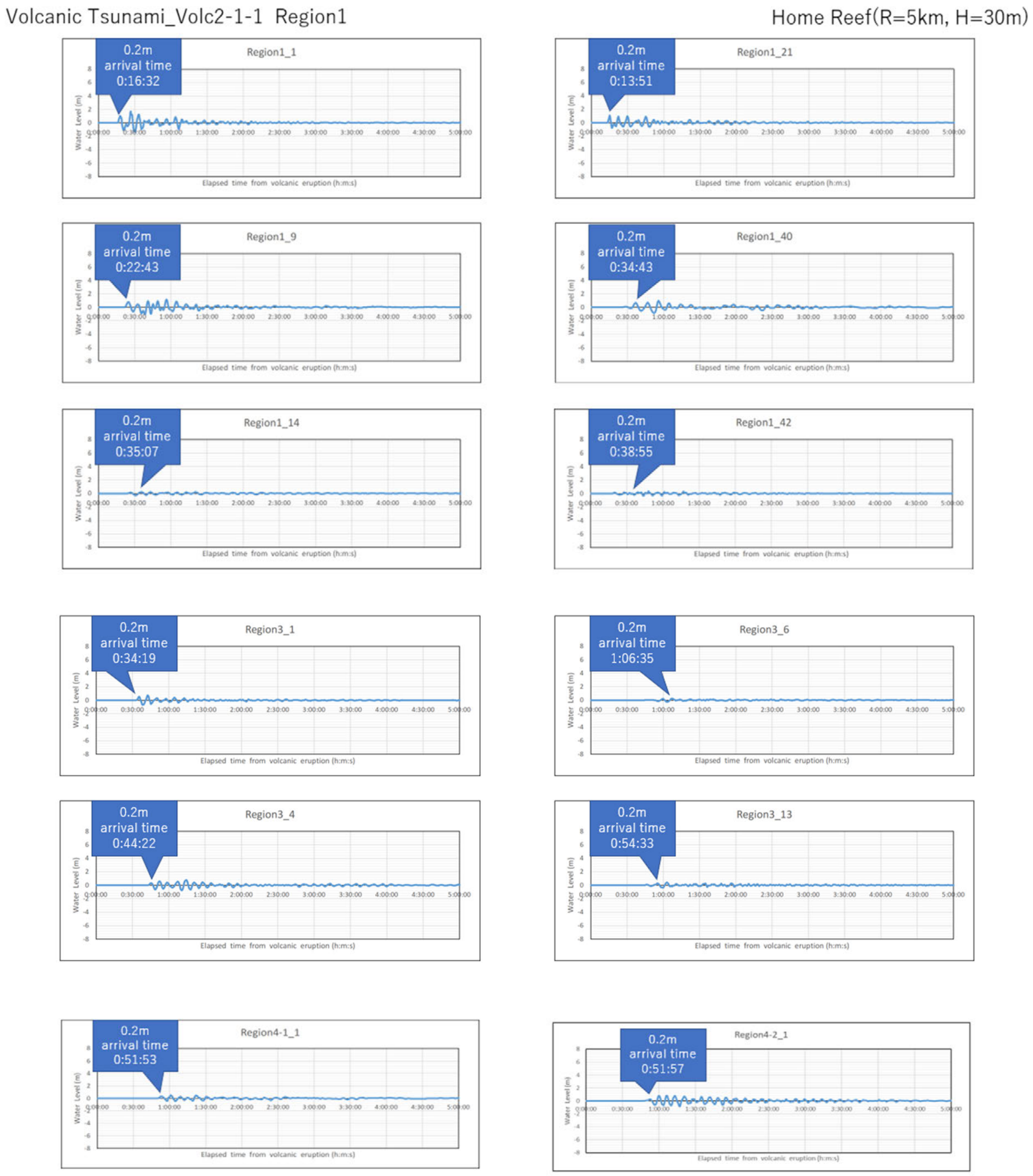
1. Volcanic tsunami waveforms

Source: JICA Study Team

Figure 1 Waveform (Hunga Tonga-Hunga Ha'apai, R=5km, H=30m)

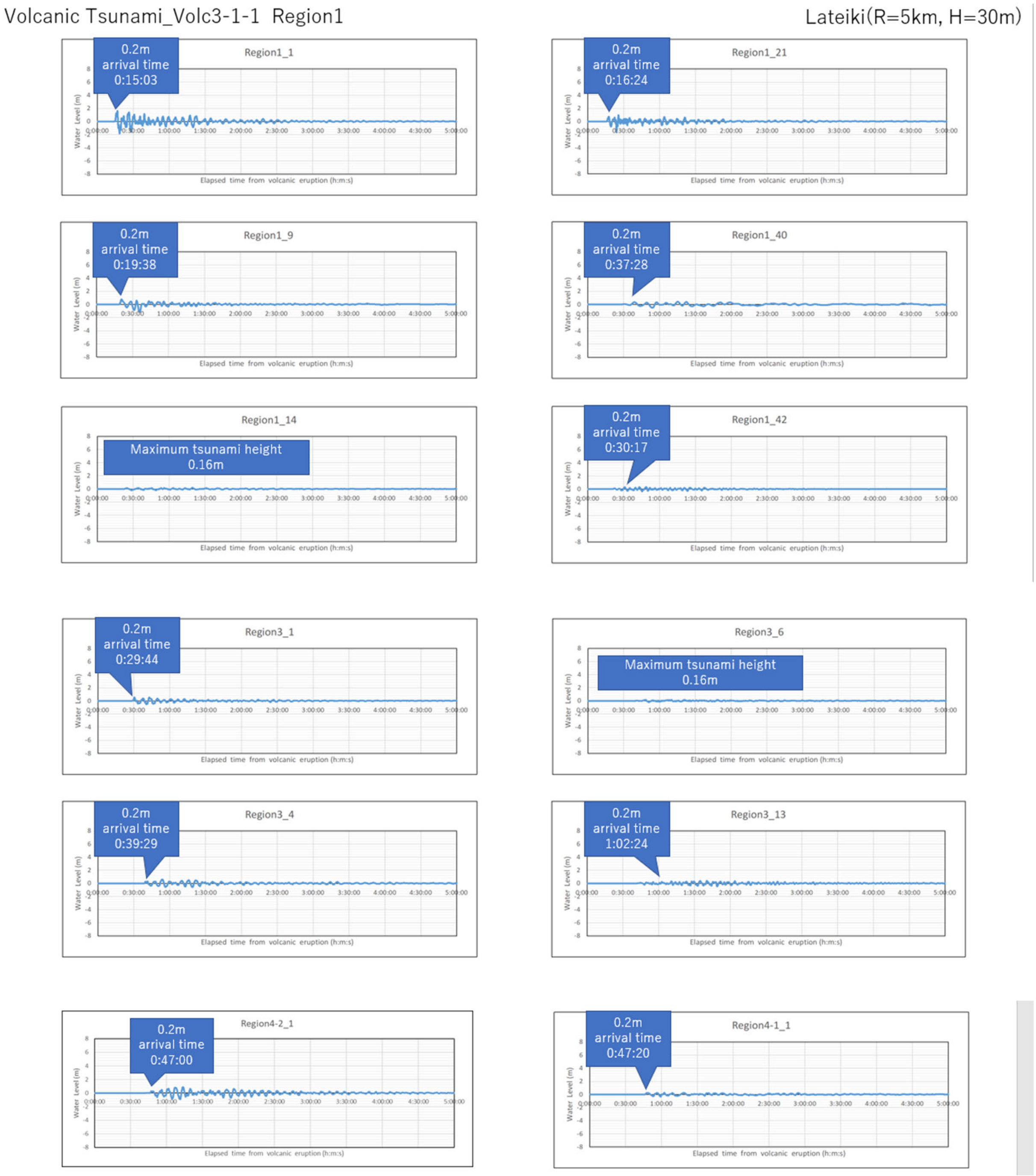
Source: JICA Study Team

Figure 2 Waveform (Unnamed1, R=5km, H=30m)



Source: JICA Study Team

Figure 3　Waveform (Home Reef, R=5km, H=30m)



Source: JICA Study Team

Figure 4 Waveform (Lateiki, R=5km, H=30m)

Source: JICA Study Team

Figure 5 Waveform (Fonuafo'ou, R=5km, H=30m)

Figure 6　Waveform (Unnamed2, R=5km, H=30m)

Source: JICA Study Team

Figure 7 Waveform (Unnamed3, R=5km, H=30m)

Source: JICA Study Team

Figure 8 Waveform (Unnamed4, R=5km, H=30m)

Source: JICA Study Team

Figure 9 Waveform (Hunga Tonga-Hunga Ha'apai, R=5km, H=60m)

Source: JICA Study Team

Figure 10 Waveform (Unnamed1, R=5km, H=60m)

Source: JICA Study Team

Figure 11 Waveform (HomeReef, R=5km, H=60m)

Source: JICA Study Team

Figure 12 Waveform (Lateiki, R=5km, H=60m)

Source: JICA Study Team

Figure 13 Waveform (Fonuafo'ou, R=5km, H=60m)

Source: JICA Study Team

Figure 14 Waveform (Unnamed2, R=5km, H=60m)

Source: JICA Study Team

Figure 15 Waveform (Unnamed3, R=5km, H=60m)

Source: JICA Study Team

Figure 16 Waveform (Unnamed4, R=5km, H=60m)

