Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production

A roadmap of actions

November 2019

Ministry of Disaster Management & Meteorological Services' Department of Meteorology in partnership with the Ministry of Economy's Climate Change and International Cooperation Division

This report is a joint initiative of the Fijian Ministry of Disaster Management & Meteorological Services' Department of Meteorology, the Fijian Ministry of Economy's Climate Change and International Cooperation Division, the NAP Global Network and the Finnish Meteorological Institute (FMI).

About the NAP Global Network

The NAP Global Network was created in 2014 to support developing countries in advancing their NAP processes, and help accelerate adaptation efforts around the world. To achieve this, the Network facilitates sustained South-South peer learning and exchange, supports national-level action on NAP development and implementation, and enhances bilateral support for adaptation and climate-sensitive sectors through donor coordination. The Network's members include participants from more than 135 countries involved in developing and implementing National Adaptation Plans, as well as 11 donor members. Financial support for the Network has been provided by Austria, Canada, Germany and the United States. The Secretariat is hosted by the International Institute for Sustainable Development (IISD). For more information, visit www.napglobalnetwork.org

Fiji's Hydrometeorological Observation Equipment Maintenance and Service Production was developed through the United States In-Country National Adaptation Plan (NAP) Support Program in Fiji, which is implemented by IISD. Any opinions stated herein are those of the author(s) and do not necessarily reflect the policies or opinions of the NAP Global Network, its funders or Network participants.

About the Finnish Meteorological Institute

The Finnish Meteorological Institute (FMI) is the National Meteorological Service of Finland, a research institution and service agency under the Finnish Ministry of Transport and Communications. The FMI was founded in 1838 in Helsinki, Finland and the current specialised fields are weather, climate, air quality, marine research, space physics and geomagnetism. The main objective of the FMI is to provide the best possible information about the atmosphere above and around Finland, to ensure public safety relating to atmospheric and airborne hazards and to satisfy requirements for specialized meteorological products. In addition to public and commercial weather services, FMI participates each year in more than 100 international research and consultancy projects and FMI has experience on technical cooperation projects in about 100 countries around the world.

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NAP Global Network

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Abbreviations

AWS	Automatic Weather Station
AWOS	Automated Weather Observing System
BoM	Australian Bureau of Meteorology
CLiDE	Climate Data for the Environment
ECMWF	European Centre for Medium-Range Weather Forecasts
EFL	Energy Fiji Limited
ENSO	El Niño Southern Oscillation
FINPAC	Finnish Pacific Project
GTS	The Global Telecommunication System of the World Meteorological Organization
ICAO	International Civil Aviation Organization
NIWA	New Zealand National Institute of Water and Atmospheric Research
NMHSs	National Meteorological and Hydrological Services
NOAA	U.S. National Oceanographic and Atmospheric Administration
NWFC	National Weather Forecasting Centre
NWP	Numerical Weather Prediction
ODA	Official Development Assistance
TC	Tropical Cyclone
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UKMO	United Kingdom Meteorological Office
WAF	Water Authority of Fiji
WMO	World Meteorological Organization

1.0 Introduction

Assuring the production of—and public access to—reliable, up-to-date and understandable weather and climate information, as well as factoring in the impact of climate change, is crucial for societies around the world. Without adequately maintaining and improving its system of hydrometeorological monitoring, the Fiji Meteorological Service (FMS) will be unable to do the following: provide timely warnings of climate hazards and disaster risks; reliably predict water discharges for water resource management; provide support to other sectors; and effectively manage weather-, water- and climate-related risk assessments. It is important to strengthen information and communication technology infrastructure and systems that provide weather, climate and hydrological data. In addition, enhancing observation networks could improve all FMS services. Ultimately the FMS should have a system to meet the needs and demands of the government and the public.

This document is intended to provide the FMS with a roadmap of actions for sustainable development of the organization and sustainable utilization of the overall infrastructure, including the major steps or milestones needed to reach it. The focus is on FMS's internal organization and management observation networks and equipment, as well as forecast production tools and service provision. This document first offers an analysis of the current situation and related gaps and then provides a list of priority actions to be taken with some guidelines on how to implement them.

FMS should then have a clear view of the gaps and necessary actions covering all operational aspects from organization to management. The major action items are also prioritized to aid decision making and planning of future activities.

The gap analysis and the roadmap were developed to reflect guidance from the World Meteorological Organization (WMO) and other relevant international sources (see References) as well as best practices in use at the Finnish Meteorological Institute (FMI) and other institutes in developed countries.

The analysis is based on a review of the literature and expert field missions to FMS conducted by FMI in June and September 2019. The missions included direct observation as well as meetings and discussions with several experts from the FMS and additional relevant stakeholders.

The major part of the analysis was conducted during the first missions by FMI experts in June 2019. During the second mission in September, a validation meeting was held in Suva, FMS Laucala Bay office. A total of 16 stakeholder representatives were consulted during the field missions from the following organizations: Civil Aviation Authority of Fiji (CAAF); Fiji Airports Limited; National Disaster Management Unit of the Ministry of Rural and Maritime Development and National Disaster Management; Ministry of Economy; Ministry of Agriculture; Fiji Roads Authority and Energy Fiji Limited.

1.1 Global Context, Best Practices and Alignment With Existing Strategic Documents at the National and International Levels

The increasing gap between developed and developing countries has also been evident in hydrometeorological services in the past decade—it has been estimated that USD 1.5 billion to USD 2 billion is needed globally for high-priority modernization activities to close the gap (Rogers & Tsirkunov, 2013). This need is relatively widely recognized, which has led to increased funding availability for hydrometeorological development projects from many different sources, from development banks to national authorities using Official Development Assistance (ODA) funding (official development assistance). To make funding utilization more efficient and improve operational service provision, in 2019, the World Bank published the guide *Weathering the Change – How to Improve Hydromet Services in Developing Countries?* (Rogers et al., 2019). It provides the most current approach to development activities adopted by the global hydrometeorological community, and its guidelines should be taken into consideration when developing the FMS infrastructure and services. It is also important that future development plans align with Fiji's existing development plans and strategies. The following section summarizes and provides information on the most important existing development plans at the national and international levels. This documentation influenced the development of this roadmap.

The World Bank's guide *Weathering the Change – How to Improve Hydromet Services in Developing Countries?* supports World Bank task teams and development practitioners (and the NMHSs) to support the development activities and projects that seek to improve NHMS capacity. The document gives comprehensive background information on general development needs and activities, guidelines and framework for development: it also proposes approaches and solutions. The end of the chapter is a summary taken mostly directly from the document. Providing meteorological and hydrological services is complex. The main purpose of meteorological and hydrological services is to enable the public and economic sectors to make appropriate decisions when faced with weather, climate and hydrological hazards. Regardless of the level of development, the NMHS (National Meteorological and Hydrological Services) and its partners need to be able to:

- Make meteorological and hydrological observations.
- Combine this information with products generated by the WMO community—generally in the form of gridded numerical products, which assimilate observations from everywhere into numerical weather prediction systems.
- Make accurate and timely forecasts and warnings relevant to their national users.
- Disseminate this information, using diverse means to match different sectors of society. This information must be customized and useful to the users to support appropriate behaviours, especially during extreme weather events.

