Pacific Meteorological Council

Weather Ready Pacific – A Decadal Program of Investment

May 2021

Executive Summary

The need for a Decadal Program of Investment

Pacific island countries are vulnerable to a wide range of weather, climate, hydrological, ocean and other related environmental extreme and high impact events, including tropical cyclones and typhoons, strong winds, high waves and seas, earthquakes, volcanic eruptions, t drought, coastal inundation (including storm surges, waves, swell and tsunami) and flash floods. Already in the 2020-21 cyclone season, Fiji has been devastated by two severe tropical cyclones, causing loss of life and widespread damage, whilst Samoa was badly affected by flooding and landslides in December 2020. Economic losses from cyclones and flooding in the South Pacific region in 2020 were around $1 billion with at least 71 lives lost.

Further, the risks posed by extreme events are increasing as the Pacific region is particularly vulnerable to climate change and it is likely that extreme events will become more intense and/or frequent in coming decades. Pacific Island countries will be significantly affected by sea level rise, which will greatly increase the risks posed by coastal inundation events. Climate change and disaster risks undermine the ability of the Pacific region to reach Sustainable Development Goals.

The forecasts and warnings provided by National Meteorological and Hydrological Services (NMHSs) are essential to the safety and well-being of Pacific people and communities, protection of property and contribute to sustainable development. During the past decade, there has been significant investment in weather, climate, hydrological and ocean related capacity and infrastructure in the Pacific region, which has resulted in improvement in the capacity and capabilities of NMHSs as outlined in the Pacific Islands Meteorological Strategy (2017-2026). However, critical gaps remain: governance arrangements, mandate, strategic plans and institutional support are lacking in some countries; the observation network is patchy and the ability to invest in and maintain modern observational infrastructure is limited; similarly, computational infrastructure and capacity is not up to global standards; forecasting systems in use are highly variable in approach and quality; there are insufficient qualified meteorological and technical staff to develop and deliver accurate, localised and impact-based forecasts and warnings. This creates challenges for NMHSs in providing the information needed by government, communities and industries (e.g. agriculture, fisheries, aviation, tourism) to better prepare for extreme events and manage the subsequent impacts on livelihoods and economies.

To address these critical gaps, a decadal response is needed urgently to enable Pacific island countries and territories to better anticipate and respond to high impact and extreme weather, hydrological, climate, oceanic and other related environmental events and their associated risks. In particular, empowering Pacific NMHSs to engage credibly with the communities, customers, partners and stakeholders contributes to more informed local and regional decision making, potentially saving lives and livelihoods. Further, enhancing capability builds a stronger platform for the region to manage the impacts of climate change and equipping countries with valuable information to inform adaptation and resilience strategies.

At its fifth biennial meeting in Apia, Samoa in August 2019, the Pacific Meteorological Council (PMC) recommended the Secretariat of the Pacific Regional Environment Programme (SPREP) commission a study to scope the feasibility for a Decadal Program of Investment to enable the Pacific Small Island Developing States to better anticipate, prepare for and respond to those risks. This report is the result of the scoping project and it provides a Decadal Program of Investment to underpin the ability of NMHSs to deliver effective and timely forecasts and warnings to Pacific communities and industries. It is also complementary to regional initiatives that aim to enhance resilience to climate change and disasters such as the Framework for Resilient Development in the Pacific: An Integrated Approach to Address Climate Change and Disaster Risk Management (FRDP).

Consultation Findings

To ensure the Decadal Program of Investment and its recommendations are based on a thorough understanding of current status, gaps and needs across Pacific island countries and territories, it was critical that there was engagement with the NMHSs in SPREP member countries and territories. In parallel, a thorough review was undertaken of previous assessments and reports and ongoing and planned projects related to strategy, infrastructure and capacity to gain insights and avoid duplication and repetition.

Key points to emerge from these consultations and document review were:

(a) **Governance and coordination**

- Many countries identified the need for more specific Meteorological Acts and/or strategic plans;
- A holistic approach to improving meteorological and hydrological services is needed. At present there is a major gap in that there are many modest scale initiatives from multiple agencies and donors, resulting in a fragmented patchwork of investments;
- Meteorological, hydrology and marine/coastal services need better integration to effectively deliver impact-based forecasts for extreme events such as tropical cyclones and typhoons, strong winds, high waves and seas, drought, heavy rainfall, riverine flash flooding, coastal inundation (including storm surges and coastal floods);
- There is generally good coordination with National Disaster Management Offices (NDMOs) and the ambition for stronger hazard and risk identification, detection and assessment, and integrate these into impact-based messaging in forecasts and warnings and improving the communication systems and messaging to communities;
- There is a need for leadership and management training for Directors and senior managers to help deliver better meteorological, hydrological, ocean services and other related environmental services.

(b) **Forecast production and delivery**

- The approach of cascading forecasts from Global Production Centres (GPC) to Regional Centres and then forecasts and warnings issued locally from NMHSs is potentially most effective. This is in part achieved through the WMO Severe Weather Forecasting Demonstration Project (SWFDP, now SWFP) that provides warning and general forecast information through MetConnect, implemented by MetService New Zealand, but its long-term sustainability requires committed resources. The approach for cascading forecasts at the national level has shown to be effective via the WMO Coastal Inundation Forecasting Initiative (CIFI);
- Information, Communication and Technology (ICT) and national data systems need to be improved to better support weather, climate, water, ocean and other related environmental hazard and impact-based forecast and warning delivery systems with most NMHSs indicating a critical shortage of Information Technology (IT) staff. In many NMHSs, internet connectivity and bandwidth problems limit upload and download, and exchange of data;
- There is a need to better translate technical terms in forecasts and warnings into locally relevant risk, impact and response messages and incorporating traditional knowledge; for remote communities delivering forecasts and warnings in a timely way remains a challenge.

(c) **Infrastructure and observations**

- Observation equipment is acquired through multiple projects in an uncoordinated way, leading to a diversity of equipment types;
- Ongoing maintenance of equipment and having the required number of appropriately trained electronics technicians is a challenge for most NMHSs. Investment in new infrastructure should include in its budget provision for a long-term maintenance and operating schedule and a training program;
- Compared with surface observation equipment there is a lack of infrastructure investment in oceans (wave heights, tide gauges, salinity, sea surface temperature) and river gauging equipment (levels, flows, discharges);
- Few observations are provided to global observing networks and programmes such as the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), Global Basic Observing Network (GBON), WMO Integrated Observing System (WIGOS), Regional Basic Synoptic Network (RBSN), Regional Basic Climate Network (RBSN) though considerable data is now being captured in the Climate Data for Environment (CLiDE), a Climate Database Management System (CDMS) providing Pacific Island countries with a central database for climate data.

(d) **Capacity and training**

- Only a few of the NMHSs have forecasters trained to the level of the WMO Basic Instruction Package for Meteorologist (BIP-M) and there are also insufficient forecasters trained to the level of WMO Basic Instruction Package for Meteorological Technician (BIP-MT);
- To overcome constraints in travelling overseas for extended periods, new thinking is required around approaches to forecaster training, including hybrid models of online training coupled with more focused face to face intensive training modules. In addition to specific training, strengthening the capacity of NMHS with robust skills to deliver along the value chain from research to operations is critical.

Investment Framework

The proposed decadal program of investment seeks to cohesively and comprehensively respond to these findings, and deliver the following outcomes for Pacific island countries and territories:

1. For all nations, assured access to localised, accurate and timely forecast and warning products:
    - derived utilising world-leading forecasting capability;
    - accessed via a Pacific Weather Exchange;
2. The ability to better communicate impacts – what the weather will do rather than what the weather will be;
3. Strengthened preparedness and response to severe weather events that provides improved safety for all communities in the region and travellers;
4. Increase in adaptive capacity of industries and communities to manage the impacts of climate change related weather, hydrological and ocean extreme events;
5. Reduced economic impacts of extreme events on key industries (agriculture, fisheries, aviation, tourism) and livelihoods of small businesses, farmers etc.;
6. For some nations, the generation of revenue derived from industry partnerships (e.g. energy, aviation, agriculture, tourism);
7. Pacific issues receive greater consideration in multilateral settings.

The resulting proposed Decadal Program of Investment takes into account:

- the depth, and breadth of the needs identified by NMHSs;

- variability of existing capability and training programs across Pacific island countries and territories;
- equipment maintenance and sustainability challenges;
- the critical interdependence between the individual components of an effective; meteorological service and the need for a comprehensive, regionally coordinated approach that draws on global products and services;
- related key projects and investments underway and planned across the region and the contribution NMHSs can make to broader regional resilience initiatives such as the Framework for Resilient Development in the Pacific (FRDP).

The Program focuses on five components:

1. **Strategy and Governance:** Supporting and strengthening governance and institutional arrangements, leadership, planning, and management of NMHSs and NDMOs and provide a key coordination function in partnership with the Pacific Meteorology Desk Partnership (PMDP) and the PMC.

   Under this component the Program will:

   (i) Develop a Pacific Meteorological Leadership Program and deliver this to 60 NMHS leaders over the decade. Training will aspects of governance, strategic planning, financial management, communication;

   (ii) Put in place a Management and Advisor Team who will have responsibility for coordinating the implementation of the Decadal Program of Investment and work in partnership with the PMDP and with the PMC and its six technical panels and provide support in implementing strategic plans at the national level.

2. **Production of forecasts and warnings:** Strengthening regional and national severe weather forecasting and warning systems using impact-based approaches that better prepare communities and industries to deal with high impact and severe weather events, floods and coastal hazard impacts. The key rationale for this investment area is strengthening the cascading forecasting system that links World Meteorological Centres, Regional Centre(s), which include Regional Specialised Meteorological Centres (RSMC) and NMHSs. This approach, to some extent, is already in place through RSMCs in Fiji, Wellington and Darwin and the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Office in Guam, together with delivery mechanisms such as the SWFP. However, it needs strengthening in three areas: the integrating capability between global, regional and national forecasting processes that can deliver automated and consistent forecasts and warnings which can be used either as guidance or as products for users at the discretion of each NMHS, potentially ~~will~~ freeing up forecasters for higher priority tasks; improving the breadth and depth of forecasting services within NMHSs; and a well-supported delivery platform, the Pacific Weather Exchange. It will provide NMHSs with access to a greater suite of high quality NWP products.

   Under this component the Program will:

   (i) Develop a comprehensive suite of automatically generated forecast and warning products for NMHSs, from post-processing of numerical weather prediction, including 7-day forecasts for as many individual locations as required by each NMHS which will include graphics as a way to avoid technical terms and translation issues as far as possible. This will also include hydrological products related to riverine flash flooding and sea level products that highlight areas at risk of coastal inundation;

   (ii) In combination with (i) above ensure that:

   - forecasts and warnings are more accurate, more localised and in some cases more timely;
   - forecasts and warnings are available to every pacific island nation regardless of national capacity challenges.

   (iii) Develop or enhance an existing data delivery system to contain and transmit these new products;

   (iv) Consolidate and strengthen the aviation weather forecasting hub in Fiji and build capacity of aviation forecasters in a small number of larger NMHSs;

3. **Communication and delivery of forecasts and warnings to end-users:** Enhance the ability of NMHSs and NDMOs to communicate impact-based forecasts and warnings in a timely manner and in a way that facilitates action responses from individuals, communities, government and industries.

   Under this component the Program will improve the development and delivery of risk and impact-based messages through:

   (i) End-user workshops to identify types of messages that will lead to response actions;

   (ii) Training of NMHS and NDMO staff in development of impact-based messages including the use of traditional knowledge and how to reach groups disproportionately affected by extreme events, including women and people with disabilities;

   (iii) NMHS training workshops in the use of the WMO Common Alerting Protocol;

   (iv) Workshops between NMHSs and NDMOs to improve governance and delivery mechanisms so that pathways for forecasts and warnings are highly effective.

4. **Infrastructure:** Provide enhanced hydro-meteorological infrastructure networks and associated IT equipment that meets emerging and future needs and do this in a targeted and coordinated way to complement existing and planned initiatives.

   Under this component the Program will:

   (i) Refurbish existing Automatic Weather Stations (AWSs) and river gauge networks and ensure they have connectivity with and deliver data to, WMO's Global Telecommunications System (GTS);

   (ii) Fill significant surface observations gaps with new equipment that become evident following the refurbishment listed above;

   (iii) Establish a network of automated upper air observations stations that will complement and "ground truth" remotely sensed data to improve input into NWP systems;

   (iv) Installation of weather watch radars around major population centres and international airports to improve safety;

   (v) Retrieval of meteorological data from selected commercial aircraft that operate through the region;

   (vi) Expand ocean observations networks to provide better coverage of waves and tides;

   (vii) Refurbish existing IT infrastructure and expand it where necessary to support the strengthened forecast and warning services being proposed above. This will also ensure that the much expanded observational data can be effectively and efficiently transmitted to global observing networks. The support for observation infrastructure and observations being delivered to global observing networks needs to complement the WMO Systematic Observations Financing Facility (SOFF) initiative.

5. **Capacity building:** Build the capacity of NMHS forecasters, hydrologists, oceanographers, observers, electronics technicians, and information and data technologists. In developing training and capacity building initiatives, care has been taken to ensure that they complement rather than replace existing initiatives such as WMO Regional Training Centres in the Asia-Pacific region, WMO and other provider training courses, and the programs provided by the Pacific International Training Desk in Hawaii.

   Under this component the Program will provide:

   (i) A Secretariat to support a Regional Training Centre (RTC) in Fiji that focuses on accredited training for technicians and observers, and a hub for equipment servicing and calibration;

   (ii) Training for observers and technicians at the RTC;

   (iii) Training of WMO standard forecasters using a hybrid model of online courses complemented with an intensive face to face component;

   (iv) Training of hydrographers and hydrologists for staff in countries severely affected by flash floods;

   (v) Training of staff (especially meteorologists, oceanographers and hydrologists) in countries severely impacted by coastal inundation, including tsunamis;

   (vi) Professional development courses undertaken in the region drawing on external experts;

   (vii) Twinning program to provide mentoring from highly developed hydro-meteorological services.

A conceptual framework for how these investment areas come together to deliver an integrated package that improves NMHSs and the products they deliver is provided in Figure 1. Critical to this plan is the interaction with global and regional observing systems and centres that develop numerical weather prediction and satellite products, essential for the delivery of the proposed cascading forecast system.

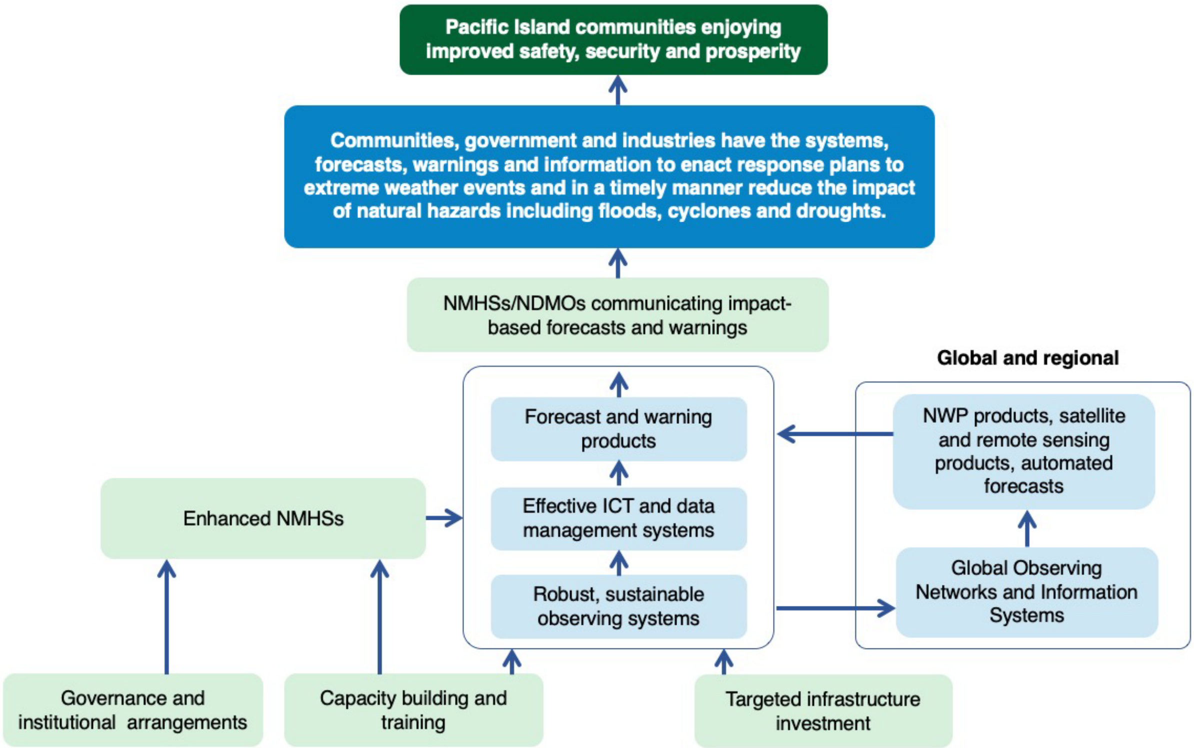

Figure 1: Conceptual representation of how the Decadal Program of Investment in the Pacific (light green boxes) needs to interact with regional and global observing networks and forecast centres (light blue box) to deliver desired community outcomes.

Summary of proposed investments

The investment required to provide a much enhanced, well-coordinated and sustainable NMHS network is significant. Table 1 provides a summary of the proposed investments over the decade. For the areas of governance, forecasts and warnings, and capacity and training it is envisioned that investment would commence in Year 1 and be sustained over decade. This is to ensure the capacity and systems are self-sustaining by the end of the decadal term of investment. There is a need to significantly uplift infrastructure capacity across the Pacific. This is not just in observational infrastructure but also in computers, servers, forecaster workstations etc. This requires both a large capital investment and, more importantly, the operating funding to ensure the equipment is maintained over the decadal timescale. It is envisioned that infrastructure will be deployed gradually over the first 5 years of the 10-year investment. This phasing in of infrastructure will allow for lessons learned with the first infrastructure deployments to be taken into account in subsequent infrastructure purchase and deployment. Consistent with this approach operating costs for infrastructure ramp up over the first three years of the decadal investment period. External reviews will be conducted after Years 3 and 6 to ensure the program is delivering and provide recommendations for program change and/or enhancement. The Year 6 Review will focus on enduring sustainability of the program beyond the decadal investment phase. Given the funding arrangements are still to be determined (single donor, multiple donors etc), the investment plan does not include any donor management and governance costs, which will ultimately need to be factored into the overall program.

Table 1: Operating and capital costs associated with the Decadal Program of Investment (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Governance	0.96	0.9	1.15	1.26	1.2	0.99	1.61	1.04	1.33	1.27	**11.71**
Forecasts production	2.99	3.48	3.15	3.67	3.77	3.83	3.86	3.86	3.86	3.91	**36.38**
Forecasts communication	0.35	0.17	0.18	0.36	0.19	0.21	0.39	0.2	0.21	0.21	**2.47**
Infrastructure - CAPEX	5.04	7.55	7.55	15.11	15.11						**50.37**
Infrastructure - OPEX	1.71	2.96	4.13	5.38	5.51	5.81	5.78	5.95	6.08	6.21	**49.52**
Capacity/training	1.98	1.32	1.37	1.38	1.55	2.14	1.57	1.47	1.71	1.63	**16.12**
Total	**13.03**	**16.38**	**17.53**	**27.16**	**27.33**	**12.98**	**13.21**	**12.52**	**13.19**	**13.23**	**166.6**

Whilst USD 167 million represents a significant investment, it is over a decade. Recent estimates of average annual losses in GDP in Pacific Island Countries due to natural disasters are in the order of USD 500 million or USD 5 billion over a decade. These estimates do not include losses of life or disruptions to livelihoods and social cohesion. If the improved services and delivery of forecasts and warnings from NMHSs could prevent just 5% of these losses (USD 250 million) that represents a positive return on investment. That superficial assessment of benefit is likely very conservative as other economic analyses of NMHS improvements to reduce disaster losses in developing countries show a Benefit-Cost Ration of 4:1 to 36:1. Clearly, the human and financial cost of not acting is higher than the cost of acting through the investments proposed in this Decadal Program of Investment.

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List of Acronyms

Acronym	Description
ACCESS-S	Australian Community Climate Earth-System Simulator – Seasonal
ADPC	Asia Disaster Preparedness Center
AMBLS	Automated Meteorological Balloon Launching System
AMDAR	Aircraft Meteorological Data Relay
AMSR-E	Advanced Microwave Scanning Radiometer
APCC	Asia Pacific Climate Center
APEC	Asia and Pacific Economic Cooperation
AWIPS	Advanced Weather Interactive Processing System
AWS	Automatic Weather Station
BIP-M	Basic Instruction Package - Meteorology
BIP-MT	Basic Instruction Package - Meteorological Technician
BoM	Bureau of Meteorology (Australia)
CAP	Common Alerting Protocol
CDMS	Climate Database Management System
CIFI	Coastal Inundation Forecasting Initiative
CIMS	Chemical Ionization Mass Spectrometer
CLEWS	Climate Early Warning System
CLiDE	Climate Data for Environment
ClimSA	Climate Services and Application
CMA	China Meteorological Agency
COSSPac	Climate and Oceans Support Program in the Pacific
CREWS	Climate Risk and Early Warning Systems
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EAR Watch	Early Action Rainfall Watch
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EMO	Emergency Management Office

Acronym	Description
EPS	Ensemble Prediction Systems
ESCAP	Economic and Social Commission for Asia and the Pacific
EWS	Early Warning System
FFGS	Flash Flood Guidance System
FMI	Finnish Meteorological Institute
FMS	Fiji Meteorological Service
FNU	Fiji National University
FSM	Federated States of Micronesia
FRDP	Framework for Resilient Development in the Pacific
GBON	Global Basic Observing Network
GCF	Green Climate Fund
GEF	Global Environment Facility
GCOS	Global Climate Observing System
GDPFS	Global Data Processing and Forecasting System
GISC	Global Information System Centres
GOOS	Global Ocean Observing System
GIZ	Gesellschaft für Internationale Zusammenarbeit
GPC	Global Production Centres
GSN	GCOS Surface Network
GTS	Global Telecommunication System
GUAN	GCOS Upper Air Network
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICT	Information and Communications Technology
IFRC	International Federation of Red Cross and Red Crescent
IHO	International Hydrographic Association
IMO	International Maritime Organisation
IOM	International Organisation for Migration

Acronym	Description
IT	Information Technology
JICA	Japan International Cooperation Agency
JMA	Japan Meteorological Agency
JTWC	Japan Typhoon Warning Centre
KMA	Korea Meteorological Agency
KMS	Kiribati Meteorological Service
LAM	Limited Area Model
LDC	Least Developing Countries
MEPS	Multi-Model Ensemble Prediction Systems
MetService	Meteorological Service of New Zealand
MFAT	Ministry of Foreign Affairs and Trade
MHEWS	Multi-Hazard Early Warning System
MODIS	Moderate Resolution Imaging Spectroradiometer
NDC	Nationally Determined Contributions
NDMO	National Disaster Management Office
NGO	Non-Government Organisation
NIWA	National Institute of Water and Atmospheric Research
NHS	National Hydrological Service
NMHS	National Meteorological and Hydrological Service
NMS	National Meteorological Service
NOAA	National Oceanic and Atmospheric Administration
NUS	National University of Samoa
NWP	Numerical Weather Prediction
NWS	National Weather Service (United States)
PASO	Pacific Aviation Safety Office
PIAWS	Pacific Island Aviation Weather Services
PHS	Pacific Hydrological Services
PICASO	Pacific Island Countries Advanced Seasonal Outlook

Acronym	Description
PICI	Pacific Island Communications and Infrastructure
PICS	Pacific Islands Climate Services
PIETR	Pacific Island Education, Training and Research
PIF	Pacific Island Forum
PIFS	Pacific Island Forum Secretariat
PIMOS	Pacific Island Marine and Oceans Services
PIMS	Pacific Islands Meteorological Strategy
PMC	Pacific Meteorological Council
PMLP	Pacific Meteorological Leadership Program
PNG	Papua New Guinea
PMDP	Pacific Meteorology Desk Partnership
PREP	Pacific Resilience Programme (World Bank)
PRP	Pacific Resilience Partnership
PTWC	Pacific Tsunami Warning Centre
QMS	Quality Management System
RAV	Regional Association V (WMO)
RCC	Regional Climate Centre
RMI	Republic of Marshall Islands
ROK-PI CLiPS	Republic of Korea-Pacific Islands Climate Prediction Services
RSBN	Regional Basic Synoptic Network
RSMC	Regional Specialised Meteorological Centre
RTC	Regional Training Centre
SDG	Sustainable Development Goals
S/GDPFS	Seamless Global Data Processing and Forecasting System
SIDS	Small Island Developing States
SOFF	Systematic Observations Financing Facility
SPC	Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme

Acronym	Description
SWFDP	Severe Weather Forecasting Demonstration Project
SWFP	Severe Weather Forecasting Programme
SWIM	System Wide Information Management
TMI	Tropical Rainfall Measuring Mission's Tropical Microwave Imager
TMS	Tonga Meteorological Services
UKMO	United Kingdom Meteorological Office
UN RESPAC	United Nations Disaster Resilience for Pacific SIDS
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UPNG	University of Papua New Guinea
USAID	United States Agency for International Development
USP	University of the South Pacific
VMS	Vanuatu Meteorological Service
WCRP	World Climate Research Program
WFP	World Food Programme
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMC	World Meteorological Centres
WMO	World Meteorological Organisation
WRF	Weather and Research Forecasting model

1. Background and Approach

1.1. Background

Pacific island countries are vulnerable to a wide range of weather, climate and ocean extreme and high impact events, including tropical cyclones and typhoons, high waves and seas, earthquakes, volcanic eruptions, drought, coastal inundation (including storm surges, and tsunami), heavy rain and flash floods. Already in the 2020-21 cyclone season, Fiji has been devastated by two severe tropical cyclones, causing loss of life and widespread damage, whilst Samoa was badly affected by flooding and landslides in December 2020. Economic losses from cyclones and flooding in the South Pacific region in 2020 were around USD 1 Bn with at least 71 lives lost[1]. Individual events can cause very significant losses – Tropical Cyclone Winston in 2016 affected over half of Fiji's population resulting in USD 900 M in losses whilst Tropical Cyclone Pam in 2015 reduced Vanuatu's GDFP by 60%[2].

More recent estimates put the average annual loss in GDP in the South Pacific for a natural disaster to be around 14.4% with a 34% likelihood of a natural disaster occurring in any year[3]. That analysis also includes the impacts of drought, which plays out over a longer timescale but usually impacts far more people than short-term weather or oceanic events. The damage estimates from these combined events equate to an average annual loss in GDP of 4.9% and with a total GDP in the Pacific Islands of USD10.35 billion that equates to an average annual loss of USD 507 million. These estimates do not include losses of life or disruptions to livelihoods and social cohesion.

Further, the risks posed by extreme events are increasing as the Pacific region is particularly vulnerable to sea level rise and climate change and it is likely that extreme weather events will become more intense and/or frequent in coming decades. Climate change and disaster risks increase the vulnerability of Pacific Island people, and significantly undermines the ability of the Pacific region to reach Sustainable Development Goals. As WMO and the World Climate Research Program note[4], coastal sea level rise is among the most severe consequences of climate change and the Pacific is at particular risk from this aspect of climate change. Contemporary global mean sea level rise will continue over many centuries as a consequence of climate warming and it will exacerbate coastal inundation events associated with storm surges and tsunamis.

The services provided by National Meteorological and Hydrological Services (NMHSs) are essential to the safety and well-being of Pacific people and communities, protection of property and contribute to sustainable development. They support key economies and livelihoods across a wide range of sectors; agriculture, tourism, water resource management, aviation, shipping, energy, infrastructure and transportation. As the global climate changes and extreme events become more intense or frequent, the need for enhancing climate change adaptation and resilience through the role and integration of meteorological and hydrological services across all social, environment and economic areas is becoming more important. The Framework for Resilience Development in the Pacific (FRDP) Goal 3 calls for improving Pacific island countries and territories to prepare for emergencies and disasters ensuring timely and effective response and recovery to rapid disasters such as extreme weather, water and ocean events. Effective NMHSs can also contribute to the achievement of the Sustainable Development Goals (SDG) in the Pacific, especially SDG Goal 13.1, Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries and Goal 11.5, "By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations."

In addition to national mandates, the role of NMHSs is shaped by a number of initiatives and strategies at regional and global scales. These range from high level strategies through to working groups and expert

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[1] Weather, Climate & Catastrophe Insight. 2020 Annual Report AON.
[2] Weathering Financial Shocks from Disasters in the Pacific Islands: https://www.worldbank.org/en/news/feature/2018/11/01/weathering-financial-shocks-from-disasters-in-the-pacific-islands
[3] Lee, D., Zhang, H., & Nguyen, C. (2018). The economic impact of natural disasters in Pacific Island countries: Adaptation and preparedness. International Monetary Fund.
[4] WCRP (wcrp-climate.org)

panels such as the Pacific Islands Meteorological Strategy 2017-2026 (PIMS), the Pacific Roadmap for Climate Services, the WMO Global Framework for Climate Services, WMO Global Climate Observing System (GCOS) Implementation Plan in the Pacific, the Pacific Meteorology Council Expert Panels, etc.

During the past decade, there has been significant investment in the development and improvement in the capacity and capabilities of NMHSs as outlined in the Pacific Islands Meteorological Strategy 2017-2026 (PIMS). NMHSs have achieved these improvements by working closely with the national, regional, global communities and development partners including the World Meteorological Organisation (WMO), United Nations Development Programme (UNDP), Food and Agricultural Organisation (FAO), United Nations Environment Programme (UNEP), International Civil Aviation Organisation (ICAO), International Maritime Organisation (IMO), International Hydrographic Organisation (IHO) United Nations Educational, Scientific and Cultural Organisation (UNESCO), World Food Programme (WFP), World Bank (WB), Asian Development Bank (ADB), Japan International Cooperation Agency (JICA), European Union (EU), New Zealand Aid, Australian Aid, United States International Cooperation Programme (USAID), United States National Ocean and Atmosphere Administration (US NOAA), Australian Bureau of Meteorology (BoM), MetService New Zealand, Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), New Zealand National Institute of Water and Atmospheric Research (NIWA), Asia and Pacific Economic Cooperation (APEC) Asia Pacific Climate Center (APCC), China Meteorological Agency (CMA), Korea Meteorological Agency (KMA), Japan Meteorological Agency (JMA), Asian Disaster Preparedness Center (ADPC), United Kingdom (UK) Met Office, European Center for Medium Range Weather Forecast (ECMWF), International Federation of Red Cross and Red Crescent (IFRC), Metéo France, Pacific Island Forum Secretariat (PIFS), Secretariat of the Pacific Regional Environment Programme (SPREP), Pacific Community (SPC), Pacific Aviation Safety Office (PASO) and developed country (Australia, France, New Zealand, Republic of Korean, China, Japan, Finland, Germany, Canada, Italy, Denmark, United Kingdom and USA). They also benefit from their close association the World Meteorological Organisation (WMO) and its global network of meteorological and hydrometeorological observations, information and services. As a result, most NMHSs have improved their technical skills required to process, prepare and deliver weather, water, climate, and other related environmental services to their governments, communities and other customers.