Source: JICA Study Team

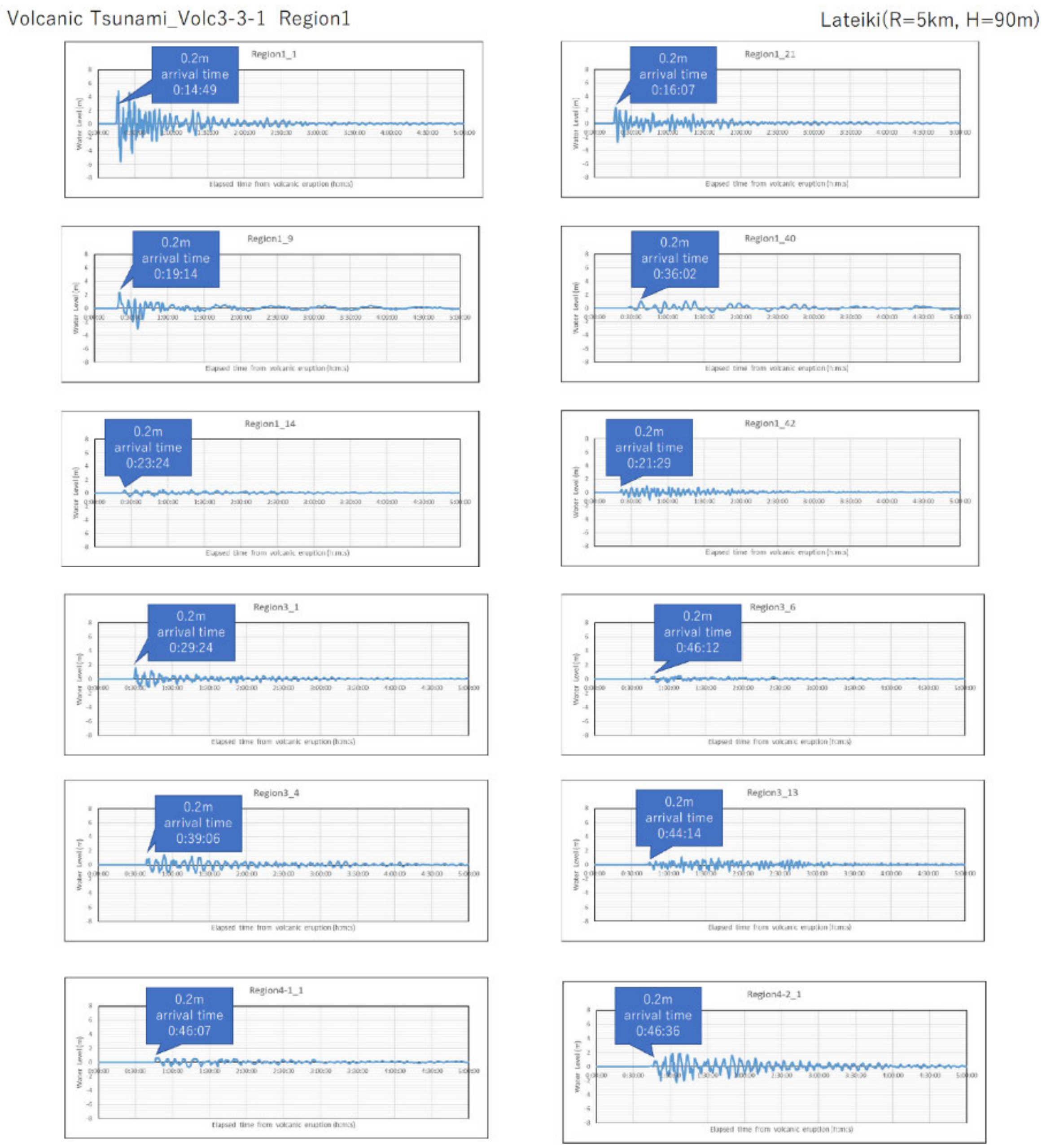
Figure 17 Waveform (Hunga Tonga-Hunga Ha'apai, R=5km, H=90m)

Source: JICA Study Team

Figure 18 Waveform (Unnamed1, R=5km, H=90m)

Source: JICA Study Team

Figure 19 Waveform (HomeReef, R=5km, H=90m)



Source: JICA Study Team

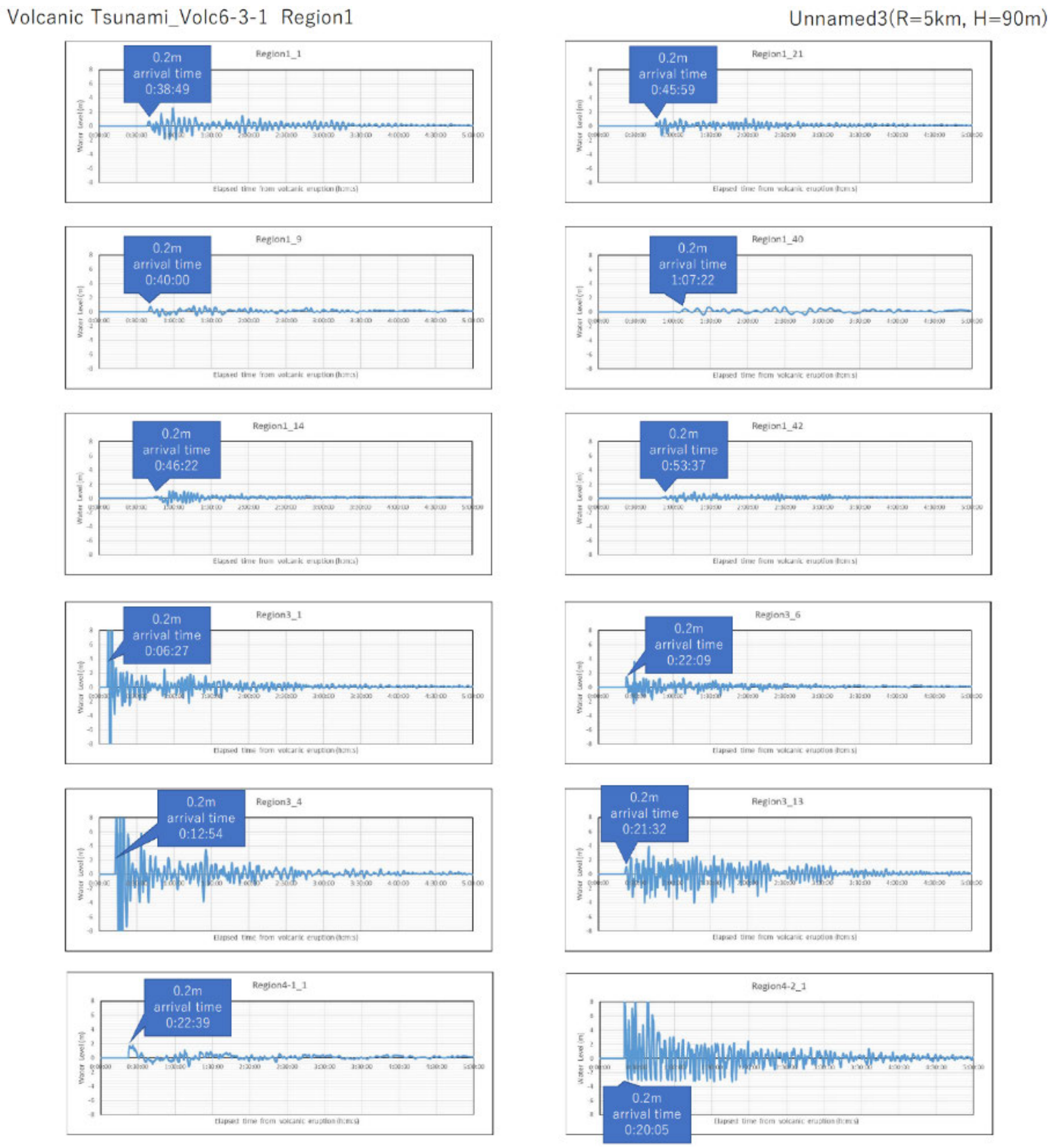
Figure 20 Waveform (Lateiki, R=5km, H=90m)

Source: JICA Study Team

Figure 21 Waveform (Fonuafo'ou, R=5km, H=90m)

Source: JICA Study Team

Figure 22 Waveform (Unnamed2, R=5km, H=90m)



Source: JICA Study Team

Figure 23 Waveform (Unnamed3, R=5km, H=90m)

Source: JICA Study Team

Figure 24 Waveform (Unnamed4, R=5km, H=90m)

2. Seismic tsunami waveforms

For seismic tsunamis, tsunami arrival waveforms were also compiled for all islands except Tongatapu and Eua, in order to contribute to future disaster prevention. The waveforms provide an approximate idea of tsunami height and arrival time.

The location of the extracted waveforms is the same as for volcanic tsunamis.

Source: JICA Study Team

Figure 25 Waveform (Fault 1976)

Source: JICA Study Team

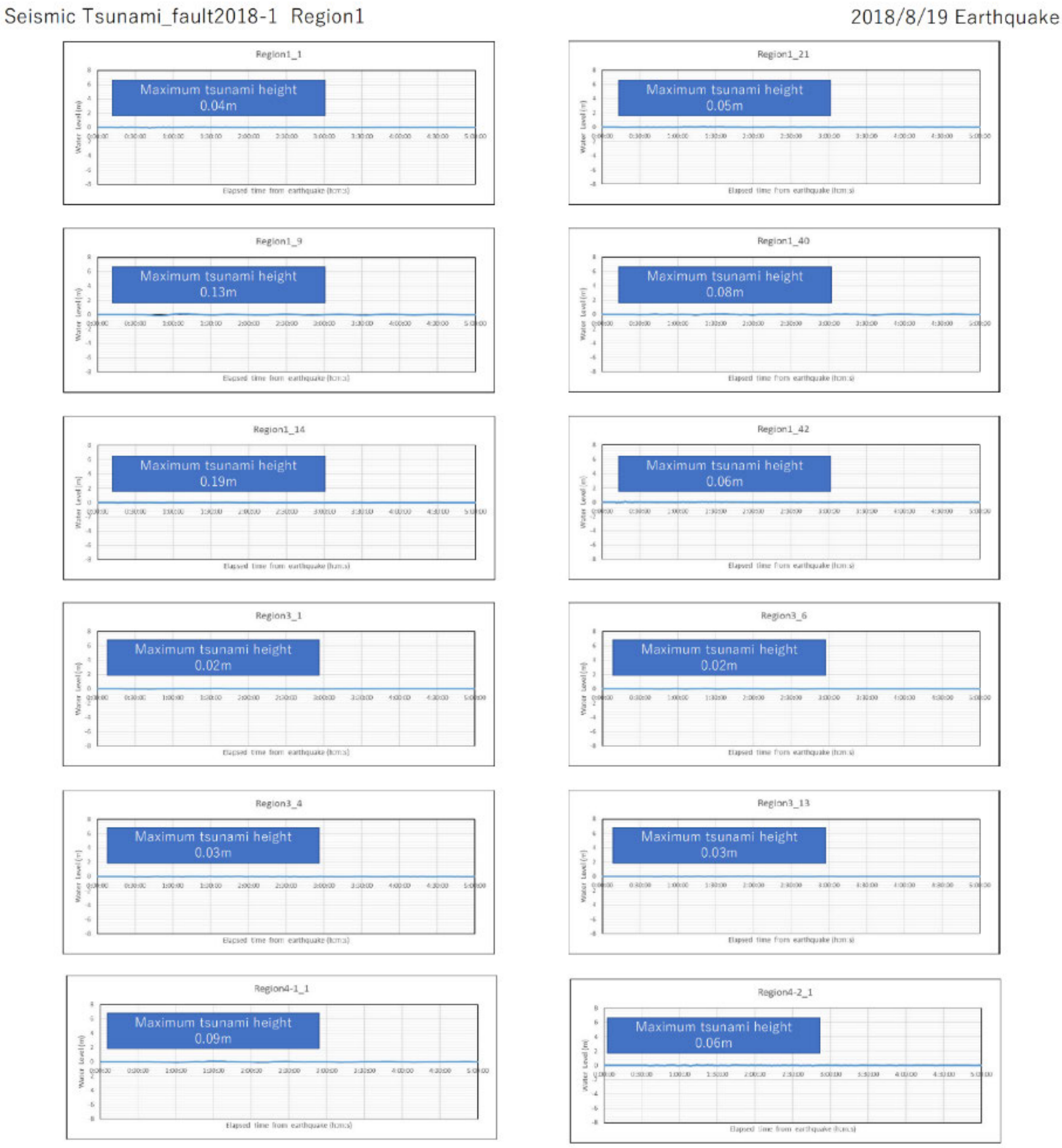
Figure 26 Waveform (Fault 2006-1)