In general, when developing the capacity of the meteorological institutes too much emphasis is placed on buying observation equipment and not enough on the delivery of services using the "best available" information. Information and communication technology (ICT) and infrastructure are central to a modern NMHS. ICT is the means by which all data is managed, and products and services generated. It is impossible to overstate the critical importance of a central system for data management and the need for data policies that requires compliance from all suppliers of equipment—especially observing systems. Compliance with data standards (and governance of these standards by the NMHS) ensuring local, regional and international interoperability should be prioritized. Investments must also be sustainable. Many development projects focus on meeting NMHS demands for more observations and observation equipment; however, sustaining this capability is difficult, and the benefit of the investment often short-lived. Convincing governments to follow initial funding of new equipment with investment to sustain their public services is a challenge—one for which there is no easy remedy. Convincing development partners to donate equipment without having assurances that the resources exist to maintain that equipment is equally challenging.

Meteorological and hydrological services can be considered a "system of systems" that can be grouped into three categories: delivery systems, production systems and support systems. This is often referred to as the value chain of meteorological and hydrological services, which links the production and delivery of services to user decisions and the outcomes and values resulting from those decisions. These are underpinned by support systems.

1.1.1 Service Delivery

Given that NMHSs must compete for scarce public resources, they need to demonstrate their value by realizing cost efficiencies while delivering high-quality and useful products and services (WMO, 2014). Policy-makers and the public continually assess the effectiveness of NMHSs based on their ability to meet the service delivery standards of the nations they serve. Even the best forecast, issued on time, will have little effect if it does not generate the desired response from those at risk. This means that the utility of weather-, climate-, water-, and environment-related information depends on the degree to which it has a beneficial effect on development outcomes (WMO, 2015a). When available information is underutilized, value can be increased by improving the forecast, enhancing communication and refining the decision-making process. Thus, **effective service delivery is about providing products and services that bring utility to users.** It is essential to understand the users' value chain[1] in order to gain knowledge about them, the decisions they must make, and how weather-, climate-, water- and environment-related information is applied to minimize risks and provide benefits, not only for specific user groups but also for a nation as a whole. With this knowledge, service providers can develop, produce and deliver services that are useful, relevant and responsive. NMHSs should be able to measure the value of their information to society and continually evaluate and improve these services. Adopting a more collaborative approach provides everyone in the service delivery process—providers, users and partners—with a clear understanding of service needs.

1.1.2 Approaching Modernization and Development Activities

A systematic approach to modernization and development is recommended. The preparation of complex projects requires considerable effort, and it is useful to adhere to some basic practices—road mapping, business planning and modelling and strategic planning. Tools such as the development of a "concept of operations" provide the means of developing consensus among stakeholders so that there are both a common understanding and support for the proposed operational system. The rigour imposed allows the NMHS and stakeholders to understand the implications of any change in the current system—which may provide new capabilities but also increase operating costs, in turn affecting the overall sustainability of the

[1] Understanding of value chain refers to understanding the overall process of the user or customer. For example, in the case of a service provider, this includes understanding the production process of the service and identifying the opportunities and needs for weather-related data or services to add value to the original service.

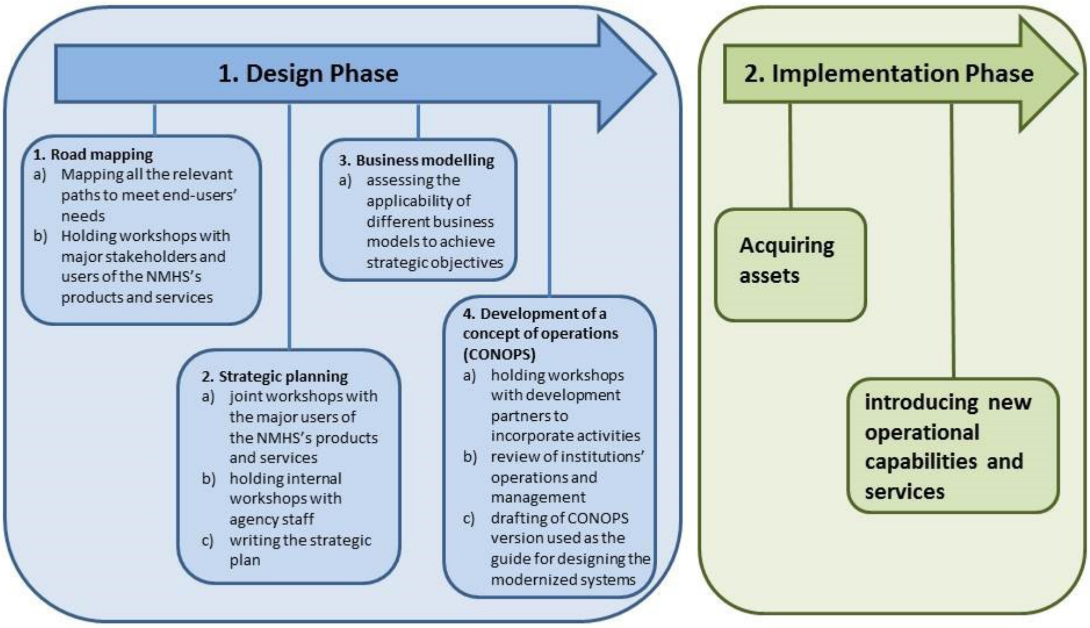
organization. In addition, changes expected in the Global Weather Enterprise (GWE) should be taken into account when designing and planning for the future. According to the Thorpe and Rogers (2018), the GWE needs should grow substantially in the future with better and more frequent dialogue and co-designed initiatives between the various actors in the public, private and academic sectors. Here, a key element will be continuing improvement in the NMHSs—which form the public backbone of the GWE—as well as more private sector investment. A failure to manage these changes to the GWE may have detrimental consequences, as competition between the public and private sectors instead of mutual cooperation could become the norm.

Generally, it is preferable to develop any modernization projects or activities in two phases:

1. Design phase, which focuses on service delivery, strategic planning, business modelling, and the Concept of Operations (CONOPS).
2. Implementation phase, which focuses on acquiring assets and introducing new operational capabilities and services.

These phases (with the design phase divided into sub-phases) is represented in Figure 1.

Figure 1. Two phases of the modernization process.



Source: Author diagram based on Rogers et al., 2019.

1.1.3 The Fiji Implementation Plan for Enhanced Climate Services

The Fiji Implementation Plan for Enhanced Climate Services provides guidance to the Fijian Government on how to enhance the development and delivery of the climate services of the FMS. It addresses the priorities for both the FMS's Climate Services Division and the key climate-sensitive sectors that rely on its information and advice to inform their decision making and planning. Successful implementation of the plan will result in both the provision of timely and relevant climate information by the FMS and the sectors' engagement in co-generating products and services to build their own resilience and contribute to sustainable development.