> As the global climate changes and extreme events become more intense or frequent, the need for enhancing climate change adaptation and resilience through the role and integration of meteorological and hydrological services across all social, environment and economic is becoming more important.

However, compared with the investment to support preparedness for climate change impacts through adaptation, there has been much less direct investment in resources to support preparedness and response to extreme weather, water, ocean and other related environmental events at shorter timescales. Much of the investment at weather timescales has been in the context of changing frequency and intensity of extreme events as a result of climate change.

Without dedicated investment at these shorter time scales there has been a lack of coherence and coordination in activities resulting in a patchwork of capacity building efforts and incompatibility of infrastructure, technology, methodology and approach in the weather, hydrology, and ocean domains. This has created downstream maintenance and replacement cost challenges and has hindered the necessary meteorological, hydrological and oceanic collaboration between Pacific countries and the crucial input of the needed data to global and regional Numerical Weather Prediction (NWP) models from the data sparse Pacific to Global Data Producing Centers and Regional Centers. Consequently, this limits the opportunity to generate and provide NWP products through the cascading process and eventually to enable NMHSs to provide the most basic of forecasting and warning services for their respective communities.

To address this critical gap, a decadal response is needed urgently to enable the Pacific island countries and territories to better anticipate and respond to extreme weather events, hydrological and oceanic risks. At its fifth biennial meeting in Apia Samoa in August 2019, the Pacific Meteorological Council (PMC) recommended that SPREP commission a study to scope the feasibility for a Decadal Program of Investment to enable the Pacific Island Countries and Territories to better anticipate, prepare for and respond to those risks. In addition to the Decadal Program of Investment underpinning the ability of NMHSs to deliver effective and timely forecasts and warnings to Pacific communities and industries, it will enhance resilience to climate change and disasters and support the guidance provided by the Framework for Resilient Development in the

Pacific: An Integrated Approach to Address Climate Change and Disaster Risk Management (FRDP). In doing so it will also recognise the critical role of integrating gender and disability considerations.

A Decadal Program of Investment would seek to:

(a) Provide enhanced hydro-meteorological, ocean and other related environmental infrastructure networks and systems, including weather radars, automated weather stations, riverine flood monitoring and prediction, upper air measurement stations and equipment, tsunami, sea level, physical and chemical ocean observation systems, wave buoys and coastal bathymetry;

(b) Support and strengthen institutional capacity including planning, management, operating, coordination, communication and public/communities' relations capacity of National Meteorological and Hydrological Services (NMHSs) and National Disaster Management Offices (NDMOs);

(c) Strengthen the capacity of NMHSs technologists, engineers and scientists to maintain and utilise the infrastructure and the data and products generated from investment in hydro-meteorological (including ocean) and other related environment sectors;

(d) Strengthen national and regional severe weather forecasting and community decision support capabilities including access to raw and especially post-processed output from high resolution numerical weather models;

(e) Support and strengthen NMHSs coordination with NDMO on identification, detection and assessment of hazards and risk and integrate these in risk, impact and response-based messaging in forecasts and warnings;

(f) Support the provision of tailored hydro-meteorological, ocean and other related environmental services for people disproportionately disadvantaged by extreme weather, hydrological and ocean events including women and people with disabilities.

A well-developed Decadal Program of Investment at a regional scale will complement existing initiatives that are often focused on a single issue or constrained to a few countries. It aims to drive a step-change in NMHSs that is sustainable in the long-term.

Achieving weather-ready Pacific island countries and territories will deliver significant economic, safety and security benefits to the region and the Pacific Islands' communities. Effective hydro-meteorological services improve the resilience of the region against risks of weather, climate, hydrological, ocean related natural disasters and can further improve the quality of critical decisions made in sectors sensitive to the extreme weather events, climate, water and ocean (agriculture, energy, water, tourism, fisheries, transportation, infrastructure, etc). It will reduce undue human losses and suffering and minimise consequences for the natural environment, social and economic systems upon which the Pacific Islands' communities depend on for their subsistence and livelihoods.

With this need identified, the Pacific Meteorological Council (PMC) commissioned the Weather Ready Pacific Program Scoping Project, with SPREP, WMO and the Australian Bureau of Meteorology (BoM) to work with Pacific stakeholders to develop a costed and phased plan for a Decadal Program of Investment to build the capacity of Pacific NHMSs.

Image 1: Samoa Meteorological Office at Mulinu'u, Apia, Samoa. This is one of the oldest weather observatories in the Pacific

1.2. Objectives of the Weather Ready Pacific Scoping Project

The scoping exercise aimed to:

(a) Identify existing and future severe weather, climate, water, ocean and other related environmental capacity needs for each Pacific island country and territory, including:

- hydro-meteorological infrastructure network;
- technical capacity;
- institutional capacity;
- human resources capacity; and
- products, services and stakeholder engagement.

(b) Assess the alignment and effectiveness of relevant existing and proposed programs in addressing Pacific island countries and territories needs.

(c) Identify priority investments for Pacific island countries and territories that are:

- economically, technically, and environmentally sound;
- targeted at addressing key risks to public safety and economic prosperity; and
- reflect due consideration of optimum and minimum viable approaches.

(d) Evaluate the capacity of Pacific island countries and territories to implement and sustain capability resulting from the delivery of priority investments and to determine resource requirements for ongoing sustainment.

(e) Present a Decadal Program of Investment in a format suitable to support consideration and decision by regional stakeholders during 2021.

To achieve these objectives the program scoping team undertook a consultation and engagement process with Pacific NHMS Directors and their staff, NDMOs, water resources agencies, SPREP and SPC, WMO and other National Meteorological Services (NMS) and agencies in the region. Due to COVID-19 travel restrictions all consultations and presentations occurred online.

1.3. Approach

(a) Initial planning discussions with SPREP, WMO, BoM

To assist in formulating this Scoping Plan, a series of discussions were held with SPREP and WMO and key BoM staff with experience in the Pacific region. The discussions with SPREP and WMO were particularly important for the design of the engagement and consultation process and in providing important background documentation.

(b) Document Review

Reports and assessments relating to current and recent initiatives in the Pacific were assessed to gain a good understanding of the breadth and diversity of activities in the Pacific. These were categorised into four areas: governance and institutional arrangements and strategies; infrastructure and observations; forecasts and warnings and delivery systems; and capacity building and training.

(c) Consultation with key stakeholders

(i) National Meteorological and Hydrological Services (NMHSs)

To achieve a high level of ownership of a Decadal Program of Investment and its recommendations, there was a consultation phase with individual NMHSs. This engagement process aimed to:

- Quantify existing infrastructure, institutional arrangements and human capacity in NMHSs and their effectiveness in addressing Pacific island countries and territories needs;
- Identify existing and future severe weather, water and ocean capacity needs, including priority investments that are economically and technically sound;
- Evaluate the capacity and training needs of each Pacific Small Island Developing State to implement and sustain new infrastructure, forecasting systems, and data and information delivery across the Pacific.

The consultation with NMHSs commenced with a high-level discussion with country NMHS Directors to discuss the project scope and deliverables and to seek feedback to help guide deeper engagement with individual NMHSs.

(ii) Other meteorological agencies and donors/funders

There are many governments, institutions and agencies involved in assisting Pacific Island countries improve their meteorological and hydro-meteorological services, as listed in the background above. Consultations were undertaken with a number of these key stakeholders to gain a better understanding of current activities, future plans, challenges, and opportunities. These included WMO, SPREP, SPC, the Australian BoM, MetService New Zealand, NIWA, NOAA NWS, UNDP, ADPC.

(iii) The Aviation Industry

Consultation was undertaken with the International Air Transport Association (IATA) and Fiji Airways on their perceptions of the state of aviation weather services in the region and the changes that were likely to be required of those services over the next decade.

Appendix 1 lists the NMHSs and various agencies who were consulted with during the course of this project.

(d) Development of Decadal Program of Investment

Based on the consultation and engagement with NMHSs, SPREP, WMO and other key stakeholders and analysis of reports and assessments, a Decadal Program of Investment was developed, which is the basis for what follows in this document. Key elements include:

- a summary of gaps and needs as identified in the review and consultation process;
- the rationale for the areas of investment, including a Pathway to Impact; and
- a fully costed program of interventions.

2. Synthesis of status, gaps, and needs from consultations and document review

To ensure the Decadal Program of Investment and its recommendations are based on a thorough understanding of current status, gaps and needs across Pacific Island countries, it was critical that there was (a) engagement with the NMHSs in SPREP member countries and territories to help identify gaps and needs, and (b) a thorough review of previous assessments and reports and ongoing and planned projects related to strategy, infrastructure and capacity to gain insights and avoid duplication. This section of the report provides a summary of the consultation process and the document and project review activities.

2.1. Consultation with NMHSs and other agencies

2.1.1. Summary

Consultations were undertaken with 16 Pacific Island Countries and Territories as well as other agencies important to the delivery of forecasts and warnings issued by NMHSs. Key points to emerge from these consultations were:

- Many countries identified the need for more specific Meteorological Acts and/or strategic plans;
- Hydro-meteorological, ocean and other related environmental services and risks need to be better integrated to effectively deliver risk, impact and response-based forecasts and warnings for tropical cyclones and typhoons, strong winds, high waves and seas, heavy and continued rain, riverine flash floods and coastal inundation (including storm surges, waves and swell) and other related events;
- There is generally good coordination with NDMOs and the ambition for stronger risk, impact and response-based messaging in forecasts and warnings and improving the communication systems and messaging to communities;
- There was a need expressed for leadership, coordination, communication, and management training for Directors and senior managers to help deliver better meteorological and hydrological, ocean and other related environmental services. This needs to be addressed in parallel with any constraining policies and institutional structures;
- There is little coordination amongst donors' projects which creates challenges in developing a coherent approach to infrastructure and capacity building. The PMC can play an important role here through its donor partner and engagement strategy;
- There is a significant diversity in approaches at national level to the preparation of forecast and warning information and a more coordinated system for this is worthy of consideration;
- Getting the messages to remote communities is still a challenge in many parts and in some jurisdictions the communication systems need improvements. The need for improved communications infrastructure is a specific country by country requirement that requires deeper understanding and is best addressed through the responsible the Ministry and through commercial communication infrastructure systems;
- There is a need to better translate technical terms in forecasts and warnings into locally relevant risk impact and response-based messages and incorporating traditional knowledge in warnings shows promise;
- Marine forecasts (ocean and coastal) and warnings and riverine flash flood warnings need strengthening to improve community safety;
- The coverage, appropriateness and operational status of observing equipment and related infrastructure varies widely across the Pacific;
- Ongoing maintenance of equipment and having the required number of appropriately trained electronics technicians is a challenge for most NMHSs and could be addressed through the proposed Regional Training Centre;

- Compared with surface observation equipment there is a lack of infrastructure investment in ocean (wave heights, tide gauges) and river gauging (level, flow, discharge) and in maintenance of upper air stations and consumables;
- Information Technology (IT) and data management was consistently raised as a high priority need by NMHSs as few Services have sufficient dedicated IT support;
- Few observations are provided to global observing networks such as the Global Observing Network (GBON), GCOS Global Climate Observing System (GCOS), Global Ocean Observing System (GOOS)Upper Air Network (GUAN), GCOS Surface Network (GSN) though considerable data is now being captured in the CLiDE climate database;
- Only a few of the NMHSs have forecasters trained to the equivalent BIP-M and there is also insufficient BIP-MT forecasters;
- Nearly all NMHSs indicated that they needed staff trained to a higher level, WMO accredited BIP-M and BIP-MT forecasters and BIP-MT observers and technicians;
- To overcome constraints in travelling overseas for extended periods, new thinking is required around approaches to training, including hybrid models of online training coupled with more focussed face to face intensive training modules. This needs to be addressed in the context of proposals such as the Regional Training Centre;
- NMHSs supported previous (WMO coordinated) short training workshops done in the region by experts from overseas.

2.1.2. Background

A key component of the *Weather Ready Pacific* scoping project was a consultation phase with Pacific island countries and territories. Due to COVID-19 related travel restrictions this was by necessity an online consultation process. This process commenced with a letter sent to PMC members and Directors of National Meteorology Services (NMS) and partners from the Acting Director General of SPREP informing them of the Scoping Program and inviting them to participate in a meeting on October 27, 2020. At the meeting on October 27, the plan for the Scoping Program received support from PMC members and this provided the direction to proceed to the consultation phase with individual countries and territories.

The consultation phase commenced on November 12 and was mostly concluded by December 7, by which time 16 Pacific island countries and territories had engaged in online consultations. Seven of these consultations (Tuvalu, Nauru, Kiribati, Niue, Cook Islands, Tokelau and Fiji) were conducted in collaboration with the Asia Disaster and Preparedness Center (ADPC) who are in parallel undertaking a study for WMO, "Assessing the capacities, gaps, and needs of National Meteorological and Hydrological Services (NMHSs) and their national (multi-hazard) early warning systems ((MH)EWS) including regional and global support mechanisms in Pacific Small Island Developing States (SIDS)". Given some overlaps in aims between the ADPC project and the Weather Ready Pacific Program Scoping, and to avoid over-consulting Pacific Island countries it was deemed sensible to undertake these discussions as joint exercises. Prior to the consultations a list of questions was sent to NMHSs to help prepare them for the consultations. Eleven of the Pacific island countries and territories provided written responses prior to the discussions.

NMSs were asked to include National Hydrological Services and National Disaster Management Offices (NDMOs) in the invitations to the consultations. In countries with significant water resources or hydrological services there was mostly some involvement or input in the consultations. There was less direct involvement from NDMOs or Emergency Management Office (EMO) equivalents. However, the consultations included considerable discussion on how arrangements and coordination between NMHSs and NDMOs or equivalent were mandated and implemented in practice.

Within a few days of each consultation, notes from the discussions as well as a country profile that provided some general information on each country and territory plus the key points from the consultations under a consistent set of headings were sent back to each country and territory. This provided an opportunity to correct misinterpretations and include additional material to the country profile.

Due to the short-time frame and the remote approach of the consultation process there was no systematic country by country consultation with end user groups. However, a narrow set of discussions were held with some key industry sector groups (e.g. tourism, aviation) and community preparedness projects where international and national Non-Government Organisations (NGOs) are heavily involved.

A number of other agencies and NMSs were consulted in addition to Pacific island countries and territories. These included NOAA, ADPC, BoM, MetService New Zealand, SPREP, SPC, NIWA, and WMO. Comments and data from these meetings have been incorporated into the discussion below.

2.1.3. Synthesis of discussions

This section provides a synthesis of the discussions undertaken with the 16 countries and territories. Individual country profiles can be found in Appendix 2.

2.1.3.1. Mandate, Governance, Coordination

(a) Mandate and governance of NMHSs

Most Pacific island countries and territories have a well-defined mandate for their NMSs either proscribed in specific legislations (Acts, regulation, etc) and strategic plans or embedded in other national legislations and higher-level strategic policies and planning frameworks. In a number of countries and territories (Niue, Solomon Islands, Tonga and Vanuatu), mandates of meteorological services are couched in specific enacted Meteorology Act whilst some of these countries (Fiji, Kiribati, Solomon Islands and Tuvalu) are currently either reviewing their Meteorology Acts, developing a specific Meteorology Bill, or their Meteorology Bill is undergoing discussion in national Parliament.

Some countries (Kiribati, Papua New Guinea, Tuvalu and Vanuatu) have developed and approved specific strategic plan for their NMSs. A few other countries (Federated States of Micronesia, Fiji, Palau, Republic of Marshall Islands) have processes in place to develop strategic plans for their NMSs. The Cook Islands, Samoa, and the Solomon Islands are developing strategic plans under the WMO Climate Risk and Early Warning Systems (CREWS) 2.0 initiative. Other countries indicated they needed assistance to develop their NMSs' strategic plans and other related documents.

Some countries have a specific Meteorology Division or Department that sits within a larger Ministry, most commonly environment, climate change, or transport. Small countries have the Meteorology Service or its home Division or Department sitting within Ministries such as Finance or in the Office of the President/Prime Minister.

The US-affiliated countries (Federated States of Micronesia, Palau and Republic of Marshall Islands (RMI)) and US territories (Guam and American Samoa) are part of the US National Weather Service (NWS) that sits within NOAA and operate under the US National Weather Service mandate and operating procedures. The offices in the Federated States of Micronesia (FSM), Palau and RMI have a limited role in development of forecasts and warnings and most of their products are issued by the Guam or Honolulu NWS Offices. Staff in FSM, Palau and RMI then provide invaluable intermediary and interpretive roles in translating forecasts and warnings into local languages, in disseminating them to remote communities and working with the local National Disaster Management/Emergency Management Offices.

> Water resources and hydrological services are generally not as well mandated as meteorological services and they need to be better integrated to effectively deliver impact-based forecasts for floods and inundation events.

Water resources and hydrological services are not as clearly defined or mandated. Even in countries where riverine flooding is a significant issue, the mandate and role of water resources is not always well defined. Exceptions to this include Tonga, where water resources and hydrology are defined in the Water Resources Act 2020 and in Samoa where water resources and hydrology are defined in Water Resources Management Strategy. In terms of organisational arrangement of hydrology services, there is a mixture of approaches with water resources/hydrology sitting either with Meteorology or in its own Department or Division, often within the same Ministry. In some Pacific island countries and territories, especially atoll countries and territories, there is no prescribed hydrology service.

There was a general view expressed that the meteorological. hydrological and oceans services need to be better integrated to effectively deliver impact-based forecasts for flash floods and coastal inundation events.

Discussions with IATA revealed their view is that their members would be better served if there was only one or two Meteorological Authorities in the Region to better focus the services provided. This would also allow for a central source to provide information during extreme weather events, for example, the communication of activation of contingency measures by airports, and this would also simplify the process of cost recovery. IATA also commented that such a centralisation of services could be necessary, or may provide the capacity, to adapt and respond to the emerging International Civil Aviation Organisation (ICAO) concept of System Wide Information Management (SWIM) and its associated applications. SWIM consists of standards, infrastructure, and governance enabling the management of ATM-related information (including weather information) and its exchange between qualified parties via interoperable services. It is possible that smaller meteorological agencies may struggle to provide aviation weather information in the format required. The Pacific is a huge, remote expanse of water but nonetheless, very important for both international and local/regional aviation. In addition, the South Pacific enjoys liberalised airspace allowing suitably equipped airlines to fly where they wish to. This supports the future need for improved hazard information so that these hazards can be more efficiently avoided. Whilst this is a specific area of forecasting in the overall NMHS mandate of forecasts and warnings for extreme events, there is a need to ensure the capability because of its criticality to maintaining connectivity across the Pacific, and between the region and the rest of the world.

(b) Regional governance – the Pacific Meteorological Council and The Pacific Meteorological Desk Partnership (PMDP)

Whilst the Pacific island countries and territories Meteorological Services have their own national mandates and governance arrangements, an important umbrella governance arrangement is the Pacific Meteorological Council (PMC). The PMC is a specialised subsidiary body of SPREP, established to facilitate and coordinate the scientific and technical program and activities of the National Meteorological Services. The PMC provides policy relevant advice to the SPREP Meeting on the needs and priorities of its member countries and territories in relation to meteorology (weather and climate) and related fields.

Specific roles of the PMC include:

- Provide an open forum for its members to discuss and collaborate on the needs of Pacific Island Countries and Territories with respect to weather and climate services, and related issues;
- Promote capacity development within the region, focused on improving members' capability to provide accurate, timely and reliable weather forecasts, and warnings of severe weather, climate outlooks and scenarios, and associated hazards;
- Develop strategies with associated goals and targets to support the advancement of meteorological and related services in the Pacific, in collaboration with WMO and relevant partner organisations;
- Oversee progress in the implementation of strategies to support the advancement of meteorological and related services in the Pacific;
- Provide guidance to Members and the SPREP Secretariat and partner organisations with respect to programs related to weather, climate and associated environmental matters in the Pacific;
- Collaborate with the Pacific Meteorological Desk Partnership on the implementation activities and priorities of Members, and contribute to the monitoring and evaluation of the Pacific Meteorological Desk Partnership;
- Report regularly on the activities of the NMS so as to assist the advancements of meteorological services in the Pacific.

The PMC meets approximately every two years.

The Pacific Meteorological Desk Partnership (PMDP) is a regional coordinated response to meeting weather and climate services development in the Pacific Islands region. It works closely with the PMC and member countries to develop capacity and advance the sustainability of weather and climate services in Pacific Islands. It therefore serves as the regional weather and climate services coordination mechanism, managed by the SPREP and WMO RA-V.

The Pacific Meteorological Desk Partnership is made up of two core components:

- The Apia Secretariat Component. This component is made up of the Apia-based Secretariats of SPREP and the WMO working in close collaboration and is responsible for overall coordination and leadership of the Pacific Meteorological Desk Partnership function in terms of linking national and regional priority needs. It has reporting responsibility to the SPREP Meeting and the PMC, including monitoring and evaluation;
- The Partners Component. This component, operating through a collection of partners, provides the key technical expertise that is help building the capacity of Pacific NMS. Key SPREP partners institutions include NOAA, BoM, MetService New Zealand, NIWA, JMA, JICA, Meteo-France, APCC, KMA, Finnish Meteorological Institute (FMI), among others.

The Decadal Program of Investment will propose a significant investment to keep building the capacity of NMHSs in the Pacific region. It is critical that there is strong coordination between the proposed investments and the PMC and PMDP. There is an opportunity and need to link specific investments to the PMC Panels, which were established to provide technical advice to the PMC. Six panels have been established:

- Pacific Island Climate Services (PICS) Panel;
- Pacific Island Marine and Oceans Services (PIMOS) Panel;
- Pacific Island Aviation Weather Services (PIAWS) Panel;
- Pacific Island Communications and Infrastructure (PICI) Panel;
- Pacific Island Education, Training and Research (PIETR) Panel;
- Pacific Hydrological Services (PHS) Panel.

There is also a need to provide a Secretariat or similar support mechanism to help coordinate input and implementation of the Decadal Program of Investment with the workings and directions of the PMC, PMDP and the six Panels.

(c) Coordination with National Disaster Management Offices or Emergency equivalents

There is across nearly all countries a formally legislated or regulated arrangement between NMSs and National Hydrological Service (NHSs) and NDMO or Emergency Office (EMO) equivalents. In practice, the working arrangements vary widely across the different countries but overall, the NMHSs appear to be well connected to the NDMOs and seem to be an integral part of their country’s emergency management plans.

There is a drive by most NMHSs towards risk, impact and response-based messaging and improving the communication systems and messaging to their communities to make it more effective and the need to do this in partnership with NDMOs was clearly expressed by both NMHSs and NDMOs.

(d) Leadership and institutional positioning

Leadership was raised as an issue with a need expressed for leadership and management training for Directors and senior managers to help deliver better hydro-meteorological, oceans and other related environmental service. Possessing stronger leadership qualities in governance, strategic planning, workforce planning, financial management and communications is also important in better positioning NMS and NHSs within government organisational structures and integration of the services across sectors. Related to this point, NMHSs or NMSs or National Hydrological Service (NHSs) are not prominent in many ministries and this flows through to career structure and the lower remuneration of professional and technical officers

> Leadership is critical to the long-term success of NMHSs. Developing and retaining leaders is critical for effective management of NMHS operations and for the broader positioning the role of hydro-meteorological services in government.

compared with other areas of government and the private sector with a couple of notable exceptions. It also relates to organisational structure of NMSs and NHSs, some are either not accommodating for changes, progressing of staff career and academic. This can lead to challenges in retaining staff with well-credentialed staff being lost to other government departments or regional agencies or developed NMSs or international agencies. Technicians, especially in electronics and IT/ICT, are attractive to the private sector, especially telecommunications companies. Where the issue of better remunerating qualified hydro-meteorological and technical staff and/or providing appropriate incentives has been addressed, staff turnover and retention is markedly improved.

(e) Multiple projects and donor agencies

There are many different development and collaborating/agency initiatives, programs and projects involving a large number of international institutions e.g. World Bank, Asian Development Bank, WMO, UNDP, UNEP, Food and Agriculture Organisation, Adaptation Fund, Global Environment Facility (GEF), ADPC, UNESCO, World Food Programme (WFP), Economic and Social Commission for Asia and the Pacific (ESCAP), International Organisation for Migration (IOM), United Nations Office for Disaster Risk Reduction (UNDRR), IMO, ICAO, SPREP, SPC, PASO, PIFS, APCC, JICA, JMA, KMA, CMA, ECMWF, UK Met Office, United Kingdom, New Zealand, Japan, Australia, US, France, Finland, Italy, Denmark, China, Republic of Korea, Russia. All these initiatives have their own context and objectives and a challenge expressed by NMHSs was to bring some cohesion to these various activities so that the whole is greater than the sum of the parts. This requires stronger involvement of regional partners such as SPREP and the WMO Regional Association that includes the Pacific (RA-V) in aligning initiatives to overarching strategies such as the PIMS 2017-2026. The need for better alignment is especially evident in infrastructure where different projects can result in a wide diversity of equipment types, which creates additional overheads and stretches already limited capacity in equipment maintenance and sustainability. Lessons may be learned from other infrastructure areas such as power utilities which have faced the same issue with regard to generators and solar systems.

Many development projects involve a number of countries and the needs of individual countries vary widely across the areas of governance, infrastructure, delivery and capacity building and a “one-size fits all” approach is not appropriate. Better targeting of projects and activities to specific country needs was highlighted as a challenge.

2.1.3.2. Production of forecasts and warnings

During the consultation process it became clear that there is diverse capacity and approach to the development and delivery of forecasts, warnings and related information across the NMHSs, NMSs or NHSs.

Countries with NMHSs/NMSs that have sufficiently developed forecast and warning capacity (Fiji, Papua New Guinea (PNG), Samoa, Solomon Islands, Tonga, Vanuatu) develop their own forecasts by obtaining data, forecast products and warning information from a diverse range of sources and providers. For example, NWP output is obtained from various sources such as the SWFP which is accessed through the MetConnect site maintained by MetService New Zealand, the RSMC-Nadi maintained by Fiji Meteorological Service (FMS), the Australian Bureau of Meteorology (BoM) and the European Centre for Medium-Range Weather Forecasts (ECMWF).

The US Territories of American Samoa and Guam also have well developed forecasting and warning capabilities as they are part of the US National Weather Service (NWS) and both are supported by the Pacific Region Headquarters in Hawaii. The NWS in Hawaii also supports the Compact countries of Federated States of Micronesia, Palau and the Republic of Marshall Islands. Guam also supports these three Compact countries.

Tropical cyclone and typhoon warnings from Fiji, NZ, Australia and the Joint Typhoon Warning Centre (JTWC) in Hawaii are accessed as are tsunami warnings and data issued by the Pacific Tsunami Warning Centre (PTWC) in Hawaii, which in some cases, supplements locally produced seismic and tsunami modeling data. Data from RSMC Tokyo is also accessed by some centres and JMA's Himawari satellite data is extremely valuable and accessed by all NMHSs in the region.

The FMS/RSMC-Nadi is responsible for issuing advisories on tropical cyclones in the area from the equator to 25˚ south and 160˚ east to 120˚ west. FMS/RSMC-Nadi – Tropical Cyclone Centre names and tracks all tropical cyclones in this area and issues regular tropical cyclone and other warning and advisory services for marine and public interest and safety. In addition, RMSC-Nadi recently (2019) became operational in coastal inundation early warning, developed from the Coastal Inundation Forecasting Initiative delivered to the FMS through WMO.

Image 2: Manual Weather Chart Analysis by a weather forecaster

The Central Pacific Hurricane Center (CPHC) is co-located with the Honolulu Weather Forecast Office, and issues all typhoon warnings, watches, advisories, discussions, and statements for tropical lows and typhoons in the Central Pacific north of the equator from 140 Degrees West Longitude to the International Dateline. RSMC Tokyo has responsibility for issuing warnings for tropical lows and typhoons west of the dateline under WMO arrangements. Additionally, the JTWC also provide a tropical cyclone/typhoon monitoring and forecasting service to the west of the dateline in the northern hemisphere and for the South Pacific for all branches of the U.S. Department of Defense and other U.S. government agencies, with a range of products available publicly.

Forecasters in these higher capacity non-US NMHSs interpret the data together with forecasts and warnings provided by FMS/RSMC-Nadi and modify and tailor them for their local conditions and user requirements. These products are then issued as the local forecasts and warnings. NMHSs work closely with their NDMOs and associated emergency services during high impact events. Some of these NMHSs have the capacity to deliver aviation forecasts and warnings although this is entirely dependent on them having a sufficient number of appropriately trained (Basic Instruction Package - Meteorologist (BIP-M)) and accredited forecasters, which is mostly a significant limitation.

Countries with more limited meteorological and hydrological capacity most frequently use forecasts and warnings issued by the regionally mandated centres of FMS/RSMC-Nadi (Cook Islands, Kiribati, Nauru, Niue, Tokelau, Tuvalu) and Guam National Weather Office (FSM, Palau, RMI) and do varying amounts of local interpretation. Their main role is to provide invaluable intermediary and interpretive roles by undertaking some local translation of the forecasts and warnings they receive from FMS/RSMC-Nadi and Guam National Weather Office and then disseminating them They often communicate with remote communities and work with the local NDMO/Emergency Management Office to ensure the local communities are aware of warnings and the expected impacts and outcomes of high impact weather and climate events. However, the coarse spatial resolution of these regional forecasts is viewed by some as a limitation. To enable these NMHS to effectively support preparedness and response to extreme weather events, water and ocean risks they require the ability to autonomously access increasingly accurate and localised forecasts, and empowerment to engage more authoritatively with government and community decision makers.

> Improving forecasting technologies to deliver more locally relevant forecasts and warnings from regional centres within and outside the Pacific, rather than trying to build a comprehensive technical forecast centre for every country allows more effort to deliver more tailored, risk, impact and response-based, information and engagement with their NDMOs and their local community.

As such, whilst improving the number and capacity of meteorologists and hydrologists is a recognised requirement of most NMHSs there is an opportunity through improving forecasting technologies to deliver more locally relevant forecasts and warnings from regional centres within and outside the Pacific, rather than trying to build a comprehensive technical forecast centre for each individual country. This would have the effect of freeing up the time of each NMHS's forecasters and puts more emphasis on each country's forecasters and hydrologists using data and forecasts received from the larger centres to deliver more tailored, risk, impact and response-based, information and engagement with their NDMOs and their local community.

A niche area of forecasting and associated capability is aviation forecasting. This is a particularly demanding area for forecasting because of the multiple stakeholders involved (industry, governing body), regulatory requirements, direct impacts on passenger safety, the economy of operations, the level of forecasting capability and critical mass of appropriately qualified forecasters needed to run a full-time aviation forecasting operation. Relatively few NMHSs (less than 25%) have the required number of WMO qualified forecasters (BIP-M plus additional capabilities) to meet the demands of aviation forecasting. Where this is not possible, effective bilateral agreements with FMS, the regional leader in meteorological services, need to be formalised. Some countries have bilateral agreements in place with Fiji and the US for the production of their aviation forecast and warning services but more consistent governance arrangements are needed. However, assuming that these agreements and governance arrangements can be satisfactorily resolved, the model of a central or regional aviation forecast and warning production centre distributing products to NMSs, appears to work well (noting the comments from IATA below) and offers a mode of operation to build upon.

