Draft Early Warning System Needs Assessment and Investment Plan for the Pacific Islands - Tonga

1. Key Findings and Recommendations

Finding 1: While the current arrangements in place for data and information sharing appear adequate, they appear to be ad hoc and would benefit from more formal regulation

> **Recommendation 1:** Review and revise existing legislation to ensure that the regulatory framework for warning and response including data sharing, the issuance of warnings and the expected response from local officials and communities are in place. The importance of "self-rescue" needs to be emphasized within communities.

Finding 2: While there is always room to improve weather forecasts and warnings, TMD provides a high level of service, utilizing national and regional sources of data.

> **Recommendation 2:** Ongoing support for training is essential to maintain currency of staff and to introduce new techniques to improve forecasts and warnings.

Finding 3: Representatives of sectors impacted by hazards do not necessarily have in place adequate coping mechanisms and may not always heed advice and warnings from TMD.

> **Recommendation 3:** Make training workshops available to sectors to improve their capacity to respond appropriately to hazard warnings. This would also encourage international organizations to cooperate more effectively with Tonga authorities, such as TMD and NEMO.

Finding 4: Communication between TMD headquarters and TMD stations, NRD, NEMO, emergency services and the public on remote islands and mariners is inadequate to ensure essential information is conveyed to those that need it.

> **Recommendation 4:** Upgrade the marine HF radio network and the VHF network to communicate with communities. A common frequency for information sharing between civil, military and other responders is essential. This would also improve communication among TMD, NRD and NEMO.

Finding 5: The Geo-hazards monitoring and visualization tools are limited.

> **Recommendation 5:** Upgrade the operational facilities used to monitor and visualize geo-hazards, and ensure continuity of operations by mirroring capabilities outside of high risk zone; for example, by co-located services with TMD at the airport.

Finding 6: The TMC facilities at its headquarters need to be repaired or replaced.

Recommendation 6: Upgrade the operational facilities at TMC headquarters at the airport or another location.

Finding 7: The NEMO headquarters is located in a hazard zone and risks operational failures in the event of a tsunami or major storm surge.

Recommendation 7: If for operational reasons, NEMO is to remain at its current location attention needs to be paid to minimize failure of the operations center in the event of damage from debris flows commonly associated with tsunami wave-fronts. Where possible back up systems should be located with TMD at the airport, so that NEMO could re-locate to this location in the event operations at the existing facility is compromised. This would also be the likely center of any relief operations following a major disaster. Alternatively TMD, NEMO and seismic monitoring operations of NRD could be co-located in a new facility outside of the Tsunami zone, but closer to existing government facilities. Consideration should be given to relocating all government activities to a safe zone to ensure continuity of operations.

Finding 8: Despite good severe weather forecasts and warnings, the population does not fully understand the information communicated to them often resulting in an inadequate response.

Recommendation 8: Introduce impact forecast and warning services as a part of a revised Multi Hazard Early Warning System. This would include building tools designed to take into account vulnerability and exposure information.

Finding 9: Vulnerability mapping has been a critical effort of NRD. This is an ongoing effort that needs to be sustainable since vulnerability assessments need to be updated frequently. This effort needs to be comprehensive to ensure all aspects of vulnerability are captured. Much has already been done in this area: this should be reviewed and updated. All available data should be made available to the Government of Tonga.

Recommendation 9: Ongoing vulnerability assessments should be supported. This includes mapping the natural environment as well as infrastructure assessments (roads, residential, public and commercial buildings)

Finding 10: Despite best efforts, public education of hazard risks is limited.

Recommendation 10: An ongoing and frequently repeated education campaign is needed including television, production of educational videos, etc. A TV weather studio should be created, which would serve the purpose of providing daily broadcasts of weather, as well as educational programming. This could be developed jointly by TMD, NRD, and NEMO. Programming should be designed to reach all of the Kingdom's people. Frequent drills would also accompany this and other activities designed to increase the capacity of the public to respond to an emergency appropriately.

Finding 11: On the 01 October 2014, Pacific Tsunami Warning Center (PTWC) will no longer issue warning/watch bulletins requiring all Pacific Island Countries including Tonga to undertake their own threat assessments and issue warnings.

Recommendation 11: Strengthen the capability of national tsunami warning centres to undertake their own threat assessments using either the new PTWS information products or expanding the tsunami model to include other islands and scenarios. This is a critical activity, which should be undertaken in partnership with other PICs in the region.

Finding 12: The seismic monitoring network is not fully integrated into the regional network and some equipment is outdated.

Recommendation 12: Upgrade and expand the seismic observing network.

Finding 13: Tonga participates in a number of regional WMO programs to improve severe weather forecasts and storm surge forecasts.

Recommendation 13: Adequate resources should be available for operational training related to these regional activities either as part of recommendation 2 or as a separate regional effort.