The Fiji Implementation Plan for Climate Services will enhance FMS's capacity to support decision making in climate-sensitive sectors and drive the development and application of climate services at the national level. Its implementation will benefit from existing best practices at the regional and international levels. The purpose and objectives of the plan are as follows:

a) **Purpose**
The purpose of the Plan is to act as a guide to the Fijian Government in providing the necessary support to the FMS to a) deliver climate services for planning and decision making in key socioeconomic sectors, and b) facilitate the uptake of the services within those sectors.

b) **Objectives**
   i) Understanding by the FMS of the climate information needs of key user sectors.
   ii) Establishing strategies for addressing FMS and stakeholder capacity constraints.
   iii) Establishing effective stakeholder engagement mechanisms for tailoring information products and services.
   iv) Effective application by stakeholders of climate information in key user sectors, with special emphasis on:
      - Agriculture and food security
      - Disaster risk management
      - Energy
      - Health
      - Water resources
      - Tourism
      - Fisheries
   v) Establishing effective institutional arrangements, partnerships and processes to implement the plan.
   vi) Benefiting from existing best practices by drawing on both regional and international experience.

1.1.4 National Adaptation Plan Document

In the context of the United Nations Framework Convention on Climate Change (UNFCCC), the National Adaptation Plan (NAP) is a strategic process that enables countries to identify and address their medium- and long-term priorities for adapting to climate change (NAP Global Network, forthcoming). The ultimate objective is to reduce the country's vulnerability to the negative impacts of climate change.

Fiji's NAP process started in September 2017, and it released its first NAP document in 2018. The document identifies 160 priority adaptation measures within a five-year timeframe. These measures were identified through a review of key national policies and strategies along with stakeholder consultations.

Adaptation measures are organized according to 10 components (five themes and five sectors). "Climate information services and management" is one of the five priority themes. The NAP document explicitly calls for the enhancement of meteorological and hydrological infrastructure and technical capacity (under Action 7.01—see the NAP chapter on climate information service and management). It recommends that government: "upgrade the existing FMS infrastructure and technical capacities (e.g., early warning systems, flood forecasting, weather stations, hydrological services, telemetry system) to develop and provide access to hazard and risk information including multi-hazard early warning systems, and to monitor and provide timely and effective warning services to the public." Adaptation actions prioritized under the theme "climate information and management" from the Fiji NAP report are shown in Figure 2.

Figure 2. Adaptation actions prioritized under the theme "climate information and management" in Fiji's NAP document.

Adaptation Measures

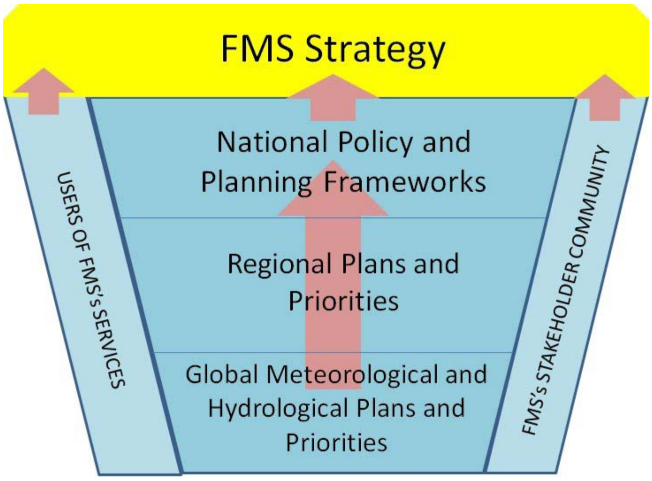
#	Action	Time Scale	Linkages
7.1	Upgrade the existing FMS infrastructure, resources, and technical capacities[52] to provide the basis for climate monitoring and projecting, user-friendly climate information services, hazard and risk information, and early warning and prediction systems to stakeholders and community groups (including disadvantaged groups).	Ongoing	NCCP, FRDP, CVA, DRRP
7.2	Promote on-going collaborative research with national, regional, and international research and academic institutions to update climate change and disaster management related data and information and to share knowledge and strategies to increase resilience.	Ongoing	NDP, GGF, NCCP
7.3	Institutionalise a mechanism to collect, integrate, and analyse hazard, vulnerability and exposure data.	Within 5 years	NDP, GGF
7.4	Collect, use, share and manage accurate data and information in user-friendly formats to inform sound risk reduction decision-making by the public and sectors by using appropriate decision-making tools and services.	Within 5 years	DRRP, FRDP
7.5	Catalogue and review all vulnerability assessments and their methodology that have been used in Fiji to date to understand differences and best practices to facilitate the development of a common methodology to be used by public and sectors (including loss and damage).	Within 5 years	NDP, GGF, NCCP
7.6	Develop and make accessible user-friendly hazard assessments, maps and models focusing on site-specific risks across coastal, riverine, urban and inland areas in Fiji, for all potential hazards (including sea level rise, storm surge, flooding, drought, salt intrusion, landslide, tsunamis etc) to guide development planning at both national and sub-national level.	Ongoing	NDP, GGF, NCCP, CVA, DRRP, FRDP
7.7	Ensure sufficient resources are made available to fully implement the Fiji Implementation Plan for Enhanced Climate Services.	Within 5 years	
7.8	Enhance meteorological prediction systems for flooding and droughts as well as a Forest Fire Watch System.	Within 5 years	DRRP
7.9	Establish a payment system for providing tailor-made meteorological, hydrological and earthquake services which are used by researchers, private sector entities, and development planners.	Within 5 years	DRRP
7.10	Establish a standardised approach to collecting information on climate change interventions to facilitate monitoring and evaluation of outcomes relative to policy targets, including the use of Data Supply and Reporting Obligation Agreements to ensure that the data and information needed to track adaptation are provided to a centralised Data Repository.	Within 5 years	NCCP

Source: Government of the Republic of Fiji, 2018.

1.1.5 The Strategic Plan of the Fiji Meteorological Service 2018–2023 (Draft)

The draft FMS Strategic Plan provides guidance to the FMS over the next five years. It takes into account the risks and opportunities from both external and internal factors affecting the organization as well as the changing needs of its clients and end users, the impacts of climate change, and scientific and technological advances (FMS, forthcoming).

Figure 3. Environmental influences on the FMS planning process.



Source: FMS, forthcoming.

1.1.6 The WMO Strategy for Service Delivery and Its Implementation Plan

The WMO Strategy for Service Delivery (WMO, 2014) provides development practitioners—and, more importantly, the NHMSs—guidance in strategic planning and development of the service delivery process, which ultimately should strengthen the status of the NHMSs as national service providers. Moreover, according to the document: "The Strategy explains the importance of service delivery; defines the four stages of a continuous, cyclic process for developing and delivering services and the elements necessary for moving toward a more service-oriented culture; and describes practices to strengthen service delivery across the entire WMO."