During consultation with two key user groups (IATA and Fiji Airways) it was evident that they consider that there is considerable scope for improvement in aviation weather services in the region. IATA urges NMHSs in the region to undertake a review of aviation weather services similar to that undertaken by the Australian Bureau of Meteorology (BoM). The BoM undertook a Review of Aviation Weather Services which consulted extensively with Industry and reviewed the services required and then developed a holistic plan to deliver those services in the most efficient and effective manner, utilising modern technology and techniques. IATA considers that such a review is necessary to reduce duplication of effort across services and fully utilise the capacity of the NMHSs.

Ocean observations and forecasting services are quite limited overall and it has been stated by a number of NMHSs that this is an area for which improvements are required to improve community safety. Much of the existing service is derived directly from NWP output with little verification. It is felt that significant improvements in ocean services could be achieved with additional observations of swell and tides and improved training of the forecasters. To address some of these challenges there has been significant effort in recent years through the COSSPac initiative, which has in partnership with SPC and Pacific island countries and territories improved the collection and delivery of ocean observations for improved forecasting. A key output from this work has been the development of the Pacific Ocean Portal. The Pacific Ocean Portal was originally designed to support climate services but it has evolved to also support operational forecasting. SPC has also been coordinating the installation of ocean observing equipment funded by a range of donors and is a regional agency with critical mass and technical capacity to be playing this role. Output from these observations have been important in developing swell-driven coastal inundation forecasting and modelling, which is one component of the overall coastal inundation forecasting capability at Fiji Meteorological Service (and later adapted for RSMC-Nadi). This enhanced capacity in coastal inundation was delivered by the WMO Coastal Inundation Forecasting Initiative (CIFI), which implemented a demonstration project in Fiji. This is now operational (since 2019), with an integrated approach to storm surge, wave and riverine flood forecasting for improved operational forecasts and warnings capability for coastal communities.

In April 2020, Severe Tropical Cyclone Harold impacted several Pacific Islands. In response to this impending dangerous storm, the FMS was able, for the first time ever during a cyclone, to issue wave and storm surge warnings enabled by this new and unique coastal inundation forecasting system. It also enabled evacuation warnings, which minimised fatalities from such a devastating storm.

The overall coastal early warning system also incorporated contributions from JMA, NIWA, BoM, and Tonkin and Taylor – combining data and models from multiple sources of inundation (waves, swell, storm surge, tide and river floods). It has been identified by FMS as a valuable tool and it has the potential to be scaled up, and implemented in other Pacific island countries and territories, with appropriate funding and expertise to support its implementation, including training.

There is a stated need for improved flash flood forecasting and warnings in some of the larger volcanic countries with significant river catchments. The benefit of such warnings is that it allows people to reach safety and put in place preparedness actions to lessen the damage of floods such as sandbagging, moving valuable equipment and goods. The use of the Flash Flood Guidance System (FFGS) in Fiji represents one option. The system uses rain gauge observations rather than river gauges and when these data are used in conjunction with remotely sensed information, such as weather satellite and radar data, and NWP rainfall data they provide the inputs into hydrological models that provide forecasts, and ultimately, can be used to predict potential of flooding. However, the FFGS is technically demanding because of the reliance on NWP output, its time-critical availability and the capacity needed to interpret the output and views were expressed around using simpler rainfall-runoff models to develop warnings. The nature of floods is that they are generally rapid-rise flash floods and so manual collection of river gauge information is not suitable to real-time forecasting. However, manual collection data can still be used to help parameterise and validate rainfall-runoff models.

Weather watch radar data can also provide important evidence to hydrological and meteorological forecasters of heavy rain and this can be linked to hydrological modelling to provide guidance on flash flood warnings. In some cases, this process can be automated through numerical weather prediction processes. Many countries expressed a need for a weather radar to assist with preparedness, not just for flood events, but also for communities in managing the impacts of heavy rainfall. Of the countries consulted, only Fiji has a weather watch radar capability, although X-band radars are scheduled to be installed in the Cook Islands, Niue, Palau, the Republic of the Marshall Islands (RMI) and Tuvalu over the next 5 years as part of a GCF project. There are also plans to acquire a C-band radar in Vanuatu through the GCF VanKirap project.

Overall, hydrological information appears to be quite limited and only a few countries have well developed hydrological services, reflecting, in many cases, a limited need because flooding risks are minimal e.g. atoll countries. However, in countries prone to flooding such as Fiji, PNG, Samoa, Solomon Islands and Vanuatu there is a demonstrated requirement for observations together with forecast and warning systems and services. One example of meeting this need is the recent development of a flood warning and decision support system for the Vaisigano catchment on Upolu Island, Samoa. It brings together observations and forecasting in real-time to provide impact-based messages and actionable warnings to communities in the Vaisigano catchment (Box 2.1). The work forms part of the Government of Samoa's Vaisigano Catchment

Box 2.1 Building resilience through enhanced flood monitoring and warnings for Samoa

Gaps in rain and rivel level monitoring were addressed through Water Resources Division technicians installing five automatic rainfall gauges and three river level/flow monitoring gauges at strategic locations in the Vaisigano catchment. All gauges were configured to telemeter data in real time to base stations located in the Water Resources Division and the National Emergency Operations Centre. These data were used along with empirical rainfall-runoff relationships to facilitate 'nowcast' based predictions of river levels/flows exceeding pre-defined flood thresholds, with lead times of up to 3 hours in advance. Global numerical weather prediction (NWP) rainfall models available for Samoa at 3 km grid-resolution were used to provide forecast rainfall information for the catchment.

Flood hazard maps were used along with details of the current distribution of the built environment in Apia, to estimate flood exposure levels and threat to safety of buildings, roads and road usage by vehicles. This provided a set of pre-computed impact scenarios that could be used to translate the flood alerts from 'what event might occur', to 'what the event might do' in terms of direct impacts.

The effectiveness of this flood warning and decision support system was demonstrated by the extreme rainfall events on 18 December 2020, 7 January 2021, and 22-23 February 2021. For the case of the 18 December 2020 event, flood officers were able to alert National Emergency Operations Centre responders up to several hours before the Vaisigano River overtopped its channel, leading to the successful evacuation of residents living in affected floodplains.

Project financed by the Green Climate Fund (GCF) and operationalised through the Water Resources Division in the Ministry of Natural Resources and Environment.

Many countries provide some seasonal information particularly in the context of drought in coral atoll islands where fresh water supplies are at a premium. This is disseminated via alerts, billboards, etc. There is a need to strengthen seasonal forecasting approaches, for example, using the BoM seasonal forecast model, ACCESS-S, the Korean multi-model ensemble developed for the Pacific (CliPS - PICASO), NOAA, or other seasonal prediction products, and delivering messages more effectively to key sectors such as agriculture and water supply authorities.

Most countries indicated that they receive tsunami advisories or guidance from the Pacific Tsunami Warning Centre in Honolulu, from which they derive and deliver warnings. Some NMHSs use these messages directly and forward them to their NDMOs and in some cases, in the interests of timely delivery, issue the warnings directly to the public directly themselves. Others use the PTWC information as guidance to develop their own warnings messages which are then distributed to the NDMOs and the public. A few NMHSs have no responsibilities to deliver tsunami warning information because this is a responsibility of another agency.

For countries in the northern Hemisphere in the western Pacific such as Palau, the Republic of Marshall Islands and the Federated States of Micronesia, tsunami information is also accessed from Japan. For Samoa and Tonga, which are located close to the Tongan Trench, a local observation and warning system is maintained because the lead times can be very short between an earthquake and the resulting tsunami reaching land. Such a system requires sophisticated geophysical observational equipment and modeling capacity, all of which requires expensive maintenance and staff trained with an additional set of competencies. At the request of countries, WMO is now working towards incorporating tsunami early warnings into the overall Multi-Hazard Early Warning Systems (MHEWS) approach for coastal inundation warnings.

2.1.3.3. Communication and delivery of forecasts and warnings

There is a strong awareness of the need to deliver risk, impact and response-based messages i.e., what the weather will do rather than what the weather will be, but the extent to which this is implemented varies widely. Most NMHSs expressed a desire for further training in the use of risk, impact and response-based approaches to forecasts and warnings. Nearly all countries have processes, or are developing processes, to gain community and industry feedback on how to better deliver messages and develop content that is response oriented in a local context with appropriate impact statements.

There is evidence of good coordination and cooperation between NMHSs and NDMOs across the Pacific. However, the way in which messages are delivered varies and this often relates to the respective mandates and legislative obligations of NMHSs and NDMOs. In most countries NMHSs deliver their warnings to the general public, government and media via websites, emails and through direct contact (some even hand delivering messages). NDMOs take responsibility for delivering impact messages to regions, local government, village heads and communities via radio, emails, SMS, chatty beetles, phone calls, Non-Government Organisation (NGO) networks etc. NDMOs are also mostly responsible for the activation of tsunami warning sirens during a tsunami event, although this can sometimes be undertaken by the NMHSs under certain circumstances. Getting the messages to remote communities - “the last mile” effectively is still a challenge in many parts and in some jurisdictions the communication systems need improvements and apparent ‘gaps’ need to be filled.

One of the challenges consistently raised in the consultations was the need to better translate technical terms in forecasts and warnings into locally relevant impact messages because many technical terms do not exist in local languages. Further, traditional knowledge approaches to communicating weather and other extreme events need to be better incorporated into warnings and preparedness messages delivered by NDMOs and NMHSs. In the consultations it was emphasised this needs to be a two-way process and there are examples of how traditional knowledge can be used with science to strengthen early warning systems. For example, in Makira Province in the Solomon Islands, frigate bird flight patterns are a good indicator of approaching strong winds. This information is being captured in a database to provide an evidence base of how contemporary and traditional knowledge forecasts can be integrated.

There is little coordination amongst donors in developing a consistent approach to infrastructure in the Pacific. Further, there is often few resources provided for long-term maintenance of equipment and building capacity of appropriately trained electronics technicians.

In another example, public awareness material was developed at the request of stakeholders in Fiji to enhance the public's understanding of coastal early warnings. Two public awareness cartoon – explaining the dangers of coastal flooding and inundation, and 'what to do' when a warning is issued, and the value ocean buoys in keeping people safe along the coast were developed specifically for distribution to communities in Fiji. These may also be relevant for the broader Pacific island countries and territories.

2.1.3.4. Infrastructure

In this section, infrastructure is examined across the entire hydro-meteorological forecast and warning spectrum from observational equipment through data processing, forecasting and warning production through to dissemination of NMHS products and services.

1. Observational equipment

The amount and operability of observing equipment across the SPREP countries varies considerably, as does technical capability to maintain instrumentation, process data and transmit the final products.

Some countries rely on just one or two manual surface observation stations to maintain their climate record and for weather forecasting, whilst in some countries there is a wide network of manned stations and/or Automatic Weather Stations (AWS). During consultation with representatives from the aviation industry, the representative commented that their company had been adversely impacted by the reduction in observations through the region over the last few years due to capacity constraints. In some cases the loss of observations data had resulted in a reduction in aviation weather services which had impacted negatively on their ability to operate efficiently and profitably to some destinations. This was placing these services in jeopardy.

A number of countries maintain an upper air observation program by flying GPS radiosondes attached to balloons and/or in a couple of cases, using wind profilers. A few NMHSs have balloon launching equipment that is not operational, or they have insufficient resources available for the consumables (gas, balloons and radiosondes). For a number of NMHSs, ongoing radiosonde consumables are provided from outside the country, for example by SPREP with funding from the UK Met Office (UKMO) and the US NWS. A more consistent and better resourced approach to upper air observations is required.

Aircraft Meteorological Data Relay (AMDAR) is a component system of the WMO Integrated Global Observing System (WIGOS) which contributes aircraft-based observations to the World Weather Watch Programme. AMDAR represents one, very cost effective, option for the provision of upper air observations. AMDAR data could potentially be retrieved from a number of aircraft operating in the Pacific basin providing regular and frequent observational data that could be used locally, and once ingested by the WMO Information System (WIS), regionally and globally by the WMO Global Information Centres for use in NWP.

Ongoing maintenance of NMHS equipment and having the required number of appropriately trained electronics technicians is a challenge for most NMHSs. Frequently, at the conclusion of projects that provide infrastructure, no ongoing budget is provided for further maintenance, forcing NMHSs to attempt to maintain the equipment from their own, often meagre, maintenance budgets. Different types of equipment from different donors provides additional challenges in that technicians are required to be competent to service these particular types of equipment. This is not always the case, resulting in equipment lapsing into disrepair for lack of training and capacity.

A wide range of donors have provided Automatic Weather Stations (AWSs) into the Pacific including the UNDP RESPAC program (Russia supported), Finland, JICA, NIWA, NOAA. NIWA has developed a robust AWS with fit for purpose components suited to the Pacific environment together with good training support program. They have provided a variety of technical and research related services across the Pacific Region for more than 30 years and are extremely well respected. They have very wide experience of working as consultants with many donor funds and implementation agencies such as UNDP, Gesellschaft für Internationale Zusammenarbeit (GIZ) and WMO on projects across many nations such as:

- PNG for the Bumbu Flood warning and climate monitoring system, amongst other projects in the country;
- Vanuatu CLEWS network development;
- Cook Island Climate network development;
- Samoa Rainfall Project;
- Fiji Hydrological Network upgrade;
- Fiji Meteorological Services Rainfall and climate network upgrades (~40 stations);
- Fiji Meteorological Service - ocean observations and river gauges set up for the Coastal Inundation Forecasting initiative (CIFI).
- Kiribati – Remote Island Climate stations for food security (3 stations);
- Solomon Islands – Climate and Rainfall network development;
- Tonga – Climate and coastal network development project;
- Palau Climate network automation (ongoing).

Building on this model of service delivery and maintenance and making it more robust and sustainable could potentially offer a good approach for the installation and maintenance of meteorological, hydrological and ocean infrastructure across the Pacific.

There is currently significant investment in new infrastructure underway and planned (for example AWSs, Wind Profilers, Weather Watch Radars, Wave Buoys, Ocean Observing Equipment and communications equipment) by a wide range of donors/agencies and under a number of different projects (including the Green Climate Fund (GCF), the Adaptation Fund, World Bank's PREP, the United Nations Disaster Resilience for Pacific SIDS (UNDP RESPAC), WMO Climate Risk and Early Warning Systems (WMO CREWS Pacific SIDS project), Climate And Oceans Support Program In The Pacific (COSSPac), PIFS, APCC, European Union Climate Services and Application (ClimSA).

Under the UNDP GCF project, "Enhancing Climate Information and Knowledge Services for resilience in 5 island countries of the Pacific Ocean", the project countries (Cook Islands, Tuvalu, Niue, Republic of the Marshall Islands and Palau) will extend the geographical coverage of their climate and weather observations through enhancement of infrastructure and local technical capacity in alignment with draft GBON provisions for surface-based observations. Each NMHS has committed to securing sound Operations and Maintenance (O&M) budgets for its expanded hydrometeorological networks during and for up to 20 years after the end of the Programme. Robust and user-friendly new communications equipment will make it possible to contact remote communities reliably, even in extreme conditions, and will also be covered by the maintenance schedules.

The following planned interventions are expected to contribute to the achievement by the five countries of WMO Category 2 (Essential) status for climate services:

- Strengthen the network of land-based observation stations measuring atmospheric pressure, temperature, humidity, horizontal wind and precipitation and regular reporting of data in compliance with Global Basic Observing Network (GBON) requirements and obligations. The Programme will install new/upgraded climate monitoring stations in all five countries that will feed data into GBON for use in global Numerical Weather Prediction (NWP). In addition, Cook Islands will procure upper air land-based consumables and a DigiCORA receiver to ensure that Chemical Ionization Mass Spectrometer (CIMS) can collect, contribute and use data from its existing network;
- Improve observation station density based on established and known national requirements in each of the five countries and compliance with GBON;
- Introduce weather radar for severe weather and climate monitoring through infrastructure and capacity building. The Programme will install a dual-polarisation X-band Doppler radar system in each of the five countries and provide technical training to build in-country capacity for radar operations, maintenance and data applications for weather and climate monitoring and analyses;

- Improve observations through compliance with WMO Integrated Global Observing System (WIGOS) regulatory and guidance material. All five countries will strengthen their maintenance schedules, procure spare parts and calibration equipment, and undertake iterative training in calibration and maintenance with development partners; Niue will source in-country IT expertise to ensure that all equipment is maintained and operational;
- Enhance data and data management so that historical as well as real-time observations in the atmosphere, the ocean and over land of the Essential Climate Variables (ECVs) prepared by GCOS, and Essential Ocean Variables (EOVs) prepared by GCOS and GOOS, and partners for climate purposes are exchanged freely for use in Regional Climate Centres (RCCs) for at least one Global Surface Network site in each country;
- Adopt a well-documented strategy including vision and operating manual for ensuring security, integrity, retention policy and technology migration for data archival process and systems;
- Generate generic monitoring products (i.e. drought monitoring, climate watch, etc.). For example, the Programme will build on the CREWS Pacific SIDS Project to enhance Climate Risk Early Warning Systems (CREWS) and Early Action Rainfall Watch (EAR Watch) in Niue, Palau and Tuvalu.

Investment in infrastructure to support observations is not just about the use of observations locally. It is important that observations are transmitted in a timely manner back into the Global Observing Network to improve global and regional scale numerical weather prediction models being run by WMO Global Information System Centres (GISC). At present, few Pacific Island Countries or Territories are providing all their local observations into this global network on a regular basis. However, through the COSSPac program and other initiatives, an increasing number of observations are being uploaded to the CLiDE climate database, which is helping in providing a more robust climate record.

Image 3: Preparing to Launch a weather balloon to collect atmospheric data to inform National Meteorological Services. Many of these upper air stations are currently not operational in the region.

A contributing factor to the lack of data being ingested into GBON revolves around the sustainability of observational equipment in the long term. There has been widespread lack of infrastructure support and funding in the period following projects that have provided infrastructure. There is a requirement for long-term legacy maintenance contracts to be built into equipment provision perhaps, for example, using a trust fund. Other approaches include countries committing to long-term maintenance of new infrastructure as indicated above for the five countries involved in the upcoming GCF project. Also, the establishment of the Systematic Observations Financing facility (SOFF), led by the World Meteorological Organisation in collaboration with a wide range of international organisations, aims to support countries in generating and exchanging basic observational data. A key area of investment for SOFF is contributing to the costs for operating and maintaining observing systems in the long-term.

The Pacific Islands Meteorological Strategy (2017-2026) is quite explicit about improvements in observations and maintaining existing equipment. However, a clear national or regional strategy to coordinate new infrastructure investment is not evident largely as a consequence of the diversity of donor projects, each with their own context and focus. This issue is exacerbated by much of the funding for infrastructure being implemented through climate change projects rather than as improvements to meteorological services per se. Whilst the funding provided through climate change programs is welcomed in the region, efforts are focused in countries based on vulnerability to climate change and often in the context of particular sectors, for example agriculture and/or water security and disaster risk reduction, which means there is no integrated, holistic approach to infrastructure.

One significant gap in infrastructure is river gauging equipment in larger, volcanic countries that are vulnerable to major flood events. Much of the existing river gauging equipment is outdated or not operational or may exist but is not included in official networks as it was purchased for a particular project. Flooding leads to much loss of life and property and improving the rain and river gauge networks and delivery of information in a timely way is a priority need.

Ocean and marine observations are overall quite limited and it has been stated by a number of NMHSs that this is an area for which improvements are required to improve the safety and livelihoods of those in coastal communities, the fishing industry and coastal shipping. Much of the existing service is derived directly from NWP output with little verification because of the sparse observing network. It is felt that significant improvements could be achieved with additional observations of swell and tides and improved training for the forecasters. AS indicated above, SPC has a program of installations of tide gauges and wave buoys underway and coordination with them over any future infrastructure installations of this type would ensure the most effective distribution of it and avoid duplication.

Satellite infrastructure is essential to cyclone warnings The JTWC uses NASA satellite data such as the Tropical Rainfall Measuring Mission's Microwave Imager (TMI) and its precipitation radar, Aqua's Advanced Microwave Scanning Radiometer (AMSR-E), the CloudSat cloud radar, and the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard both of NASA's Aqua and Terra satellites. RSMC-Nadi uses data from Japan's Himawari satellite. Himawari-8 and -9 are geostationary weather satellites operated by the Japan Meteorological Agency (JMA).

2. Information and Communication Technology (ICT) and data management

Another area of infrastructure (and capacity) that was consistently raised as a high priority need was Information Technology (IT) support and data management. As offices become increasingly technology dependent and complex, the requirement for IT support and development and data management is growing strongly. Nearly all NMHSs indicated that they had a shortage of IT staff. In addition, expanding the observation network with modern instrumentation that transmits more frequent observations increases the load on existing IT infrastructure and data management processes. Similarly, outputs generated from external products such as data rich high resolution NWP model output requires enhanced IT infrastructure and support. The existing infrastructure in some of the countries was not designed with this new load in mind and are generally only receiving a small proportion of the investment necessary to keep pace with these expanding bandwidth requirements, making upgrades difficult and expensive.

While not all the new observations are making it into the WIS for global consumption, there has been good progress in ensuring the data is entered into climate databases such as CLiDE. However, strengthening the ability of the existing observation network to send data into the global observing systems in a timely way will be beneficial to Pacific countries through improved NWP models and products.

The infrastructure for disseminating forecasts and warnings to communities, especially those in the most remote islands, remains a challenge, particularly reaching outlying and remote islands. Traditional means such as radio and messages sent to individual villages are still important in many places and these approaches are being strengthened by additional, robust technologies such as chatty beetles. Increasingly forecasts and warnings are also being disseminated through digital technologies utilising websites, Facebook and other social media and SMS.

Internet and mobile networks are also expanding across the Pacific and uptake is rapidly increasing, though costs are high and reliability limited in many areas. In particular, mobile phones and smart phones are increasingly common in more remote communities, which is better enabling the delivery of forecasts and warnings. However, further improvements are needed in satellite coverage for digital phone networks and in affordability of phones and plans in remote communities. This is critical because distribution of forecasts and warnings is increasingly utilising digital technologies and to facilitate this, it is strongly recommended that warnings messages are delivered by NMHSs in Common Alerting Protocol (CAP) to enable the messages to be distributed on and by any digital platform.

CAP is a digital format for exchanging emergency alerts and allows a consistent alert message to be disseminated simultaneously over multiple communications pathways both in the region of impact but also through Global Warning Centres. A single emergency alert can trigger a variety of public warning systems, increasing the likelihood that people receive the alert by one or more communication pathways. CAP can:

- Add rich multimedia such as photographs, maps, streaming video and audio.
- Geographically target emergency alerts to a defined warning area. This is limited only by the capacity of the delivery system used.
- Serve the needs of people who are deaf, hard of hearing, blind or have low vision.
- Send alerts in multiple languages.

In addition, CAP enables the easy exchange of warnings between countries and the integration of these warnings into national and international platforms such as WMO's Severe Weather Information System.

3. Forecast and warnings production platforms

During consultation it was evident that there are a wide variety of forecast and warning production platforms in use across the NMHSs. Some countries such as Samoa and Tonga are actively seeking to update their forecast and warnings platforms while a number of others acknowledged that their platforms are ageing and in need of refurbishment but are currently unable to take action on this. The NMHSs affiliated with NWS have access to the Advanced Weather Interactive Processing System (AWIPS). AWIPS is an advanced information processing, display, and telecommunications system that is the cornerstone of the NWS modernisation and restructuring process. Similar to most modern forecast production platforms, AWIPS is an interactive computer system that integrates all meteorological and hydrological data with satellite and radar imagery.

2.1.3.5. Capacity and Training

(a) Capacity

The numbers of staff in NMHS varies considerably according to the size of country and the stage of development of the NMHS capacity. Consequently, staff numbers vary from 1 or 2 in the smallest met/hydrology services to over 50 in the largest. Overall, there are more than 500 staff in NMHSs across the Pacific based on the consultation with the 16 countries undertaken in this project. Of the more than 500 staff across the NMHSs, approximately 35% are involved in forecasts or climate services, which is consistent with other meteorological services across the world (Table 2.1). However, only a minority of forecasters (approximately 20%) have a BIP-M or equivalent qualification. As a consequence, only a few of the NMHSs have the capacity to undertake aviation forecasting because this requires a roster of WMO forecasters with BIP-M qualifications and accredited aviation forecasting competencies.

Table 2.1: Summary of NMHS capacity across the 16 countries and territories consulted during this Decadal Investment Plan scoping project.

Country	Forecasters, hydrologists, climate services	Observers, technicians, IT staff	Administration, management, general support	Total
American Samoa	6	4	1	**11**
Cook Islands	8	5	1	**14**
FSM	2	29	3	**34**
Fiji	68	39	38	**145**
Guam	16	8	1	**25**
Kiribati	5	19	6	**30**
Nauru	2	3		**5**

Country	Forecasters, hydrologists, climate services	Observers, technicians, IT staff	Administration, management, general support	Total
Niue	2	5	1	**8**
Palau	1	9	1	**11**
PNG	2[1]	47	5	**54**
Samoa	8	15	2	**25**
Solomon Islands	4	13	2	**19**
Tokelau	0	3	3	**6**
Tonga	11	19	2	**32**
Tuvalu	5	14	2	**21**
Vanuatu	22	35	6	**63**
Total	**162[2]**	**267**	**74**	**503**

[1]This number only includes BIP-M qualified forecasters; other staff also undertake forecasting duties
[2]Of the 162 forecasters, approximately 20%, have BIP-M or equivalent qualifications

A number of countries indicated they had sufficient overall numbers while the majority indicated they needed more capacity across forecasting, electronics technicians and IT support. For forecasting it was more of an issue of raising the skills and capacity of existing staff. However, for IT and electronics technicians it is mostly an issue of absolute capacity with most NMHSs either having no dedicated IT capacity or just one or two staff. With the increasing amount of electronic and automated equipment (e.g. NIWA alone has installed 260 Hydro/Met Stations over the last decade) the need for electronics technicians, and IT/data management staffing has increased dramatically. There was less concern raised about observational capacity.

Only a few of the NMHSs have the capacity to undertake aviation forecasting because this requires a roster of forecasters with BIP-M qualifications and accredited aviation forecasting competencies) which frequently, they lack. This is an important consideration since aviation forecasting is a means for some NMHSs to generate income through a globally accepted user pays mechanism. A number of NMHSs indicated that they wish to start doing their own aviation (and marine) forecasting, possibly with a view towards generating this income.

Similar to aviation services, FMS/RSMC-Nadi delivers the marine weather forecasts and warnings to many countries. Whilst currently this activity does not need to be undertaken by a BIP-M qualified and certified forecaster the International Maritime Organisation (IMO), the body responsible for such specifications, is likely to mandate shortly that such a qualification and competency set is required. This is another reason why some NMHSs in the region wish to upskill their forecasters to this level. Finding sufficient numbers of suitably qualified people to undertake this level of training will be a challenge that is addressed in the investment section below.   WMO is in the process of rolling out a new model of capacity development for marine weather services. The course aims for a meteorological service to self-assess their capacity in marine weather forecasting services, via an online forum in collaboration with others in the region. On completion of the online component, and gaps identified, the course will be tailored to deliver the appropriate training to meteorological services in the region. This will help to address part of the marine forecasting competencies.

Staff turnover is a significant issue in some NMHSs whilst in others it was not considered to be a significant constraint. As indicated above, major drivers of high staff turnover are poor remuneration compared with other areas of government or the private sector and uncertain pathway for career and academic advancement. In some Services the majority of staff are nearing retirement age and this will likely leave a gap unless recruitment strategies are implemented. Even where this shortfall is anticipated it can be difficult to secure funding to bring on cadets or new graduates from departmental funding. In a few countries staff turnover is not an issue and this can be ascribed to good leadership, provision of incentives, better aligning of salaries with other commensurate qualifications in government and a young, enthusiastic staff cohort.

Image 4: Forecasters at the Vanuatu Meteorology and Geohazards Department's briefing trainees on the type of services they provide.

(b) Training

Nearly all NMHSs indicated that they need staff trained to a higher level, whether that be WMO accredited forecasters (BIP-M), or observers and technicians (BIP-MT or equivalent). For higher level training as BIP-M forecasters, which is mostly undertaken in NZ, Australia or the Philippines, funding was not seen as the biggest constraint though it can be a factor because of limited national funds. Ongoing regional and international funding together with increased national funding through a national scholarship program could overcome this funding constraint.

> Only a few of the NMHSs have forecasters trained to the equivalent BIP-M and there is also insufficient BIP-MT forecasters. Further, Information Technology (IT) and data management was consistently raised as a high priority need by NMHSs as few Services have sufficient dedicated IT support.

Spending 6-9 months overseas away from family or the lack of sufficient undergraduates with adequate maths/physics training were identified as higher level issues. Incentives to develop more undergraduates is needed and a possible hybrid model for higher level training using a mixture of online and in-person training either overseas or in the Pacific using existing training centres was seen as a possible solution. The idea of a WMO Regional Training Centre (RTC) in Fiji was viewed as important for observational/electronics technician training because Fiji Meteorology Services already plays this regional role and the interest expressed by USP to provide support. For introductory forecasting and observer training the Pacific International Training Desk in Hawaii was also raised as an important option to train assistant forecasters and observers. However, for higher level BIP-M training, the use of established training centres in NZ, Australia, Philippines, United Kingdom, Germany and Japan was more commonly viewed favourably with the added option of the hybrid approach indicated above.

There was a need expressed for training in riverine flood forecast modelling – flood forecasting is relatively new and immature within most NMHSs and with a move to more model-based flood warnings, supported by observations, there is a need for training in this area. Further, a few countries identified the need for enhanced skills in marine and ocean forecasting, especially where they were acquiring observational equipment to better support forecasts for marine weather and coastal inundation.

The US-affiliated countries and US territories have a well-established training system with observers/technicians trained on the job and through short courses in Hawaii at the Pacific International Training Desk. Meteorologists receive degrees in meteorology from recognised universities and then undertake on the job training and courses within the US NOAA NWS.

As indicated in section 2.1.3.1 on Mandate, leadership training for Directors and senior managers in strategy, organisational management, and financial management was identified as being important for both better managing NMHS delivery but also in influencing the positioning of NMHSs within government.

There were positive views expressed about previous (WMO coordinated) short training workshops done in the region by experts from overseas e.g. (BoM) on courses such as the Southern Hemisphere biannual Tropical Cyclone Training Course. It is also noted that SWFP has organised and undertaken regular training courses for staff from many NMHSs in the region since 2009, both in person and recently, online. Further, approaches to training such as NIWA provides in maintenance of AWSs and hydrology equipment are seen as valuable initiatives. NIWA uses a buddy or twinning system where a specialist in NIWA works in an ongoing way with technicians from individual Pacific Island countries to build a relationship that becomes less dependent over time. For example, Cook Islands technicians recently installed two AWSs without NIWA providing in-country visits due to COVID. This was only possible because of the capacity built up over time through the buddy/twinning system. These approaches to the use of external experts in building capacity could be explored and developed further.