2. EWS in the Pacific

Pacific Island Countries (PICs) are among the most vulnerable nations in the world due to the combined impact of meteorological and geophysical hazards. Flash floods, river floods, high winds, storm surges, earthquakes, volcanic eruptions and tsunamis frequently affect people and property. Droughts are also common and climate change is contributing to sea level rise and an overall increase in the risk of extreme weather events. In the absence of adequate response, these hazards result in disasters that affect PICs' entire economic, human, and physical environment and impact their long-term development.

The effectiveness of early warning systems designed to reduce exposure to hazards depends on people's capacity to understand and respond to a given situation. This remains a challenge in most countries and is a high priority in PICs, where early action is essential to save lives and to protect livelihoods and property.

A common approach to multi-hazard early warning systems (MHEWSs) has been advocated by National Meteorological Services (NMSs), which are primarily responsible for forecasts and warnings of weather, climate and geo-hazards. MHEWS inform the people of the potential impacts of impending natural hazards, the risks on their lives and livelihoods, and the action they should take. To be effective, this approach entails multi-stakeholder cooperation and coordination between and among national science, disaster risk management agencies, and other relevant stakeholders. It also needs to be combined with actions to make communities more disaster resilient so that they can respond more effectively to natural hazards.[1] In addition, translating technical warning information into impacts is important to ensure that people take early action to minimize their exposure to extreme events.

Impact forecast and warning services depend on forecasts of hazards and a comprehensive understanding of vulnerability and exposure, which in turn depend on data sharing and cooperation among multiple government agencies and civil society. Therefore, it is important to ensure that institutional capacity is increased, monitoring

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[1] Concept Paper on International Network for Multi-Hazard Early Warning Systems (IN-MHEWS). Jointly proposed by WMO, WHO, UNDP, UNESCO-IOC, UNESCAP, UNISDR, UNOOSA/UN-SPIDER, IFRC, ITU, GFZ, GIZ. 24 Feb 2016. Available from: https://www.wmo.int/pages/prog/drr/events/2016-EAG-MHEWS/documents/2016.02.24-Doc10-IN-MHEWSConceptPaperDRAFT.pdf

and forecasting systems are strengthened, and service delivery to the public and economic sectors is enhanced.

Working with multiple PICs within a regional framework will allow the introduction of good practices in MHEWSs, introduce impact forecast and warning services, and streamline warning and response coordination.

PICs work closely with each other and with regional organizations, such as: the WMO Regional Specialized Meteorological Centers (RSMCs); the Pacific Tsunami Warning Center (PTWC), which provide operational guidance; and with regional entities such as the Secretariat of the Pacific Community (SPC) and the Secretariat of the Pacific Regional Environment Programme (SPREP), which provide capacity building and training. Improving the capabilities of the regional operational centers is also recognized as a high priority by NMSs since they provide the regional guidance essential for accurate and timely national forecasts and warnings.

The expected outcomes of a regional framework for PICs include a common, easy to understand multi hazard warning system; greater understanding of the impact of hazards by people at risk and therefore more effective response enabling communities to "self-rescue" mitigating potential disasters; and greater cooperation among PICs to improve the accuracy and timeliness of forecasts and warnings.

3. Country Assessment

Background

The World Bank team conducted meetings with 'Ofa Fa'anunu, Head of the Tonga Meteorological Department (TMD) and Leveni 'Aho, Director of the National Emergency Management Office (NEMO) in the Ministry of Environment, Energy, Climate Change, Disaster Management, Meteorology, Information and Communications, and Taaniela Kula, Head of Natural Resources Division (NRD), Ministry of Lands and Natural Resources.

The aim of this assessment is to validate gaps, which have been identified in the capacities of these agencies to minimize the adverse impacts of meteorological and geophysical hazards (hereafter natural hazards), which can result in disasters that affect the entire economic, human, and physical environment and impact the long-term development of the Kingdom of Tonga.

Tonga is frequently impacted by severe weather, including tropical cyclones, which cause extensive damage due to winds, rain and storm surges. Tonga is also highly vulnerable to tsunamis and earthquakes because of its proximity to an active subduction zone. The minimum lead-time for a tsunami impact can be as short as 10 minutes.

Although relatively small, the TMD has qualified staff (Class 1 Meteorologists), operating 24 hours by 7 days (24/7), to provide a full range of weather forecasts and warnings, TMD is also responsible for providing warnings of tsunamis based on data provided by Natural Resources Division. The latter has recently started 24/7 monitoring of earthquakes to ensure the warning system is able to meet the requirements of the population. Staffing levels prevent TMD from supporting aviation meteorological services, which are provided by the Fiji Meteorological Service.