PART 1:

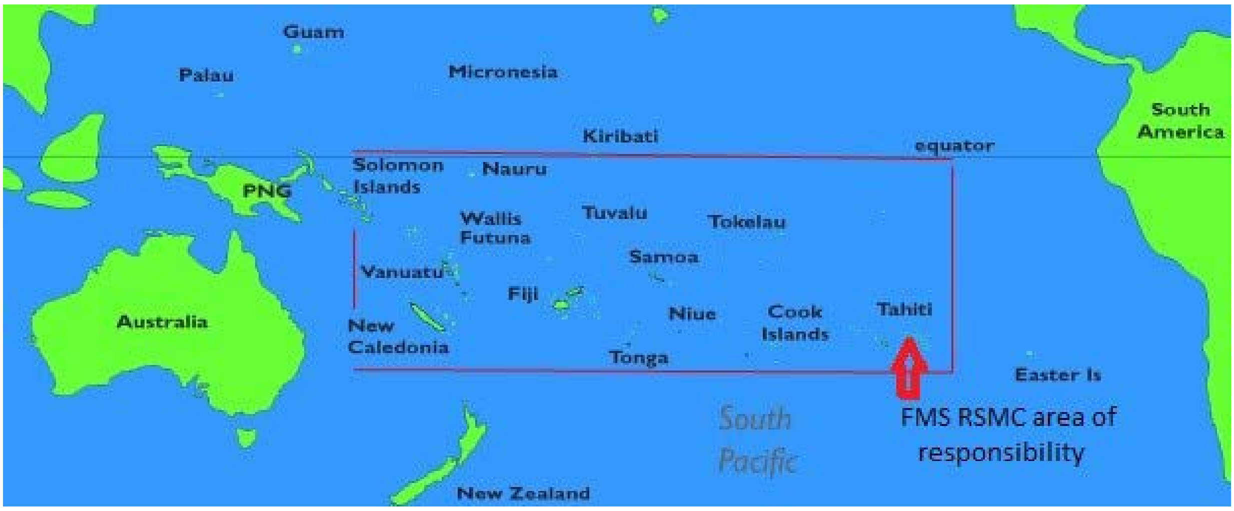
Gaps and Needs Assessment

2.0 Current Situation and Gaps in the Management and Organization of the Hydrometeorological Service in Fiji

The FMS is a recently established department under the Ministry of Disaster Management and Meteorological Service. The current Ministry for Fiji Meteorological Service lacks its own minister, and currently works under the umbrella of the Ministry for Infrastructure and Transport. At the time of this analysis, an act on Hydrometeorological services is missing; however, it is being prepared.

In addition to FMS's role as a national hydrometeorological service, the central weather office in Nadi is one of the six Regional Specialized Meteorological Centers (RSMC) within the World Weather Watch program of the WMO. The Nadi RSMC is responsible for forecasting tropical cyclones south of the equator to the 25th parallel south, and between the 160th meridian east and 120th meridian west longitude. The RSMC-Nadi-Tropical Cyclone Centre was officially designated by WMO and tasked with providing information on tropical cyclones in the South-West Pacific Ocean, such as present and forecast position, movement and intensity. It is the official source of reliable first-hand information on tropical cyclones in the South-West Pacific Ocean, and its development activities should thus be considered a high priority regionally.

Figure 4. FMS RSMC area of responsibility (the area enclosed by the light red rectangle).



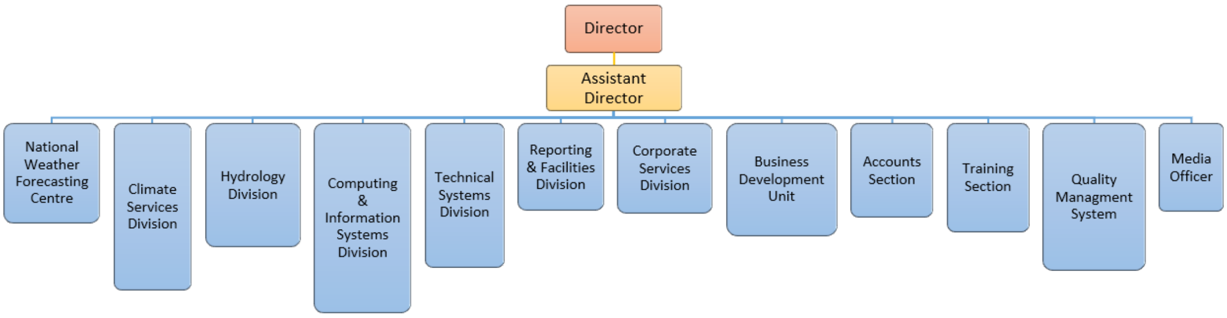
Source: FMS, forthcoming.

FMS's vision, mission, objectives and values are formalized and well defined: they do not require urgent action. These can be found in detail from the web pages of the FMS: http://www.met.gov.fj/index.php?page=about_us

2.1 Staffing

As of June 2019, the FMS has a total of 179 positions, 34 of which are vacant. Under the Director's leadership, there are 12 divisions/ sections with the principal or senior officers in charge. Figure 5 shows the FMS organizational structure. It must be noted that the scale of the items or boxes in the following figure does not represent their actual size or staff resources.