Most training that is undertaken regionally (at FMS) or further away (such as at BoM Regional Training Centre, PAGASA, Victoria University in Wellington, PITD, University of Hawaii and Reading University is funded from donor projects, which results in training being somewhat opportunistic. A longer-term training and capacity building plan is required within individual NMHSs to provide a more stable flow of capacity enhancement.

2.1.4. Summary matrix of capacities

Table 2.2 presents a matrix of current capacities of sixteen NMHSs across a number of criteria in the four areas of governance and institutions, infrastructure, forecasts and warnings and capacity and training. It highlights areas that require strengthening that are identified in the synthesis summary e.g. surface and ocean observations, IT infrastructure and capacity, and training needs.

Table 2.2: Essential elements of effective meteorological services: current status of 16 Pacific Island countries and territories.

	American Samoa	Cook Islands	FSM	Fiji	Guam	Kiribati	Nauru	Niue	Palau	PNG	Samoa	Solomon Islands	Tokelau	Tonga	Tuvalu	Vanuatu
GOVERNANCE AND MANDATE																
Well defined mandate																
Legislative authority and/or Meteorology Act	USA NWS	Met Act	USA NWS	Met Act to be passed	USA NWS	No Act but under review	Met Act	Met Act	USA NWS	No Act	Met under Disaster Act	Met Act 1985 – under review	No Act	Met Act	No Act but under review	Broad Act 2016
Strategic plans in place		INV	INV	INV		INV	No	National Plan	INV		INV	INV	National Plan			
Effective institutional partnerships e.g. NDMO																
OBSERVATIONS AND INFRASTRUCTURE																
Extensive network of surface observations									INV						INV	
National marine observations data	N/A				N/A				INV							
Upper air observations		INV					No	No	No	No	No	No	No	No		No
River gauging (rain and/or river heights)	N/A	N/A	N/A		No	N/A	N/A	N/A	No				N/A	N/A	N/A	

Weather radar	No	INV	No	Yes	Yes	No	No	INV	INV	No	No	No	No	No	INV	No
Sufficient IT infrastructure																
Observations transferred to global network (G), climate database (CliDE) (C) or no transfer (N)	No	C	No	C	No	No	No	No	C	No	C	C	No	C	No	C
DATA, FORECAST PRODUCTION AND SERVICE PROVISION CAPABILITY																
Develop forecasts in country (C), regional forecasts, locally interpreted (R), fully dependent (D)	C/R	R	R	C	C	D	D/R	R	R	C	C	C	D	C	R	C
Use of SWFP/MetConnect	N/A		N/A		N/A				N/A							
Source of cyclone warnings (e.g. RSMC-Nadi, JTWC)	RSMC-N, JTWC	RSMC-N, NZ, Aust	JTWC	National	JTWC	RSMC-N, National	RSMC-N, NZ	RSMC-N	JTWC	National	RSMC-N, National, JTWC	RSMC-N, National	RSMC-N, National	RSMC-F	RSMC-N, National	RSMC-N, National
Source of Tsunami warnings (PTWC, JMA, In country)	PTWC	PTWC	PTWC	PTWC	PTWC	PTWC	PTWC	PTWC	PTWS, JMA	N/A	Samoa	PTWS, JMA	PTWC Samoa	Tonga	PTWC	PTWC
Ability to generate aviation forecasts	No	No	No	Yes	Yes	No	No	No	No	Limited	No	Yes	No	Yes	No	Yes + Fiji
Use of global data products e.g. GFS, ECMWF, Himawari																
Use of forecast production or visualisation systems (e.g. AWIPS, Visual Weather)														INV		

Communication platforms or equipment sufficient to get timely forecasts and warnings delivered																
Use of impact-based forecasts and warnings																
CAPACITY AND TRAINING																
Sufficient qualified forecasters and/or hydrologists to deliver on mandate																
Sufficient qualified observers and electronics technicians																
Sufficient IT staff to process data																
Overall training needs being met																

Key	
	Existing organisation, capacity, processes or equipment are well developed/strong
	Existing organisation, capacity, processes or equipment are moderately developed
	Existing organisation, capacity, processes or equipment are limited in their development
INV	Current/planned project, effort and/or investment
N/A	Not applicable to the country's requirements

2.2. Document and Project Review

2.2.1. Background

To provide insights on key priorities, issues, challenges and opportunities for National Meteorological and Hydrological Services (NMHSs) in the Pacific region, a range of documents and reports were reviewed. These reports and documents covered the areas of strategy and governance, infrastructure, forecast and warning delivery and capacity and training. They included reports undertaken at a global scale and which were relevant to Pacific Island countries, regional reports applicable across the Pacific, and reports that were country specific. The reports and documents accessed varied in their aim from strategic plans, reviews, completion reports, to implementation proposals. Approximately 50 documents were reviewed, based on recommendations from SPREP and WMO and additional documents found during the scanning process. Appendix 3 provides a listing of key documents and the main summary points.

In addition, a listing of current projects was compiled and, where appropriate, project documentation reviewed to provide insights into existing investments (Appendix 4). Key gaps and needs identified in project background and rationale have been incorporated into the key points below.

2.2.2. Document and project review key points

Listed below are key points from the document review. Some of the summary points are common across a number of reviews/reports whilst others are specific to a single report.

(i) Strategy and governance

- A holistic approach to improving meteorological, hydrological, ocean and other related environmental services is needed. At present there is a major gap in that there are many modest scale initiatives but which are quite fragmented;
- Multiple donor systems, many of which ultimately either are unsustainable in themselves, or create a negative burden on the recipient service;
- To achieve a sustainable and systemic outcome, strategic plans with supporting investment commitments are needed for 10-20 years;
- These strategic plans need coordinated “buy-in” from development partners with an appropriate balance of strategy and governance, capacity building, infrastructure and delivery systems.

(ii) Production of forecasts and warnings

- The current WMO Severe Weather Forecasting Demonstration Project (SWFDP) now renamed the Severe Weather Forecast Programme (SWFP) that provides warning and general forecast information through MetConnect Pacific (operated out of NZ MetService) requires committed resources so as to be sustainable long-term;
- The SWFP approach of GPCs providing Numerical Weather Prediction (NWP) products to Regional Centres (Nadi, Wellington, Darwin) and then Regional Centres interpreting this information received and refining it through use of limited-area models (and post-processing of model outputs) for NMHSs to then issue alerts, advisories, severe weather warnings has been recommended by the WMO as the best long-term approach;
- For implementation of Multi-Hazard Early Warning Systems (MHEWS), based on recommendations for a World Bank Pacific Resilience Program (PREP) initiative in Tonga and Samoa, meteorology, water/hydrological services and disaster management offices should be brought together under one roof. It is proposed that the warning and response entities work much closer together in order to establish a proper risk, impact and response based and actionable warning system; An important feedback loop in this cascading model is that observational data at a country level should increasingly be going into NWP models that are provided by GPCs rather than trying to develop local Limited Area Models (LAM) at a national scale or maintain in-country deterministic forecasts;

- There is a need to move to providing open data both regionally and as inputs into Global Production Centres (GPCs);
- Ensembles of NWP are needed to provide probabilistic forecasts;
- More emphasis is needed on forecast verification.
- The WMO Coastal Inundation Forecasting Initiative (CIFI), as demonstrated in Fiji, could be scaled up for development across all the Pacific island countries and territories. This is a significant opportunity to enhance the capacity of met services with multi hazard early warning capability for coastal flooding and inundation – from all sources including storm surges, swell, waves, river-floods and tsunami.

(iii) Communication and delivery of forecasts and warnings

- There is a gap in fully understanding user needs and developing appropriate delivery models.
- More needs to be done on developing impact messages;
- There is a need to better integrate modern NMHS forecast and warnings with traditional knowledge, which requires engagement with communities;
- Women are overrepresented in deaths resulting from natural disasters. People with disabilities are also disproportionally affected by disasters.

(iv) Infrastructure and observations

- There is too much emphasis on buying observation equipment, especially AWSs in an uncoordinated way by different donors leading to diversity of equipment types and standards which provides challenges for operation, data harmonisation and maintenance;
- A significant number of Automatic Weather Stations (AWS) are non-operational. For example, a FINPAC assessment found in 2015 that 21 Regional Basic Synoptic Network (RBSN) stations in the Pacific were not operational, with most of these 21 stations being AWSs. The FINPAC report went on to say that the Pacific is among the worst regions in the world in terms of availability of weather and climate data, only second to Sub-Saharan Africa;
- There is often little ongoing funding provided for upskilling technicians or providing a long-term vendor contract for maintenance and repairs, though the NIWA approach to AWS equipment provision and training is an exception to this constraint;
- Improved ICT and central data systems need to be improved for data exchange and injection to data processing, forecasts and warning production and delivery systems;
- A significant gap in infrastructure and associated operating costs is upper-air observations and ocean observations and more attention is needed in this area;

> "Systematic upper air observations in the Pacific region, tend to have the highest measured impact, of all ground-based measurements, on the quality and accuracy of weather and climate analysis and prediction. Both the spatial density and observing frequency of the upper air network over the South Pacific region currently fall short of GCOS and WMO requirements. The upper air network over the South Pacific therefore needs sustained international support" (GCOS-WMO workshop, Fiji, 2017).

- The Systematic Observations Financing Facility (SOFF) has been established by WMO and collaborators to support countries to generate and exchange basic observational data critical for improved weather forecasts and climate services. In its initial five-year implementation period, SOFF aims to support 68 Small Island Developing States (SIDS) and Least Developed Countries (LDCs) to achieve sustained compliance in the Global Basic Observing Network (GBON). This will lead to more than a 10-fold increase of observational data from radiosonde observations and more than a 20-fold increase of data from weather stations, which will be internationally shared. USD 400 Million are needed to cover the first 5-years of operation of SOFF to support all SIDS and LDCs in achieving GBON compliance. However, no funding as yet been secured to support SOFF.

(v) Capacity building and training

- There is little recognition of in-house non-accredited training in advancement of forecasters and technicians;
- The career structure for professionals and technical staff is not well identified in a number of NMHSs;
- The number of people that need training each year provides a critical mass challenge for establishing both a BSC in Meteorology degree at universities in the Pacific Islands region such as the University of the South Pacific (USP), Fiji National University (FNU), National University of Samoa (NUS), University of Papua New Guinea (UPNG) or a local Regional Training Centre that can deliver a graduate diploma BIP-M course;
- Sustainable funding for a Pacific Based (most likely Fiji) Regional Training Centre (RTC) needs to be addressed;
- Other options (RTCs in Asia-Pacific region) need to be explored for relative benefits and costs compared with a Fiji-based RTC;
- The workforce in many NMHSs is relatively young so retirement isn't a major concern. However, there are a few NMHSs where there is a cohort of staff approaching retirement age;
- Demand for education and training is highest for operational forecasting, climate services, marine and ocean services, ICT and equipment maintenance;
- With an increase in automated observation equipment and data generation there is a rapidly increasing demand for IT capacity, which is lacking in most NMHSs;
- The dependency on external funding for training and capacity building is unsustainable.
- The new WMO Marine Services Course is an opportunity for meteorological services to self-assess their capacity, fulfil part of the competency requirements, and receive recognition of the training effort.

3. Developing the Decadal Program of Investment

3.1. Conceptual Approach to the Decadal Program of Investment

The rationale for the Decadal Program of Investment is based on four key inputs:

- the objectives for the Decadal Investment Plan as set out in the Statement of Requirements for this Scoping Project;
- the Pacific Islands Meteorological Strategy 2017-2026;
- consultation process with sixteen Pacific island countries and territories, discussions held with other National Meteorological Services (NMSs) in the region, and other agencies (see also Appendix 1);
- review of documentation associated with various implementation projects, strategies, and capacity and training needs relevant to the Pacific Islands to avoid duplication and to target gaps (see also Appendices 2 and 3).

Emerging from these inputs is a clear need to invest in five key areas over a decadal timescale:

(a) Support and strengthen governance and institutional arrangements, leadership, coordination, planning, and management of NMHSs and NDMOs.

(b) Strengthen regional and national severe weather forecasting and warning systems using risk, impact and response-based approaches that better prepare communities and industries to deal with high risk, impact and severe weather events, riverine flash floods and coastal hazard and inundation impacts, while utilising improving Numerical Weather Prediction (NWP) techniques to automate routine tasks, provide better services and free up forecaster resources for higher priority tasks.

(c) Improve the communication and delivery of forecasts and warnings to government, communities and industries through strengthening engagement with NDMOs and ensuring delivery of impact-based messages that trigger appropriate and timely responses.

(d) Provide enhanced hydro-meteorological, oceans and other related environmental infrastructure networks and associated IT/ICT equipment that meets emerging and future needs and do this in a targeted and coordinated way to complement existing and planned initiatives.

(e) Build the capacity of NMHS forecasters, hydrologists, observers, electronics technicians, and information and data technologists.

Forecasts and warnings for weather, flash floods, coastal and other related environmental hazards and risks increasingly rely on numerical weather prediction models and satellite products that are developed in advanced forecasting centres. Pacific Island countries already draw on the outputs from meteorological satellites, advanced NWP models, and flash flood models in a variety of ways. These include direct use of NWP outputs from their source e.g. globally GPCs, 9 WMCs in particular Melbourne WMC, ECMWF, Tokyo WMC, Washington WMC/US NOAA NCEP, Exeter WMC and Toulouse WMC and/or interpreted forecasts and warnings through Wellington RSMC for severe weather forecasting and marine meteorological services (SWFP), Darwin RSMC for geographical specialisation; RSMC-Nadi for tropical cyclone forecasting. These RSMCs interpret the information received and refine it through use of limited-area models and post-processing and make the information available to NMHSs in a cascading forecasting process. A Decadal Investment Plan needs to address the linkages between these global and regional centres and investments in NHMSs because of the growing dependency of NMHSs on these centres and the concept of cascading and automated forecasting processes.

Figure 3.1 provides a conceptual representation of how a Decadal Program of Investment needs to link investment at a national level with global and regional networks to deliver risk, impact and response-based forecasts and warnings that deliver the desired outcomes for communities and livelihoods.

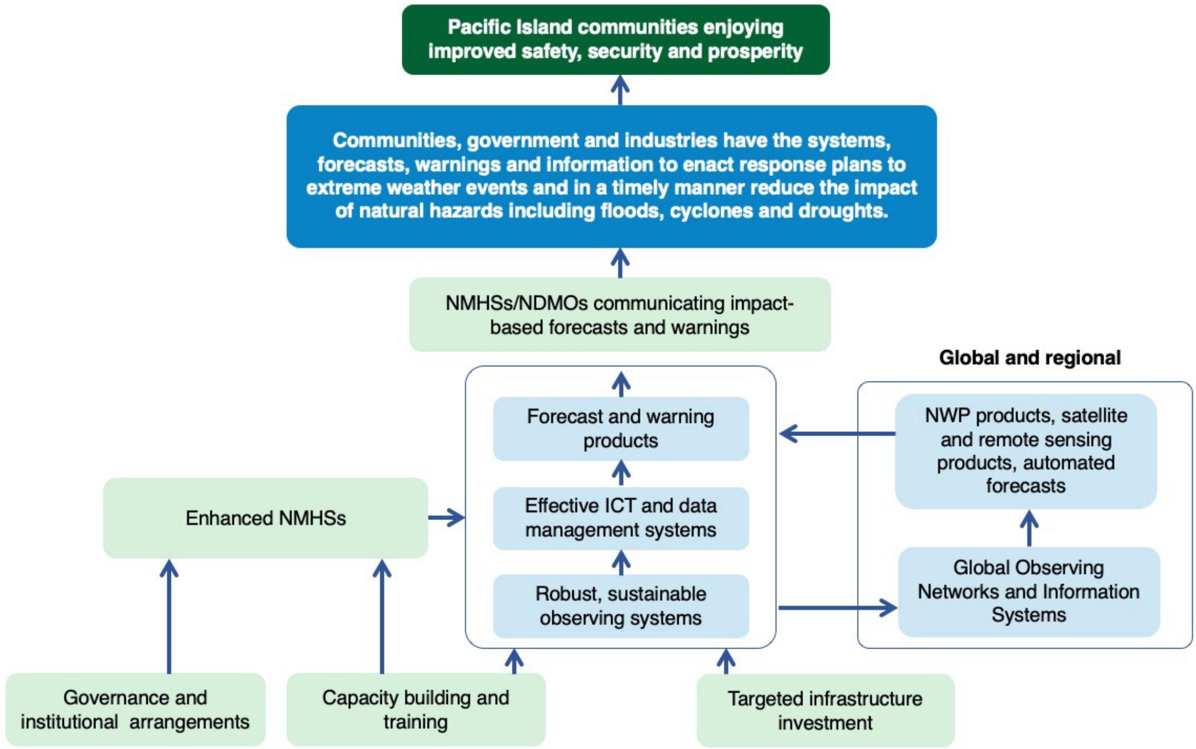


Figure 3.1: Conceptual representation of how the Decadal Program of Investment in the Pacific (light green boxes) needs to interact with regional and global observing networks and forecast centres (light blue box) to deliver desired community outcomes.

The approach taken to the Decadal Program of Investment has been to understand existing programs and initiatives and complement them rather than duplicate investments. Appendix 4 lists 58 ongoing or recently completed projects that directly relate to the Weather Ready Pacific initiative. Some of the existing initiatives are very significant in terms of the quantum of investment. For example, two Green Climate Fund projects that are providing significant infrastructure and capacity building support to NMHSs (USD 80 million), World Bank Pacific Resilience Program (PREP I and PREP II) (USD 75 million), and the Australian Department of Foreign Affairs and Trade COSSPac program over two phases (USD 41 million). It is important that this Decadal Program of Investment leverage off these existing initiatives (Box 3.1).

Box 3.1 How the Weather Ready Pacific and an existing program (COSSPac) could be complementary

COSSPac benefits for Weather Ready Pacific

- Pacific NMHSs are using the climate data management system CliDE which can be used to quality control and archive observations from the AWSs installed by Weather Ready Pacific.
- Weather Ready Pacific will support capacity building in observations, instrument maintenance and data management. CliDE contains a metadata archive which can be used to log instrument details, site photographs, calibration information etc.

Weather Ready Pacific benefits for COSPPac

- The quality of NMHS observational data used for climate change has been gradually declining. The investment in observations infrastructure, training, and instrument calibration will assist in quality control required to assess long term change in temperature and rainfall.
- COSPPac has identified a deficiency in the number of stations with long records required for drought monitoring. The expansion of the AWS network may allow longer-term records to be restored through creation of composite data sets using closed manual stations and new AWSs.

The following sections provide more detail on the rationale for the five key investment areas with proposed investments included.

3.2. Investment rationale and costings

3.2.1. Governance and leadership

Key activities:

1. Develop a Pacific Meteorological Leadership Program and deliver this to 60 NMHS leaders.
2. Put in place a Management and Advisor Team who will have responsibility for coordinating the implementation of the Decadal Program of Investment, and
   (a) work in partnership with the PMDP;
   (b) work with other projects and donors to coordinate the implementation of the investment plan
   (c) work with the PMC and its six expert panels; and
   (d) provide support in implementing strategic plans at the national level.

Core deliverables:

1. Enhanced leadership capability in NMHSs that is capable of driving a dynamic service with a focus on partnership and delivery.
2. Effective coordination and governance of the Program and increased effectiveness of regional coordination and donor relationships.

For there to be effective meteorological and hydrological services, there needs to be a strong mandate, leadership, governance and institutional arrangements, and coordination. Across the SPREP member countries and territories, the mandate for meteorological services is clear and the need for appropriate governance and institutional arrangements is a key outcome in the *Pacific Islands Meteorological Strategy 2017-2026*, which includes the need to strengthen:

- public governance;
- communication;
- public financial management;
- project management;
- information technology; and
- technical education, training and research.

Whilst the intent is clear there is in a number of countries insufficient investment in supporting governance arrangements, coordination across departments within governments, and leadership and management capabilities. For example, some countries have a specific Meteorology Act and Hydrology or equivalent Water Resources Management Act and strategic plans for meteorology and hydrology or equivalent water resources management whilst others are developing or aspire to put in place these Act and strategic plans. Some of the small countries lack the capacity to move forward on a Meteorology Act and/or developing strategic plans and require support in doing so. Resourcing to support these governance initiatives is generally lacking.

Water resources and hydrological services are not as clearly defined or mandated. Even in countries where flash flooding is a significant issue, the mandate and role of hydrology and water resources is not always well defined or budgeted for in recurrent funding. In larger countries, there is a mixture of approaches with water resources/hydrology sitting either with Meteorology or in its own department, most often within the same Ministry. Water resources/hydrology services need to be better integrated to effectively deliver risk, impact and response-based forecasts and warnings for floods and inundation events. This requires both changes in institutional, governance and coordination arrangements and investment to support better integrated services.

Across the Pacific, NMHSs are developing approaches to Multi-Hazard Early Warning Systems (MHEWS). This requires good coordination between NMHSs, NDMOs or their emergency management office equivalent and users of forecasts and warnings, to deliver timely and appropriately communicated warnings that are risk, impact and response-based and lead to effective preparedness in communities and industries. There is, across nearly all countries, a formally legislated or regulated arrangement between meteorological and hydrological services and NDMOs and the NMHSs appear to be well connected to the NDMOs and seem to be an integral part of their country's emergency management plans. However, in practice, there is scope for much improved operations, especially in communication systems and messaging to communities, especially those in remote islands (see sections below on Forecasts and warnings and Infrastructure).

Building leadership and management capacity is important for better positioning the meteorological and hydrological services within government organisational structures. NMHSs are not prominent in many Ministries and this flows through to career structure and the lower remuneration of professional and technical officers compared with other areas of government and the private sector. This can lead to challenges in retaining staff with well-credentialed staff being lost to other government departments or regional and international agencies. Technicians, especially in electronics and IT/ICT, are attractive to the private sector, especially telecommunications companies.

One of the Key Outcomes of the Pacific Islands Meteorological Strategy 2017-2026 is to ensure support to NHMSs from donors is coordinated. This is because there are many different development/agency initiatives, programs and projects involving a large number of international institutions. There is a need to bring cohesion to these various activities so that the whole is greater than the sum of the parts. This requires stronger coordination among donors, development and collaborating partners, and between and the involvement of regional partners such as SPREP and WMO RA-V aligning initiatives to overarching strategies. The need for better alignment is especially evident in infrastructure where different projects can result in a wide diversity of equipment types, which creates additional overheads and stretches already limited capacity in equipment maintenance and sustainability. Further, the needs of individual countries varies considerably and a "one-size fits all" approach is not appropriate. The PIMS 2017-2026 strategy focuses on creating databases, strengthening engagement and promoting coordination to address some of these challenges.

There are existing mechanisms for coordination of meteorological services and their development in the region. Key amongst these is the PMDP, which is based at SPREP and is coordinated by SPREP and WMO. It has as its mandate regional coordination and support of PMC work areas, including the six expert panels. It is critical that the governance of the Decadal Program of Investment be linked closely to the PMDP to create synergies with its overall regional coordination function. A PMC Donor and Partner Engagement Strategy and Implementation Plan recommended that the coordination function of the PMDP be reviewed and its resourcing strengthened and that a key activity for the PMDP be to develop and consult on a donor and partner coordination platform. The Decadal Program of Investment should support these aims for the PMDP as it should lead to more effective program outcomes and in parallel provide a strengthened PMDP.

It is proposed to invest in two activities that will address the governance and institutional needs of NMHSs in the region:

- a Pacific Meteorological Leadership Program (PMLP) developed and delivered biennially to build leadership and management capacity in existing and future leaders and promote regional collaboration;

- a Management and Advisor Team to oversee and coordinate the implementation of the Decadal Program of Investment. This team will be integrated with the PMDP. In addition to overseeing the Decadal Program of Investment the team will work closely with the PMDP and the PMC six technical panels. They will also coordinate the development of PMC donor and partner engagement platform and operationalise the platform through biennial

> Investing in leadership and management capacity in NMHSs will lead to a higher performing service that provides better outcomes in delivery of forecasts and warnings that impact positively on people's lives. It will also provide the leadership qualities that can drive an internal culture focused on excellence and fostering opportunities for staff development and training.

meetings. Further, they will provide support to NMHSs in implementing strategic plans.

3.2.1.1. Pacific Meteorological Leadership Program (PMLP)

The PMLP will be developed as a leadership program tailored to the needs of Pacific NMHSs. The PMLP will be focused on providing participants with a mix of technical competencies and core leadership skills together with the interpersonal linkages with other Pacific NMHSs and key regional Meteorological Services (Australia, New Zealand, Hawaii) needed to generate a critical mass of Pacific leaders. Leadership training will include aspects of governance including emerging opportunities such as public-private partnerships, strategic planning, financial management, communication.

The PMLP will be delivered biennially over a three-week period and in partnership with a suitable academic institution or service provider (Tables 3.1 and 3.2). The deliverer of the PLMP will have a key role in its design, development and delivery, including the delivery of course sessions, facilitating site visits, providing access to senior leadership and an informal mentoring program.

To ensure maximum benefit from peer engagement it is proposed that the PLMP be held every second year with approximately 12 participants in each intake resulting in 60 NHMS staff trained in leadership. Particular attention will be placed on ensuring opportunities are provided to women to improve the gender balance of senior managers and Directors over the decadal investment timeframe.

Table 3.1: Costs of Pacific Meteorological Leadership Program (five courses over 10 years)

	Cost per participant	Cost per program
Travel, accommodation and meal costs for 3 weeks	USD 8,300	USD 99,600
Cost of course delivery (two trainers for three weeks plus one week preparation)		USD 36,400
Venue and meal costs		USD 8000
Follow-up online mentoring		USD 4900
Total cost over 10 years (allowing 2.5% increase per year in annual costs)		**USD 0.87 M**

Table 3.2: Annual total costs of PMLP over the 10-year investment plan term (USD millions)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.19	0.005	0.15	0.01	0.16	0.01	0.17	0.01	0.18	0.01	**0.87**

3.2.1.2. Implementation of the Decadal Program of Investment and coordination with PMC and Donors

To effectively implement a Decadal Program of Investment will require significant investment in management and coordination. The management and coordination are required not just for oversight and coordination of project activities but also to work closely with the PMDP, the PMC and its six panels, and donors. The proposed management team will be part of and located with Pacific Meteorological Desk Partnership. The exact nature of this implementation and coordination function will be determined ultimately by the funding model and arrangements for the Decadal Program of Investment (See Section 4.4) so the proposed investments here will be subject to the funding model and approach to implementation.

Three investment activities are proposed:

(a) Decadal Program of Investment Management and Advisor Team. Given the scale of the proposed investment there will need to be a management and advisor team to coordinate the activities of the Decadal Program of Investment (Tables 3.3 and 3.4). This will comprise a Program Manager, a Senior Advisor/Manager, two internationally recruited Advisors (one governance, one technical), a Finance/Administration Officer and a Communications specialist who will be functionally located with the PMDP and will provide oversight across the five areas of investment. The Technical Advisor will take responsibility for the areas for forecasts and infrastructure, whilst the Governance Advisor will be responsible for institutional strengthening and capacity building. By being integrated with the PMDP, the management and advisory team will be well placed to work closely with the PMC and especially in linking the workings of the six PMC technical panels with the investment activities in forecasts and warnings and infrastructure (Figure 3.2).

The two internationally recruited Advisors will provide governance and technical support. For governance the roles will include:

- Working with NMHS' senior leadership to identify and deliver organisational reform priorities and, where needed, support the negotiation of donor funding for implementation;
- Assisting NMHSs management establish operational policies and processes needed to implement the strategies and plans that have been developed and assist with the completion of the strategic plans that are under development;
- Working with counterparts in weather services across the region to support strengthened national engagement in RA-V and other regional fora, and in turn, strengthened regional engagement in multilateral fora;
- Providing high level advice on implementation of the capacity building and training program, including the establishment of the Regional Training Centre Secretariat in Fiji;
- Advising on workforce planning and other operational aspects such as processes to ensure the safety and well-being of NMHS staff.

The Technical Advisor's role will include:

- Providing support on development and implementation of regionally coordinated forecast and warning systems;
- Working with NMHSs in contracting of and deployment of proposed infrastructure and maintenance schedules;
- Input into the implementation of an instrument maintenance and calibration centre in Fiji that will be tied to the RTC and FMS.

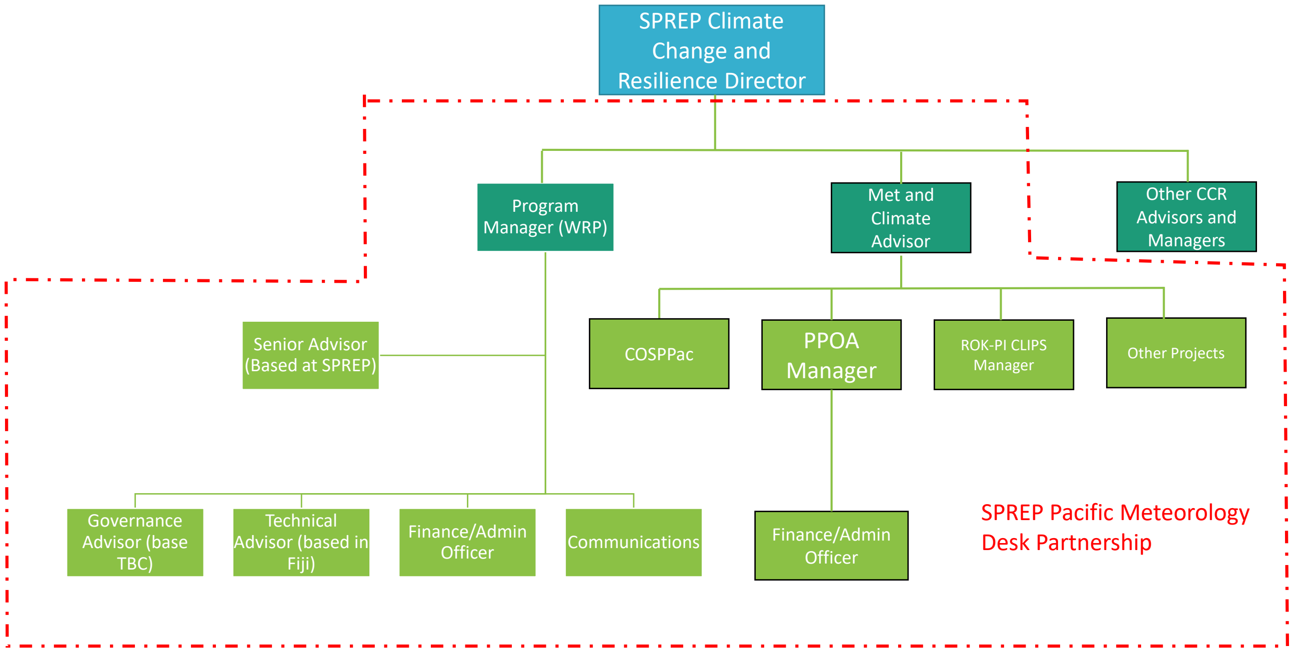


Figure 3.2: Proposed governance arrangements for the Weather Ready Pacific (WRP) Management and Advisor team

Table 3.3: Establishment and annual costs for Management Team and Advisors

	Establishment cost	Annual cost
Recruitment costs (Years 1, 4, 7)	USD 160,000/pp	
Salaries for Director, Manager, Finance Manager, Admin Officer		USD 260,000
Salaries for two advisors		USD 230,000
Housing and other allowances		USD 180,000
Travel, office space and operating costs		USD 150,000
Demobilisation costs (Years 4, 7, 10)	USD 170,000/pp	
Total cost over 10 years (allowing 2.5% increase per year in annual costs)		**USD 10.30 M**

Table 3.4: Annual total costs of Management Team and Advisors (USD millions)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.59	0.89	0.91	1.26	0.96	0.98	1.35	1.03	1.06	1.27	**10.30**

(b) Development of PMC donor and partner engagement platform. Regardless of the funding model for this Decadal Program of Investment there will inevitably be a diversity of donor programs and projects into the future. It has already been recommended by the PMC that a donor and engagement platform be established and this activity would support the hosting of a biennial donor engagement and discussion workshop (Table 3.5 and 3.6). This activity will improve the targeting of activities within the Decadal Program of Investment and achieving synergies across the full range of meteorological, hydrological and ocean investments. It would occur at the same time as the biennial PMC meetings. It is assumed in the costings below that donors cover their own costs.