TMD maintains meteorological staff (observers) at 5 synoptic stations (a sixth station is in the process of being installed) covering the territory of the Kingdom of Tonga. This is critical for communication of warnings to the public in remote locations. TMD is headquartered at the domestic terminal of Fua'amotu Airport. This is a relatively secure location because of its elevation, unlikely to be directly impacted by a tsunami or storm surge; however the current building is unlikely to withstand a Category 2 Tropical Cyclone. NRD and NEMO are located adjacent each other within Nuku'alofa in an area designated as vulnerable to the impact of a tsunami. Neither building is constructed to withstand extreme weather or water damage.

Multi Hazard Impact Forecast, Warning and Response System

Multiple threats require an integrated response. This has led to the development of Multi Hazard Early Warning Systems (MHEWSs), although there is no commonly accepted approach to achieve a functional operational system. The World Meteorological Organization (WMO) and the Global Facility for Disaster Reduction and Recovery (GFDRR) have favored an approach developed by the Shanghai Meteorological Service and now adopted by the City of Shanghai, China (Tang et al. 2012) and by WMO as a global good practice. The system is structured in such a way that decisions are optimized to minimize delays in communication and effective action. On its own however, this system does not guarantee that those threatened by a natural hazard understand the warning, their vulnerability and exposure, and consequently the risk they face.

The response to Tropical Cyclone Ian illustrates this point. Despite receiving warnings and frequent updates from TMD on the worsening weather situation, people did not evacuate to designated safe areas until their homes were destroyed, unnecessarily risking their lives.

A new approach is needed that emphasizes weather impacts, rather than conveying technical information about the weather itself. This evolution from forecasting what the weather will be to forecast what the weather will do is now a high priority of the WMO Public Weather Services to ensure that advances in weather forecasting result in greater public safety and security.

The foundation of this approach is the extension of well-functioning hazards forecast and warning system to an impact forecast and warning system. This requires access to information on the vulnerability and exposure of those at risk. It is also an opportunity to monitor the response of the public if communities and individuals can feedback information on the actions they have taken to reduce their exposure. In this way, emergency operations can be better informed about the changing risk of impact through the course of an event, enabling the limited resources of the emergency services to be targeted to those most in need.

Gaps and Recommendations

While many aspects of such of end-to-end impact forecast, warning and response system are in place; some gaps need to be addressed. These include:

Introducing an Impact Forecast and Warning System

There is a need to introduce and develop an impact forecast and warning system based on the latest World Meteorological Organization (WMO) guidelines. In many regions of the world forecasts and warnings of hazards have become very reliable, but this has not necessary resulted in more lives saved. Understanding the impact of weather, for example, is much more critical than understanding the weather. In Tonga, while there is a high degree of skill in meteorological forecasts and warnings, translating these forecasts and warnings into impacts is limited. A critical component of any effective warning system is the ability to understand the warning and take effective action. This requires greater emphasis on understanding vulnerability and exposure of everyone and providing individuals with the means to take effective action to reduce their own exposure. In Tonga, it is well-recognized by government agencies that impact forecasts and warning are needed. Additional capacity is needed to capture sufficient information on vulnerability and exposure and to build the impact forecast and warning system into the MHEWS. In effect, this requires creating an Impact Forecast Multi Hazard Early Warning System (I-MHEWS) that facilitates effective communication of impacts and enables an informed response. The same system would help emergency services target their response to those most at risk. It would also be used to monitor changes in impact risks as the hazard evolves and exposure is reduced, for example, through adequate sheltering.

Partnerships for Data Sharing

A system that focuses on impacts requires significantly more information than is routinely available to meteorologists and hydrologists. Partnerships among agencies should, wherever possible, be formalized so that critical data are always available. Therefore, it is recommended that existing legal frameworks be reviewed with the aim of revising regulations and institutional arrangements to facilitate the exchange of data and information among agencies required for a fully operational multi-hazard impact forecast, warning and response system. Such a framework is usually implemented through a set of bilateral agreements among the stakeholders.

Identifying All Relevant Hazards

The impact forecast, warning and response system needs to consider all contingencies and therefore needs to include all likely hazards, both natural and as a consequence of human actions, such as congestion on highways due to an evacuation or breakdown in communication due local customs and behaviors. Discussions between all national stakeholders will be instrumental in identifying the hazards and vulnerabilities that need to be quantified and included in such a system.

Facilities

TMD, NHD, and NEMO operate in three separate facilities. The location of NRD and NEMO are within a tsunami impact zone and therefore there is a high risk of inundation and damage during an event. The TMD is located at the airport, which is safely above the risk of inundation due to a tsunami, but vulnerable to damage by a category 2 tropical cyclone or greater. It is recommended that TMD, the seismic monitoring functions of NHD and the emergency operations center functions of the NEMO co-locate in a new purpose built facility. This would help ensure continuity of operations for all three activities.

Observations

The seismic network is not fully operational and not reporting to the regional network. Upgrading and enhancing this network would improve the capability of NRD to monitoring local earthquakes enabling earliest alerting of the risk of a locally generated tsunami.