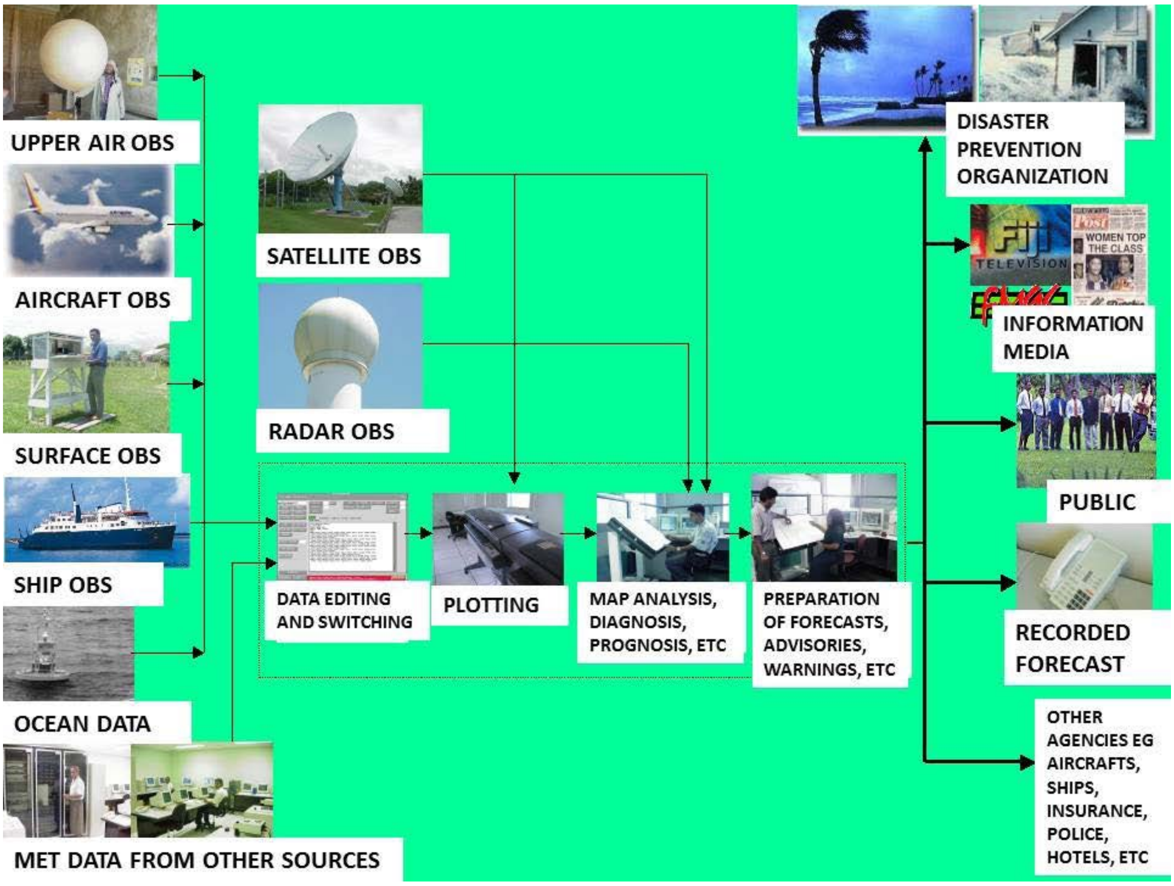
Figure 5. Organization of FMS.



Source: FMS, 2018.

The three output divisions—the Forecasting Centre, Hydrology Division and Climate Services Division—produce outputs and services catering to a wide range of users from government, NGOs, public and private sector agencies, and the public, at both local and international levels (see Figure 6). These are also the largest divisions by staffing (National Weather Forecasting Centre [NWFC] 40 persons, Climate Services 24, Hydrology 13). At the time of this analysis, the FMS does not do any (constant and operative) scientific research activities, and dedicated research departments or units are inexistent. Based on the detailed organizational diagram (not shown here), customer liaison and financial operations related to services are fragmented between different sections. **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 modernization activities.** For example, at FMI in 2019, overall staffing is approximately 650 persons, and the overall staffing of different IT units is approximately 100.

Figure 6. FMS activity and service provision flow chart. Service provision starts from the left-hand side with different observations and forecasting models that are modified with different methods and operations (centre) to different products (on right).



Source: FMS internal documentation.

Staff consultations conducted in June 2019 as part of this analysis revealed that staff are generally devoted to their jobs and see their work as very important to the community. However, due to the low salaries of academic experts, the branch is not seen as being very attractive for young people.

Most staff members are technicians or professionals with lower-level academic degrees (BSc), while the number of staff with higher academic education (MSc., PhD) and the number of qualified ICT staff is very low. **The educational levels of the staff and the number of specialized technical people do not meet current demands.** This is especially true considering the requirements associated with the upcoming implementation of automated data collection and production systems, along with improved forecasting systems and increased cooperation with economic sectors.

2.2 Quality Management System

The Fiji Meteorological Service has a functional quality management system, and both the Climate and Aviation services are ISO certified. No certificate exists for other departments or divisions. The current level of the quality management system is adequate and compliant with (for example) International Civil Aviation Organization (ICAO) standards: it does not need urgent actions for development. Obtaining and maintaining a quality management system certificate is demanding and costly, and therefore certification of other operations or units of FMS is not necessary.

2.3 Strategic Planning

The strategic planning process and strategy documents (such as the strategic plan and its monitoring and evaluation documentation) are cornerstones of any institute, including FMS—they form the backbone of effective development and operations. The FMS has its strategic planning process well underway; however, **the process and associated documentation are not completely finished and operational at the time of this analysis.** Typically, strategic planning is done for a few years ahead (for example at FMI the timeframe is five years). However, strategic planning should also take into consideration the future over greater time scales (e.g., 10 or 25 years) in order to meet future challenges over the longer term. Typically, longer-term plans reflect broader and larger-scale changes in both society and the overall operational environment.

Presently, the main function of meteorological services is the production of services to meet the needs of stakeholders and customers. Typically, this is reflected in a strategic plan document and a business plan. As of September 2019, the FMS's strategic plan document is being prepared (and is nearly finished), but its **business plan is still missing**. The work had been started in collaboration with a consultant from the Australian Bureau of Meteorology (BoM) but appears to be stalled since 2017.

2.4 Capacity Building and Staff Training

The FMS has well-documented staff training records that indicate staff is trained on a regular basis. Due to its role as an RSMC in the South Pacific region, FMS also provides trainings for participants and experts from neighbouring countries. For example, the Basic Instruction Package for Meteorological (Observation) Technicians (BIP-MT) (WMO, 2015b) is organized based on needs, typically once a year or every two years. especially when new staff is hired in FMS. Forecasters are also provided with trainings by overseas experts (from the BoM and the Meteorological Service of New Zealand) on topics such as: tropical cyclone analysis, storm surges, numerical weather prediction, radar, satellites and aviation weather forecasting.

Some of the training and education is funded by FMS, but most of it relies on external funding by, for example, WMO, Japan International Cooperation Agency (JICA) or United Nations Development Programme (UNDP). This makes the situation unsustainable.