Table 3.5: Cost of Biennial Donor meetings

	Cost per meeting
Travel and per diem costs	USD 57,500
Venue cost	USD 20,000
Facilitator cost	USD 2,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 0.43 M**

Table 3.6: Annual total costs of Biennial Donor meeting (USD millions)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.08		0.08		0.09		0.09		0.09		**0.43**

(c) Reviewing the PMDP and its future needs. Given the proposal to locate the management team with the PMDP it is proposed that the functions of the PMDP be reviewed to ensure that there is a good strategy and working arrangement over the decadal period. This review is consistent with a PMC request for the PMDP to be reviewed. A cost of $100,000 has been provided for this activity.

Table 3.7: Summary of proposed investments in Governance and leadership strengthening (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
PMLP	0.19	0.005	0.15	0.01	0.16	0.01	0.17	0.01	0.18	0.01	**0.87**
Management team	0.59	0.89	0.91	1.26	0.96	0.98	1.35	1.03	1.06	1.27	**10.30**
Donor meetings	0.08		0.08		0.09		0.09		0.09		**0.43**
PMDP Review	0.10										**0.10**
Total	**0.96**	**0.90**	**1.15**	**1.26**	**1.20**	**0.99**	**1.61**	**1.04**	**1.33**	**1.27**	**11.70**

3.2.2. Production of forecasts and warnings

Key activities:

1) Development of a comprehensive numerical weather prediction suite of automatically generated forecast and warning products for all NMHSs based on post-processing of numerical weather prediction, including 7-day forecasts for as many individual locations as required by each NMHS. This will enable every country to access reliable, accurate, localised forecasts and warnings via a centralised data and forecast exchange, with individual countries then able to direct their resources to where in the meteorological value chain they see national capability can add most value, particularly into impact-based forecasting and warning.

2) Development of a data exchange to contain and transmit these new products, or the enhancement of existing delivery systems.
3) Consolidation and strengthening of the aviation weather forecasting hub in Fiji.

Core deliverables:

1) Advanced impact-based warnings products that can be tailored by forecasters from each NMHS as required and as capacity permits to suit the requirements of NDMOs and community users of warnings throughout the region. This will enable better community preparation for high impact weather events which will lead to greater resilience.
2) 7-day public and marine weather forecasts derived from multi-model ensembles that contain estimates of uncertainty, that can be modified by forecasters as required which will provide the community and various industry sectors with information that will enable them to make improved decisions about weather critical activities.
3) Accurate, reliable aviation forecast and warning services tailored to the aviation industry's requirements that will enhance their safety and improve the efficiency of their operations, achieved through strengthening the aviation weather forecasting hub in Fiji and building capacity of aviation forecasters in a small number of larger NMHSs.
4) Improved ocean forecast and warning systems which will enable better preparation for high impact weather events by those industry sectors and communities that have direct links to the ocean which, in turn, will lead to greater resilience.

Background and rationale:

The development of a Decadal Program of Investment for the hydro-meteorological services of the Pacific requires detailed examination of how services may best be delivered and structured to deliver optimum effectiveness and value for the users of those services, which are often the governments of the nations involved, while providing a flexible and scalable approach. The Decadal Program of Investment needs to be consistent with the Pacific Islands Meteorological Strategy 2017-2026 and its priorities that relate specifically to the delivery of forecasts and warnings: Improved weather services, in particular aviation, marine and public weather services, and establishment of ocean weather services to support the safety and productivity of sectors and; Integrated observing and communication systems to support data exchange and processing and the preparation of weather, climate, water and ocean information and services including warnings.

Flexibility and scalability of approach are essential since no two nations in the Region are the same and trying to establish a single benchmark level of capability and service delivery for all services is not feasible. The challenge therefore lies in investing in, and developing, a system that will enable the delivery of essential services to all nations regardless of their NMHS's level of capability and capacity. This approach is consistent with another of the PIMS priorities: Coordinated support to ensure NMHSs have resources and access to services to undertake their legislated requirements and service their stakeholders.

> Adopting a cascading forecasting approach for the Pacific region and a delivery mechanism through the Pacific Weather Exchange ensures that no country is left behind in the production of weather, riverine flash floods, ocean forecasts and warnings and related coastal inundation. It will result in better outcomes for safety, community preparedness, livelihoods and economies.

To develop a flexible and scalable solution requires consideration of the entire value chain of the hydro-meteorological cycle, from observation to analysis to prognosis to forecasts and warnings to transmitting the message to the final users, as well as examining the processes and components that link and underpin the elements of the chain. It will also require each nation to closely examine their own value chains to determine exactly where they wish to place their resources to gain the best returns on their investments. Does every nation require their NMHS to be a WMO Level 1 NMHS with the attendant requirements that this demands, or are there alternatives to this model which will deliver the same level of service at a fraction of the cost using new and emerging technologies?

The model described below is designed to ensure that every single Pacific Island country can access reliable, accurate, localised forecasts and warnings via a centralised *Pacific Weather Exchange*, with individual nations then able to direct their resources to where in the meteorological value chain they see national capability can add most value. Nations with better forecasting capability can still produce their own forecasts but can provide more value by drawing on the wider range of products that will be produced through an enhanced regional data and information exchange. Nations with limited forecasting capability will be able to draw on the strengthened regional exchange and RSMCs but receive products better targeted to their location and needs than are currently delivered. This approach also builds resilience in that if a nation with better forecasting capacity suddenly experiences challenges through an unexpected loss of capability or a change in government priorities that reduces resources to the NMHS, then high quality forecasts and warnings can still be accessed through the regional exchange. The model ensures that no country is left behind in the production of weather, flood and ocean services with state of the art forecasts and warnings provided to the population to enable them to make critical weather related decisions.

The model is not dissimilar to that which currently operates through the Region and is proven to be effective (Figure 3.3). However, the level of service delivered is significantly different.

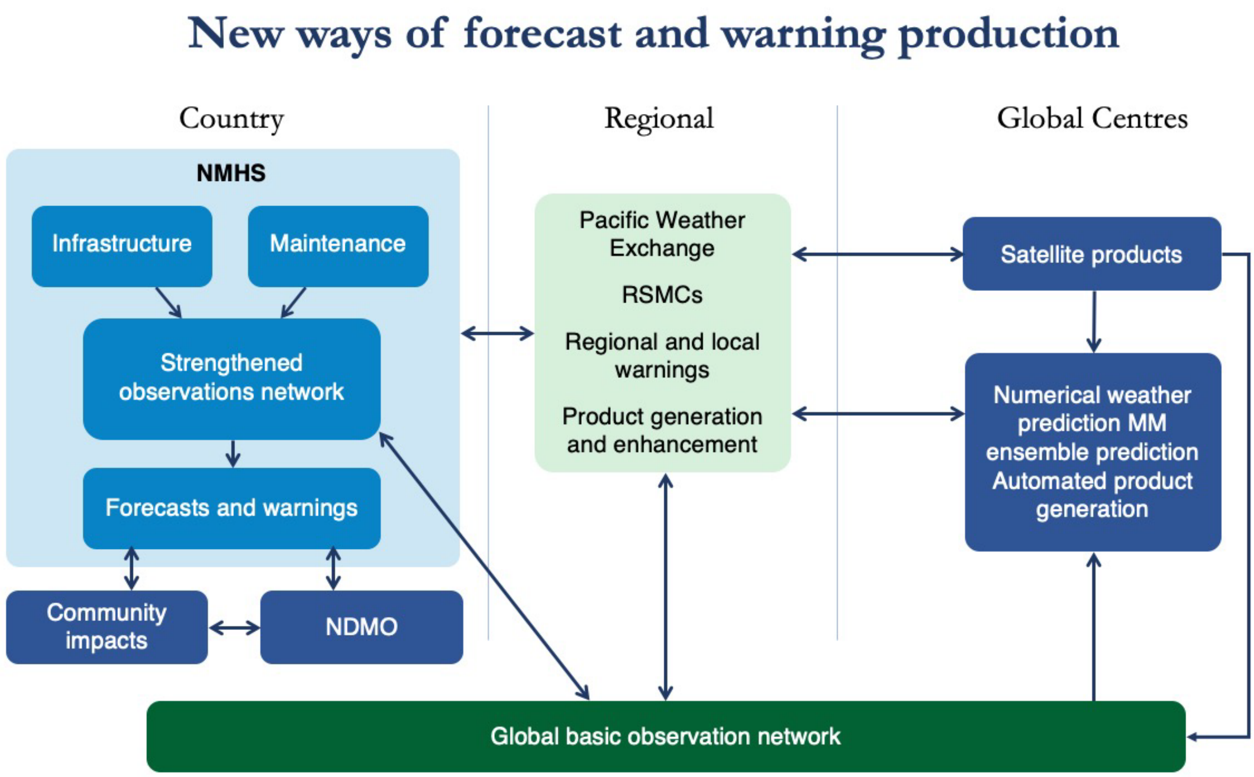


Figure 3.3: Concept of Operations

This concept of operations has three main components: 1) World Meteorological Centres (WMC), 2) Regional Centre(s), which include Regional Specialised Meteorological Centres (RSMC) and 3) National Meteorological and Hydrological Service (NMHS) providers, producing, exchanging and transmitting data in a cascading forecast process.

All three components are underpinned by the Global Basic Observation Network which provides the necessary observational data and linked by the WMO Information System.

3.2.2.1. Global Data Production and Forecasting System Centres

The Global Data-Processing and Forecasting System (GDPFS) is an international mechanism that coordinates WMO Member capacities to prepare and make meteorological analyses and forecast products available to all Members. It enables delivery of harmonised services and is currently organised as a network of Global, Regional and National Centres. Figure 3.4 shows the GDPFS Centres generating nowcasting and weather forecasting products for up to 30 days.

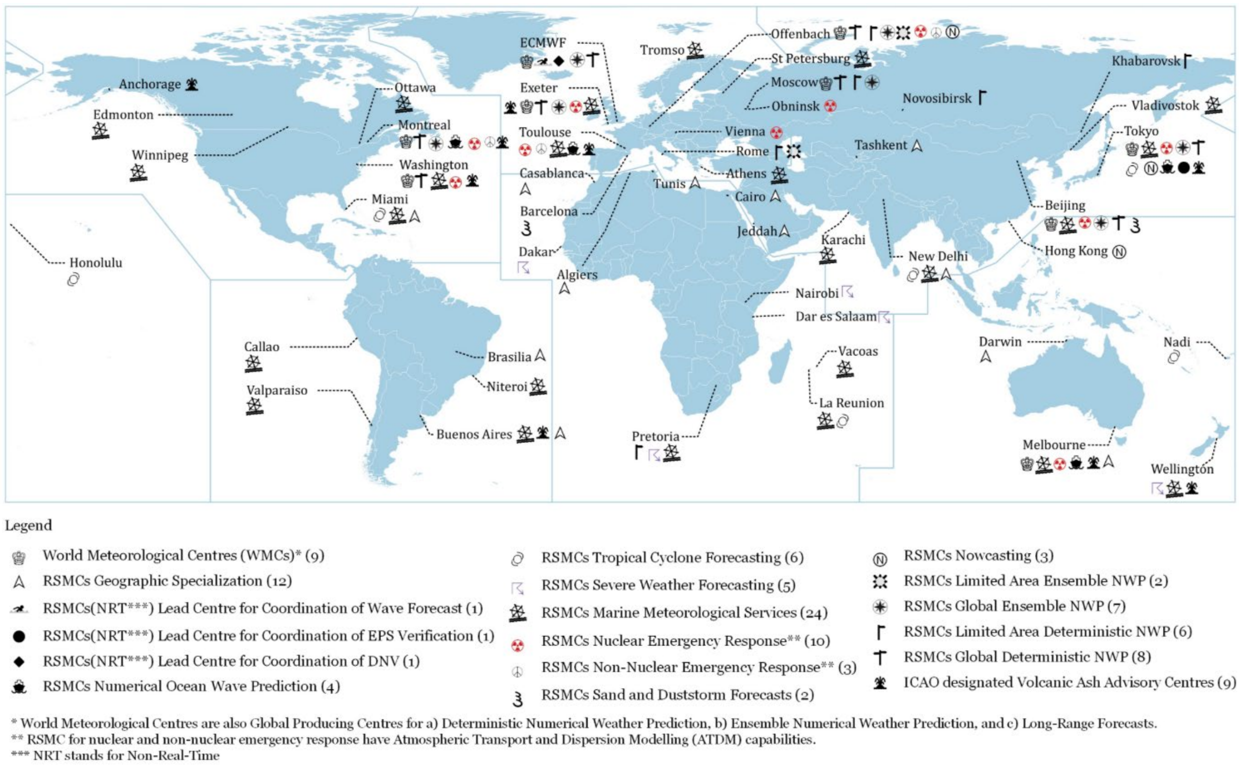


Figure 3.4: WMO designated Global Data Production and Forecasting System (GDPFS) Centres

Numerical Weather Prediction

The advances in Numerical Weather Prediction (NWP) in the last decades have been significant as a result of more, and better assimilated, observations, higher computing power and progress in the understanding and modelling of the dynamics and physics of the atmosphere. These advances, which have led to increasingly skilful weather forecasting, will become even more relevant in the future. Consequently, the emphasis in operational meteorology, hydrology, oceanography and climatology has shifted towards the implementation of increasingly sophisticated and diverse numerical models and applications in order to serve an ever-increasing variety of users. Operational NWP systems generally provide an accurate indication of developing weather events from hours to days ahead. They are, therefore, one of the most relevant components of routine and severe weather forecasting and warnings issued by NMHSs. However, the weather forecasting capability among NMHSs varies considerably across the Region: the more advanced are making use of the progress in NWP, but those that are less developed are less able to use these advancements due to limited budgets and capabilities. Moreover, it is apparent that the gap between the two extremes of capability is increasing.

The accuracy of forecasts and warnings derived from NWPs can be enhanced by using limited-area NWP models and moving beyond single NWPs to include Ensemble and Multimodel Ensemble Prediction Systems (EPS and MEPS) using multiple model runs. However, due to their high computational cost, few NMHSs have the operational capacity to implement such systems. Further, many of the latest advances in NWP systems, such as so-called “convection-permitting” models that are particularly suitable for severe weather forecasting in tropical and sub-tropical regions are extremely computationally intensive, thus they are supported only by those NMHSs that have access to significant super-computing facilities. To help overcome these constraints in NMHSs with limited capacity, the Severe Weather and Disaster Risk Reduction Forecasting Demonstration Project (SWFDDP, now SWFP, of which most SPREP members are a part) of the Global Data-Processing and Forecasting System was established to make products from NWP models, including EPS, from a number of the World Meteorological Centres, available to all using a Cascading Forecasting Process.

The Cascading Forecasting Process

The GDPFS encompasses all systems operated by WMO Members and enables them to make use of the advances in NWP by providing a framework for sharing data related to operational meteorology, hydrology, oceanography and climatology. The main support for the exchange and delivery of these data is the WIS. One of the key benefits of the WIS is the expansion of the range of centres that can connect to the system, increasing the range of Global Data-Processing and Forecasting System applications.

The SWFP contributes to capacity building by helping countries to access and make use of existing NWP products for improving hazardous weather warnings. It encourages operational forecasters to use relevant standards and newly developed products and procedures. The Project outcomes are expected to:

- Enhance the capability of NMHSs to forecast severe weather and issue warnings at the national level, including improved accuracy and longer lead-times;
- Establish processes for multi-hazard early warnings with national disaster management and civil protection authorities, with planned responses for protection of lives and property;
- Establish forecast processes and Quality Management Systems (QMS), and strengthened forecast capabilities in support of other socio-economic (such as agriculture and food security, aviation, marine safety and transportation, etc.) at the national level;
- Raise awareness of the value of NMHS with national governments and their agencies, leading in the long-term to greater national support and investment leading, in turn, to improved supply of observations and feedback into the Global Data-Processing and Forecasting System;
- Reduce loss of life and damage to property and contributions to the 2030 Development Agenda and the Sendai Framework for Disaster Risk Reduction.

It is anticipated that the planned intervention would build on the successes of SWFP by providing NMHSs with a broader range of products and these will be further described below.

Future Integrated, Seamless Global Data Processing and Forecasting System Collaborative Framework (S/GDPFS)

Building on the existing architecture, the future S/GDPFS will become a flexible and adaptable ecosystem of independent centres that will expand and strengthen prediction of the environment, making impact-based forecasts and risk-based warnings accessible, thus enabling NMHSs and their NDMO partners to make better-informed decisions. The S/GDPFS will provide standardised state-of-the-art interfaces to facilitate partnerships and collaboration globally and regionally among jurisdictions, academia and the private sector to access and make available related information of relevance to the mandate of WMO across all timescales and domains of the Earth system. The S/GDPFS will, as much as possible, share authoritative weather, water, climate and related environmental data, products and services freely and openly and in a viable and sustainable way, ensuring no Members are left behind. As stated in the draft WMO strategic plan for 2020-2023 (Strategic Objective 2.3), the fundamental responsibility of GDPFS will be to enable access to, and use of, the state-of-the-art numerical analysis and prediction products at all temporal and spatial scales. It is a high priority that the Seamless GDPFS will assist Developing and Least Developed Countries to make significant progress towards community resilience and reaching Sustainable Development Goals.

The Future S/GDPFS will also bring benefits to broader user communities, including stakeholders responsible for preparedness for a wider variety of high-impact events; sectors impacted by weather and climate (e.g. energy, agriculture, health, integrated water resource management); and urban stakeholders, city planners, United Nations and other humanitarian agencies, including nongovernmental organizations. This is encapsuled by the development of impact-based forecasting which is discussed below.

3.2.2.2. Role of World Meteorological Centre (WMC) in the Pacific

Bringing together the WMC and GDPFS means that a huge range of products can be developed and provided to WMO Members that enable all NMHSs in the region to deliver a comprehensive range of services to their users and provide more informed support to their NDMOs.

Using Multimodel Ensemble Prediction Systems (MEPS) is not new. It is a technique that has been used extensively to develop forecasts of tropical cyclone tracks for a number of years. However, MEPS can be used more widely for weather and climate forecasting and is shown to be more accurate than any one single numerical model[5], or single model ensemble prediction system. It is therefore possible, following a relatively modest investment in the WMCs, to develop and deliver a significantly higher level of forecasts than those currently delivered by many NMHSs, with the advantage that the ensemble system will also enable expressions of uncertainties in the forecasts to be incorporated. To an extent, these are already being delivered, but what is suggested is that this is taken to a much higher level, delivering 7-day forecasts for as many centres as each country requires, in addition to marine forecasts and forecasts for locations that are deemed critical for their communities. This will provide each country with a level of service far greater than that delivered currently by the numerous web-based weather providers such as Google and Windy, which frequently do not use official NMHS data. By using a MEPS, over any given period, the products will outperform anything provided by the platforms in the private sector because they all use single models. These forecasts would be delivered to each country through the WIS and then via the Pacific Weather Exchange (potentially an upgraded version of the MetConnect portal), which would be maintained by the RSMCs.

It is likely that the WMCs will also have a training role for the Region and that will be discussed further below.

Pacific Weather Exchange

Currently, the MetConnect portal is maintained by MetService New Zealand and contains a large amount of forecast guidance material for the southwest Pacific region. Some of this material is prepared by RSMCs in Wellington, Nadi and Darwin and some is direct model output from the UK, Australia, the US and the ECMWF. The MetConnect portal also contains links to the NMHSs in the region. During consultations with the NMHSs, it was unanimously acknowledged that MetConnect was useful and most NMHSs actively used the data contained within it.

Under the proposal, the Pacific Weather Exchange would contain all the information contained by the MetConnect portal in addition to the new data described above. The additional data contained in the Pacific Weather Exchange would be country and location specific, containing both graphical and text output and could be easily assimilated into a forecast and warning production platform to enable further products to be produced locally, as and if required. In addition, through the use of single model prediction systems and MEPS as described above, levels of uncertainty could be incorporated into key elements of each forecast providing valuable guidance and information for forecasters and emergency managers during high impact weather events.

There is also an opportunity to create synergies between the proposed Pacific Weather Exchange with the existing Pacific Ocean Portal, which is maintained by the Pacific Community (SPC). The Pacific Ocean Portal contains links to seven 'tabs' that provide sector specific information and guidance, mostly in the form of graphical computer model outputs. It also contains tidal information and information relating to coral bleaching and ocean salinity. Much of the information is historical and more related to climate services but there is also 7-day forecast information on wave heights and wind speeds using the Global AUSWAVE Forecast model. Whilst the wind speed and direction information, together with wave and swell height data is useful guidance to forecasters, it requires skilled interpretation to use it properly and requires further development for the information to be incorporated easily into a forecast product. It requires post processing to incorporate the data into another, more location specific product which is generally done manually by a forecaster and not all NMHSs have the capability to undertake this task.

Generation of the new generation of products proposed for the Pacific Weather Exchange will require the significant computing resources of a WMC. However, while maintaining the Exchange itself will require

[5] Multimodel Ensemble Forecasts for Weather and Seasonal Climate in: Journal of Climate Volume 13 Issue 23 (2000) (ametsoc.org)

strong commitment and 24x7 backup and maintenance, it will not require large computers. As such, under agreement by PMC, this could be undertaken by one or more of the RSMCs.

To develop the NWP post-processing capability described above will require a team of modelling post-processing scientists together with programmers and computer time over a 12 month period, followed by around 0.5 fulltime equivalent staff to maintain and enhance the system once it is operational (Tables 3.8 and 3.9). The modellers scientists will also be involved in assimilating the significantly increased amount of observational data that is expected to result from this project and be put into the WIS. There will be an ongoing cost to maintain the systems and communications.

Table 3.8: Proposed investment to support an NWP capability in the Pacific.

Activity	Establishment cost	Annual cost
NWP team of 4 post-processing scientists at a WMC (equivalent time) in 1st and 2nd years, 2 staff ongoing	USD 800,000	USD 400,000
3 (equivalent fulltime) IT staff in 1st and 2nd years, 1 staff ongoing	USD 600,000	USD 200,000
Super Computer time	USD 100,000	USD 200,000
Total costs	USD 1.5M	USD 800,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 10.58M**	

Table 3.9 Annual total costs to support NWP capability in the Pacific over the 10-year investment plan term (USD millions)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	1.60	1.64	0.84	0.86	0.88	0.91	0.93	0.95	0.97	1.00	**10.58**

3.2.2.3. Role of the RSMCs

The RSMCs in Wellington, Darwin and Nadi would continue their existing roles of monitoring the weather over the relevant areas of the Pacific and providing a range of data and services – and in particular, their current role in providing warnings. However, further investment in the RSMCs is recommended to:

1. Develop the Pacific Weather Exchange to cope with the new products generated by the WMCs as described above.
2. Increase computational capacity to run high resolution relocatable models over areas considered to be likely to produce high impact weather. These areas are likely to be flagged by the EPS and MEPS run by the WMCs and running high resolution models over a domain that covers the area of likely genesis of significant or severe convection is likely to provide greater granularity and accuracy in forecast output than that of the lower resolution global ensembles. While running models of this nature requires relatively powerful computers, it does not require the resources of a supercomputer and so is suitable for installation and operation in an RSMC. It is likely that this high resolution model could also be used to provide enhanced hydrological forecasts for Pacific countries, particularly when this model is linked to improved hydrological observations and data assimilation.
3. Strengthen regional aviation weather services to provide a robust, high quality service that supports national services and meets the Industry's requirements, while being flexible enough to respond to the technological changes that are set to emerge. Aviation weather services are currently provided by FMS for a number of countries and it is suggested that this process be strengthened through the provision of

more BIP-M qualified forecasters with appropriate aviation forecasting competencies (Tables 3.10 and 3.11). This will enable Nadi to enhance its current service levels, support to those countries that may not have enough qualified forecasters to undertake 24x7 aviation forecasting, and/or take on a larger role in service provision in the event that any future review recommends a more centralised service. To recognise the importance of this role this service needs to be strengthened and formalised with bilateral agreements between all relevant parties. In addition, once formally established, a cost recovery mechanism could be developed to eventually recoup the costs of the services from the aviation industry over the ten-year period. With improved, formalised services, the aviation industry is more likely to look upon proposals of this nature in a positive manner. The costings reflect a greater degree of cost recovery of these positions over time as agreement is reached with Industry after the appropriate consultation period. A stronger service in Nadi will also need to have greater technical capacity to respond to changes that will inevitably occur or be required as Industry requirements evolve.

Table 3.10: Proposed investment to support and strengthen RSMC aviation forecasting.

Activity	Establishment cost	Annual cost
6 RSMC BIP-M aviation forecasters (5 + 1 leave relief)	-	USD 300,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs but phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 then cost recovery @10% from year 6 scaling to 80% at year 10)	**USD 1.92M**	

Table 3.11: Annual total costs of additional aviation forecasting staff over the 10-year investment plan term phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.075	0.154	0.236	0.323	0.331	0.306	0.253	0.158	0.067	0.015	**1.92**

4. Strengthen public and marine weather services

Forecasters in the RSMC will continue to have a role in monitoring the forecasts and warnings in those countries which do not have sufficient capacity of their own. In most cases, the forecasts can be automated to flow directly from the WMCs through to the NMHSs of all countries, however, an oversighting role is still recommended, particularly during (expected) high impact weather events. It should be noted however, that similarly to aviation and public weather forecasting, marine weather forecasting and warning is likely to soon require BIP-M forecaster qualifications and this reflected in the investments in Tables 3.12 and 3.13.

Similarly, the RSMCs' roles in climate monitoring and forecasting will continue, working as they have been with the extensive number of projects and initiatives that are running in the Pacific Region, as will their role in training, which will be described below. Moreover, it is recommended that a proportion of the additional RSMC forecasting positions are made available to appropriately trained forecasters from PIC NMHS on a rotating basis to enable knowledge transfer and exchange as well as providing valuable experience and subsequent opportunities for advancement for all forecasters.

An important element of public climate services is seasonal prediction, which is especially important for drought preparations and predictions of increased cyclone activity. It is expected that this enhanced capacity will help strengthen the delivery of seasonal outlooks. This area needs to be undertaken in collaboration with other initiatives. For example, the Republic of Korea-Pacific Islands Climate Prediction project (ROK-PI CLiPS), being implemented by the APEC Climate Center (APCC) and SPREP, has built a system to provide locally tailored seasonal climate prediction information and training on downscaled climate predictions to Pacific island countries and territories. It is a web-based dynamical multi-model ensemble prediction system (MEPS) optimised for the Pacific. It is used in conjunction with PICASO, a hybrid statistical-dynamical seasonal forecast software based on the MEPS data. Further, through the COSPPac program, funded by the Australian government's Department of Foreign Affairs and Trade, the ACCESS-S seasonal prediction model has been made available to Pacific island countries and territories. ACCESS-S brings enhanced resolutions, skill and capabilities to forecast with more regional details.

Table 3.12: Proposed investment to support and strengthen RSMC public and marine forecasting.

8 RSMC BIP-M forecasters for public and marine weather, ocean and climate services (6 +2 leave relief) to assist NMHSs	Annual cost	USD 400,000
3 NWP modelling staff	Annual cost	USD 135,000
4 IT staff	Annual cost	USD 160,000
Total annual costs once fully established	-	USD 695,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs) phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4	**USD 6.73M**	

Table 3.13: Annual total costs of additional public and marine forecasting staff and IT and modelling staff over the 10-year investment plan term (USD millions) **phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4**

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.17	0.36	0.55	0.75	0.77	0.79	0.81	0.83	0.85	0.87	**6.73**

3.2.2.4. Role of the NMHSs

The role of the NMHSs will be determined by the level of investment of each country in their NMHSs, where the country feels it can add value to the process, and their ability to attract suitably qualified people to become technicians and observers, and graduates to become forecasters. National NMHSs will be clarified through the supported strategic planning process under 3.2.1.

Through the cascading forecasting process, the level of forecast and warning services can be very similar across countries. However, the ability of the forecasters to provide interpretation of those forecast products for their end users, and NDMOs in particular, will determine how much advice and guidance is provided on impact assessment of the impending weather on their communities. For example, instead of saying "Southerly swells 3 to 4 metres", saying "Southerly swells 3 to 4 metres, which are likely to be dangerous in all areas and may cause damage to moored boats and coastal flooding in some very low-lying villages along southern coastlines."

Where NMHSs have the capacity to provide impact-based services, forecasts would be ingested into their local forecast and warning production systems, which similarly to the dissemination systems mentioned above, may require additional investment. The forecasts provided by the WPCs and RSMCs would then become the "initial forecast" and further developed or edited as, and where, qualified forecasters consider that they can add value. At WMO's 2018 Executive Council Meeting a decision was made that the production of public weather forecasts should be undertaken by those forecasters who have successfully completed a BIP-M as defined by Technical Regulation WMO No. 49, Volume 1, Part IV. However, interaction with the NDMO and other user groups does not require BIP-M qualified forecasters, so this can be undertaken by forecasters who have completed an appropriate level of training at the Pacific Training Desk or similar.

Similarly, aviation weather forecasting requires forecasters to have BIPM qualifications together with aviation competencies and as such, little change to current arrangements is anticipated under the proposed concept of operations. Where NMHSs have the capacity to recruit, train and maintain a roster of appropriately qualified staff, they will have the capacity to provide their own aviation weather forecasting services and possibly scope to cost recover some of these services from the aviation industry under standard ICAO guidelines. Where NMHSs do not have the scope or capacity to maintain a roster of BIP-M qualified forecasters for 24x7 operations, then it is likely that services will be provided through, or shared with, an RSMC under bilateral and Service Level Agreements.