Training

New ways of working require appropriate levels of training. Training should be available to all of the participating agencies to improve their understanding of warning services and their ability to develop the appropriate communication tools to convey actionable warning information. Training is required to increase skills in the development of applications, management of ICT systems, technical support, and effective communication of scientific information to end-users. As introducing impact forecast and warning would require extensive training, twinning arrangements with the institutions leading the development of these skills could be beneficial. These activities are common to all participating PICs.

Visualization Tools

Investment is needed in common visualization tools, such as real-time maps of forecast impact risks based on a common color-coded system, consistently generated for all hazards and impacts. Existing donor support is contributing to this type of system, but additional effort is required to create an effective public interface for a MHEWS. This system would consist of a warning dissemination system able to communicate hazard impact warnings with DRR stakeholders, media, communities and individuals through new technology platforms (e.g. mobile phone application, web platform).

The need for a MHEWS is common to all PICs. Therefore, a regional approach to defining warning thresholds, color-coding of warning levels, and common symbols is recommended. Responsibility for hosting the servers supporting Web-based visualization tools would be distributed among all participating countries to ensure continuity of operations.

Communication

Communication with remote islands is critical in Tonga to distribute warnings and enable two-way communication on impacts and recovery. The preferred means of communication is HF and VHF radio. This system would consist of a two-way communication system to give the opportunities to exchange efficiently timely warnings and receive feedback from communities on the current threat for better Disaster Risk Management from the NEMO.

Regional Integration

Better integration into regional organizations needs to be considered for the MHEWS, as an operational component of the existing WMO regional institutions and systems (e.g., Regional Specialized Meteorological Center Nadi, Regional Specialized Meteorological Center Wellington, and the WMO Severe Weather Forecasting Demonstration Project or SWFDP) and the WMO Coastal

Inundation Forecasting Demonstration Program, in which the NMS already participates.

Seismological monitoring has been integrated into the Oceania Regional Seismic Network (ORSNET) and needs to be further strengthened with addition of new sensors.

Although each of these relationships is governed by international conventions (e.g., WMO), specific details on data sharing, continuity of operations, communications, etc. tends to be ad hoc. MOUs are recommended to formalize some of these regional relationships to assure continuity of operations.

Community Preparedness and Response

Community preparedness and response needs to be strengthened to include natural hazard risk considerations. Technical advice from TMD and NRD on these can strengthen the approaches used by agencies working with communities. Consultations with all communities in Tonga were undertaken in 2009 to identify community focused priorities for implementation under the Joint National Action Plan for DRM and CCA. Those priorities are being implemented by a number of community-based agencies and partners. There is still a need to harmonise the support by various partners to reduce duplication, maximize resources made available for community implementation and ensure the approach used is complementary to advise being provided by NEMO. The approach used is particularly important when working with communities to address natural hazard related risks including the development of response procedures that correlate to warnings disseminated from the warning center.

Comprehensive vulnerability and risk assessments need to be done for a range of hazards across all the islands. Tsunami modeling has been completed for Tongatapu and used in community tsunami evacuation planning. Similarly, consultations with communities on Lifuka were also held to identify acceptable mitigation options to future storm surge impacts. These activities can strengthen community capacity to prepare for and respond to natural hazard impacts and also identify suitable evacuation centers. An evaluation of the structural integrity and capacity of identified evacuation centers will need to be undertaken and recommendations for improvement provided to Government.

4. Proposed Investment

Based on the above assessment, the proposed investment considered consists of two components focused on early warning and preparedness and community resilience. The needs assessment identified several areas requiring investment to strengthen the interpretation and communication of warning information and to improve the capacity of more communities to respond effectively to warnings.

Component 1: Early Warning, Preparedness and Resilience

The objective of this component is to increase the resilience of each participating country and the region as a whole to meteorological and geophysical hazards. This component has two sub-components: (i) Early Warning and Preparedness, and (ii) Resilient Investments, each with a number of tasks involving regional cooperation among PICs.

Sub-Component 1.1: Early Warning and Preparedness

This sub-component will strengthen the following key elements: (i) detection, forecasting and warning of natural hazards; (ii) dissemination of timely warning to the population, including last mile communication; and (iii) emergency preparedness and response mechanisms.

Investments under this sub-component will form an end-to-end multi-hazard warning and response system that considers the combined threats posed by all potential hazards based on an understanding of the vulnerability of people, assets and their specific exposure. Ensuring people take appropriate life-saving steps requires forecasts and warnings that are easily understood and actionable. Historically, all National Meteorological and Hydrological Services (NMHSs) have featured forecasting of the weather, hydrology, and climate events as central to their mission, and many also issue warnings in the case where hazardous weather, hydrological, climate and geological events are expected. Usually, in the case of both weather forecasts and warnings, the focus is on what the weather will ***be***. This project will help the Tonga Meteorological Department evolve from this weather-based paradigm to one that is focused primarily on forecasting impacts (Annex 1). In other words, the focus should evolve to what the weather will ***do***. The same paradigm shift would also apply to hydrological, climate and geohazard forecasts and warnings within this program.