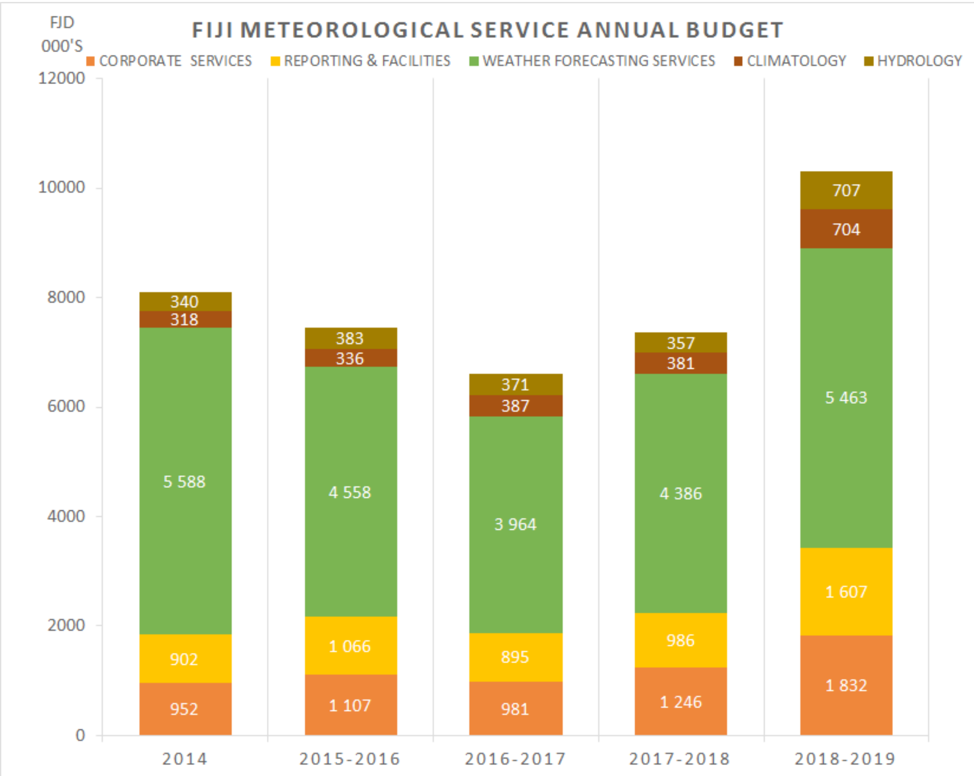
The FMS also provides meteorological training for different sectors in Fiji, such as air traffic controllers, special courses for cabin crews and marine weather training for mariners. These trainings are delivered free without a cost recovery or revenue as a part of their mandate.

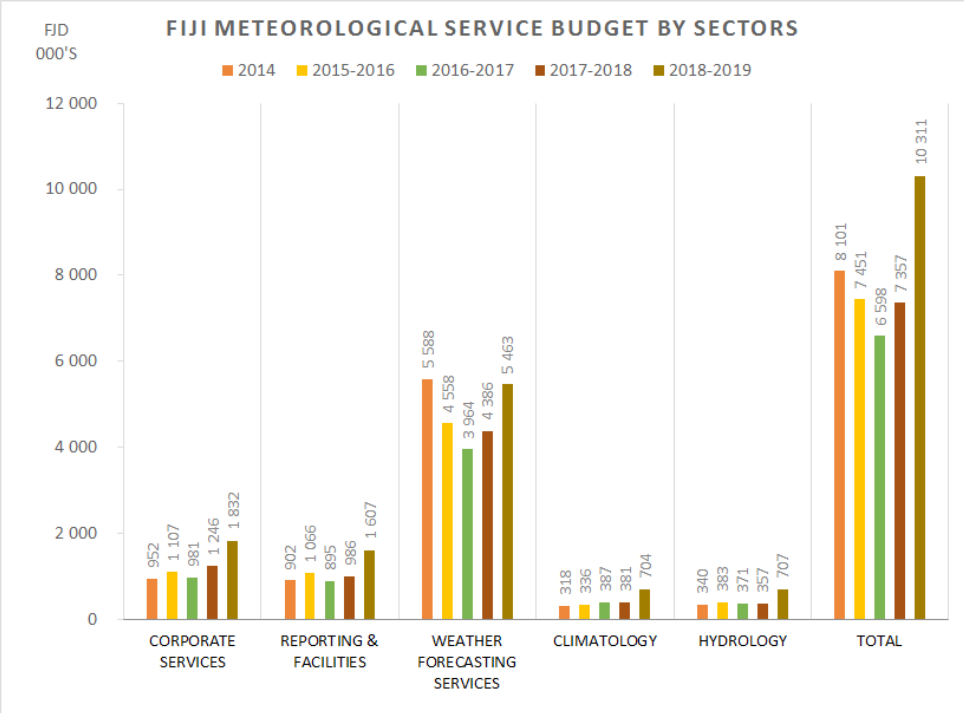
2.5 Financial Analysis

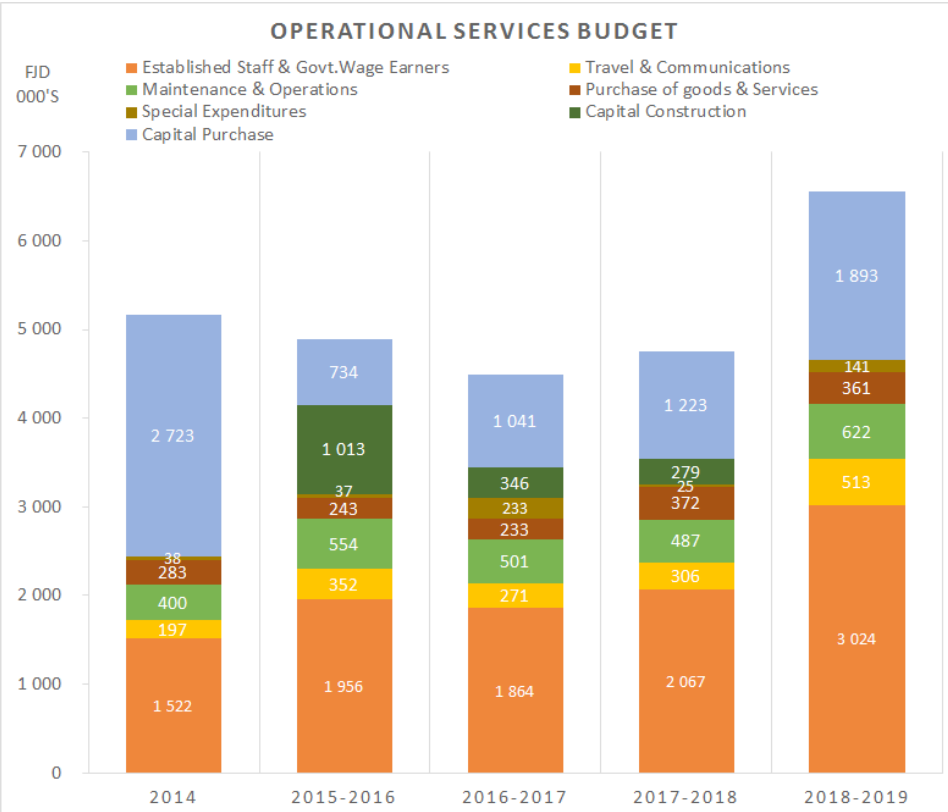
A rapid financial analysis was made based on a review of the FMS's bookkeeping records from the past five years made available during the field mission conducted in June 2019: the results are shown in Figure 7. The years 2014–2018 are based on actual expenditures, and fiscal year 2018–2019 is based on the revenue estimate.