While it is not yet mandated that marine forecasting will only be undertaken by BIP-M qualified forecasters, WMO is expecting this to become mandatory by 2023, so it should be assumed that such qualifications will become necessary to issues these forecasts. Approaches to improving capacity of marine and coastal forecasting are detailed in Section 3.2.5.4.

With further investment in modelling, IT and observations infrastructure, there is significant scope to improve hydrological forecasts for riverine flash flooding using this delivery model. Improved rainfall observations and modelling, as described above, will improve the advice that NMHSs provide to NDMOs and the communities at risk, increasing their resilience to high impact weather events. For those countries which maintain an interpretive capacity, this data can be passed through forecasters to NDMO staff, while for those which do not have this capacity, the model data and tailored products can be routed directly to the relevant authorities.

Similarly, coastal flooding and inundation is a significant issue across the Pacific Islands. It can be caused by various sources including from the sea (e.g. swell, storm surge, waves, tides, tsunami) and/or rivers and estuaries. These coastal hazards are likely to be exacerbated by the anticipated increased frequency of extreme weather and sea level rise due to climate change impacts. The WMO Coastal Inundation Forecasting Initiative (CIFI)[6] would boost the Pacific Islands' resilience to impacts from coastal hazards. It is designed to support national agencies in developing and implementing reliable forecasting and warning services for coastal inundation from multiple sources and using forecast products operationally to inform national decision-making for coastal inundation management.

A project in Fiji with an integrated approach to storm surge, wave and riverine flood forecasting for improved operational forecasts and warnings capability for coastal communities has transitioned from a demonstration project[7] to an operational system. It considers flooding by swell, storm surges (especially those caused by tropical cyclones) and river flooding, also often linked to heavy rainfall from tropical storms, and which allows issuance of alerts and potential warnings of flooding in a complicated surge-riverine environment.

The infrastructure design has allowed the Fiji Meteorological Service to forecast for the first time, coastal inundation. Capacity development was also needed for all the component forecast systems, and for life cycle management of the new measurement systems for waves, ocean and river levels. In addition, public awareness of coastal inundation was addressed by the development of videos about the dangers of coastal inundation, what to do in the case of a dangerous event, and the value of ocean buoys for safety and livelihoods.

The CIFI could be scaled up and implemented across all the Pacific Islands, providing NMHSs with the tools and capacity for self-reliant coastal forecasting. In addition, the Fiji system could be strengthened with consideration that RSMC Nadi would have the capacity to issue regional coastal alerts, reinforcing local capacity.

The resources required to develop CIFI projects requires a mix of ocean buoys, tide, and river gauges. wave, bathymetry, topography, and river flow data are combined for modelling and verification. IT infrastructure is also needed to strengthen the capacity of a met service to model the input data for early warning products. WMO has provided some broad estimates of the costs of scaling out the CIFI to other countries in the Pacific and although it includes aspects of forecast production, infrastructure and capacity building, they are integrated in Tables 3.14 and 3.15 to keep intact the total costs for each CIFI initiative. The costings include rolling out the CIFI to five countries over the decade of investment.

[6] Swail, V., S. Grimes, P. Pilon, R. Canterford, C. Barrett and Y. Simonov, 2019: Early Warnings of Coastal Inundation. WMO Bulletin, Vol. 68 (2): 48-55

[7] WMO, 2018a: Assessment Report, Coastal Inundation Forecasting Demonstration Project (CIFDP). Part A (Barrett, C. and R. Canterford). Geneva, World Meteorological Organization.

Table 3.14: Proposed investment to support implementation of the Coastal Inundation Forecasting Initiative in five countries.

Activity		Cost per CIFI
Bathymetry	-	USD 100,000
Topography		USD 150,000
Monitoring network (in addition to wave buoys in Section 3.2.4.4		USD 200,000
Stakeholder engagement/workshops		USD 100,000
Training		USD 200,000
Forecast system development		USD 900,000
Project management		USD 300,000
Total cost per CIFI		**USD 1.95M**
Total cost over 10 years (allowing 2.5% increase per year in annual costs)		**USD 10.92M**

Table 3.15: Costs of implementing the CIFI in five countries over the decade, assuming one CIFI implementation every two years and each one being implemented over a two-year period (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
CIFI	0.98	1.00	1.02	1.05	1.08	1.10	1.13	1.16	1.19	1.22	**10.92**

As was described in 2.1.3.4 Section 2 on IT infrastructure, improved and increased support of IT and data management was consistently raised as a high priority need by those countries that were consulted which are not supported by US NWS. This requirement is set to increase as offices become more technology dependent and complex as they deal with the significant increase in forecast output that is likely under the Investment Plan. To address this apparent gap, it is proposed to provide an additional two ICT staff in the FMS to support the increasingly complex ICT activities that are expected in the RSMC-Nadi and one additional ICT staff member in each of the 14 NMHS not aligned with US NWS or Meteo France to support the significant increase in ICT and communications activity likely in each country (Tables 3.16 and 3.17).

Table 3.16: Proposed investment to support and strengthen ICT capacity and forecast delivery.

Activity	Establishment cost	Annual cost
16 IT staff (2 in Fiji, 1 elsewhere)	-	USD 640,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs) phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4	**USD 6.19M**	

Table 3.17: Annual total costs of additional ICT staff over the 10-year investment plan term **phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4** (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
ICT staff	0.16	0.33	0.50	0.69	0.71	0.72	0.74	0.76	0.78	0.80	**6.19**

Table 3.18: Summary of proposed investment in forecasting and warning capabilities (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
NWP capability	1.60	1.64	0.84	0.86	0.88	0.91	0.93	0.95	0.97	1.00	**10.58**
Additional RMSC aviation staff	0.08	0.15	0.24	0.32	0.33	0.31	0.25	0.16	0.07	0.02	**1.92**
Additional RSMC IT, public wx and marine staff	0.17	0.36	0.55	0.75	0.77	0.79	0.81	0.83	0.85	0.87	**6.75**
CIFI scale out	0.98	1.00	1.02	1.05	1.08	1.10	1.13	1.16	1.19	1.22	**10.92**
Additional NMHS IT staff	0.16	0.33	0.5	0.69	0.71	0.72	0.74	0.76	0.78	0.8	**6.19**
Total	**2.99**	**3.48**	**3.15**	**3.67**	**3.77**	**3.83**	**3.86**	**3.86**	**3.86**	**3.91**	**36.37**

3.2.3. Communication and delivery of forecasts and warnings to end-users

Key activities:

1. Improve the development and delivery of risk and impact-based messages through:
   - end-user workshops to identify types of messages that will lead to response actions;
   - training of NMHS and NDMO staff in development of impact-based messages including the use of traditional knowledge and how to reach groups disproportionately affected by extreme events, including women and people with disabilities.;
2. NMHS training workshops in the use of the WMO Common Alerting Protocol.
3. Workshops between NMHSs and NDMOS to improve governance and delivery mechanisms so that pathways for forecasts and warnings are highly effective.

Core deliverables:

1. NMHSs have much better understanding of end-user needs to inform their approach to impact based messaging.
2. Well-trained NMHS staff in how to develop and target impact-based messaging with the ability to incorporate traditional knowledge.
3. Ability to target the needs of women and disability groups in the impact messages that are developed and delivered.
4. NMHSs and NDMOs well-positioned in governance arrangements and partnerships to deliver warnings in the most effective way.

For the Decadal Program of Investment to achieve its intended outcome of improving the safety and livelihoods of Pacific communities, forecasts and warnings must be delivered in a timely manner and must be communicated in a way that facilitates action responses from individuals, communities, government and industries. This information will provide those exposed to a hazard with a better understanding of the risk and will enable them to take appropriate action. However, impact-based forecasts requires that NMHSs put a greater emphasis on service delivery. Moving beyond weather forecasting requires effective partnerships with NDMOs, many different government agencies and understanding the needs of end-users.

3.2.3.1. Improving impact-based messages

The need to develop and deliver risk, impact and response-based messages i.e., what the weather will do rather than what the weather will be. Based on the consultations there is a good understanding across NMHSs to be able to deliver impact-based forecasts but at present the ability to deliver these impact-based forecasts is limited. Most NMHSs expressed a desire for further training in the use of risk, impact and response-based approaches to forecasts and warnings. In this area, a key challenge consistently raised in the consultations was the need to better translate technical terms in forecasts and warnings into locally relevant impact messages because many technical terms do not exist in local languages. Further, traditional knowledge approaches to communicating weather and other extreme events need to be better incorporated into warnings and preparedeness messages delivered by NMHSs and NDMOs. Given the activities below mostly involve training, it could be argued this should fall within the more general area of Capacity and Training. However, given the very specific nature of this training it is better implemented as its own investment area.

> To better protect lives and livelihoods people need to know what the weather will do rather than what the weather will be. Through this program of investment, there will be a transformation in the way forecasts and warnings are developed and delivered. This is much more than improving the capacity within NMHSs – it needs better and new ways of engaging with communities and industries, including integrating scientific forecasts with traditional knowledge.

There are many climate change projects in the Pacific region that are working with community and industry groups to better prepare them for the impacts of climate change. The lessons learnt from these projects on communication and engagement and how to incorporate traditional knowledge would be a valuable input into these impact message training workshops. It is proposed to include staff from two different climate change projects in each workshop as key resources on communication and engagement.

The key activities to develop and deliver impact-based forecasts and warnings are:

(i) User workshops

This activity will develop a series of workshops with user groups of forecasts and warnings, including aviation, tourism, agriculture, fisheries, maritime transport, energy, community/village, women's groups, and disability organisations on how to better deliver information and messages and develop content that is response oriented in a local context with appropriate impact statements. It is proposed to run this series of user workshops across a large number of Pacific island countries and territories. It is assumed that on average there will be 10 workshops per country to cover arrange of user groups from industries through to community groups. It is expected smaller countries may not need 10 workshops whilst other countries may need more than 10 workshops. It is assumed there will be 20 participants per workshop with each workshop to be facilitated by a professional, locally based facilitator. The user workshops will be undertaken in Years 1, 4 and 7 over the decadal period of investment (Tables 3.19 and 3.20).

Table 3.19: Costs associated with delivery user workshops in each of 17 Pacific island countries and territories.

Activity	Costs per country for 10 workshops	Total costs for the region
Workshop costs (facilitator, venue, incidentals)	USD 10,000	USD 170,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs)		**USD 550,219**

Table 3.20: Annual total costs of conducting end user workshops (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.17			0.18			0.20				**0.55**

(ii) Impact messaging training workshops

Training workshops on how to better develop risk, impact, and response-based forecasts and warnings will be conducted. These training workshops need to include aspects related to incorporating traditional knowledge and to ensure messaging is socially inclusive so that women and people with disabilities are not disproportionately affected by extreme events.

It is proposed to implement a workshop with key staff from NMHSs and NDMOs in each of 17 Pacific island countries and territories. This will be an intensive three-day training workshop on developing impact-based messages using international expert trainers. The costings assume the workshops will be run every year with 8 or 9 Pacific island countries and territories covered each year such that each Pacific island country and territory receives a workshop every second year. It is assumed there is an average number of 15 participants, recognising there may be fewer than 10 in smaller countries/territories and more than 15 in larger countries/territories (Tables 3.21 and 3.22). An important aspect of these workshops will be involving staff from climate change projects as indicated above.

Table 3.21: Costs associated with impact-messaging training workshops.

Activity	Costs per country for a workshop	Total costs for the region per workshop
Workshop costs (Expert trainer, climate change staff, venue, incidentals)	USD 14,302	USD 228,800
Total cost over 10 years (allowing 2.5% increase per year in annual costs)		**USD 1.31 M**

Table 3.22: Annual total costs of conducting impact-messaging training workshops (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.13	0.12	0.12	0.12	0.13	0.15	0.13	0.14	0.14	0.14	**1.31**

(iii) Training in Common Alerting Protocol

WMO already offers a 1.5 to 2 hour, self-directed course, which is offered through the WMO Education and Training (ETR) programme's course site. All resources, assignments, and assessments are available on this site. Given this is already in place there is no need for additional investment in this area. However, there needs to be commitment from Directors and senior managers in NMHSs to ensure this course is taken.

3.2.3.2. NMHS/NDMO cooperation workshops

The consultation phase showed that there is good collaboration between NMHSs and NDMOs, which is enabled by generally good governance arrangements and clear lines of responsibility. In most countries NMHSs deliver their warnings to the general public, government and media via websites, emails and through direct contact. NDMOs take responsibility for delivering impact messages to regions, local government, village heads and communities via radio, emails, SMS, chatty beetles, phone calls, etc. Whilst this cooperation and collaboration is good there is an opportunity to further strengthen the arrangements through targeted workshops to develop better governance (where required) and delivery mechanisms. These will be annual, two-day workshops aimed at building and maintaining NMHS/NDMO relationships, identifying ways of improving messaging and its delivery and any improvements to governance and operating arrangements. They will be facilitated by a professional local facilitator. It is assumed there will be 20 participants for each workshop (Tables 3.23 and 3.24).

Table 3.23: Costs associated with NMHS/NDMO workshops.

Activity	Costs per country for annual workshop	Total costs for the region
Workshop costs (facilitator, venue, incidentals)	USD 2,700	USD 54,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs)		**USD 604,983**

Table 3.24: Annual total costs of conducting NMHS/NDMO workshops (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.60

Table 3.25: Summary of proposed investments in communication of forecasts and warnings (USD millions)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
End-user workshops	0.17			0.18			0.20				**0.55**
Impact message workshops	0.13	0.12	0.12	0.12	0.13	0.15	0.13	0.14	0.14	0.14	**1.31**
NMHS-NDMO workshops	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	**0.60**
Total	**0.35**	**0.17**	**0.18**	**0.36**	**0.19**	**0.21**	**0.39**	**0.20**	**0.21**	**0.21**	**2.47**

3.2.4. Infrastructure

Key activities to be phased in:

1. Refurbish existing AWS and river gauge networks and ensure they have connectivity with and deliver data to, WMO's Global Telecommunications System (GTS).
2. Fill significant surface observations gaps that become evident following the refurbishment listed above.
3. Establish a network of automated upper air observations stations that will complement and "ground truth" remotely sensed data to improve input into NWP systems.
4. Installation of weather watch radars around major population centres and international airports to improve safety.
5. Retrieval of meteorological data from selected commercial aircraft that operate through the region.
6. Expand ocean observations networks to provide better coverage of waves and tides.
7. Refurbish existing IT infrastructure and expand it where necessary to support the strengthened forecast and warning services being proposed above.

Core deliverables:

1. Fully functional, integrated regional observation network which provides a strong basis for improved NWP performance.
2. Improved monitoring of riverine floods and improved ability to monitor heavy rainfall in major population centres and international airports resulting in improved flash and riverine flood forecasting and warnings.
3. Improved ocean monitoring systems providing input into automated warning processes, including coastal inundation.
4. New or improved ICT equipment to process, store and transmit data generated by the new observations technology as well as receiving and storing the proposed NWP outputs.

Image 5: A National Meteorological Service and some of the basic infrastructure required to collect and communicate accurate data

Background and rationale:

Meteorological, hydrological and ocean observations are vital for both immediate needs such as weather, flood and ocean forecasting and their associated early warning systems, and longer-term needs such as supporting and planning adaptation to climate change and ensuring sustainable development. Reliable observational data is the foundation of science's ability to predict and monitor high impact weather, water and oceanic events to mitigate their impact, and to enable economic growth and prosperity.

The observations and data gathered by NMHSs form the foundation for the monitoring and prediction of weather, climate, water and related environmental conditions as well as the issuance of warnings and alerts.

Observation networks within the region are sparse and do not adequately represent the weather and climate conditions affecting these countries. The sparse observation networks ultimately affect the quality and range of services that NMHSs can provide and importantly, adversely affect the accuracy of numerical weather prediction in this region.

Observations equipment through the region has been noted to be heterogeneous, posing significant challenges for data integration into the systems which in turn model weather and climate information. The diverse observations equipment produces equally diverse data types, quality and formats.

With an inconsistent and in many cases, ageing, observations fleet, training on such equipment provides many challenges, further limited by the skilled workforce able to operate, maintain and calibrate, or repair such equipment. Further, outdated and unreliable telecommunications equipment and a lack of investment in or ability to connect to high-speed data networks combine to hamper efficient observations and data flow, including the ability to provide early warnings of potentially hazardous conditions. These inefficient networks are in turn expensive to maintain and provide a poor return on investment. Even where high quality data can be collected, the IT infrastructure required to store this data and convert it into climate information is, in many cases, aging and requires intense manual intervention and assistance.

Computer systems within the NMHSs to produce forecasts and warnings are also ageing and, in many cases, require updating to improve services. While some NMHSs are actively pursuing new integrated workstations that combine observation, analysis, and production into one platform thereby eliminating the requirement to maintain three or more different software applications (and licences), others are unable to do so due to a lack of resources, not only to purchase the equipment, but also to install and maintain them.

The nature of a decadal plan would require that a more homogenous approach be taken to infrastructure across the Pacific. This does not necessarily mean that all NMHSs should have the same type of observations equipment or forecast and warning production platforms, but rather, that the equipment which is purchased is capable of being easily integrated into the Pacific network – “plug and play” style, and the production platforms are capable of assimilating an array of data types that enhances every NMHSs output and each country’s Multi-Hazard Early Warning Systems. To achieve this, it is recommended that a set of standards and specifications for observational equipment are developed across the region. Once in place, these standards will ensure that equipment which installed will be compatible with existing networks and maintenance and data retrieval will become much easier to achieve. In addition, there should be a formal regional observation equipment calibration centre and team established, most likely in Fiji in conjunction with the Training Centre that is described below, which is equipped appropriately and certificated to maintain and calibrate aviation observation equipment. It is likely that the calibration centre will require at least two staff, fully qualified to BIP-MT standard with the appropriate aviation competencies, to fulfil this requirement.

The Technical Advisor that sits in the Management and Advisor Team structure will be an important resource person for ensuring standards in equipment purchase and calibration are developed and maintained.

Most NMHSs do not have the internal budget resources to maintain expensive infrastructure, which is mostly provided by relatively short-term donor projects. A key rationale in this investment program is to provide a decadal operating and maintenance budget with all infrastructure. Where investments need to be prioritised it is strongly recommended that the amount of infrastructure acquired be reduced so that the long-term operating and maintenance budget can be maintained for each piece of infrastructure that is installed.

It should be noted that investment in the US (American Samoa and Guam) and French Territories will be undertaken by the USA and France respectively and the Plan has made no assumptions about their service or infrastructure requirements.

Phasing of investment

The investments recommended in the following sections are expected to follow a phased implementation to suit the countries involved, the donors and the key stakeholders. It is assumed that the CAPEX costs are incurred over the first five years with 10% in Year 1, 15% in each of Years 2 and 3, and 30% in each of Years 4 and 5. This provides for a ramp-up in acquiring infrastructure and learning from early challenges. Operating costs for infrastructure are assumed to ramp up over four years with 25% in Year 1, 50% in Year 2, 75% in Year 3 and 100% from Year 4 onwards. This is at a slightly higher pro-rata rate than the capital expenditure costs to allow for additional training if required. A 12% contingency has been added to all capital expenditure to allow for additional freight and/or installation costs. Table 3.26 provides an overall summary of the proposed infrastructure investments.

Table 3.26: Summary of proposed infrastructure by country.

Country	Radar Systems	Upper Air (AMBLS)	River Gauges	AWS	Wave rider buoys	Tide gauges	NWP server	TC Module server	Forecaster work- stations
Cook Islands	*	*	0	*	6	4[c]			1
Fiji	2[a]	0	10	tbd	6	4	1	1	1
FSM	3	0	0	tbd	6	4			1
Kiribati	1	1	0	tbd	6	4			1
Nauru	1	1	0	tbd	6	4			1
Niue	*	*	0	*	6	4			1
Palau	*	*	0	*	6	4			1
PNG	3	1	10	tbd	6	4		1	1
RMI	*	*	0	*	6	4			1
Samoa	1	1	4	tbd	6	4		1	1
Solomon Islands	3	1	2	tbd	6	4			1
Tokelau	0	0	0	tbd	5	4			0
Tonga	2	1	0	tbd	6	4		1	1
Tuvalu	*	*	0	*	6	4			1
Vanuatu	1	1	4	tbd	6	4		1	1
Total	**17**	**7**	**30**	**100[b]**	89	**60**	**1**	**5**	**14**

*Provided under GCF Project
[a] Replacement C-band radars
[b]AWS placed at airports should have C&V sensors (assume 10) [c]Consists of two fixed tide gauges and two relocatable tide gauges
tbd – to be determined

3.2.4.1. Automatic Weather Stations (AWS) and hydro-meteorological networks

Existing automatic observations equipment and networks, including hydrological and ocean observations, should be fully revitalised, activated and their data transmission modernised and automated to ensure a reliable and consistent flow of data into a central data store in each NMHS and then further transmission to the GTS.

For example, through the commitment of their current staff, NIWA has installed more than 260 AWSs across the southwest Pacific using reliable, fit for purpose, infrastructure albeit for individual programs and projects. The decadal plan should build on this effort by revamping the network, ensuring that it is fully operational and its data is accessible by the broader meteorological and hydrological community through the GTS. By adopting a more holistic and consistent approach to the installation of AWSs, data "black spots" should be identified and filled using this approach to AWS technology. Such an approach would also help to overcome the reliance on a few committed individuals.

Consideration should be given by each NMHS to the placement of an AWS at each existing manual observation station to enhance the value of the observations taken at those stations and the climate record.

Where manual observations continue without the addition of an AWS, the stations should be enhanced by a Weather Observers Terminal, which will ensure that the observations are coded correctly prior to transmission and sent digitally into the central database in the NMHS prior to further transmission to the GTS.

Following the upgrade and integration of existing networks, where the observations network is still not reaching the WMO specification for observational density[8], up to 100 additional AWSs, 50 automated rain gauges (ARG) and 30 river gauges in total are recommended to be placed in accordance with the requirements of each NMHS (Tables 3.27 and 3.28). These AWSs, automated rain gauges and river gauges should be of a type that can be easily integrated into existing networks as described above and should complement those being purchased by other existing projects such as that sponsored by the GCF. Figure 3.5 below indicates the suggested data flow for both manual and automatic observations that could incorporate weather, climate, hydrological or oceanographic observation types.

Table 3.27: Proposed investment in AWSs, river gauges and ARGs over the 10-year investment plan term phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 (USD millions).

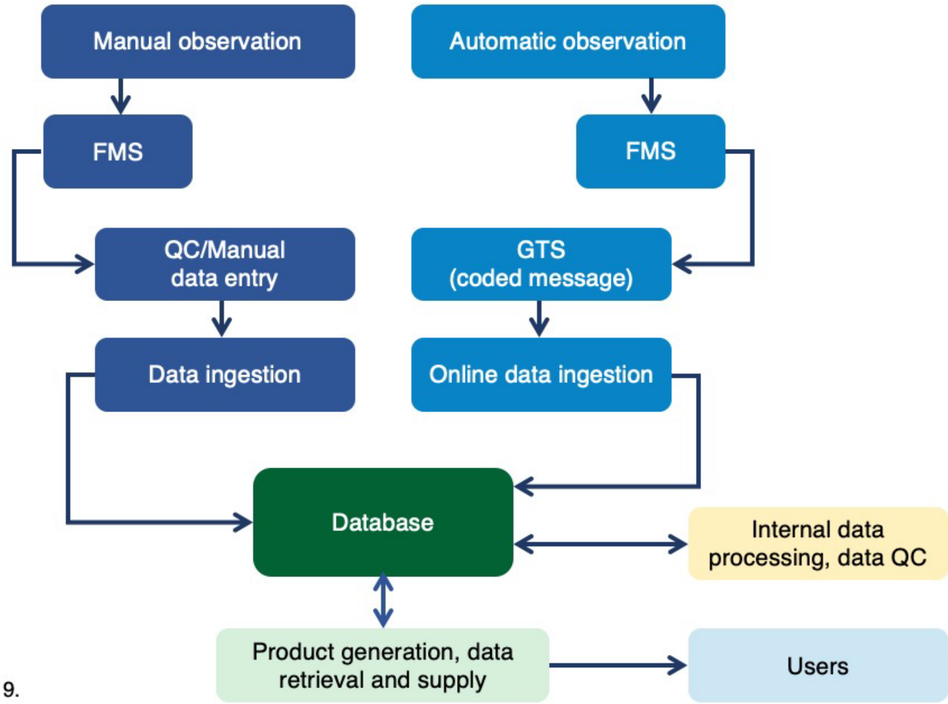
Element	Number Req'd	CAPEX[a]	10-year OPEX[b] (with 2.5% inflator)	Total
AWS	100	6.00	4.50	**10.50**
River Gauges	30	1.80	2.04	**3.84**
Automatic rain gauges (ARG)	50	0.80	2.35	**3.15**

[a]CApital EXpenditure (CAPEX); [b]OPerational EXpenditure (OPEX)

Table 3.28: Annual costs to support AWSs, river gauges and ARGs in the Pacific over the 10-year investment plan term phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
AWS	0.17	0.24	0.36	0.50	0.51	0.52	0.53	0.55	0.56	0.57	**4.50**
River Gauges	0.06	0.10	0.21	0.22	0.23	0.23	0.24	0.24	0.25	0.25	**2.04**
ARG	0.09	0.12	0.19	0.26	0.26	0.27	0.28	0.29	0.29	0.30	**2.35**

[8] World Meteorological Organisation. (2019). *Guide to the WMO Integrated Global Observing System.*



Source: FMI, 2019.

Figure 3.5: Schematic description of integrated end-to-end observation and production system[9]

3.2.4.2. Upper Air Observations

According to WMO's Manual of Global Observing Systems (2019 Edition)[10], the recommended maximum spacing between upper air observation points for the purposes of effective NWP is 500km. Currently, with the exception of areas around New Zealand and Fiji, this density is not achieved anywhere in the Pacific Basin. Moreover, the geographical distribution of islands in the Pacific makes it almost impossible to achieve this specification. It is therefore recommended to establish one automated balloon release station in each of seven countries (Table 3.26) to be located in their preferred location. Resources need to be provided to ensure that each country can fly two balloons each day with each balloon carrying a GPS radio sonde and launched using an Automated Meteorological Balloon Launching System (AMBLS) (Tables 3.29 and 3.30). While this does not achieve the WMO observation density specification, it will provide sufficient ground truthed data to allow accurate wind and temperature estimates to be retrieved from remotely sensed satellite data. The support necessary for the continued provision of this data (such as consumables like radio sondes, balloons and gas) is likely to be provided through direct support from donors and also through the emerging Global Basic Observing Network (GBON)[11].

In 2019, the World Meteorological Congress and its 193 member countries and territories agreed to establish the GBON. GBON sets out an obligation and clear requirements for all WMO Members to acquire and internationally exchange the most essential surface-based observational data at a minimum resolution and timeframe level. GBON is an agreement that offers a new approach in which the basic surface-based observing network is designed, defined and monitored at the global level. Reliable, real-time access to observational data is critical to the quality of weather forecasts and climate analysis. Global numerical weather prediction (NWP) is the basis on which all weather and climate services are built, and it requires a constant supply of observations from around the world. Achieving sustained compliance with the GBON requirements needs substantial investments and strengthened capacity in many countries. The Systematic Observations Financing Facility (SOFF) is being established to provide technical and financial assistance in new, more effective, ways.

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[9] Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production: A roadmap of actions. November 2019
[10] https://library.wmo.int/doc_num.php?explnum_id=10145
[11] https://library.wmo.int/doc_num.php?explnum_id=10377

SOFF is to be launched in 2021 and will cover foundational surface and upper-air observations, which would include upper air land-based consumables. The five countries involved in the GCF Project “Enhancing Climate Information and Knowledge Services for resilience in 5 island countries of the Pacific Ocean” (Tuvalu, Niue, Marshall Islands, Palau and Cook Islands) have been confirmed as pilots for the GBON initiative through this GCF Programme. Therefore, they are in a leading position to demonstrate the value of investing in GBON both to protect local communities and benefit local populations, but also as a critical element of regional and global forecasting and climate analyses. After the Programme implementation period they, and other countries in the Region, will therefore be well positioned to access the SOFF. Support from the SOFF is expected to be available to the countries to continue maintaining GBON standards, including for their upper air observations.

In addition to utilising upper air data from balloon borne radio sondes, it is also recommended to utilise the Aircraft Meteorological Data Relay (AMDAR) system (see part 2.1.3.4) to retrieve as many aircraft observations as possible, including those on approach and departure from each airport in the Pacific Basin. These data should be put into the GTS and made accessible for NWP purposes and also placed on a server accessible by all NMHS to be retrievable and viewable by their observation visualisation platforms.

The addition of this combination of upper air observations should enable significantly improved NWP performance over the Pacific, which in turn will enable each NMHS to provide better services to their NDMOs and their other key stakeholders.

Table 3.29: Proposed investment in AMBLs and AMDAR data retrieval over the 10-year investment plan term (USD millions).

Element	Number Req’d	CAPEX	10 yr OPEX	Total
Automatic Balloon Launching Systems	7	7.28	10.50	**17.78**
Development of AMDARS data capture	1	0.18	0.34	**0.51**

Table 3.30: Annual costs to support AMBLS in the Pacific over the 10-year investment plan term. AMBLS phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
AMBLS	0.28	0.56	0.85	1.17	1.20	1.23	1.26	1.29	1.32	1.35	**10.50**
AMDAR	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	**0.34**

3.2.4.3. Weather Watch Radar

The GCF Project is about to install five radars through the Pacific– one each in Palau, Marshall Islands, Niue, Cook Islands and Tuvalu. While few technical details are known at this point, it is known they will be X-Band radars which don’t require the extensive site works of the larger C- and S-band weather watch radars. It is recommended that the program to extend weather watch radars to major population centres should be extended to all countries and every centre that has an international airport with more than 10 international movements per week should have radar coverage with the same radars as installed by the GCF Project. Vanuatu also has provision for a C-band radar as part of the VanKirap GCF project and that is also factored into the radar investments with just one additional X-band radar proposed for Vanuatu. Data from these radars should be made accessible to NWP centres to enable it to be assimilated into convective rainfall prediction models and meso scale models.

The radars should also be accompanied by a network of automatic rain gauges in key, critical locations to facilitate observations of heavy rainfall which can then be linked to expert systems that can provide advanced warning of flash flooding through flash flood guidance systems. This will be automated using the servers mentioned below and warnings will require only limited forecaster intervention.

The costing and maintenance figures for X-band radar has been based on the figures contained within the GCF Project - USD320,000 for CAPEX and USD 45,000/annum OPEX plus a 2.5 % inflator (Tables 3.31 and 3.32).

During consultation it was also noted that two of the three Fiji C-band radars are reaching the end of their useful lives. In the interests of maintaining adequate radar observations in a cyclone prone area, it is recommended that replacements for these radars be included in the Investment Plan.

Table 3.31: Proposed investment in Weather Watch Radars over the 10-year investment plan term (USD millions).