Source: JICA Study Team

Figure 27 Waveform (Fault 2006-2)

Source: JICA Study Team

Figure 28 Waveform (Fault 2009)



Source: JICA Study Team

Figure 29 Waveform (Fault 2018)

Source: JICA Study Team

Figure 30 Waveform (Fault 2021)

Appendix to Chapter 4

Appendix 4-1 Results of DCP test

Appendix 4-1
Result of DCP test

Cross-Sectional Survey Results

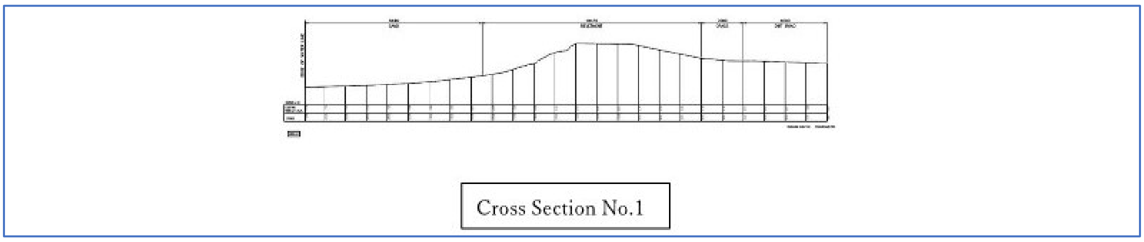


Figure 1 No.1 (CH0+000) Near the start point of West Revetment of Japan Grant Aid

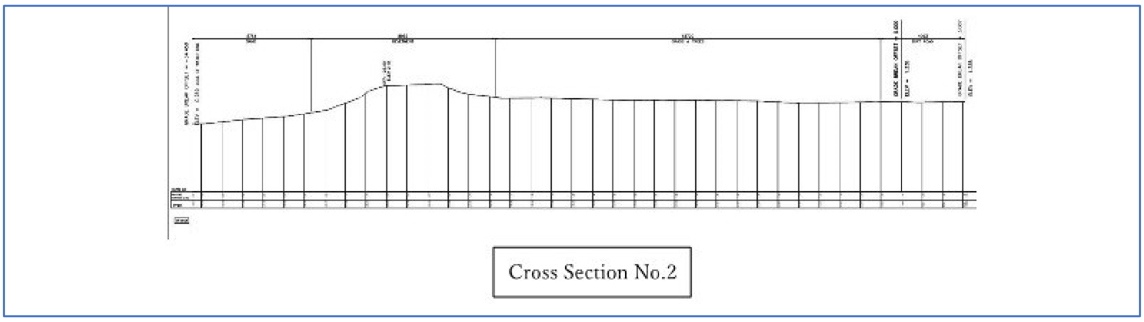


Figure 2 No.2 (CH0+220.28) West Revetment of Japan Grant Aid

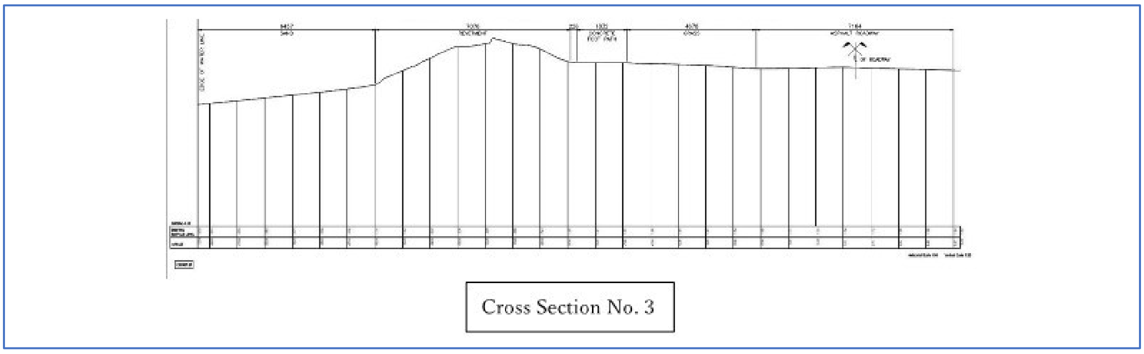


Figure 3 No.3 (CH0+907.31) West Revetment of Japan Grant Aid

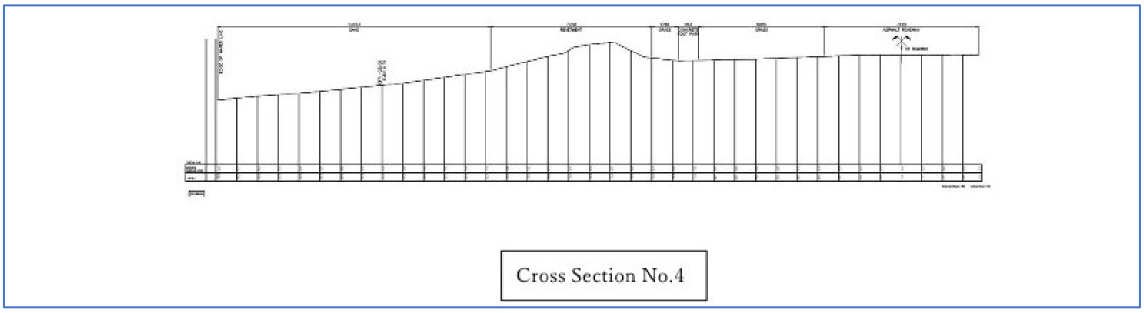
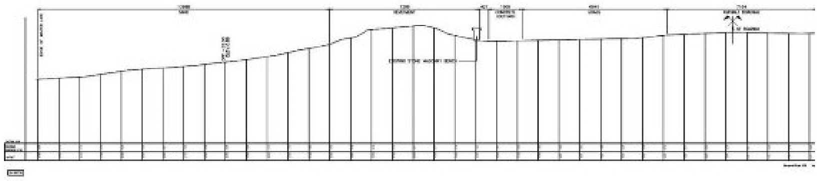
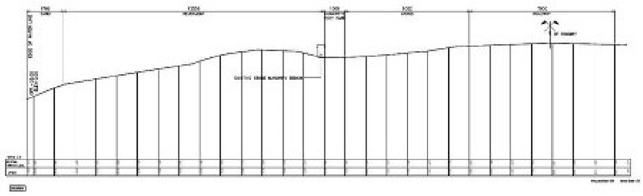


Figure 4 No.4 (CH1+949.61) West Revetment of Japan Grant Aid



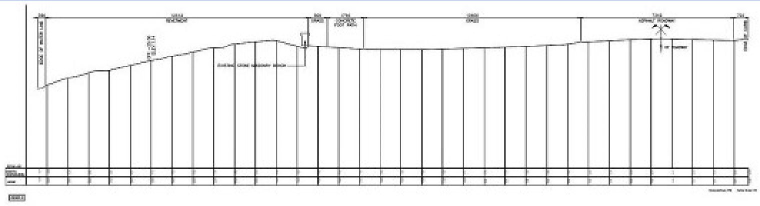
Cross Section No.5

Figure 5 No.5 (CH2+657.82) Near the east end of West Revetment of Japan Grant Aid