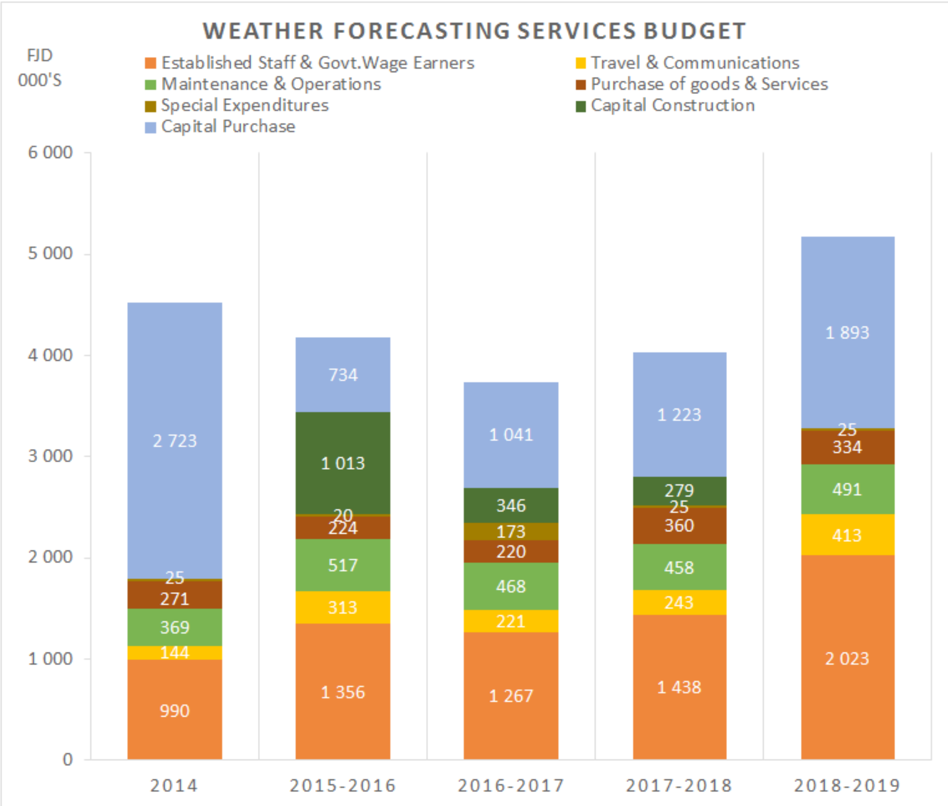
The analysis indicates that FMS's overall budget decreased between 2014 and 2016 and then started to increase. Over the past five years, the Weather Forecasting Services received more funding compared to other services/units, while the Reporting facilities and Corporate Services received the least funding, which may be an indicator of undeveloped customer liaison activities. The relatively small portion of funding allocated to Climatology and Hydrology indicates that these services may be underbudgeted, although for the fiscal year 2018–2019 their budget has almost doubled. The major increment in the budget for the last two years seems to be mainly due to increased staff salary costs and capital purchase, which indicates that FMS is expanding its staff resources and investing in new infrastructure. **Interestingly, weather services revenue from the civil aviation (FJD 600 000 per annum from Fiji Airports ltd.) represents only 11 per cent of the Weather Forecasting Service budget and about 5.6 per cent of the overall FMS budget. This is a relatively low percentage, especially considering that the forecast production of FMS concentrates heavily on aviation sector services.** For example, according to FMI aviation weather service provision experts, it is estimated that in Europe the ratio between recovered costs and whole institute budget is typically around 10 per cent—and it must be noted that developed country institutes are also running operations unrelated to aviation weather services (such as research activities).

Figure 7. Annual budget of the FMS 2014-2019 by different sectors. From top to down: Total budget of FMS, total budget of FMS by sectors, total budget of operational Services (Weather Forecasting Services, Climatology, Hydrology) and total budget of Weather Forecasting Services by cost item.




FIJI METEOROLOGICAL SERVICE BUDGET BY SECTORS
FJD 000'S
2014
2015-2016
2016-2017
2017-2018
2018-2019
12 000
10 000
8 000
6 000
4 000
2 000
0
952
1 107
981
1 246
1 832
902
1 066
895
986
1 607
5 588
4 558
3 964
4 386
5 463
318
336
387
381
704
340
383
371
357
707
8 101
7 451
6 598
7 357
10 311
CORPORATE SERVICES
REPORTING & FACILITIES
WEATHER FORECASTING SERVICES
CLIMATOLOGY
HYDROLOGY
TOTAL


OPERATIONAL SERVICES BUDGET
FJD 000'S
Established Staff & Govt.Wage Earners
Travel & Communications
Maintenance & Operations
Purchase of goods & Services
Special Expenditures
Capital Construction
Capital Purchase
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
2 723
38
283
400
197
1 522
734
1 013
37
243
554
352
1 956
1 041
346
233
233
501
271
1 864
1 223
279
25
372
487
306
2 067
1 893
141
361
622
513
3 024
2014
2015-2016
2016-2017
2017-2018
2018-2019



Source: Author diagrams based on data from FMS bookkeeping documents.

2.6 Cost-Recovery Mechanism for Aviation Weather Services

At the time of this analysis, there are no cost-recovery mechanisms in place in the FMS in any services or products they provide. Typically, the biggest single source of income for any meteorological service in developed or developing countries is the aviation weather services, which also holds true for FMI. **Currently Fiji Airports Limited disburses a fixed rate of FJD 50,000 to the FMS per month from the aviation weather services: this situation is unsustainable and contrary to ICAO and WMO guidance for cost-recovery mechanisms.** The financial analysis strongly indicates that producing all the services for aviation and maintaining a relevant observation environment (for the aviation services) cannot be done with the current fixed rate from Fiji Airports Limited. A service-level agreement (SLA) between FMS and Fiji Airports Limited is currently under preparation, and it is essential that it include a cost-recovery mechanism.

FMS also provides services (described in more detailed later) for some neighbouring countries' airports. However, **the contractual arrangement for service provision is unclear to the authors of this report because FMS could not provide any documentation or information concerning these international services. This is an extremely unsustainable—and even dangerous—situation.** For one thing, it does not enable the establishment of a cost-recovery mechanism for these international services. Moreover, the question of accountability is unclear in the event of accident (e.g., who is responsible if a plane crashes due to false weather forecast information in Tonga where FMS is providing the aviation forecast services?). It is critical to have formalized agreements in place regionally for the services provided by FMS. The first step could be a signing of memorandums of understanding (MoUs) at the meeting of the Pacific Meteorological Council between FMS and international meteorological institutes or countries to whom the services are provided. A second step would be the development of single SLAs between FMS and the countries in the region concerning different products. For example, in the Northern Europe Aviation Meteorology Consortium (Namcon[2]) duties and responsibilities are defined in such a way through an SLA.

2.7 Summary of the Biggest Identified Gaps in Management and Organization

The following table summarizes the biggest gaps found at the management level and organization of the FMS. Each gap has been evaluated according to its level of criticality (low = green, middle = yellow, high = red) to help identify which gaps are most urgent to fill.

Table 1. Biggest gaps found at the management level and organization of the FMS.