The Tonga Meteorological Department (TMD) and the National Emergency Management Office (NEMO) are part of the Ministry of Environment, Energy, Climate Change, Disaster Management, Meteorology, Information and Communications, and together with the Natural Resources Division (NRD) of Ministry of Lands and Natural Resources monitor, forecast, warn and respond to meteorological and geophysical hazards. TMD is responsible for meteorological forecasts and warnings, as well as tsunami warnings based on data provided by NRD.

Cooperation between TMD, NRD and NEMO is well developed enabling rapid dissemination of warnings and early handling of emergency situations. This is ensured by distinct and well-defined roles and responsibilities for each entity.

The principle concern is continuity of operations in case of tsunami impact on NRD and NEMO, which would compromise their capability, and the risk of destruction of the TMD offices in the case of Category 2 or greater tropical cyclone.

Tonga is similar to all countries in that it faces multiple threats from natural hazards and the consequential cascading threats, such as contamination of water supplies, disruption of connections between communities; loss of electrical power, disease outbreaks and so forth. Tongan society needs to be well informed about the actions to take to minimize the risk of loss of life, livelihoods and property.

The TMD has indicated the need to implement warning services based on a Multi Hazard Early Warning System (MHEWS). The program will focus on expanding this capability to include forecasts and warnings of meteorological, hydrological and geological impacts. This would enable those at risk, and those responsible for public safety and economic security, to know exactly what actions to take.

The MHEWS depends on good meteorological, hydrological and seismological forecasts, as well as cooperation among a large number of stakeholders, some of whom are expected to supply critical data to underpin the impact warning service as well as issuing warnings within their area of responsibility. For example, the ministry responsible for schools may be tasked to issuing specific directives to protect the lives of children; the highways agency may provide warnings to avoid potential loss of life and property on damaged roads and bridges; the same agency may also be responsible for electricity supply and would provide warnings of the risk of electrical hazards associated with damaged power-lines. These examples highlight the need for a high level of cooperation among government agencies and civil society in general to sustain a resilient society. Effective Standard Operating Procedures (SOPs) are a critical element of the MHEWS (Annex 2).

In addition to introducing impact forecast and warning services, TMD needs to expand its capabilities to include coastal inundation forecasts to minimize the impact of storm surges and continue to improve its forecasting of severe convective weather events. The observational networks for meteorology, hydrology and seismology required to achieve these improvements will also be strengthened partially through this project and other donor support. The project will also help enhance participation in the WMO Severe Weather Forecasting Demonstration Project and the WMO Coastal Inundation Forecasting Demonstration, as well as strengthen operational ties with the Pacific Tsunami Warning Center and the WMO Regional Specialized Meteorological Centers in Nadi and Wellington, and with other regional bodies that can assist with training and capacity building.

The sub-component will improve the quality of forecasting and warning services by providing i) a stronger institutional and regulatory framework; ii) modernizing the observing and forecasting infrastructure; and iii) enhancing the services TMD delivers to the public and to its partners.

A. Institutional and regulatory strengthening, capacity building and implementation support

This task aims to strengthen the legal and regulatory framework of TMD, NRD, NEMO and their partners to exchange data and information critical for the implementation of impact forecast and warning services as an integral part of a MHEWS. Experience elsewhere suggests that an operational partnership between stakeholders would be needed that may go beyond current institutional arrangements. It will also be necessary to build capacity with the TMD, NRD, and NEMO, and among stakeholders to ensure the operability of the future systems, and to support project design and implementation. This task comprises three parts:

A.1) Institutional strengthening and development of a legal and regulatory framework, which includes (1.1) Institutional development and strategic planning, review and revision of legal and regulatory frameworks for TMD, NRD, NEMO and other key partners' operations including the revision and/or development of standard operating procedures (SOPs); and (1.2) twinning support to enable TMD to work closely and sustainably with more advanced National Meteorological and Hydrological Services (NMHSs) and the WMO.

A.2) Capacity Building and Training, which includes (2.1) developing and implementing a capacity building and training program consisting of (a) Personnel training and retraining; professional orientation for senior staff, and study tours; and (b) training in WMO Regional Training Centers, WMO RSMCs, PTWC and other regional entities as needed; and (2.2) implementing training activities (workshops, round tables, etc.) for major users of warning services (e.g., provincial disaster management, agriculture, water resources, energy, health, surface transportation).

A.3) Systems design and integration, component management and monitoring, which includes (3.1) detailed design of the updated MHEWS systems and support for implementation (Systems Integrator Consultant); and (3.2) project management, monitoring, reporting and evaluation of subcomponents A, B, and C.