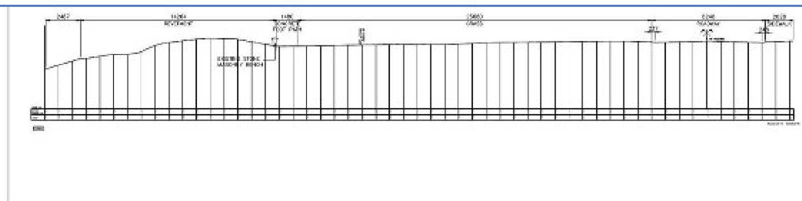
Cross Section No. 6

Figure 6 No.6 (CH3+082.96) Near the start of West Revetment of German Grant Aid



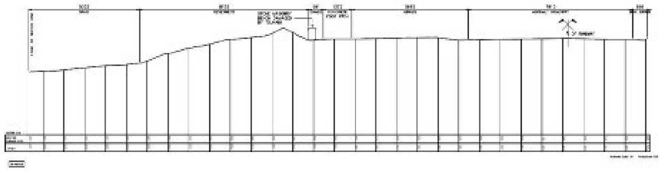
Cross Section No.7

Figure 7 No.7 (CH3+315.10) West Revetment of German Grant Aid



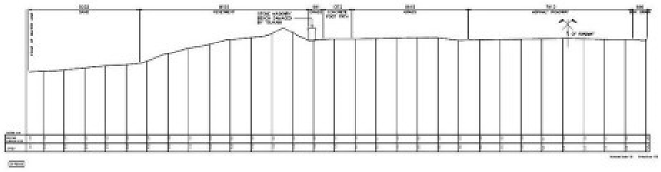
Cross Section No.8

Figure 8 No.8 (CH3+896.94) East Revetment of German Grant Aid



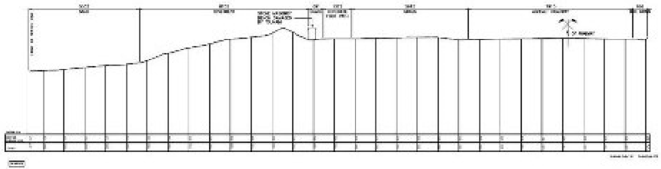
Cross Section 9

Figure 9 No.9 (CH4+859.08) East Revetment of German Grant Aid



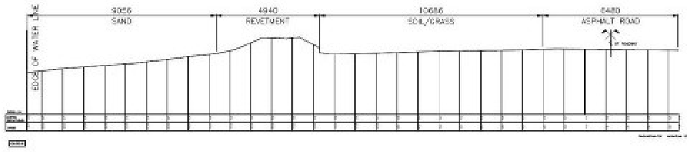
Cross Section No.10

Figure 10 No.10 (CH6+301.74) Near the start of East Revetment of Japan Grant Aid



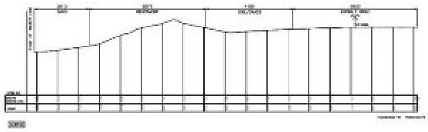
Cross Section No.11

Figure 11 No.11 (CH7+324.13) East Revetment of Japan Grant Aid



Cross Section No.12

Figure 12 No.12 (CH7+918.00) East Revetment of Japan Grant Aid



Cross Section No.13

Figure 13 No.13 (CH8+574.16) East Revetment of Japan Grant Aid

Appendix to Chapter 5

Appendix 5-1 Project List

1 Project List

2 Water supply related Project List

Appendix 5-1
Project List

No.	Items	Summary
1.	Name	Reconstruction of Seawall
2.	Location	Tongatapu Nuku'alofa city 
3.	Beneficiary	Direct Beneficiary：Residence of Nuku'alofa Indirect Beneficiary：Tonga National
4.	Background	On January 15, 2022, a large-scale eruption occurred at the submarine volcanoes Hunga Tonga and Hungaha'apai, located approximately 65 km north of Nuku'alofa, the capital of the country.・Extreme damage such as communication infrastructure failure occurred. In this disaster, a volcanic tsunami was generated due to the eruption of the volcano, and the tsunami caused damage to houses in Nuku'alofa City. In addition, there is damage to the seawall facilities. (Attachment 1) Around Tonga, cyclones occur in January (20 times) and February (18 times), mainly during the rainy season in January and February. Cyclone Harold hit Tonga from April 7th to 8th, 2020, causing extensive damage to Tonga. On February 12, 2018, Cyclone Gita hit in the Kingdom of Tonga in Oceania. Cyclone Gita is said to be the strongest cyclone since the founding of Tonga, and caused extensive damage to houses due to strong winds and floods. In addition, tsunamis caused by trench-type earthquakes have been recorded in Tonga. Twenty-three tsunamis have been recorded since 1860, most of which were smaller than 1m and caused little damage. However, a 2.5m tsunami was recorded in the Haipai Islands. Three tsunamis have been recorded from the 1977 earthquake. In this way, in addition to annual disasters such as cyclones, Tonga has the potential for large-scale disasters, even if they occur infrequently, and there is a high need for seawall protection facilities. The Government of Japan implemented a grant aid project from 1987 to 1988 called the " The project for the Extension of Nuku'alofa Foreshore Protection in the Kingdom of Tonga, in which a bank protection facility was constructed in Nuku'alofa City over a length of about 5.2 km, excluding the central part of the city (about 3 km) (Attachment 2). Seawall facilities). In the future, when reconstructing the seawall facilities, it will consider not only volcanic tsunamis but also possible future disasters, and reconstruct them based on the BBB concept.
5.	Summary of the Project	Rehabilitation of existing seawall facilities. Distance of revetment facilities: Approximately 8.2 kilometers including the city center Structure: Adopting the CSG (Cemented Sand and Gravel) construction method (see attached 3 CSG construction method), sand and gravel that are easily available locally are mixed with water and cement to create the core of the cut-off wall, and the sea By reusing existing corals and rocks on the side and setting them up, embanking the inside and planting plants on top of it, it is possible to create a stronger seawall that is environmentally friendly. Kajima Corporation has acquired a patent, but it can be used Additional consideration is required for cross-sectional structure and height
6.	Expected Outcome	1) By using the CSG construction method, a stronger embankment body can be created compared to masonry revetments. 2) Through the reconstruction of the seawall facilities, it is possible to transfer technology to the Tongan side for facility design methods based on scientific grounds. 3) Damage from tsunamis and storm surges caused by earthquakes will be mitigated, and the resilience of Nuku'alofa urban areas will be enhanced.
7.	Rough Cost	2.1 billion yen (assuming a unit price of ¥780,000/m, H=4m, L=2.0km)
8.	Counterpart	MOI, MLNR
9.	Consideration for Implementation	It is necessary to examine the height using the results of the hazard examination.

No.	Item	Summary
1.	Name	Construction of Bridge in Eua island
2.	Location	Eua Island 
3.	Beneficiary	• Direct Beneficiary：Residence of Eua • Indirect Beneficiary：Residence of Tonga
4.	Background	Due to the volcanic eruption on January 15, 2022 and the accompanying tsunami damage, buildings, port facilities, and seawalls were also damaged on Eua Island. Even before the disaster, transportation facilities were inadequate on Eua Island, and there were obstacles to the transportation of supplies. The distribution of emergency supplies after the disaster also exposed the vulnerability of the transportation network. In addition to the particularly fragile road network around the port of Eua Island, the culvert near the port was damaged, rendering the road unusable. In response to this situation, it is necessary to strengthen the road network on the island by connecting the missing links of the road network before the disaster with bridges. In accordance with the BBB Vision, this project aims to complete the road network by eliminating the missing links in the road network.
5.	Summary of Project	There are three ways of thinking about new bridge candidate sites as shown in the attached materials. Alternative 1: Install a road including a new bridge up to the highest point of the tsunami (the house with a blue roof), and consider the approach road to the harbor separately. (Assumed bridge type: steel girder bridge S=50m) Alternative 2: Depending on whether or not the target vehicles are limited, the structure of the bridge may change significantly, but considering access from the current road, it can be said to be the best candidate (assumed bridge type: steel floor board box) girder bridge S=150m) Alternative 3: There is a possibility that the span length of the bridge can be shortened by constructing an approach road at a point about 100m upstream from the location in 2 above. (Assumed bridge type: steel deck past girder bridge S=100m)
6.	Expected outcomes	1） The road network on Eua Island will be strengthened. 2） Easier movement of goods and people on Eua Island
7.	Rough Cost	Alternative 1: Excluded due to excessive cost Alternative 2: Around 2.1 billion yen Alternative 3: Same as above
8.	Counterpart	MOI、
9.	Consideration of Implementation	There is information that the project will be implemented with the support of the World Bank. Implementation will require coordination with the World Bank.

No.	Items	Summary
1.	Name	New port construction of Vavau
2.	Location	Vavau group main Island 
3.	Beneficiary	• Direct beneficiary：Residence of Vavau • Indirect beneficiary：Residence of Tonga •
4.	Background	On January 15, 2022, a massive eruption occurred at the submarine volcano Hunga Tonga Hungaha'apai, located about 65 kilometers north of the country's capital, Nuku'alofa. Fortunately, Vava'u Island suffered no major damage, but the eruption brought the transportation of supplies to Vava'u Island back into the spotlight. Although there are existing port facilities on Vava'u Island, the navy and fishing ports are located on both sides, making it too cramped and an obstacle to the transportation of goods. The recent disaster has reaffirmed the importance of transporting goods to remote islands, and there is a need to develop port facilities that will not hinder the transport of goods in an emergency. Vava'u has already made a request, and the selection of a new port is already underway. This project will start from site selection.
5.	Summary of Project	The construction of Vava'u Port will contribute not only to the improvement of transportation of goods to Vava'u Island in normal times, but also to the promotion of the development of Vava'u Island. The development of infrastructure facilities at a higher level than the current level through the BBB vision will make it possible to realize that there is also an effect of promoting development, and it is expected that it will lead to the construction of infrastructure with disaster mitigation effects. This project includes the following components: Selection of new port New port design Including the construction of a new port and the construction of access roads. The new port will serve private cargo and passengers, and the development of a passenger terminal can also be expected to attract tourists.
6.	Expected Outcome	1) Secure transportation of goods to Vava'u Island, including in case of emergency 2) Passenger transportation is also secured 3) Expected to contribute to the development of Vava'u Island
7.	Rough Cost	About 5.2 billion yen: 2 billion yen for port facilities (including passenger terminal), road construction and contingency 3.2 billion yen
8.	Counterpart organizations	MOI、MLNR、PA
9.	Consideration of Implementation Period	When selecting a new port, it is necessary to carefully conduct an environmental assessment of the natural environment.

No.	Items	Summary
1.	Name	Construction of slipway for ship inspection and maintenance
2.	Location	Tungatapu 
3.	Beneficiary	• Direct Beneficiary：MoI • Indirect Beneficiary：Tonga Residence
4.	background	On January 15, 2022, a large-scale eruption occurred at the submarine volcanoes Hunga Tonga and Hungaha'apai, located approximately 65 km north of Nuku'alofa, the capital of the country. Extreme damage such as communication infrastructure failure occurred. After the eruption, the Tongan government took emergency measures, but Tonga is made up of four islands, including the main island of Tongatapu. Port facilities and ships are required to distribute aid to these islands. On the other hand, ships require regular maintenance, and there are no facilities for that in Tonga. In many cases, facilities such as New Zealand are used, but the loss of time for this is large restricted. In Tonga, it is necessary to transport goods by ship. Therefore, securing a system that can carry out maintenance at an early stage will contribute to the stable transportation of daily necessities in Tonga, and will also facilitate rapid response after a disaster. We can definitely move forward. Based on the BBB concept, this project is expected to contribute to the construction of a disaster-resistant nation.
5.	Summary of the Project	According to a Chinese investigation report, there are four candidate sites within Tongatapu Island. It is necessary to select suitable sites based on the results of this survey. Construction of slipway (about 65m) Introduction of necessary equipment Implementation of human resource development
6.	Expected Outcome	1) Ships that could not be maintained in Tonga can now be maintained domestically, and the maintenance time will be greatly shortened. 2) The maintenance fee can be saved in Tonga 3) Develop maintenance personnel 4) Increased chances of acquiring foreign currency
7.	Rough cost	3 billion yen (approximate) from cases in other Pacific countries
8.	Counterparts	MOI、MLNR、PAT
9.	Consideration during implementation	It is necessary to confirm with MOI in advance about the operation after the completion of the facility. Due to the burden on the environment around site, it is necessary to carry out environmental assessment carefully.