Element	Number Req'd	CAPEX	10 yr OPEX	Total
X-band radars	15	4.80	6.97	**12.87**
C-band	2	7.52	0.77	**8.29**

Table 3.32: Annual costs to support Weather Watch Radars over the 10-year investment plan term phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
X-band	0.18	0.37	0.57	0.78	0.79	0.81	0.83	0.86	0.88	0.90	**6.97**
C-band	0.02	0.04	0.06	0.09	0.09	0.09	0.09	0.10	0.10	0.10	**0.77**

3.2.4.4. Wave buoys

To facilitate improved ocean services, a number of wave buoys are required by all countries (Tables 3.33 and 3.34). These will provide valuable information for seafarers and fisherfolk as well as providing verification of the NWP, which should result in an overall improvement of the NWP outputs. Following consultation with SPC it is considered that initially, four wave buoys per country (with two additional in reserve/spares) should provide adequate verification to the NWP to provide a significantly improved service. It is also recommended that one maritime stakeholder engagement workshop be held in each country to determine site selection, establish standard operating procedures (SOP) and develop communications processes, etc.

Finally, two workshops are proposed to strengthen regional cooperation and to determine how the utility of the new regional wave buoy network may be maximised as an early warning detection system. These will be conducted over the first two years.

Table 3.33: Proposed investment in wave rider buoys over the 10-year investment plan term (USD millions).

Element	Number Req'd	CAPEX	10 yr OPEX[a]	Total
Wave Buoys	89	5.70	12.59	**18.29**
Workshop for SOPs	14		0.14	**0.14**
Regional Workshop	2		0.20	**0.2**

[a] OPEX includes data transmission and maintenance.

Table 3.34: Annual total costs to support Wave Buoys over the 10-year investment plan term phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Buoys	0.33	0.67	1.02	1.40	1.44	1.47	1.51	1.55	1.58	1.62	**12.59**

3.2.4.5. Tide Gauges

The Climate and Ocean Support Program in the Pacific (COSPPac) installed 13 tide gauges around the south-west Pacific to provide ocean observations and enhance the tsunami warning services of all countries. During the consultation process, it became clear that additional tide gauges were considered necessary to enhance the safety of seafarers, fisherfolk and coastal residents in certain additional key, critical locations and in particular, ports and port entrances. The location of these gauges will be the subject of discussion with each country but following consultation, it is likely each country will require at least two more gauges to provide each NMHS with enough data to enable them to provide an enhanced service (Tables 3.35 and 3.36). It is also recommended that a number of portable tide gauges be purchased that can be deployed to specific locations to establish tide tables.

Table 3.35: Proposed investment in Tide Gauges over the 10-year investment plan term (USD millions).

Element	Number Req'd	CAPEX	10 yr OPEX	Total
Tide Gauges	30	9.60	2.12	**11.72**
Relocatable tide gauges	30	0.15	0.46	**0.61**

Table 3.36: Annual costs to support tide gauges (fixed and relocatable) over the 10-year investment plan term phased in at 25% in Y1, 50% in Y2, 75% in Y3 and 100% in Y4 (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Tide Gauges	0.09	0.14	0.21	0.28	0.29	0.3	0.31	0.31	0.32	0.33	**2.58**

As stated above, SPC are currently coordinating the installation of ocean observing equipment across the region and have critical mass and capacity to coordinate the implementation of the proposed ocean infrastructure. To further coordinate the significant increase in ocean observation equipment it is recommended to invest in an additional staff resource within SPC to assist in this process (Table 3.37). This position would be phased in over the first two years.

Table 3.37: Proposed investment in SPC coordinator over the 10-year investment plan term (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
SPC staff	0.02	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	**0.43**

3.2.4.6. Information and Communications Technology (ICT)

Investment in new ICT equipment will be required to process, store and transmit data generated by the new observations technology in addition to receiving and storing the proposed new NWP outputs. As such, new data servers will be required by each country and some consideration will likely be necessary for facilitating or improving the transmission of the new forecast and warning products to users in some countries. TC Module servers, which were first installed in the 1990's, also require updating to facilitate recent TC Module upgrades and increased computing and storage requirements. Rather than purchasing these outright and then replacing them after 5 years it is proposed to lease these servers so that they are always up to date and supported. The leasing costs have been factored into the costings (Tables 3.38 and 3.39).

In addition, another server will also be required to run the very high-resolution mesoscale models, such as the National Centre for Atmospheric Research's Weather and Research Forecast (WRF) model, that are able to assimilate radar and rain gauge data. These can be a mix of small, fixed domains over large cities and towns which have radar coverage and also high-resolution relocatable models that can be run over a larger domain of interest, for example, where there may be significant areas of convection or strong pressure gradients. While a standalone server could achieve this, to avoid issues around periodically renewing obsolescent equipment and maintaining hardware, using a cloud-based service is likely to offer a better solution that will ultimately prove to be less costly in the long term.

During consultation it was evident that connectivity to upload and download large quantities of data was lacking in a number of countries. This is likely to remain a constraint to operations even where internal NMHS infrastructure and capacity is improved. To enable all countries to benefit from this initiative, it is likely that communications links (both speed and volume) to some countries will require upgrading to a minimum level, however, this is potentially a national infrastructure issue that will require further scrutiny.

The infrastructure for disseminating forecasts and warnings to communities, especially those in the most remote islands, is critical and remains a challenge, particularly in reaching outlying and remote islands. This would seem a logical area for investment. However, communication infrastructure in the Pacific region is evolving rapidly with internet and mobile networks expanding their footprint. Uptake of these digital technologies is increasing at a fast pace even though costs are high and reliability limited in many Pacific island countries and territories. Even though simpler technologies such as radio and chatty beetles will continue to play an important role for some years, the future is in digital technologies. The private sector is expanding its coverage to remote communities through satellite communication initiatives such as Kacific and Starlink. Given how dynamic technology development is in this domain an in-depth review of needs and opportunities by a communications specialist is recommended. This will provide the most effective means of identifying the most appropriate way NMHSs and NDMOs can utilise these new digital delivery platforms.

Table 3.38: Proposed investment in additional data servers over the 10-year investment plan term (USD millions).

Element	Number Req'd	CAPEX	10 yr OPEX	Total
NWP servers	1	0.08	0.89	**0.97**
TC Module servers	5	0.11	0.30	**0.41**

Table 3.39: Annual costs for additional data servers over the 10-year investment plan term (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Servers	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	**1.18**

3.2.4.7. Forecaster workstations

While a number of countries are currently investing in new forecaster workstations, others will require assistance to update their equipment to cope with the greater requirements of the proposed system. As stated above, the production platforms must be capable of assimilating an array of data types that will enhance every NMHS's output and each country's Multi-Hazard Early Warning Systems. Ideally, the software should encompass all applications into a single system and there are a number available on the market that achieve this outcome. Online solutions that offer a variety of modes of operation are becoming available in the market. Some of these offer the capacity to run using limited downloads and using a large remote server to do much of the more intensive computing. This is likely to offer a most attractive solution for those countries operating in a bandwidth constrained environment as described above. A mix of stand-alone and online workstations have been used in the costings (Tables 3.40 and 3.41).

Table 3.40: Proposed investment in forecaster workstations over the 10-year investment plan term (USD millions).

Element	Number Req'd	CAPEX	10 yr OPEX	Total
Forecaster Workstations	14	0.7	4.06	**4.23**

Table 3.41: Annual costs for forecaster workstations over the 10-year investment plan term (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Workstation	0.29	0.29	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	**4.06**

3.2.4.8. Equipment Calibration Centre

The establishment of a formal regional observation calibration office will require capital expenditure to equip it properly and then operational expenditure to maintain a fully qualified team of technicians to undertake the work. The Centre would most likely be located in Fiji to formalise the work currently undertaken by FMS in calibrating equipment and would work in conjunction with the Training Centre. It is proposed that the calibration team is at least initially staffed by two technicians who are fully qualified to BIP-MT standard and who also have the appropriate aviation competencies. Similar to the forecasting positions in the RSMCs, these positions could be open for rotations of staff from other Pacific countries to assist in capacity development, as well as personal development for the individuals involved.

To assist in the process of calibrating instruments across the Pacific, the operating expenses of the Equipment Calibration Centre to offset the costs of sending and returning equipment from the field for calibration have been included.

The Centre would be established over two years with one position in the first year and two in the second year (Tables 3.42 and 3.43).

Table 3.42: Proposed investment in a regional Equipment Calibration Centre over the 10-year investment plan term (USD millions).

Element	Number Req'd	CAPEX	10 yr OPEX	Total
Equipment Calibration Centre	1	0.25	0.86	**1.11**

Table 3.43: Annual operating cost of Equipment Calibration Centre staff over the 10-year investment plan term (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Staff	0.09	0.13	0.13	0.14	0.14	0.14	0.15	0.16	0.16	0.17	**1.41**

Table 3.44 provides an overall summary of the proposed investment in infrastructure. In addition to the totals identified above, a 12% cost has been added to the infrastructure associated with additional freight costs and other contingencies. Table 3.45 provides the year by year investment costs for the CAPEX and OPEX.

Table 3.44: Summary of proposed investments in infrastructure (USD millions).

	Number	CAPEX	CAPEX + 12%	10 yr OPEX	Total
AWS	100	6	6.72	4.50	**11.22**
River Gauges	30	1.8	2.02	2.04	**4.06**
Automatic rain gauges	50	0.8	0.90	2.35	**3.25**
AMBLS	7	7.28	8.15	10.50	**18.65**
AMDARS	1	0.18	0.20	0.34	**0.54**
X-Band radars	15	4.8	5.38	6.97	**12.35**
C-Band	2	7.52	8.42	0.77	**9.19**
Wave Buoys	89	5.7	6.38	12.59	**18.97**
Tide Gauges	30	9.6	10.75	2.12	**12.87**
Relocatable Tide Gauges	30	0.15	0.17	0.43	**0.61**
SPC Coordinator	1		0.00	0.43	**0.43**
Servers	6	0.19	0.21	1.18	**1.39**
Forecaster workstations	14	0.7	0.78	4.06	**4.84**
Workshops	16		0.00	0.34	**0.34**
Equipment Calibration Centre	1	0.25	0.28	1.41	**1.69**
Total		**44.97**	**50.37**	**49.52**	**99.89**

Table 3.45: Annual operating cost of Infrastructure (CAPEX and OPEX) over the 10-year investment plan term (USD millions).

Item	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
CAPEX	5.04	7.55	7.55	15.11	15.11						**50.37**
OPEX	1.71	2.96	4.13	5.38	5.51	5.81	5.78	5.95	6.08	6.21	**49.52**

3.2.4.9. Geophysical observations

This project has not considered the requirements around geophysical observations because few NMHSs have these responsibilities in their mandates. These exceptions include Samoa, Tonga, Vanuatu and Solomon Islands because the proximity of the active Tonga Trench and the New Hebrides Trench means that tsunamis can occur within a short time after an earthquake. The World Bank PREP project is addressing geophysical observations and monitoring for Samoa and Tonga and so infrastructure requirements are not addressed in this Decadal Program of Investment. Many NMHSs are responsible for issuing tsunami warnings when their countries are under threat and the improvements proposed in each country's ICT will also improve their ability to respond to these situations and issue warnings promptly. capacity development to assist in issuing of tsunami warnings is provided in Section 3.2.5.

3.2.5. Capacity and training needs

Key activities:

1. Establish a Secretariat to support a Regional Training Centre (RTC) in Fiji that focuses on accredited training for technicians and observers, and a hub for equipment servicing and calibration.
2. Training for observers and technicians at the RTC.
3. Training of WMO standard forecasters using a hybrid model of online courses complemented with an intensive face to face component.
4. Training of hydrographers and hydrologists for staff in countries severely affected by flash floods.
5. Training of staff (especially meteorologists, oceanographers and hydrologists) in countries severely impacted by coastal inundation;
6. Professional development courses undertaken in the region drawing on external experts.
7. Twinning program to provide mentoring from highly developed hydro-meteorological services.

Core deliverables:

1. A Regional Training Centre is in place that has the staff and ability to coordinate the BIP-MT training in partnership with FMS and USP.
2. Effective training programs in place that are producing NMHS staff with qualifications for observations and technical support (BIP-MT), forecasting (BIP-M), and for hydrography and hydrology.
3. NMHS staff have contemporary knowledge of processes and techniques as a result of professional development courses.
4. Communities of practice developed for different disciplines in the Pacific as a result of training, professional development and the twinning/mentoring program.

A key challenge for the Pacific Island NMHSs is to develop and maintain sufficient numbers of staff with qualifications required for delivery of high quality meteorological and hydrological services. Of the more than 500 staff across the NMHSs, approximately 30% are involved in forecasts or climate services, which is consistent with other meteorological services across the world. However, only a minority of forecasters (approximately 30%) have a BIP-M or equivalent qualification. As a consequence, only a few of the NMHSs have the capacity to undertake higher level activities such as aviation forecasting because this requires a roster of WMO Class 1 forecasters (forecasters with BIP-M qualifications and accredited aviation forecasting competencies).

Many of the NMHSs have a large percentage of observers or observer technicians. Given the number of remote islands in many of the Pacific nations, a geographically dispersed network of observers is understandable. However, the nature of observation networks is changing rapidly with a transition to automated equipment with a reduced requirement for manual observations. With this increasing amount of electronic and automated equipment (e.g. NIWA alone has installed 260 Hydro/Met Stations over the last decade) the need for electronics technicians, and IT/data management staffing has increased dramatically. This is a major constraint for most NMHSs, especially in the area of IT and data management with most services having no dedicated IT capacity or just one or two staff. This is highlighted in a recent report[12] assessing the maintenance and service needs of Fiji's hydrometeorological observation equipment, "Staffing of the computing and information systems division amounts to eight persons. This appears to be a relatively low number if considering operating a modern and highly IT centralized meteorological institute and poses a challenge for future modernisation activities." The need for much increased capacity in IT, data management and electronics maintenance is not just for within country observations and data management but also to meet the need to transfer quality controlled local observations into global observing systems.

These challenges provide a case for significant investment in training in the NMHSs. A range of projects have provided training over many years with the best supported of these being regional initiatives such as the JICA-funded training for observers and technician (BIP-MT) undertaken in partnership with the Fiji Meteorology Service and NOAA's Pacific International Training Desk in Honolulu which provides foundation skills in basic meteorology and interpretation of various data, model and satellite products. In addition to these regional initiatives, there has also been bilateral investment in forecaster training to a BIP-M standard undertaken internationally e.g. NZ, Australia, Philippines.

A more sustainable approach to training is required and this was a trigger for the UNDP-RESPAC study to assess the feasibility of a Regional Training Centre in Fiji (Feasibility Study for a Pacific Based WMO Regional Training Centre, Geoff Love et al. 2018). This study highlighted the clear and ongoing need and the capacity to support training for observers and technicians in a Regional Training Centre in Fiji. It also canvassed the potential to deliver higher level BIP-M accredited training for WMO accredited forecasters in Fiji through the University of the South Pacific. The study highlighted the challenges in developing and maintaining the graduate and post-graduate training required for BIP-M forecasters in a Regional Training Centre. Apart from the funding needed to support such an RTC, these challenges related to having sufficient participants on an annual basis to support a dedicated BIP-M equivalent course and in maintaining the staff required to support such a course.

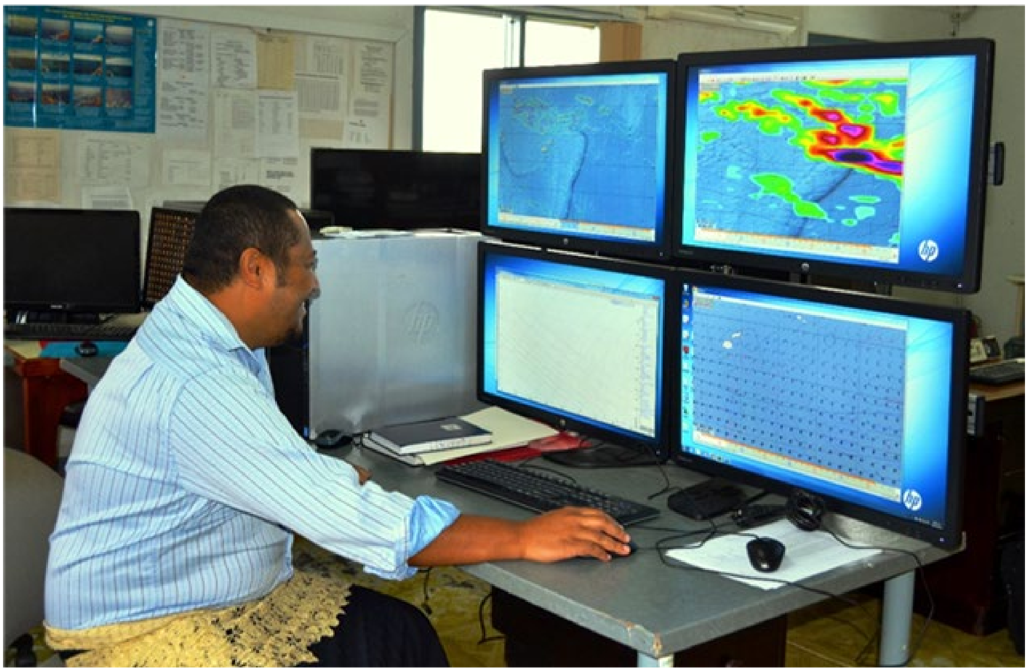

Image 6: Lead Weather Forecaster of the Tonga Meteorological Service utilising weather models to prepare weather information for Tonga

The consultations with NMHSs revealed support for increased investment in a Regional Training Centre in Fiji that focused on training in observation networks, especially in electronics maintenance, data management and IT support. The recommendation to invest in an instrument calibration centre in Fiji (see above) would link to the training of electronics technicians. For introductory forecasting and observer training the ongoing role of Pacific International Training Desk in Hawaii was also raised as an important option. This Decadal Investment Plan builds on the approach recommended in the Feasibility Study for a Pacific Based WMO Regional Training Centre for the training of

[12] Government of the Republic of Fiji. Department of Meteorology. (2019). *Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production: A roadmap of actions*. Ministry of Disaster Management & Meteorological Services, Ministry of Economy, NAP Global Network and Finnish Meteorological Institute.

observers and technicians. This involves short courses in Fiji through the Fiji Meteorological Service in partnership with USP that will result in BIP-MT accreditation. Apart from the resident training capacity in Fiji, these courses would be complemented by bringing in short-term experts from overseas. This recommended approach needs to be developed in the context of the evolving Systematic Observations Financing Facility (SOFF), a major WMO initiative, which aims to support countries in generating and exchanging basic observational data. One of the key outputs for the SOFF is developing capacity to operate and maintain the observing network, which will align with parts of the proposed Regional Training Centre courses for observers and technicians. There is also a need to build on expertise developed in the region over recent years e.g. NIWA approaches to training NMHS staff in use and maintenance of Automatic Weather Stations.

For higher level training (BIP-M equivalent), the use of established training centres in NZ, Australia and Philippines was viewed by NMHSs in the consultations as more practical than a Regional Training Centre in Fiji. This approach to BIP-M comes with caveats and opportunities. Spending 6-9 months overseas away from family and/or the workplace is seen as a constraint to higher level training. Further, the pipeline of graduates with suitable maths/physics training constrains the potential number of people who can undertake a BIP-M course.

Investing in a hybrid model for higher level training using a mixture of online courses run by existing accredited training centres and short bursts of intensive in-person training in Fiji is a possible solution. Some of these regional training centres, e.g. Bureau of Meteorology Training Centre in Melbourne, are already in the process of developing online courses for BIP-M equivalent training. A distinct advantage of this hybrid approach is that it is more family friendly and provides greater opportunities for women to participate which will lead to better gender balance in forecasting roles over the decadal timeframe of investment.

Alternative approaches include the system used in the US-aligned countries and US territories, which has a well-established training system with observers/technicians trained on the job and through short courses in Hawaii at the Pacific International Training Desk. Meteorologists receive degrees in meteorology from recognised universities and then undertake on the job training and courses within the National Weather Service.

One of the constraints to staff undertaking higher level post-graduate training is the lack of staff with undergraduate qualifications in maths/physics. This is a particular challenge for some of the smaller countries. Supporting staff to undertake primary degrees in maths/physics through targeted investments warrants consideration, with a particular focus on less well-endowed smaller countries.

The changing nature of the forecasters' role needs to be considered when assessing training requirements for the future and associated investments. As outlined in the context section above, automated forecasting processes are increasing around the world, which is taking some of the emphasis away from the technical aspects of forecast development. At the same time, forecasters are being required to better communicate the impacts of weather and severe events and how people should prepare rather than emphasising in technical terms what the weather will be. Whilst forecasters and hydrologists will still be required to have the core underpinning technical competencies in order to recognise and intervene when the NWP is not providing good guidance, broader skills of engagement and communication will become increasingly important.

Short training workshops done in the region by experts from overseas, e.g. (BoM) on tropical cyclones, are viewed very positively. Also, approaches to training such as NIWA provides in maintenance of AWSs and hydrology equipment are seen as valuable initiatives. NIWA uses a buddy or twinning system where a specialist in NIWA works in an ongoing way with technicians from individual Pacific Island countries to build a relationship that becomes less dependent over time. These approaches to the use of external experts in building capacity appear to offer a good return on investment.

Providing training for hydrologists and hydrographers is more problematic because unlike meteorology there aren't the equivalent WMO accredited standards or a formal network of training centres. There are however in Australia and New Zealand, industry bodies that link with vocational training institutions to provide training for observers and technicians in surface and groundwater monitoring. There are also tertiary institutions that provide degrees and postgraduate diplomas in areas such as water resource management, catchment hydrology etc. These options can meet the training needs for staff in NMHSs. All of the options raised in the area of training need to be undertaken with a long-term strategic plan within individual NMHSs to provide a more stable flow of capacity enhancement. To ensure longer-term success of investments in training there needs to be strong support and co-investment from NMHSs to overcome reliance on shorter-term, less coordinated fully funded external projects.

Although not yet implemented, there are plans by the WMO to revise the curriculum for the BIP-MT course with modules on hydrology to be included in the revised course. This may go some way to meeting the training needs of observers and technicians in the hydrography area. Finally, it must be emphasised that in developing training and capacity building initiatives, care has been taken to ensure that they complement rather than replace existing initiatives such as WMO Regional Training Centres in the Asia-Pacific region, WMO and other provider training courses, and the Pacific International Training Desk.

3.2.5.1. Support the establishment of a WMO Regional Training Centre that focuses on training of observers, technicians and IT specialists

Whilst there is ongoing funding from JICA to support training of observers and technicians through the Fiji Meteorological Service, it is acknowledged that this funding stream is not sustainable. To provide a stronger basis for the training of observers and technicians, this proposed investment activity supports the establishment of a Regional Training Centre in Fiji through a partnership between the Fiji Meteorological Service and the University of the South Pacific for the benefit of all SPREP member countries. The ultimate objective of this activity is to the establish an enduring regional training capability that can address immediate needs and mature over time. There needs to be a Secretariat to administratively support this Regional Training Centre and the investment recommendation is this be achieved through a Director and two support staff (one technical and one administrative) (Tables 3.46 and 3.47).

Table 3.46: Establishment and annual costs for implementing the Secretariat for the Regional Training Centre.

Activity	Establishment cost	Annual cost
Recruitment and establishment costs in Years 1, 4,7	USD 20,000	
Salaries for Director and two staff		USD 100,000
Office, operating and travel costs		USD 10,000
Housing costs for Director		USD 20,000
Demobilisation costs Years 4,7, 10	USD 20,000	
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 1.53M**	

Table 3.47: Annual total costs of Regional Training Centre Secretariat over the 10-year investment plan term (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.09	0.13	0.14	0.18	0.14	0.15	0.20	0.15	0.16	0.19	**1.53**

3.2.5.2. Training of technicians and observers

The approach used for this activity is based on the Feasibility Study for a Pacific Based WMO Regional Training Centre with a focus of training on electronics technicians, observers, and IT skills in data management. As observation equipment is now mostly electronic and automated, the emphasis in training is on electronics and data management. This involves a 3-month study program to be undertaken in Fiji. The feasibility study identified that places need to be made available for 10 course participants per year and a proactive recruitment strategy is needed to ensure that women are well represented. Based on the consultations undertaken as part of this scoping project the need to support 12 participants per year has been identified. Costs required include airfares, accommodation and fees for each of the participants. It also provides for two experts from overseas to contribute, each for two weeks. The total cost over a decade timeframe for this activity is USD 1.93 Million and would result in training of 120 observers and technicians (Tables 3.48 and 3.49).

Table 3.48: Costs associated with providing BIP-MT training at the Regional Training Centre.

Activity	Annual cost/participant	Total cost for 12 participants/annum
Airfares for participants	USD 2,000	USD 24,000
Accommodation and living expenses for 3 months based on USP Lodges/Flats	USD 9,000	USD 108,000
Course fees (USP member countries based on other USP course costs)	USD 1,100	USD 13,200
Airfares for two overseas experts		USD 2,000
Accommodation and living expenses for two experts for two weeks each		USD 7,000
Expert salaries and oncosts and institutional overheads (two salaries)		USD 18,210
Annual costs		USD 172,400
Annual costs per participant		USD 14,370
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 1.93M**	

Table 3.49: Annual total costs of BIP-MT training over the 10-year investment plan term (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.17	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.21	0.22	**1.93**

3.2.5.3. Training of forecasters to a BIP-M standard

As indicated above the approach adopted to training of forecasters to a BIP-M standard is based on a hybrid model of online training over a 7-month period, including a one month in-person intensive training component in Fiji. The costs of training are based on the Bureau of Meteorology Training Centre postgraduate course. Costs are similar for the University of Victoria, Wellington postgraduate course as identified in the Feasibility Study for a Pacific Based WMO Regional Training Centre. Online training considerably reduces the costs of travel, accommodation and living expenses and allows participants to stay in their home environment, which addresses a concern raised during the consultations about spending a 6 to 9-month period away from families. Related to this, there should be a proactive approach taken to provide opportunities for women and people with disabilities to undertake BIP-M training to ensure greater social inclusion over the decadal period of investment.

The costings below are based on 8 participants per year and over the decadal investment plan period would result in the training of 80 forecasters with a total cost over the 10 years of USD 3.04M (Tables 3.50 and 3.51).

Table 3.50: Costs associated with providing BIP-M training using an online course complemented by an intensive face to face training session.

Activity	Annual cost/participant	Total cost for 8 participants/annum
Online training course – approximately 6 months	USD 21,000	USD 168,000
Airfares for participants	USD 2,000	USD 16,000
Accommodation and living expenses for 1 month based on USP Lodges/Flats	USD 7,500	USD 60,000
Airfares for a trainer		USD 1,500
Accommodation and living expenses for one trainer for one month each		USD 7,500
Expert salary and oncosts and institutional overheads		USD 18,210
Annual costs		USD 235,210
Annual costs per participant		USD 33,900
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 3.04 M**	

Table 3.51 Annual total costs of BIP-M training over the 10-year investment plan term (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.27	0.28	0.28	0.29	0.30	0.31	0.31	0.32	0.33	0.34	**3.04**

3.2.5.4. Increasing the capacity of forecasters for forecasting in riverine flash floods and coastal inundation

The ability to better forecast the impacts of floods (from river sources including flash floods) and coastal inundation (from multiple sources including storm surge, swell, waves, river floods and and tsunamis) is important in better preparing for and managing the impacts of extreme events. For the river component of flooding, there is a need for training hydrologists and hydrographers that are located in larger countries with rivers and streams where flash flooding is a significant contributor to loss of life and property e.g. PNG, Palau, Solomon Islands, Vanuatu, Fiji, and Samoa. Similarly, in all the Pacific island countries and territories there is a need for coastal early warnings for vulnerable communities in coastal areas. Marine meteorologists and oceanographers require training to enhance the capacity to provide early warnings for floods from marine sources. WMO has recognised the need for such capacity development and have worked since 2018 to develop a course to enhance marine weather forecasting services in coastal countries, especially developing ones.

(a) Riverine Hydrology

Training needs for hydrologists are quite specialised and the number of people that require training is much less than for meteorological services. As indicated above addressing these needs are best served by utilising existing courses e.g. postgraduate certificates and diplomas or specialised short courses that are available in the region (Australia, USP-Fiji, NZ, Hawaii), rather than developing specialised within region institutional capacity.

Both New Zealand (Primary Industry Training Organisation) and Australia (Australian Hydrographers Association) have industry associations that work with accredited training institutions to provide diplomas in practical operations and maintenance of water instrumentation and infrastructure. The NZ training is provided through on the job support with an assessor visiting the workplace whilst the Australian training is through a series of online subjects/units. Both assume students are in full-time employment with a 2-year period to complete the part-time diploma. Costings below are based on the Australian course as the online structure would appear to be more aligned to distance learning. In addition, there is provision for an expert to visit the region every second year to provide in-country support (Tables 3.52 and 3.53).

In addition to practical training for data collection, and monitoring and maintenance of equipment related to water resources and hydrology there is also a need to build the capacity of professional hydrologist staff. The assumption for this investment activity is that two people per year receive specialised training and that they already have a relevant undergraduate degree. Indicative costings are based on postgraduate diploma/certificate courses in catchment hydrology available in NZ or Australia and assume accommodation needs for one year.

The New Zealand Ministry of Foreign Affairs and Trade (MFAT) has a scholarship program that supports the cost of undertaking courses or training in New Zealand. This has led to NMHS staff being placed with NIWA in New Zealand for a 3 to 4-month work placement that provides on the job training and experience. NIWA have also put in place a customised train the trainer, 2-week intensive course to support the Water Resources Division in Samoa. Whilst these two NZ options are already financially supported through development funding there is a need to build and maintain a community of practice of hydrographers and hydrologists in the region. A biennial hydrography/hydrology workshop is included in the costings to build and support this community of practice. It assumes there are 10 participants and an international technical expert. As with the BIP-M and BIP-MT training, actively seeking women to undertake this training should be a high priority.

Table 3.52: Costs associated with providing Diploma and Postgraduate Certificate training in hydrography and hydrology.

Activity	Annual cost/participant	Total cost for 3 participants/annum
Technical training (diploma) for hydrography staff		
Online training course: 2-year part-time diploma course	USD 6,000	USD 18,000
Expert visit to the region to support staff and provide guidance on equipment (Airfares and expenses based on one month visit every second year		USD 3,500
Salary of expert for the one month visit every second year		USD 9,600
Total cost		**USD 31,100**
Postgraduate diploma/certificate for professional staff		*2 participants/year*
Postgraduate course in Australia or NZ	USD 25,000	USD 500,000
Airfare, living and accommodation costs for the 9 month period	USD 15,000	USD 30,000
Total cost		**USD 80,000**
	Cost/participant	**Total cost for 10 participants/biennial workshop**
Travel and accommodation for a regional biennial hydrography/hydrology workshop		USD 35,000
Salary and travel costs for international consultant		USD 9,000
Total cost		
Total cost for both training activities and biennial workshops over 10 years (allowing 2.5% increase per year in annual costs)	**USD 1.49 M**	

Table 3.53: Annual total costs of hydrology training over the 10-year investment plan term (USD millions)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.17	0.10	0.18	0.11	0.19	0.11	0.20	0.12	0.21	0.12	**1.49**

(b) Coastal inundation and marine weather

WMO, though its Education and Training Office and Marine Services Division, has recently developed a hybrid course to promote best practice for Impact-Based Forecasting, with a focus on familiarisation and effective implementation of the regulations for provision and continuous improvement of marine meteorological services. The course also addresses the Marine Weather Forecasters Competencies.