B. Modernization of the Observation Infrastructure, Data Management Systems, Forecasting and Warning Systems

This task focuses on expanding NRD seismic network, developing the MHEWS, upgrading of the communication networks, data management, and construction of new facilities for monitoring, warning and response operations. This task comprises four parts:

B.1) Technical modernization of the observation networks, which includes (1.1) expansion of the seismic observation network including GPS. The modernized observation network must be capable of being fully integrated with any existing observing systems.

B.2) Upgrade of data management, communication, and IT systems, which includes: (2.1) Marine and community communication infrastructure (HF and VHF) for TMD, NRD and NEMO; and (2.2) data management systems capable of fully integrating all sources of data including existing and future national observing networks, and forecast products, and with backup capability within the TMD and NRD.

B.3) Development of the MHEWS, which includes: (3.1) Computers, software and visualization tools for computation of impact forecasts and warnings including displays at NEMO and NRD; and (3.3) computers, software, furniture, generators for the Seismic Operations Center at NRD.

B.4) Reconstruction and refurbishment of facilities, which includes: (4.1) TMD; and (4.2) NRD Seismic Operations Center and NEMO emergency operations center.

C. Enhancement of the MHEWS Service Delivery System

This task aims to improve service delivery by enhancing the MHEWS to include impact forecast and warning services that delivery actionable information to the public at risk and to emergency services. This task comprises two parts:

C.1) Expansion of the MHEWS services to sectors, which includes (1.1) developing, improving and operationalizing new information services; (1.2) improving the means of delivering services to communities and individuals including the development of new mobile applications; and (1.3) providing feedback from users on the quality of services through public and sector specific surveys.

C.2) Support of MHEWS including impact forecasts and warnings, which includes: (2.1) developing SOPs, warning protocols and signals agreed with all stakeholders (2.2) Operational training and drills with government stakeholders and communities; (2.3) Vulnerability assessments for each identified hazard and for the entire country; and (2.4) introducing and pilot testing (jointly with DRM agency) of impact forecasting techniques and warnings.

Sub-Component 1.2: Resilient Investments

This sub-component will identify priority investments in physical resilience and public asset retrofitting with a view to supporting community preparedness and response efforts.

The tasks include:

A. Training for community-based organizations and national agencies working with communities to include natural hazard risk considerations.

B. Support to develop and test for each community evacuation plans and procedures that identify suitable shelters and safe evacuation routes. Evacuation procedures will need to be congruent with warnings issued from the warning center.

C. Retrofitting of public facilities, in particular schools and health facilities, identified as community evacuation centers to ensure that they conform to the national building code and meet the requirements of an emergency shelter.

Regionally Supported Activities

Several of the project activities depend on regional cooperation and would provide a common warning platform for all participating countries. These include the following:

	Activity
A1.2	"Twinning" operational support from WMO (SWFDP, FFG, Impact Forecasting, MHEWS)
A2.1	Developing and implementing capacity building training program
A3.1	Detailed design of the MHEWS systems, procurement and implementation support (Systems Integrator Consultant)
C1.1	Development, improvement and operationalization of production of basic and specialized information products
C2.1	Development of SOPs, warning protocols and signals agreed with all stakeholders
C2.3	Vulnerability assessments for each identified hazard

5. Cost Estimates

The estimated cost Component 1 of the proposed investments for Tonga is shown below.

Activity	Cost (US $)
Subcomponent 1.1 – A. Institutional and Regulatory Strengthening, capacity building and implementation support	1.95M
Subcomponent 1.1 – B. Modernization of the Observation Infrastructure, Data Management Systems, Forecasting and Warning Systems	7.85M
Subcomponent 1.1 – C. Enhancement of the Service Delivery System	2.4M
Subcomponent 1.2 – Resilient Investment	2.5M
TOTAL	14.7M

6. References

Davidson, Jim and M.C. Wong, 2005: Guidelines on Integrating Severe Weather Warnings into Disaster Risk Management. PWS-13, WMO/TD NO. 1292. http://library.wmo.int/pmb_ged/wmo-td_1292.pdf

Rogers, David P. and Vladimir V. Tsirkunov, 2013: Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services. World Bank, Washington, DC. https://www.gfdrr.org/sites/gfdrr.org/files/publication/Weather_and_Climate_Resilience_2013.pdf

Tang, Xu, Lei Feng, Yongjie Zou, and Haizhen Mu. 2012. "The Shanghai Multi-Hazard Warning System: Addressing the Challenge of Disaster Risk Reduction in an Urban Megalopolis." In Institutional Partnerships in Multi-Hazard Early Warning Systems, edited by Maryam Golnaraghi, 159–79. Heidelberg, Germany: Springer.