No.	Items	Summary
1.	Name	Disaster Management Information Center
2.	Location	Tongatapu 
3.	Beneficiary	• Direct Beneficiary：Residence of Tongatapu • Indirect Beneficiary：Residence of Tonga
4.	Background	On January 15, 2022, a massive eruption occurred at the submarine volcano Hungatonga Hungaha'apai, located about 65km north of the country's capital, Nuku'alofa. Fortunately, there were no victims this time because the people of Tonga had watched the video of the tsunami that occurred after the Great East Japan Earthquake, and they had vivid memories of it. In Vanuatu, there is also a report that the screening of tsunami videos was very effective in terms of disaster prevention education. In this disaster, a university professor from New Zealand went to the site immediately after the eruption to collect information. No trace. The data collected by the Tonga Meteorological Service is only from 2018 onwards, and there is no meteorological data from past disasters, which hinders research on disaster prediction. In this way, it is necessary to improve the facilities and equipment for collecting and recording disaster-related information and providing information that contributes to disaster prevention education.
5.	Project Summary	・Archiving records of natural disasters and constructing a disaster prevention information center for public disaster prevention education (the facility will be constructed on high ground and used as an evacuation shelter in the event of a disaster). ・Provision of observation and recording equipment to record future disasters (additional tide gauges, wave observation network, seismic motion measurement network, etc.) ・Equipment for rapid damage information collection after a disaster (long-distance observation drone, various analysis devices, simple GPS survey equipment, etc.) ・Equipment (PC, video storage) for organizing collected materials, archiving, and creating public videos
6.	Expected Outcomes	1) Video and audio recordings of damage immediately after a disaster are collected 2) Field surveys record the run-up height of tsunamis and storm surges, the thickness of waves, and the extent of inundation. 3) Based on the collected information, disaster prevention education materials are created. 4) Adjacent to the royal palace and on a hill that is one step higher than the surrounding area, it will be developed as an evacuation site not only for the surrounding residents but also for the king.
7.	Rough Cost	About 200 to 400 million yen Information center building, observation equipment, display video production equipment, etc.
8.	Counterpart	MLNR、MEIDECC、MET
9.	Consideration of Implementation	A small-scale technical project for technology transfer for effective use of equipment will be implemented in line with the development of the center and provision of equipment

No.	Items	Summary
1.	Name	Construction of Tsunami Tower
2.	Location	Urban area of Tongatapu and other areas 
3.	Beneficiary	• Direct Beneficiary：Residence of urban area • Indirect Beneficiary：Residence of Tonga
4.	Background	On January 15, 2022, a large-scale eruption occurred at the submarine volcanoes Hunga Tonga and Hungaha'apai, located approximately 65 km north of Nuku'alofa, the capital of the country.・Extreme damage such as communication infrastructure failure occurred. In this disaster, a volcanic tsunami was generated due to the eruption of the volcano, and the tsunami caused damage to houses in Nuku'alofa City. Around Tonga, cyclones occur in January (20 times) and February (18 times), mainly during the rainy season in January and February. Cyclone Harold hit Tonga from April 7th to 8th, 2020, causing extensive damage to Tonga. On February 12, 2018, Cyclone Gita made landfall in the Kingdom of Tonga in Oceania. Cyclone Gita is said to be the strongest cyclone since the founding of Tonga, causing extensive damage to houses and other structures due to strong winds and floods. In addition, tsunamis caused by trench-type earthquakes have been recorded in Tonga. Twenty-three tsunamis have been recorded since 1860, most of which were smaller than 1m and caused little damage. However, a 2.5m tsunami was recorded in the Haipai Islands. Three tsunamis have been recorded from the 1977 earthquake. Such disasters occur frequently in Nuku'alofa, the capital of Tonga, and it has experienced a lot of damage so far.
5.	Summary of the Project	A tsunami tower will be constructed to secure a vertical evacuation route in Nuku'alofa city. The Tsunami Tower will be built in areas where it is difficult to secure evacuation routes in Nuku'alofa City and where many residents who have difficulty evacuating, such as the elderly and people with disabilities. When constructing a tsunami tower, it will thoroughly check the evacuation plan and consider its use during normal times, including tourism use. For the construction of a tsunami tower, it will introduce examples of construction and operation that have already been carried out in Japan, and the plan will take into consideration the actual situation in Tonga. Furthermore, this project will contribute to the realization of the BBB vision promoted by Tonga, and is expected to play a symbolic role in reconstruction.
6.	Expected Outcomes	1) A tsunami tower will be built to facilitate evacuation of residents 2) The Tsunami Tower construction plan in Japan will be shared with Tonga. 3) Evacuation drills will be held after the construction of the tsunami tower
7.	Rough cost	About 500 million yen Construction of a tsunami tower in total
8.	Counter Part	MLNR、MOI, MEIDECC
9.	Consideration for implementation	Evacuation drill should be held at least once a year.

No.	Item	Summary
1.	Project Name	The Project for strengthening Administrative Capacity for Disaster Risk Reduction to Realization of BBB Vision in Tonga
2.	Location	The main island of Tonga
3.	Beneficiary	• Direct Beneficiary：Staff of C/P Agency • In direct Beneficiary：Tonga residence
4.	Back Ground	• The State of Tonga (hereinafter referred to as "Tonga") is an island country consisting of 172 islands, large and small, located in Polynesia in the South Pacific, with an exclusive economic zone of 700,000 km2, a land area of 720 km2, and a population of about 104,000 (2019, World Bank), GNI per capita is US$5,000 (2019, World Bank). Tonga consists of four islands from the north, Niuas, Vavau, Haapai and Tongatapu, the largest of which is the southern Tongatapu Islands, which mainly consist of Tongatapu Island, where the capital Nuku'alofa is located, and Eua Island, located about 40 km southeast, and about 80,000 of the total population. Tonga's main industries are primary agriculture and fisheries and tourism, accounting for about 20% of GDP. Although the climate is mild with an average annual temperature of 24°C and an annual rainfall of 1,700 mm, it is hit by cyclone damage every year, and there are many natural disasters such as earthquakes, active volcanic islands and undersea volcanoes. The World Risk Report (2021) ranked the third highest risk of disaster damage in the world. • On January 15, 2022, about 65 km north of Nuku'alofa, the capital of Tonga, a large-scale eruption occurred at the undersea volcano Hungatonga and Hungaha Pai, and the earthquake, tsunami, and ash fall associated with it caused enormous damage such as collapse and flooding of buildings in coastal areas and damage to transportation and communication infrastructure. Tonga has always been ranked among the world's top class in terms of disaster vulnerability, and disaster risk reduction is a major issue even when considering future development.
5.	Outline of the Project	The Tonga government, with the cooperation of JICA, has positioned the BBB Vision as a policy of the National Spatial Planning Authority (NSPA) All future projects to be implemented in Tonga will be evaluated in accordance with the BBB Vision. On the other hand, the Tonga government wants to build an evaluation system based on the BBB vision. In light of this situation, in order to promote the nation's building that is resilient to disasters in Tonga, this project aims to establish a new project formation and evaluation method based on the BBB Vision, and to establish a system that can issue an alert from the government and evacuate residents in the event of a similar disaster in the future. (1) Parent Goals The formation, evaluation and implementation of projects based on the BBB Vision will strengthen the country. (2) Project Objectives Promote activities that contribute to disaster risk reduction based on the BBB Vision and strengthen disaster prevention administrative capacity.
6.	Expected Outcome	Output 1: NEMO's administrative capacity for disaster risk reduction to promote investment in disaster risk reduction will be strengthened Output 2: Strengthening the NSPA's Administrative Capacity for BBB Vision are improved Output 3 : Technical guidelines and manuals necessary for BBB vision evaluation are developed. Output 4: MIIDEC's administrative capacity for disaster prevention for issuing early warning warnings will be strengthened
7.	Rough Cost	Experts 85 MM and C/P training in Japan
8.	Counter part	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications （MEIDECC） Ministry of Infrastructure（MoI） National Emergency Management Organization (NEMO) National Spatial Planning Authority (NSPA)
9.	Consideration in Implementation	Since multiple government agencies are involved, coordination within the Tonga government is frequently necessary.

No.	Items	Summary	
1.	Project Name	The project for Human Resource Development in the observation and monitoring of hazard in Tonga	
2.	Location	All area of Tonga	
3.	Beneficiary	• Direct Beneficiary：Staff of Counterpart • Indirect Beneficiary：Tonga Residence	
4.	Background	The State of Tonga (hereinafter referred to as "Tonga") is an archipelagic country consisting of 172 large and small islands located in Polynesia in the South Pacific. GNI per capita is US$5,000 (2019, World Bank). Tonga consists of four islands, Niuas, Vavau, Ha'apai and Tongatapu from north to south. Of these, the largest island, the Tongatapu archipelago, consists mainly of Tongatapu Island, where the capital Nuku'alofa is located, and Eua Island, located about 40km southeast of Tongatapu Island. and more than 80% of the total population live there. Tonga's main industries are primary industries of agriculture and fisheries and tourism, which account for about 20% of GDP. The country has a mild climate with an average annual temperature of 24° C and an annual rainfall of 1,700 mm. However, in addition to being hit by cyclones every year, there are many natural disasters such as earthquakes due to active volcanic islands and submarine volcanoes in the country World risk report 2021 pointed out that it is considered to be the country with the third highest risk of disaster damage in the world. On January 15, 2022, a large-scale eruption occurred at the submarine volcanoes Hunga Tonga and Hunga Ha'apai, located approximately 65 km north of Nuku'alofa, the capital of Tonga.・Extreme damage such as communication infrastructure failure occurred. Tonga consistently ranks among the top in the world for disaster vulnerability.	
5.	Outline of the Project	The recent volcanic eruption confirmed the vulnerability of Tonga's domestic hazard monitoring system. Especially in Tonga, which has a high disaster risk, it is necessary to monitor each hazard. The purpose of this project is to train specialists who can observe and monitor each hazard. (1) Overall goal Surveillance and monitoring for each hazard can be implemented (2) Project purpose A hazard monitoring system will be established and human resources will be developed.	
6.	Expected Outcome	Output 1: Observation and monitoring personnel for volcanic disasters are developed Output 2: Human resources for monitoring earthquake disasters are developed. Output 3: Human resource development for disaster monitoring and monitoring	
7.	Rough Cost	Experts 30 MM	
8.	Counterpart Agency	TGS and TMS	
9.	Considerations during implementation	Coordination among Tonga Governments organizations are required.	