The hybrid course consists of a purely online first phase over eight weeks where the emphasis is on course participants understanding and describing the gaps in their NMHS's marine weather forecasting capacity. Phase 2 consists of online (two weeks) and face to face (one week) workshops on Impact-Based Marine Meteorological Service Delivery. The course includes: case study activities and/or simulations of significant weather events with a focus on customer impacts and communication responsibilities; presentations from exemplary marine meteorological services regarding strategies for service delivery; discussions amongst participations on challenges and needs to improve their services; and presentations from other experts. For countries where tsunami warnings are provided locally rather than through the PTWC, the course can be tailored to these specific needs.

In addition, marine competencies would be assessed in Years 2, 6 and 10 to assist in maintaining standards required for delivery of marine forecasts and coastal inundation events. This would require the development of competency framework by a consultant and a regional workshop in Years 2, 6 and 10 to test competencies. The costings for the marine course and the competency testing are shown in Tables 3.54 and 3.55.

This accredited course and competency assessment would be complemented by professional development training provided by other programs e.g. the SPC Pacific Ocean Portal has been supported by COSSPac in providing professional development and training in ocean science and in the use of the Portal.

Table 3.54: Costs associated with providing Diploma and Postgraduate Certificate training in hydrography and hydrology.

	Total cost for 15 participants/workshop
Marine course delivery including course development, travel and costs of delivery.	USD 50,000
Travel and per diem costs for NMHS participants	USD 52,500
Consultancy for Marine Competency framework	USD 30,000 (one off)
Travel and per diem costs for NMHS participants	USD 52,500
Total cost	
Total cost for both marine course and competency assessment over 10 years (allowing 2.5% increase per year in annual costs)	**USD 0.51 M**

Table 3.55: Annual total costs of marine forecast training over the 10-year investment plan term (USD millions)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.13	0.05	0.00	0.00	0.11	0.06	0.00	0.00	0.12	0.06	**0.54**

3.2.5.5. Professional development workshops

Specialised training workshops in the region have proven to be of high value to Pacific NMHSs. These workshops are sponsored/funded by WMO, regional agencies such as SPC or SPREP or through the aid programs of national governments. One example of these workshops is the series of SPC-COSSPac Ocean & Tides workshops which provided the background ocean science behind the Pacific Ocean Portal, which provided technical training on how to navigate the portal, provided examples of marine applications, and supported NMSs in initiating dialogue with in-country users of ocean data. Workshops were hosted by and developed in consultation with the local NMHSs, according to their needs. Other examples include training by NIWA in Automatic Weather Stations, including data collection, maintenance etc and Australian aid providing specialised training on tropical cyclones through the Bureau of Meteorology. SPREP has provided annual regional IT, media/social media, research and climate services trainings. It is proposed that five technical workshops be held per year, each of two weeks duration, to provide professional development and training across the region (Tables 3.56 and 3.57). It is envisaged that there would be 10 participants at each workshop i.e.30 participants per year.

Table 3.56: Costs of delivering five professional development workshops per year.

Activity	Annual cost/participant	Total annual cost for 10 participants each for 5 workshops
Airfares for participants	USD 2,000	USD 100,000
Accommodation and living expenses for 2 weeks based on USP Lodges/Flats	USD 3,500	USD 175,000
Airfares for experts 2 per workshop and 5 workshops per year		USD 15,000
Accommodation and living expenses for two experts for five workshops per year		USD 35,000
Expert salaries and oncosts and institutional overheads (two salaries) for two weeks + one week preparation and follow-up, 5 courses per year		USD 136,500
Annual costs		USD 461,560
Annual costs per participant		USD 9,230
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 5.17 M**	

Table 3.57: Annual total costs of in-region professional development workshops over the 10-year investment plan term (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.46	0.47	0.48	0.50	0.51	0.52	0.54	0.55	0.56	0.58	**5.17**

With improving internet services and technologies to deliver effective online training and workshops, there is a need to invest in running workshops and training modules online. This reduces the need for travel, which is both costly and consumes additional time, especially in a region as geographically dispersed as the Pacific. There are upfront costs in developing the workshops but once established the running costs involve some IT support and experts for support and monitoring (Tables 3.58 and 3.59). Allowance is for delivery of 10 different workshops to cover the period Years 1-5 and a second tranche of 10 workshops in Years 6-10 for a total of 20 workshops.

Table 3.58: Costs of development and delivery of online professional development workshops.

Activity	Cost per workshop	Annual cost
Development of workshop content	USD 20,000	
Developing online delivery of workshops; graphics, IT etc	USD 10,000	
Ongoing expert support and revision of materials (10 days per workshop/year)	USD 6,800	USD 68,000
Ongoing IT maintenance of workshop content and its delivery	USD 3,500	USD 35,000
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 1.61 M**	

Table 3.59: Annual total costs of online professional development workshops over the 10-year investment plan term (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.39	0.09	0.09	0.09	0.10	0.44	0.10	0.10	0.11	0.11	**1.61**

3.2.5.6. Regional Twinning Program

The aim of this activity is to provide ongoing mentoring for staff in Pacific NMHSs through a regional twinning or “buddy” program. It would over time lead to a strong community of practice. This would commence through a series of virtual meetings where NMHS staff are matched to staff in the BoM, NZ MetService, NIWA and NOAA. Once this process is completed there will be a conference which will have the aim of both building capacity through professional plenary sessions and workshops and bringing the buddies face to face to establish the relationships (Tables 3.60 and 3.61). It is envisaged hat this conference will involve 40 NMHS and 40 staff from BoM, NZ MetService, NIWA. It would be undertaken in Years 1 and 6 of the decadal investment period. After this establishment phase, twinning interactions between staff will be online. Provision is made for some individual face to face interactions where NMHS staff visit Australia, NZ or Hawaii for short-term visits of one to two weeks. The coordination of the twinning program will be managed by the Management and Advisor Team sitting with the PMDP. In the costings below it is assumed the mentoring provided by staff in Australia, NZ and NOAA is contributed time.

Table 3.60: Cost of twinning program.

Activity	Costs for activities
Conference (held in the Pacific) that brings NMHS and Australian and NZ staff together (Airfares, Accommodation, Per Diems) held in Year 2	USD 300,000
Conference (held in the Pacific) that brings NMHS and Australian and NZ staff together (Airfares, Accommodation, Per Diems) held in Year 6	USD 358,000
Airfares and accommodation for individual visits to Australia and NZ (5/year) commencing in Year 3	USD 17,500/year
Total cost over 10 years (allowing 2.5% increase per year in annual costs)	**USD 0.81 M**

Table 3.61: Annual total costs of twinning program over the 10-year investment plan term (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Cost	0.30	0.02	0.02	0.02	0.02	0.36	0.02	0.02	0.02	0.02	**0.81**

Table 3.62: Summary of proposed investments in capacity and training (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
RTC Secretariat	0.09	0.13	0.14	0.18	0.14	0.15	0.20	0.15	0.16	0.19	**1.53**
Technicians	0.17	0.18	0.18	0.19	0.19	0.20	0.20	0.20	0.21	0.22	**1.93**
Forecasters	0.27	0.28	0.28	0.29	0.30	0.31	0.31	0.32	0.33	0.34	**3.04**
Hydrology	0.17	0.10	0.18	0.11	0.19	0.11	0.20	0.12	0.21	0.12	**1.49**
Marine	0.13	0.05	0.00	0.00	0.11	0.06	0.00	0.00	0.12	0.06	**0.54**
Workshops	0.85	0.56	0.58	0.59	0.61	0.96	0.64	0.65	0.67	0.69	**6.79**
Twinning	0.30	0.02	0.02	0.02	0.02	0.36	0.02	0.02	0.02	0.02	**0.81**
Total	**1.98**	**1.32**	**1.37**	**1.38**	**1.55**	**2.14**	**1.57**	**1.47**	**1.71**	**1.63**	**16.13**

3.2.6. Summary of investments and their phasing

The investment required over a decade to provide a much enhanced, well-coordinated and sustainable NMHS network is significant. Table 3.63 provides a summary of the proposed investments over the decade. For the areas of governance, forecasts and warnings, and capacity and training it is envisioned that investment would commence in Year 1 and be sustained over decade. This is to ensure the capacity and systems are self-sustaining by the end of the decadal term of investment. There is a need to significantly uplift infrastructure capacity across the Pacific. This is not just in observational infrastructure but also in computers, servers, forecaster workstations etc. This requires both a large capital investment and, more importantly, the operating funding to ensure the equipment is maintained over the decadal timescale. It is envisioned that infrastructure will be deployed gradually over the first 5 years of the 10-year investment. This phasing in of infrastructure will allow for lessons learned with the first infrastructure deployments to be taken into account in subsequent infrastructure purchase and deployment. Consistent with this approach operating costs for infrastructure ramp up over the first three years of the ten-year investment period.

By the end of Year 3, the various leadership and training programs should be in place and enhanced capacity of NMHSs is starting to be realised. The regional coordination arrangements should be functioning effectively and the cascading forecasting approach will have been designed and developed with global, regional and national processes for integration in place. The needs of end-users will have been incorporated into evolving impact-based forecasts and warnings. The first phase of infrastructure purchase and deployment will have been completed and lessons learnt to guide future infrastructure deployment. An external review of the program will be undertaken after Year 3 to guide the program and its design for the remaining 7 years. This should be factored in as part of any future funding organisation's management arrangements and has not yet been costed.

By end of Year 6, all infrastructure will have been deployed and the full suite of proposed observations will be used in local forecasts and warnings and being used by global networks to improve global numerical products. The cascading forecasting system will be operating effectively and efficiently with highly effective interactions between global and regional centres and NMHSs. Through the capacity building that has been achieved, a noticeable strengthening of numbers and skills in NMHSs can be demonstrated. There are good indications that impact-based messages are being used by individuals, communities and industries. An external review of the program will be undertaken after Year 6 with a focus on assessing early impacts, ensuring the program delivers on its outcomes by Year 10 to maximise benefits. The review should assess whether the program is on track to build a long term and self-sustaining legacy, and if not should develop a sustainability strategy and prioritise remaining activities accordingly. This review should be factored in as part of any future funding organisation's management arrangements and has not yet been costed.

The investment plan includes the costs for the operational implementation of the program within the region. Costs for overarching management of the program from a donor or group of donors have not been factored into the costings of this investment plan. This is because the funding arrangements are still uncertain and are discussed in more detail in Section 4.4.

Table 3.63: Operating and capital costs associated with the Decadal Program of Investment (USD millions).

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Total
Governance	0.96	0.9	1.15	1.26	1.2	0.99	1.61	1.04	1.33	1.27	**11.71**
Forecasts production	2.99	3.48	3.15	3.67	3.77	3.83	3.86	3.86	3.86	3.91	**36.38**
Forecasts communication	0.35	0.17	0.18	0.36	0.19	0.21	0.39	0.2	0.21	0.21	**2.47**
Infrastructure - CAPEX	5.04	7.55	7.55	15.11	15.11						**50.37**
Infrastructure - OPEX	1.71	2.96	4.13	5.38	5.51	5.81	5.78	5.95	6.08	6.21	**49.52**
Capacity/training	1.98	1.32	1.37	1.38	1.55	2.14	1.57	1.47	1.71	1.63	**16.12**
Total	**13.03**	**16.38**	**17.53**	**27.16**	**27.33**	**12.98**	**13.21**	**12.52**	**13.19**	**13.23**	**166.6**

4. Bringing it together

4.1. Pathway to impact

Implementing the rationale and vision for the Decadal Program of investment outlined above requires developing a logical framework that can link in a causative way activities and partnerships through to outcomes and impacts. Developing a pathway to impact using a Theory of Change approach is well aligned to complex problems involving multiple stakeholders and focuses on “how to make change happen” rather than an activity-based approach. Ideally, a formal Theory of Change approach involves a detailed, participatory discussion and workshops with all stakeholders to determine the desired impacts and outcomes, then working backwards through outputs and activities. This includes working through assumptions that can provide a logical and causative linkage from activities through to impacts. The nature and timeframe of this project did not permit the development of a comprehensive Theory of Change. However, to provide a logical framing to the Investment Plan activities a Pathway to Impact has been developed (Figure 4.1).

The Pathway to Impact is a first, iterative step that can be more fully developed into a Theory of Change if the Decadal Program of Investment is supported and moves to an implementation phase. The Pathway to Impact provides sufficient context, granularity, connection to existing and planned donor programs, and flexibility to support the proposed elements of the Decadal Program of Investment. Working backwards from the desired impacts and outcomes, investment activities are proposed in Governance and leadership, Infrastructure, Forecast and warning production, Communication and delivery to end-users, and Capacity and training.

The key outcomes and benefits from the Decadal Program of Investment summarised in Figure 4.1 include:

1. For all nations, assured access to localised, accurate and timely forecast and warning products:
   - derived utilising world-leading forecasting capability;
   - accessed via a Pacific Weather Exchange;
2. The ability to better communicate impacts – “what the weather will do rather than what the weather will be”;

4. Strengthened preparedness and response to severe weather events that provides improved safety for all communities in the region and travellers;
5. Increase in adaptive capacity of industries and communities to manage the impacts of climate change related weather, hydrological and ocean extreme events;
6. Reduced economic impacts of extreme events on key industries (agriculture, fisheries, aviation, tourism) and livelihoods of small businesses, farmers etc.;
7. For some nations, the generation of revenue derived from industry partnerships (e.g. energy, aviation, agriculture);
8. Pacific issues receive greater consideration in multilateral settings.

Impact	Enhanced national meteorological and hydrological organisations in partnership with national disaster management organisations reduce the human and economic cost of severe weather, hydrological and ocean events across the Pacific Island communities			
Outcomes	Communities, government and industries have the forecasts, warnings and communication systems to enact response plans to extreme weather events in a timely manner			
Intermediate outcomes	Stronger weather services, with confident leaders and clear mandate and governance arrangements, able to collaborate with regional partners and influence the decisions of government	NMHSs, NDMOs, Emergency Managers, media and communities collaborate effectively to deliver end-to-end, timely and appropriately communicated impact-based forecasts, outlooks, information and warnings	a) NMHSs increase the number and quality of weather observations in the region enabling stronger forecasts and impact predictions b) NMHSs have fit for purpose and robust infrastructure that is well maintained through multi-year service and maintenance contracts	Staff in NMHS are technically-skilled and accredited and are trusted by the government and communities
Activities	**Governance and leadership**	**Communication and delivery**	**Infrastructure**	**Capacity**
	a) Establish a Pacific Meteorological Leadership Program b) Strengthen regional coordination, especially in integration across many donor and agency programs and also with PMC and its Panels c) Advisor network to assist in governance and strategic plan implementation	a) End-user workshops b) Developing and communicating impact-based warnings c) Enhanced NMHS/NDMO collaboration **Forecast and warning production** a) Investment in increased use of remotely generated NWP products and satellite data and forecast automation in a cascading forecast process b) Strengthening RSMCs c) Develop Pacific Weather Exchange d) Investment in ensuring observations are delivered to GBON	Investment in observational infrastructure targeted to local needs a) Weather radars b) Flood gauges c) Upper air measurement d) Ocean observations e) Equipment long-term maintenance schedule f) Investment and upgrade of ICT equipment, bandwidth and data	a) RTC established for BIP-MT training b) Establish a hybrid BIP-M training program c) Training for hydrologists and hydrographers d) Professional development workshops e) Twinning program to mentor NMHS staff

Figure 4.1: Impact pathway for the Decadal Program of Investment.

4.2. Return on investment

The magnitude of funding to support this Decadal Program of Investment is significant. Will the proposed activities, outcomes and impacts as illustrated in Figure 4.1 deliver transformational and systemic change and represent a good return on investment? Whilst the proposed USD 167 million represents a significant investment, it is over a decade. As indicated in Section 1, recent estimates of average annual losses in GDP due to natural disasters are in the order of USD 500 million or USD 5 billion over a decade. These estimates do not include losses of life or disruptions to livelihoods and social cohesion. If the improved services and delivery of forecasts and warnings from NMHSs could prevent just 5% of these losses (USD 250 million) that represents a positive return on investment. That superficial assessment of benefit is likely very conservative as other economic analyses of NMHS improvements to reduce disaster losses in developing countries show a Benefit-Cost Ration of 4:1 to 36:1[13]. In the context of climate change adaptation, strengthening early warning systems provides a high return on investment with a benefit-cost ratio of more than 12:1[14].

Infrastructure for weather forecasting and climate systems is high cost and in this investment proposal represents a significant percentage of the funding. However, in terms of activities and investment of time, the most critical aspects in this investment proposal relate to building capacity. This is building capacity in governance and leadership, building critical mass of personnel in key areas of observations and forecasting, transforming the way forecasts and warnings are produced, through training and engagement with end-users communicate and deliver impact-based forecasts and warnings to government, communities and industries, and provide the underpinning training to deliver a first class NMHS workforce.

Providing support to build the capability and capacity of NMHSs and the PMDP over a decadal time period has the best chance of delivering systemic change. The idea is that innovations and new ways of operating become mainstreamed. Innovations can only be effectively mainstreamed if taken to scale and an important component of this proposal is investing at a regional scale to ensure impact is widespread. For systemic change to be realised there needs to be a shift in culture, mindsets and behaviours and it is anticipated that the substantial amount of capacity building detailed in this investment proposal will be critical to bringing about that shift in mindset and behaviours and over time build a strong community of practice at a regional scale. A change in culture will only be realised if there is appropriate leadership and the ability of that leadership cohort in NMHSs to develop policies and practices that facilitate and reinforce cultural and systemic change. This is why providing leadership training to Directors and senior staff in NMHSs is critical to realising a good return on investment.

Another area identified as critical to systemic change and providing a positive return on investment is ensuring expensive observations infrastructure remains operational. A significant number of past infrastructure investments in the Pacific region have been short-term and funding for longer-term maintenance of equipment is not provided. This has led to a situation where when that equipment goes out of service it is often left unrepaired because national NMHS budgets do not have provisions for maintenance. This represents a poor return on investment. In this investment plan we provide for maintenance and operating funding from the time of purchase until the end of the ten-year investment plan. It is expected that during this period technicians will become skilled in understanding and maintaining the equipment and the implementation of a Regional Training Centre focused on observers and technicians will provide a workforce capable of maintaining equipment in the long-term.

Achieving systemic change in NMHSs and in the impact of their services will be critical for when this Decadal Program of Investment concludes. The legacy should be a PMDP and NMHSs that are sufficiently robust in governance, coordination and capacity to be largely self-sustaining. There will inevitably be a need for ongoing investment in regional and NMHSs beyond this decadal time-frame but it is envisioned that this will be quite specific and well-targeted rather than a need for broad-scale, underpinning support. It will be critical to conduct major three-year and six-year reviews during the decadal period of investment to ensure goals

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[13] Hallegatte, S., 2012. A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation. Policy research working paper 6058. Washington, D.C., World Bank.

[14] Global Commission on Adaptation (2019). Adapt Now: A Global Call For Leadership on Climate Resilience.

are being met and take corrective action if not, and to position the program well for when the investment concludes.

Ultimately, the true test of the return on investment will be the benefits for individuals, communities and industries through reduced human and economic cost from severe weather, hydrological and ocean events. The human and financial cost of not acting is higher than the cost of acting through the investments in this Decadal Program of Investment.

Achieving the Program outcomes and return on investment will require the Program to have a detailed monitoring and evaluation plan. This M&E plan should provide the mechanisms to adjust and adapt the investment program in response to lessons learnt as the implementation of the program proceeds. The M&E Plan will also need to link to the proposed three- and six-year Program reviews. As with the staged reviews the M&E plan needs to be fully costed.

4.3. Program Risks

An ambitious decadal program of investment will carry risks. These risks need to be managed so that a cohesive and well-implemented program can deliver on its goals of much strengthened and sustainable NMHSs and result in benefits to communities and industries. Key risks to the program include:

1. Lack of legislative and policy frameworks to support NMHSs and/or weak implementation of their strategic plans. The program to strengthen NMHSs through improved infrastructure, systems and human resource capacity will not be fully effective if there is not a clear mandate or strategy for meteorological and hydrological services and the senior leadership lacks the capacity to implement the program. To mitigate this risk, the program is investing in governance and leadership activities through training for senior leaders and in providing advisory assistance to support NMHSs in development and implementation of strategic plans. By locating the Management and Advisory team for the Program with the PMDP, this will create the linkages needed not just to work with the individual NMHSs but also through the PMC so that there is also regional impetus to lifting governance and leadership capacity.
2. Limited interaction between NMHSs and NDMOs and delivery of impact-messages to end-users. Improved technical and systems approaches to forecasts and warnings will not have their intended societal benefits if they do not have a timely and effective pathway to reaching end-users. A significant risk for the program is investing heavily in improved technical capacity and production and not in parallel improving the delivery of information to communities and industries that triggers appropriate responses. Key to managing this risk is understanding user needs, providing training in development and delivery of impact-based forecasts and warnings and ensuring ongoing good communication and coordination between NMHSs and NDMOs. The program is investing in all three of these areas and to ensure this area is developing well there should be a review after three years of the program to strengthen this area if required and/or take corrective action.
3. New infrastructure is not well maintained and fails to deliver expected benefits. As indicated throughout this report a key concern with infrastructure investment in the past has been a lack of ongoing support to ensure that equipment is adequately maintained and remains operational in the years after projects are completed. To manage this very significant risk, a large investment in operating costs and maintenance is proposed over the decade and almost matches the capital costs of the infrastructure. This will involve both well-resourced external service contracts, training of staff, and the establishment of a regional equipment calibration centre.
4. The proposed approach to cascading forecast development involving global and regional centres and national meteorological services is not accepted with NMHSs. A central tenet of this investment strategy is developing a cascading forecasting system that effectively draws on the strengths of global production centres, RSMCs, and NMHSs in development and delivery of forecasts and warnings. With the aspiration of NMHSs to strengthen their own forecasting capacity there is a risk that this integrated, cascading forecast system is perceived as a threat to national capacity development. An important role for the Management and Advisor team, in partnership with the PMDP and the PMC is to work with NMHSs in demonstrating the benefits of the integrated global to national systems approach and how it can create synergies that will benefit individual NMHSs, especially in being able to focus on delivery of information to end-users.

5. Even with comprehensive training programs in place there is lack of qualified people to take up all of the new positions proposed. This program represents a significant investment to uplift capacity of NMHSs, both in numbers of staff and their training and qualifications. There is a risk that there won't be sufficient staff with foundation skills and training to take up all the new positions or undertake the proposed training. To reduce this risk, the program team needs to work with national NMHSs and other parts of government, especially in education and training, to create incentives and to promote the career opportunities in working in NMHSs. It is likely that this area will remain a significant ongoing risk.
6. Even with comprehensive training programs in place there is lack of qualified people to take up all of the new positions proposed. This program represents a significant investment to uplift capacity of NMHSs, both in numbers of staff and their training and qualifications. There is a risk that there won't be sufficient staff with foundation skills and training to take up all the new positions or undertake the proposed training. To reduce this risk, the program team needs to work with national NMHSs and other parts of government, especially in education and training, to create incentives and to promote the career opportunities in working in NMHSs. It is likely that this area will remain a significant ongoing risk.
7. Improved impact-based forecasts and warnings don't result in a change to preparedeness actions by individuals and communities. There is a risk that despite a well-functioning program that is delivering appropriate impact-based messages that individuals and communities are not adopting and acting on the information. An opportunity to reduce this risk is to work closely with the significant number of climate change projects and the overarching FRDP that has a strong focus on building resilience and adaptation responses in Pacific Island communities. These community-based programs work on building adaptive capacity and changing behaviours and through this program of investment, NMHSs should establish effective collaborations to improve preparedness actions in response to extreme event warnings.
8. Complexities of working across a region with different national needs leads to ineffective program delivery. This program will be working across a large number of countries and territories, each with their own needs, which will create challenges because "one-size fits all" approach will not work. The implementation phase of this program will require careful planning to minimise this risk and need to work closely with the PMC, PMDP and NMHSs in this planning phase to ensure delivery is well-targeted.
9. Program activities are "cherry-picked" by individual donors making it very challenging to maintain program coherence. The investment model for this program has several options (Section 2.4) below, one of which is through multiple donors. There is a risk with this model that individual program components will be cherry-picked, resulting in fragmentation of the overall decadal strategy. To minimise this risk, the program will invest in the PMC partner and donor engagement platform to ensure that the overall decadal program strategy is the context in which individual donor investments are made.
10. The benefits of the program don't endure beyond the decadal period of investment. A risk associated with nearly all development programs is that benefits don't persist and that there is little long-term legacy. In response, the aim of most contemporary development programs is to achieve systemic change so that program impacts continue to be realised long after the program concludes. This is also the aim of this Decadal Program of Investment. The key to achieving this is in the capacity building elements of the program in leadership and training. The ten-year period of building human capacity should result in a transformation of NMHSs that provides the ability to be self-sustaining in the long term. The stronger connections to regional and global programs and developed NMHSs in the region will support this systemic change beyond the decadal program.

4.4. Pathway to implementation

This investment proposal sets out the core substance of a model for comprehensively strengthening Pacific Island Countries and Territories to better anticipate, prepare for and respond to high impact and extreme weather, hydrological and oceanic events.

It is intended to provide sufficient detail such that regional organisations and development partners can meaningfully consider the merits of such an investment. Critical to this is the funding model for the investment program.

Given the scale and nature of the proposed investment, there are a variety of conceivable funding models for this program:

- Single bilateral donor
- Joint donor arrangement
- Multilateral development partner

While the eventual funding arrangements will fundamentally shape the more detailed implementation arrangements, this final stage of program design should ensure that the core objective of fostering improved consistency and coherence is retained. Fragmentation of investment (for example, different partners supplying equipment) and a 'carving out' of the five investment areas to different responsible partners is strongly discouraged. All five areas of investment activity are interdependent and single 'system' level accountability is strongly recommended under whatever funding model is progressed.

For the joint or multi-lateral funding model there are examples of how this can be implemented. In the Pacific, national commitments to the Paris Agreement through Nationally Determined Contributions (or NDCs). All donor funding is channelled to a central agency with which the donors sign financing agreements, that may include specific areas for support or conditions. Through this basket of funds, separate financing agreements are established with the recipient partner agencies and disbursed to these partners. This is the arrangement of the Pacific NDC Hub (Figure 4.2) and a similar approach could be adopted for the Weather Ready Pacific Program. For the Weather Ready Pacific Program, the Hub Implementation Unit would in effect be the Management and Advisor Team located with the PMDP and the Coordination Group would be facilitated by the PMC/PMDP.

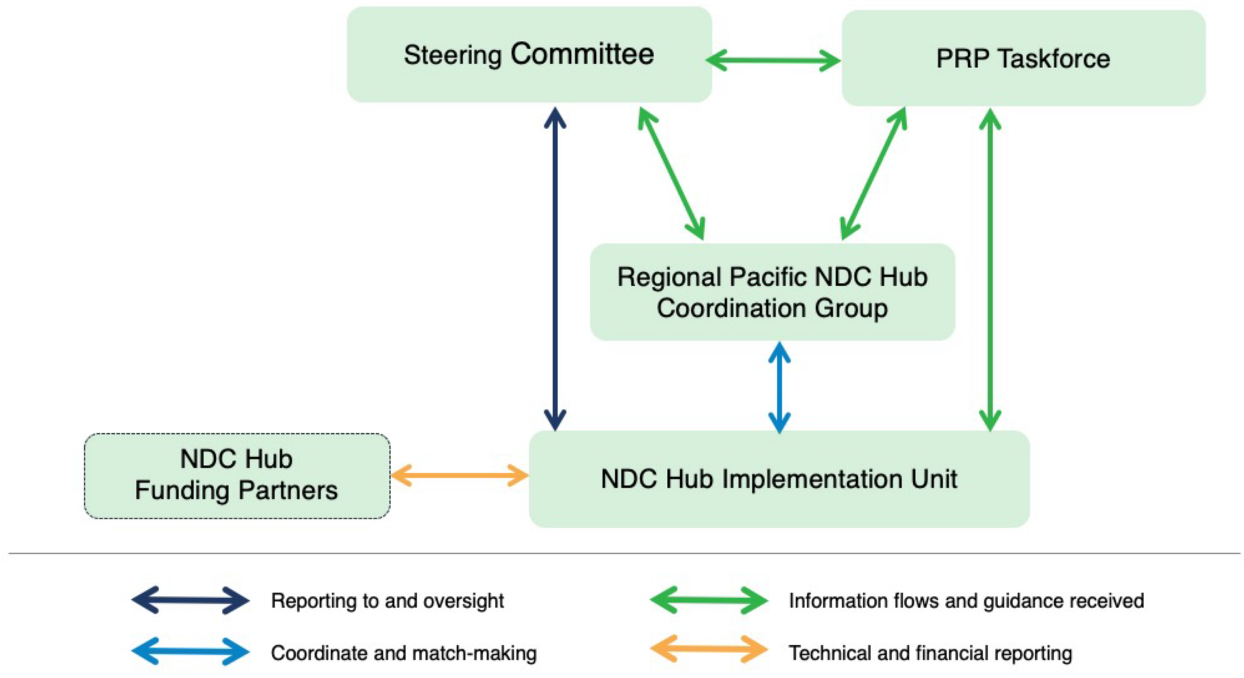

Figure 4.2: Governance and coordination arrangements for the Pacific NDC Hub.

Pending the identification of funding arrangements organisation, certain implementation and operational arrangements will need to be developed and/or finalised. These include:

- Program governance and reporting mechanisms;
- A monitoring and evaluation framework;
- Detailed workplan(s) in three-year cycles (aligned with program governance and reporting approach);
- Full costings incorporating the funding organisation's preferred program management and implementation arrangements. As indicated in Section 3.2.6, this investment plan does not include these overarching donor management and governance costs.

The formulation of work programs to implement the concept will also logically reflect the regional and international processes that are in place, such as a range of WMO initiatives (e.g. SWFP, GBON, SOFF), the Framework for Resilient Development in the Pacific (FRDP) and associated Pacific Resilience Partnership (PRP) Taskforce, PMC strategies, Paris Agreement processes and the overall contribution to long term regional resilience.

Certain aspects of implementation will require the consideration and decision by the PMC and WMO. For example:

- Allocation of responsibilities across Fiji, Wellington, and Darwin RSMCs, in particular responsibility for 24x7 servicing of the proposed Pacific Weather Exchange;
- Preferred approach to developing the Pacific Weather Exchange idea – further evolve MetConnect or establish an entirely new mechanism?
- High-level program governance arrangements – national-level vs regional-level program decisions.

All these considerations highlight that this Decadal Program of Investment is just one step on the pathway to strengthened NMHSs and regional coordination that delivers benefits to communities and industries across the Pacific. However, it is an important step and garnering support for the Weather Ready Pacific concept across the Pacific region should be the immediate goal.