WMO Guidelines on Impact Forecast and Warning Services, 2015. https://www.wmo.int/pages/prog/www/DPFS/Meetings/ET-OWFPS_Montreal2016/documents/WMOGuidelinesonMulti-hazardImpact-basedForecastandWarningServices.pdf

Annex 1 – WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services (2015)

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Annex 2 - Concept of a Multi-Hazard Early Warning System (MHEWS) including Impact Forecast and Warning Services

Multihazard Early Warning System (MHEWS) in PICs should be updated and extended in line with best international practices (Tang et al. 2012) to provide warnings of the *impact* of hydrometeorological hazards and geophysical hazards (Annex 1). The risk of the cascading impact of natural hazards highlights the importance of developing a system that can increase the capability of decision-makers, emergency services and ordinary people to take effective actions that reduce the risk of disaster. The MHEWS focuses on managing the potential cascade of disasters stemming from an initial hydrometeorological or geophysical hazard, the primary, secondary and sometimes tertiary impacts require well-ordered coordination and cooperation to support those vulnerable and exposed to the hazards (Rogers and Tsirkunov 2013).

Extensive, operational multi-agency coordination is required for a multiphase response to reduce the impact of natural hazards based on Standard Operating Procedures (SOPs). For hydrometeorological hazards, good practice indicates that these SOPs should be based on the following:

1. Early monitoring, objective weather forecasting and impact forecasting. Monitoring, hydrometeorological and geophysical hazard forecasts and warning services are the responsibility of the National Meteorological Service (NMS) and its partners using all available data, model guidance, etc. Impact forecasts and warnings would be based on these hazard forecasts combined with exposure and vulnerability information, which would need to be acquired in coordination with the Disaster Management Office (Davidson and Wong 2005).

2. Early briefing to decision-makers, special users, and agencies well in advance of public warnings. These briefing would include both information on the hydrometeorological hazard (the so-called "objective forecast"), the potential impact of the hazard and likelihood of occurrence. This would trigger the appropriate response from these stakeholders to reduce the adverse impacts of the event.

3. Early Warnings for the public would be prepared, which would include the normal hydrometeorological warning as well as impact warnings. The latter would include specific instructions about actions to be taken. The latter would evolve from impact-based warnings to impact warnings as skills evolve (see Annex 1 for WMO Guidelines on Impact Forecast and Warning Services for more details on this aspect).

4. Early dissemination of the warnings to all those who need to take action using all available means of communication appropriate to the situation and location of people.

5. Early handling of the situation by emergency services and those responsible for the safety of people and livelihoods.

The MHEWS should have two components: one focuses on management of the system: the other on the technical aspects. The management component includes a multi-agency coordination mechanism consisting of all government organizations, and a social community protection system, which includes the appropriate basic social units within communities. The technical component is based on six platforms or systems. These include:

1. Monitoring and Detection Platform – This consists of network of observations, as well as access to a various regional and global products available through WMO Regional

Specialized Meteorological Centers (RSMCs) and the Pacific Tsunami Warning Center, for example.

2. Forecasting and Warning Platform – The Forecasting and Warning Platform utilizes the data from the monitoring and detection platform, combined with numerical weather prediction and other guidance from the RSMCs, which enables the TMD forecasters to prepare objective weather forecasts, alerts and warnings and to prepare flood alerts and warnings and based on these forecasts and guidance. The next steps are to prepare hazard impact forecasts, alerts and warnings based on the likely impact of the event. This would be the primary responsibility of TMD forecasters, working in close cooperation with the Decision-making Support Platform.

3. Decision-making Support Platform – The decision-making support platform would be the means by which the objective forecast (e.g., the weather forecast) is combined with information on vulnerability and exposure. For example, the meteorologist responsible for weather forecast would provide appropriate information about the likelihood of occurrence of a hazard, while the impact forecaster/advisor or disaster risk management specialist (hereafter the Public Weather Service Advisor)[2] would be responsible for identifying the potential impact on the population and livelihoods. It is anticipated that this would be an iterative process with the meteorologist and Public Weather Service Advisor updating each other on the evolving situation as the hazard evolves or as the exposure of people changes, or both.

4. Warning Information Dissemination Platform – The Warning Information Dissemination Platform would be the primary means through which alerts and warnings are disseminated to stakeholders, specialized users and the public. It must ensure that messages are consistent, actionable, disseminated through multiple channels, communicated quickly, and received effectively. The dissemination system could use color-coded symbols, which would be consistent across all agencies responsible for providing warnings. The means of dissemination would include radio, television, mobile short messages, telephone landlines, etc. In the case of limited impact, warning communication should be targeted as closely as possible to those identified as at risk.

5. Database Platform – The Database Platform consists of historical and real-time data supplied by all the agencies and sectors at risk. It is important that this database is maintained to ensure the currency of vulnerability and exposure information.

6. Multi-Agency Support Platform – The Multi-Agency Support Platform supports the development and updating of SOPs for all of the agencies involved whether providers of information and services or users of information and services. The aim is to facilitate efficient cooperation across all government emergency managers. Early briefing prepares departments and agencies ahead of the joint response mechanisms and before warnings are issued to the public. This platform should also be responsible for ensuring that all stakeholders understand and heed warnings.