No.	Items	Summary
1.	Name of Project	The project for Tourism Development based on BBB Vision
2.	Location	All Island of Tonga
3.	Beneficiary	• Direct beneficiary：Staff of Counterpart organization • Indirect beneficiary：Tonga national
4.	Background	The State of Tonga (hereinafter referred to as “Tonga”) is an archipelagic country consisting of 172 large and small islands located in Polynesia in the South Pacific. World Bank), GNI per capita is US$5,000 (2019, World Bank). Tonga consists of four islands, Niuas, Vavau, Ha'apai and Tongatapu from north to south. Of these, the largest island, the Tongatapu archipelago, consists mainly of Tongatapu Island, where the capital Nuku'alofa is located, and Eua Island, located about 40km southeast of Tongatapu Island, and more than 80% of the total population live there. Tonga's main industries are the primary industries of agriculture and fisheries, and tourism, which account for about 20% of GDP. The country has a mild climate with an average annual temperature of 24°C and an annual rainfall of 1,700 mm. However, in addition to being hit by cyclones every year, there are many natural disasters such as earthquakes due to active volcanic islands and submarine volcanoes in the country. It is considered to be the country with the third highest risk of disaster damage in the world. On January 15, 2022, a large-scale eruption occurred at the submarine volcanoes Hunga Tonga and Hunga Ha'apai, located approximately 65 km north of Nuku'alofa, the capital of Tonga. ・ Extreme damage such as communication infrastructure failure occurred. In particular, tourism facilities in the eastern part suffered devastating damage from the volcanic tsunami. Damage has also occurred in other tourist areas, especially in coastal areas. The tourism industry is an important industry that can earn foreign currency for Tonga. Before COVID-19, around 100,000 people visited Tonga every year.
5.	Summary of Project	Focusing on tourism development, which is an important industry in Tonga, this project will broadly classify areas for tourism development according to the degree of risk of each disaster indicated by the hazard map, and indicate the direction of tourism development. . In addition, regarding the construction of facilities necessary for tourism development, in accordance with the BBB vision, we will build facilities that are resistant to disasters, make proposals on ensuring the safety and evacuation of foreign tourists after a disaster, and conduct evacuation drills in pilot areas. Implemented together. The project also intends to show the visitor disaster event for one of tourism attraction of Tonga. It may be possible to designate submarine volcanos as a Geo site by UNESCO.
6.	Expected Outcome	Output 1: Tonga's tourism development policy is reviewed according to the BBB Vision Output 2: Zoning of tourism development areas is revised due to disaster risk in Tonga Output 3: Create a standard map of disaster-resistant tourist facilities Output 4: Evacuation guidance system for foreign tourists is established
7.	Rough Cost	Expert 20MM C/P Training in Japan Equipment Costs
8.	Counter part	Ministry of Tourism, Tonga Tourism Authority
9.	Considerations during implementation	Coordination among Tonga Governments organizations are required.

① Improvement of water quality management (common for all four islands)

Item	Summary
Name	Improvement of water quality management
Target	TWB Tongatapu Headquarters, and each remote island branch office (Babau Island, Lifuka Island, Eua Island)
Background	The TWB is operating water services on the main island of Tongatapu and at each of its remote island branches, but basic water quality analysis equipment is not in place, and necessary daily tests such as turbidity, pH, and residual chlorine are not being measured or managed. The TWB does have a water quality testing lab in Nuku'alofa on Tongatapu Island, but the only items that can be measured there are fecal coliform counts, electrical conductivity, and residual chlorine - which is inadequate for the sole lab's functionality. Furthermore, the remote island branches do not have water quality analysis equipment and have adopted a system where they airlift samples to the Nuku'alofa lab once a month and receive the results of the three-item water quality tests via email, but they are not able to manage water quality daily. The main water source in the Kingdom of Tonga, groundwater sources (freshwater lenses), are susceptible to environmental impacts such as natural disasters, climate change, and external contamination, and once they are affected, they take a long time to return to their original state. Therefore, it is extremely important to understand and manage the source water quality and tap water quality on a daily basis and to accurately assess the impact of natural disasters and climate change on water quality. In the Kingdom of Tonga, the importance of water source management is increasing with the growing risk of saltwater intrusion into groundwater sources, and the basis for this is water quality management. Taking into account the above background, the purpose of this project is to " Improvement of water quality management", and we propose to improve the water quality testing lab and develop the capacity for water quality management as a small-scale grant aid.
Project Summary	**Facility Construction:** Improvement of the water quality testing lab **Equipment Provision:** • Water quality testing equipment (for daily items) • Office automation (OA) equipment for recording and analysis **Soft Component:** Guidance on water quality management (water quality testing, data analysis, manual preparation, etc.)
Estimated Cost	Approximately 400 million yen.
Expected Outcome	1) Improvement of tap water quality 2) Enhancement of daily water quality management 3) Acceleration of understanding and responding to water quality anomalies caused by natural disasters and climate change
Points to note in implementation	• Instead of constructing a new building for the lab, it is planned to make effective use of existing facilities and prepare a room in the TWB office or workshop as a lab. • Regular inspection items are expected to be analyzed by external contractors, but the actual water quality analysis equipment to be introduced will be carefully examined based on the capabilities and costs of the contractors. • In order to acquire water quality analysis techniques and ensure the sustainability of effects, it is envisaged to provide soft support using the prepared water quality testing lab.

②Enhancement of emergency recovery during disasters (common for all four islands)

Item	Summary
Name	Support for enhancing emergency recovery
Target	TWB Tongatapu Headquarters, and each remote island branch office (Babau Island, Lifuka Island, Eua Island)
Background	On January 15, 2022, the eruption of an undersea volcano and a subsequent tsunami damaged water supply pipes in 265 households in the coastal areas of Nuku'alofa, 57 households on Eua Island, and 25 households on Lifuka Island. Additionally, the accumulation of volcanic ash caused failures of water pumps, electric panels, and generators. Further, a major disruption in the communication network occurred due to the cutting off of submarine cables, which prevented the understanding of the disaster situation of the water supply facilities on the remote islands, requiring about two weeks for the recovery of the water supply system. In addition to the above, the Kingdom of Tonga has experienced numerous large-scale earthquakes and cyclones in the past, and there is a potential risk of long-term water outages due to damage to the main water distribution pipes. Therefore, the early identification and recovery of the water supply system in the event of a major disaster is a significant challenge. Based on the above background, this project proposes "Support for enhancing emergency recovery" as its purpose and suggests the improvement of workshops, provision of necessary equipment and materials, and the development of capacities related to emergency recovery as a small-scale grant aid.
Project Summary	**Facility Construction:** Improvement of workshops **Equipment Provision:** • Various equipment for repair • Water supply equipment and materials such as spare parts • Small generators • Satellite phones (for communication during disasters) • Computers for recording and management **Soft Component:** Guidance on equipment usage and water volume management
Estimated Cost	Approximately 100 million yen.
Expected Outcome	1) Early understanding of the disaster situation of water supply facilities on each island when a disaster occurs 2) Shortening of the emergency recovery period 3) Improvement of water volume management and early understanding of the affected areas of water supply during disasters
Points to note in implementation	• Since the renovation of existing workshops is planned for Tongatapu and Babau islands and new construction is envisioned for Lifuka and Eua islands, a survey for land acquisition is necessary. • For the provided equipment and materials, detailed examination of the purpose of use, specifications, quantity, etc. is required. • In order to ensure the sustainability of the effects, it is envisaged to provide soft support using the prepared workshops. • Separately, technical assistance related to "emergency recovery" by dispatching Japan Overseas Cooperation Volunteers (JOCV) or experts is being considered.

③Strengthening of the water supply system against natural disasters (Tongatapu Island)

<table>
<tr><th>Item</th><th>Summary</th></tr>
<tr><td>Name</td><td>Strengthening of the water supply system against natural disasters (Tongatapu Island)</td></tr>
<tr><td>Target</td><td>Tongatapu Island</td></tr>
<tr><td>Background</td><td>Tongatapu Island is home to approximately 74% of the entire population of the Kingdom of Tonga (around 74,454 people), with TWB providing water services to about 60% of these residents, mainly in the capital city of Nuku'alofa, using groundwater (freshwater lenses) as the water source.
During the underwater volcanic eruption on January 15, 2022, the entire Tongatapu Island lost its power supply. Although TWB's water supply areas were not affected thanks to backup generators, the surrounding village water supplies were halted due to pump power loss. This caused residents to rush to the Mataki'eu'ua Water Distribution Station operated by TWB. At that time, TWB directly supplied water to the locals, causing a tense situation for the water supply in the city. This disaster experience led TWB to strongly recognize the importance of ensuring redundancy in the water supply system during natural disasters.
Given the above, the proposal seeks to "Strengthening of the water supply system against natural disasters" by diversifying the water sources through the development of new ones and constructing connecting pipes to existing water reservoirs. As a potential site for the new water source, Fa'amotu in the southeast part of the island, which is expected to have a freshwater lens thickness of more than 10 meters, is considered promising.</td></tr>
<tr><td>Project Summary</td><td>Preparatory survey:
Water source investigation, installation of groundwater observation wells
Facility construction:
• Construction of new water wells (7 locations x approx. 400m3/day, including 1 electromagnetic flow meter per location)
• Development of solar power generation system and emergency power supply system (new water source)
• Construction of a new water tank (V = 1,000 m3)
• Laying of aqueducts (L = 5 km, new water source to new water tank)
• Laying of water supply pipes (L = 25 km, new water tank to Mataki'eu'ua water distribution station)
• Laying of distribution pipes (L = 15 km, integration of surrounding villages into the TWB water supply)
• Installation of electromagnetic flow meters (7 locations: installation to water tanks, distribution main pipes, water supply pipes, etc.)
Soft components:
Guidance on facility operation, maintenance management, and water source management.</td></tr>
<tr><td>Estimated Cost</td><td>Approximately 28.2 billion yen (Basic survey 0.8 billion yen + Facility construction 24.65 billion yen + Soft component 0.15 billion yen + Consulting fee 2.6 billion yen)</td></tr>
<tr><td>Expected Outcome</td><td>1) Improvement in emergency response to increased water demand during natural disasters.
2) Long-term stability of water supply services through the development of water sources that are less susceptible to salinization.
3) Improvement in TWB's groundwater resource management capabilities.
4) Improvement in water supply services through the integration of village water supplies, which are vulnerable in operation, into TWB's water supply system.
5) Improvement in TWB's revenue due to expansion of water supply area.</td></tr>
<tr><td>Points to note in implementation</td><td>• Detailed investigations are needed for land acquisition for the development of new water sources and the construction of distribution reservoirs and pipelines.
• The equipment to be provided needs to be carefully examined for its intended use and effects, and the specifications and quantity need to be considered.
• Additionally, technical support for "emergency water supply", including the operation of new water sources during disasters, and "water source management" for strengthening groundwater management capabilities should be considered. Support is expected through dispatching Japan Overseas Cooperation Volunteers (JOCV) or specialists.</td></tr>
</table>

Item	Summary
Name	Strengthening of the water supply system against natural disasters (Part 2) Development of Bypass Connection Pipes
Target	Tongatapu Island
Background	Tongatapu Island is home to approximately 74% of the entire population of the Kingdom of Tonga (approximately 74,454 people), and TWB utilizes groundwater (freshwater lenses) as the water source. It provides water supply services to about 60% of the population, mainly in the capital city of Nuku'alofa. TWB's water supply system operates by pumping water from the Mataki'eu'ua well cluster to nearby elevated reservoirs, where it undergoes chlorination before distribution. The current distribution system is based on the water distribution network established under the " The Project for Improvement of the Nuku'alofa Water Supply " which received grant aid from Japan in 2001. However, there are sections of the main distribution pipe (φ500 mm) from the reservoirs that are single pipes. In the event of a natural disaster causing a rupture in this pipe, there is a potential risk of a complete water outage throughout Nuku'alofa. This poses a significant concern as it would render it impossible to supply water to the Vaiola National Hospital, the largest hospital on Tongatapu Island, potentially hampering medical activities during times of disaster. The Kingdom of Tonga has experienced numerous large-scale earthquakes and cyclones in the past, which increases the possibility of a long-term water outage if the main distribution pipe is damaged. Based on these reasons, the proposal aims to establish "Development of Bypass Connection Pipes" to ensure continued water supply even if the main distribution pipe is ruptured.
Project Summary	Facility construction: • Installation of bypass connection pipes (Length: 5.5 km, Diameter: φ300-φ500mm) • Installation of electromagnetic flow meters (1 location)
Estimated Cost	Approximately 500 million yen (Facility construction: 455 million yen + Consulting fee: 45 million yen)
Expected Outcome	1) Ensuring emergency water distribution routes during natural disasters or other emergencies. 2) Improvement of water supply pressure in existing supply areas through the diversification of permanent water distribution routes.
Points to note in implementation	• Considering that the area surrounding the planned location is expected to have heavy road traffic, it is necessary to consider traffic disruptions as well as noise and vibration during project implementation. • Additionally, it is worth considering technical support for "emergency water supply" during disasters, including the operation of bypass connection pipes, through the dispatch of Japan Overseas Cooperation Volunteers (JOCV) or experts.

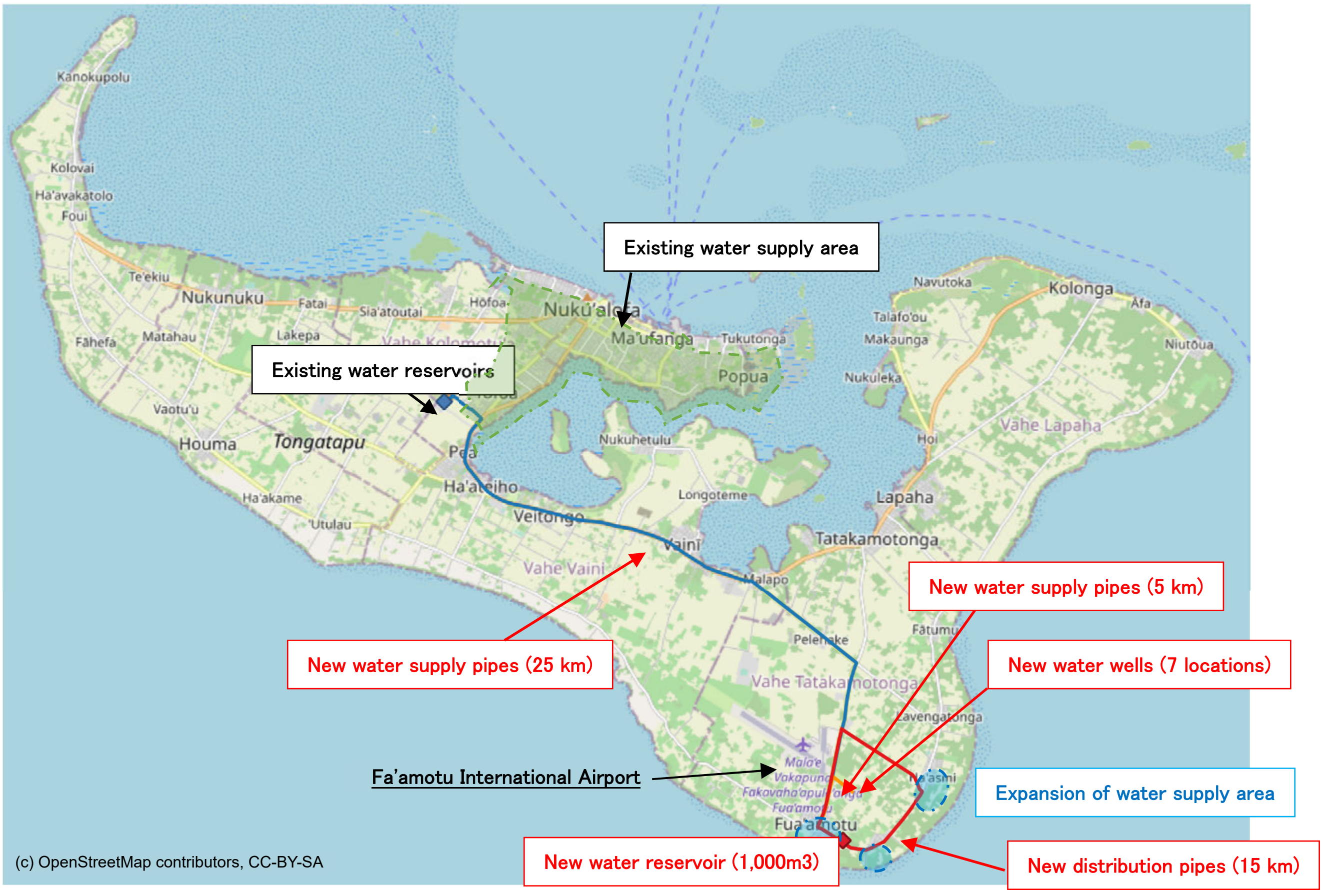


Figure 1 Project Overview: Strengthening of the water supply system against natural disasters (Tongatapu Island)

④Addressing salinization of water sources (Babau Island)

Item	Summary
Name	Addressing the salinization of water sources due to climate change (Part 1)
Target	Babau Island
Background	Babau Islanis expected to be a key hub for the tourism industry in the Kingdom of Tonga, and TWB operates the water supply system in the central area of Neiafu on Babau Island. The production wells near Neiafu have shown signs of salinization, exceeding the World Health Organization's drinking water standard of electrical conductivity of 1,500 μS/cm, both in terms of the water source (freshwater lens) and the quality of the supplied water. The increased frequency of El Niño events due to climate change in recent years has led to significant reductions in rainfall and rising sea levels, increasing the risk of salinization of water sources and making it an urgent challenge to address. During previous El Niño events, the electrical conductivity has exceeded 5,000 μS/cm due to reduced rainfall. On the other hand, groundwater in the northern part of the existing water source area (near Prison Area) has a thick freshwater lens with electrical conductivity of around 500 μS/cm, indicating high potential as a new water source. Based on these considerations, the proposal aims to address the salinization of water sources due to climate change. It includes the diversification of water sources through the development of new water sources in addition to the management of existing water sources.
Project Summary	**Baseline Survey:** Conducting water source investigations and installing groundwater monitoring wells. **Facility Construction:** • Establishing new water wells (7 locations, approximately 400m3/day each, including electromagnetic flow meters). • Implementing solar power generation systems and emergency power generation systems (for new water sources). • Constructing a new water reservoir (capacity: 1,000 m3). • Installing water supply pipes (length: 3 km, from new water sources to the new water reservoir). • Laying down distribution pipes (length: 10 km, from the new water reservoir to the existing water reservoir). • Extending distribution pipes (length: 16 km) to provide water supply to surrounding villages and upgrading AC pipes. • Installing electromagnetic flow meters (7 locations: at the water reservoir, distribution mains, and transmission pipes). **Soft Components:** Providing guidance on the operation, maintenance, and management of the facilities and water source management.
Estimated Cost	Approximately 1.42 billion yen (Baseline Survey: 50 million yen + Facility Construction: 1.23 billion yen + Soft Components: 10 million yen + Consultation fees: 130 million yen)
Expected Outcome	1) Prevention of saltwater intrusion into existing water sources through decentralized water intake locations. 2) Ensuring redundancy of the water supply system through multiple water sources. 3) Development of water sources that are less susceptible to saltwater intrusion, improving the long-term stability of the water supply system. 4) Enhancement of TWB's capacity for groundwater resource management. 5) Improvement of water supply quality. 6) Improvement of water supply conditions through the integration of vulnerable village water supplies into TWB's water supply system. 7) Improvement of TWB's revenue through the expansion of the water supply area. 8) Enjoyment of tourism demand through the provision of safe and stable water services.
Points to note in implementation	• Detailed surveys for land acquisition are required for the development of new water sources, construction of reservoirs, and installation of pipelines. • The provision of equipment requires careful examination of their intended use and effectiveness, as well as considerations for specifications and quantities. • Additionally, technical support for capacity enhancement in groundwater resource management, specifically regarding "water source management," should be considered. Support from JOCV or the dispatch of experts is anticipated.