The MHEWS should be dynamic; that is, it should be designed to evolve with changing circumstances and needs.

[2] This post could be a meteorologist or disaster management specialist with the specific task of providing advice about hazard impacts. In some countries the title Public Weather Service Advisor is used. In small services the responsibility may remain with the meteorologist/forecaster or equivalent.

Annex 3: Detection, Monitoring, Analysis, Forecast and Warning of Natural Hazards

Event	Forecast Parameters	Scale	Impacts	National responsibilities	Regional Support	Global Support	Regional/ National Strengths	Regional/ National Weaknesses
Small scale convection	Rainfall intensity / amount Wind velocity	Local, confined to individual islands or smaller (10-100 km^2)	Localized flooding /flashfloods causing damage to property and loss of life, injury	*NMHSs / DRM* National Weather forecasts and Warnings; Impact Forecasts and Warnings, Early response, Evacuation / Shelter / etc.	*WMO RSMCs with responsibility for severe weather* Interpretation and downscaling of global NWP; Guidance to national meteorologists and hydrologists	*WMO Global Centers* Global multi-model NWP outputs supplied to *RSMCs with responsibility for severe weather*	Forecasting skill exists within NMHS WMO RSMC Wellington supports Severe Weather Forecasting Demonstration Project (SWFDP)	No impact forecast and warning at national level
Large scale convection (supercells)	Rainfall intensity / amount Wind velocity	Multiple islands, affects several countries simultaneously (1,000 - 10,000 km^2)	Extensive flooding / flash floods causing damage to property and loss of life/ injury. Wind damage to structures and power-lines with potential loss of life or injury	*NMHSs / DRM* National Weather forecasts and Warnings; Impact Forecasts and Warnings, Early response, Evacuation / Shelter / etc.	*WMO RSMCs with responsibility for severe weather* Interpretation and downscaling of global NWP; Regional scale NWP; Guidance to national meteorologists and hydrologists;	*WMO Global Centers* Global multi-model NWP outputs supplied to *RSMCs with responsibility for severe weather*	Forecasting skill exists within NMHS WMO RSMC Wellington supports Severe Weather Forecasting Demonstration Project (SWFDP)	No impact forecast and warning at national level
Tropical Cyclones	Rainfall intensity / amount Wind velocity Storm surge (wind- driven, sea water inundation)	Medium scale, affects countries in path (1,000 km^2)	Extensive flooding / flash floods causing damage to property and loss of life/ injury. Wind damage to structures and power-lines with potential loss of life or injury	*NMHSs / DRM* National Weather forecasts and Warnings; Storm surge forecasts; Impact Forecasts and Warnings, Early response, Evacuation / Shelter / etc.	*WMO RSMCs with responsibility for Tropical Cyclones* Interpretation and downscaling of global NWP; Regional scale NWP; Storm surge modeling; Guidance to national meteorologists and hydrologists;	*WMO Global Centers* Global multi-model NWP products supplied to *RSMCs with responsibility for Tropical Cyclones*	Forecasting skill exists within NMHS RSMC Nadi provides support for TC forecasts and warnings	No regional NWP No impact forecast and warning at national level

Drought	Rainfall, temperature	(1,000 – 10,000 km^2)	Extensive crop failures and freshwater scarcity	*NMHSs, Agricultural Advisory Services* Climate outlook forums	*Regional Climate Centers* Downscaling climate data; Climate Outlook Forums	*WMO Global Centers* responsible for season and longer scale prediction		No drought monitoring service No regional climate center
Tsunami	Shallow water wave	Up to basin wide (100 – 10,000 km^2)	Extensive coastal flooding causing damage to property, loss of life and injury	*NMHSs / DRM / others* Impact Forecasts and Warnings, Early response, Evacuation / Shelter / etc.	*Tsunami Warning Centers* Warning guidance issued to national authorities	N/A	Geo-hazard monitoring and forecasting	Pacific Typhoon Warning Center no longer providing warnings to Tonga (As of Oct 2014) No impact forecast and warning at national level
Volcano	Volcanic ash	Local/regional; potential threat to larger scales due to air travel (10 – 10,000 km^2)	Damage to structures, loss of life and injuries, disruption to air traffic	*NMHSs / DRM* Early warning Early response, Evacuation / Shelter / etc.	*WMO RSMCs with responsibility for aviation safety* Downscaling of global NWP; Regional NWP; Volcanic ash advisories	*WMO Global Centers with specialized responsibility for volcanic ash advisories* Global NWP products supplied to *RSMCs*		VAAC should be provided for aviation via Fiji Met Service, which is the aeronautical met service provider in Tonga
Earthquake	none	Local (1 – 1,000 km^2)	Damage to structures, loss of life and injuries	*Agencies responsible for Geo-hazards / DRM* Early response & recovery	Regional monitoring	Global monitoring	National seismic monitoring	Insufficient sites