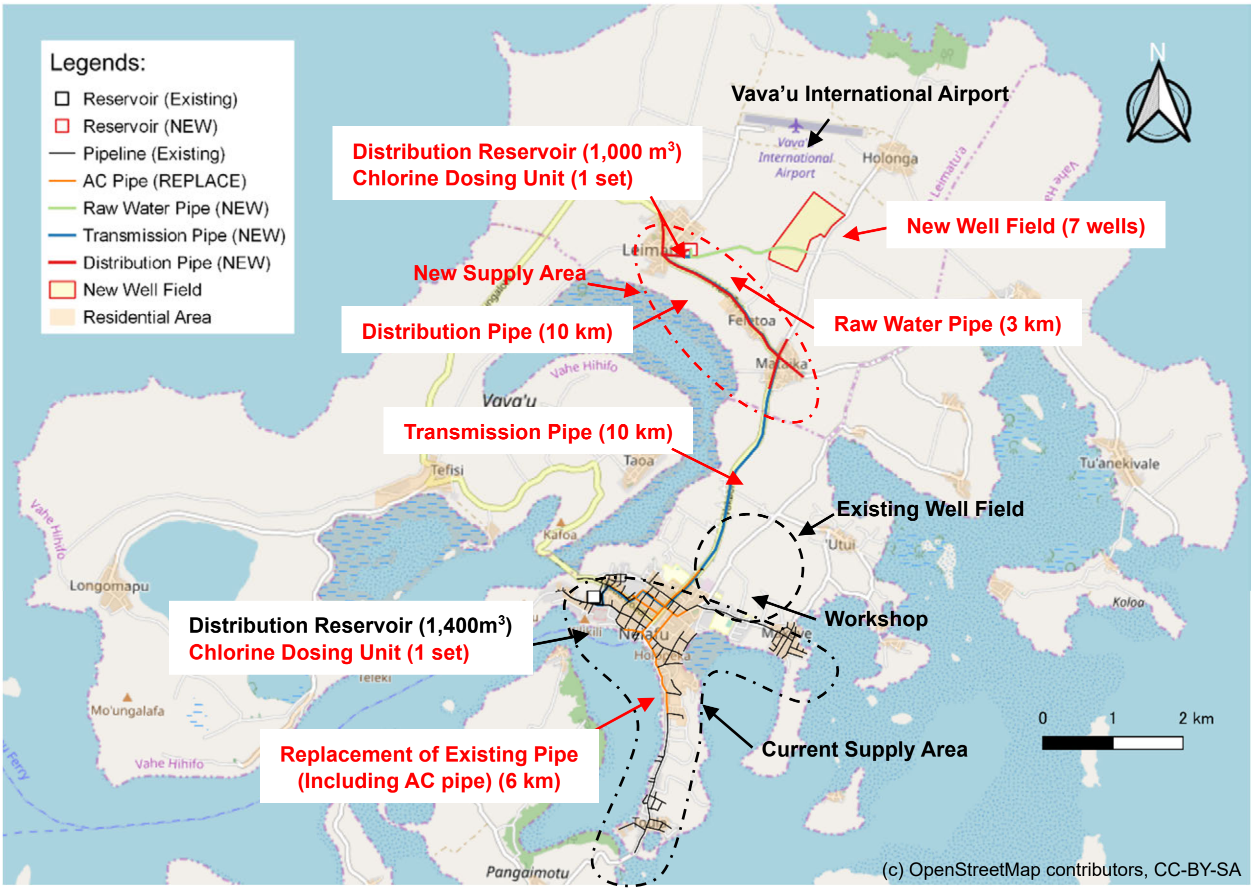
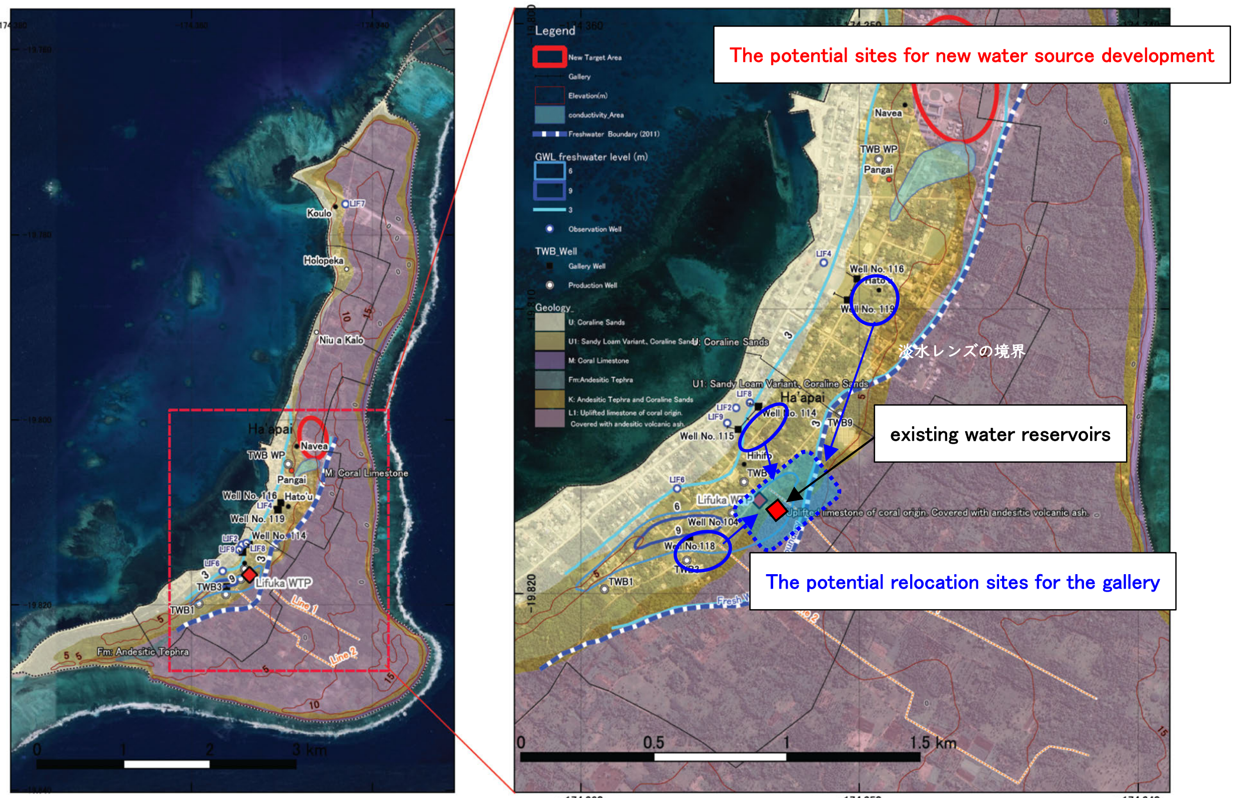


Figure 2 Project Overview: Addressing the salinization of water sources due to climate change (Babau Island)

⑤Addressing the salinization of water sources due to climate change (Rifka Island)

Item	Summary
Name	Addressing the salinization of water sources due to climate change (Part 2)
Target	Rifka Island
Background	Refkha Island, belonging to the Ha'apai Islands in the Kingdom of Tonga, is one of the regions where groundwater salinization is most advanced. Many of TWB's existing water sources on the island significantly exceed the drinking water limits set by WHO. Furthermore, the available freshwater lens, which is the underground freshwater layer, is confined to a narrow range of only 200-600m along the western coast, with a maximum thickness of approximately 9m. This results in chronic water scarcity during the dry season when groundwater recharge decreases. From a medium to long-term perspective, according to the IPCC Sixth Assessment Report (2021), sea levels are projected to rise by 0.28-1.01m by 2100 in the Kingdom of Tonga. This, combined with intensified cyclones, poses an increased risk of coastal inundation on low-lying islands like Refkha Island. Concerns are growing about the salinization of freshwater lenses and the impact on existing water supply facilities. In light of these challenges, the objective of this proposal is to address the salinization of water sources due to climate change. It includes the development of new water sources and strengthening underground management to mitigate the effects of salinization. Potential locations for new water sources include areas near the current distribution center, away from the coastline, or the northern region of the Panga'i District. (Note: Please note that the proposed locations for new water sources are mentioned for illustrative purposes and should be further assessed through detailed investigations and studies.)
Project Summary	**Field Investigation:** Water source survey and installation of groundwater observation wells **Facility Construction:** • Development of new water sources near the existing water treatment plant or in the Panga'i District (3 locations) • Installation of solar power generation systems and emergency power generation systems (for new water sources) • Installation of transmission pipelines (L = 2 km, from new water sources to existing distribution center) • Installation of electromagnetic flow meters (1 location) **Soft Components:** • Operation and maintenance management of facilities, guidance on water source management
Estimated Cost	Approximately 310 million yen (Field Investigation: 30 million yen + Facility Construction: 245 million yen + Soft Components: 5 million yen + Consultation Fees: 30 million yen)
Expected Outcome	1) Development of saltwater-resistant water sources and improvement of long-term stability in water supply services to mitigate the impact of salinization. 2) Mitigation of damage to water supply facilities caused by climate change-induced natural disasters. 3) Enhancement of TWB's capacity in managing underground water resources. 4) Improvement of water supply quality.
Points to note in implementation	• For new water source development and pipeline construction, detailed surveys for land acquisition and compensation are required. • Due to the shallow groundwater level, measures to address groundwater contamination are necessary for the construction of new water source facilities. • The equipment provided needs to be thoroughly examined in terms of its intended use, effectiveness, specifications, and quantity. • Additionally, consideration should be given to technical support for strengthening the capacity to manage underground water resources through "Water Source Management." Support from JOCV or the dispatch of experts can be considered.



Refeference:
Wilson, A.D, F.G. 1981: Soil ,ap of Ha'apai Group, Kingdom of Tonga. Scale 1:25000.
New Zealand Soil Bureau Map 198. Part of NZ Soil Survey Report 67.

Figure 3 Project Overview: Addressing the salinization of water sources due to climate change (Rifka Island)