Gaps in the FMS observation network	Criticality
Aviation weather service cost-recovery mechanism is missing	**High**
Strategic planning incomplete	**High**
International agreements on the aviation weather services are missing	**High**
Staff training and qualification inadequate	**Middle – High**
Inadequate training of hydrological staff	**Middle – high**
Customer liaison fragmented	**Middle**
Staff training mainly funded by external donors etc.	**Middle**
Business plan incomplete	**Middle**
Research activities missing	**Low**

[2] http://www.namcon.aero/

3.0 Current Situation and Gaps in FMS' Observation Network

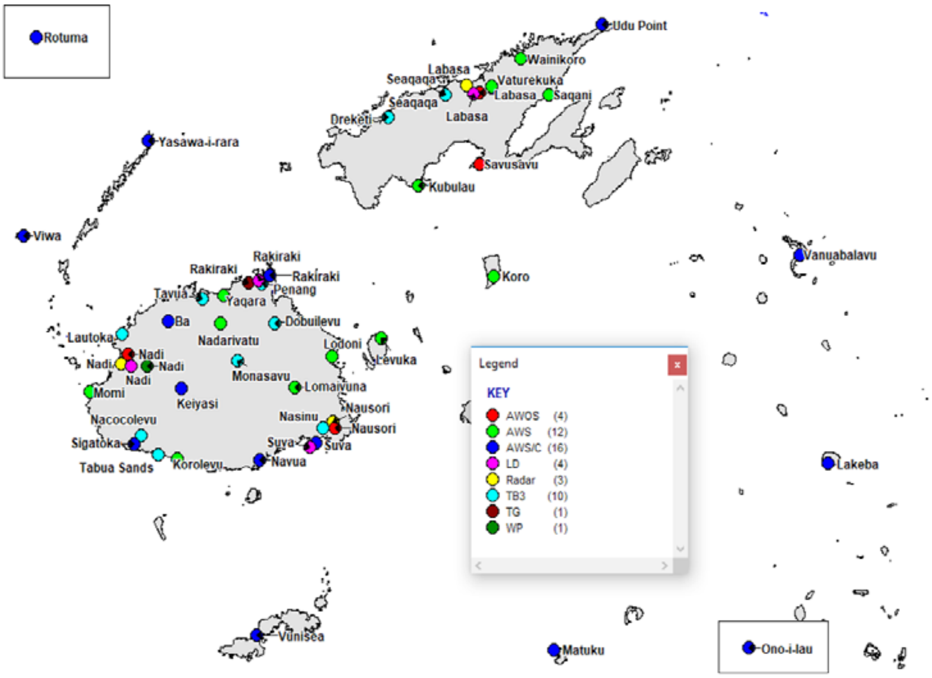
3.1 Meteorological Surface Observation Network

Fiji's observation stations are mainly manual, and the number of automatic standalone stations is low based on national needs. The number of manned stations remains quite high since the salary level of observers is extremely low compared to the cost of state-of-the-art automatic stations. Crewed stations may not provide high-frequency data, but they are needed in modern observation networks to support operations in case of emergency or to ensure the quality of observations. That said, the scalability of an automated network is much better than a manual network. The automated network can be complemented with human observers (e.g., trained citizen scientists rather than professional observers). In general, the strategy needs to move toward the implementation of automatic online hydrological and meteorological stations and active remote sensing. Based on the analysis of the Global Telecommunications System (GTS), the number of stations that send data for global and regional use through the GTS system is quite low and has a very low percentage of delivery, as well as poor quality. Only selected station data is shared, and only at 3-hour intervals. **This is a problem at the international level: other NHMS, therefore, lack important information on the surrounding areas and, even more importantly, the weather forecast models do not receive important data for their analysis conditions.** This is even more critical in the Pacific Ocean due to the very low proportion of land areas and sparse observation networks. Through GTS, FMS has access to the following international datasets: SYNOP, TEMP, CLIMAT and CLIMAT-TEMP data.

At the time of this analysis, FMS is slowly upgrading and modernizing its observation network and equipment while trying to apply new technologies. However, these activities tend to be done randomly, and they typically depend on external funding or donors. More coordination is needed to meet user requirements in terms of the accuracy and reliability of the products and information.

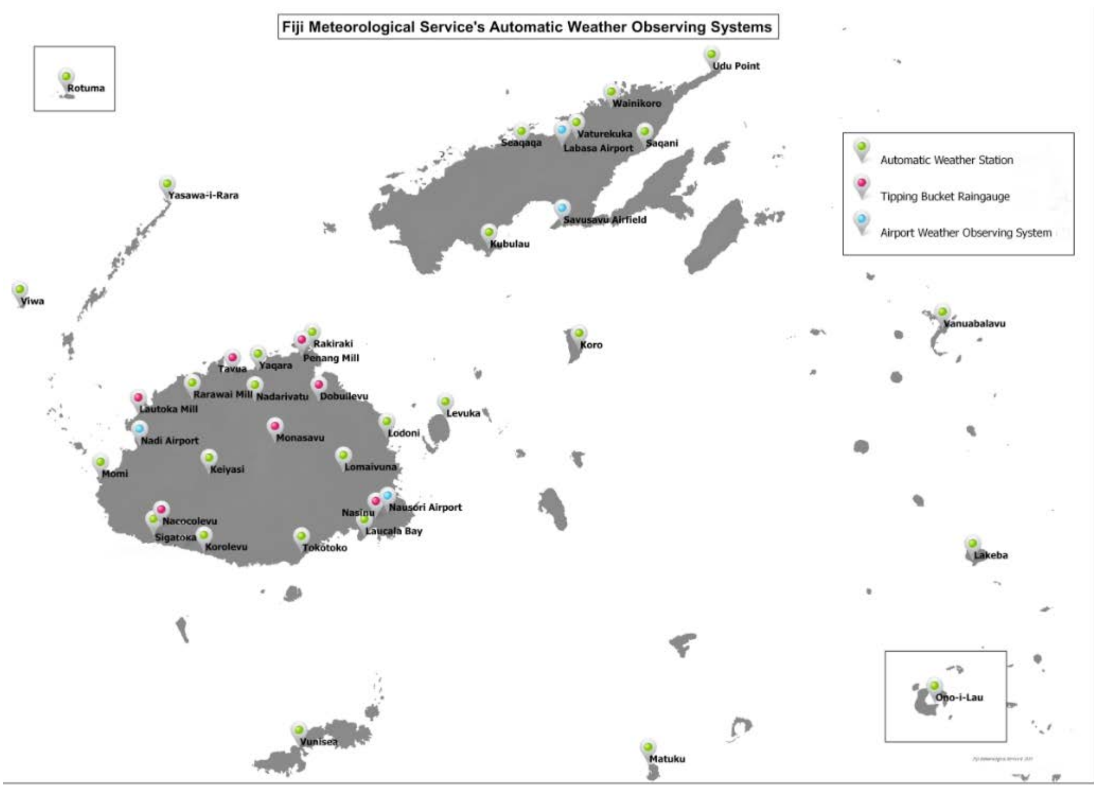
As of September 2019, the FMS meteorological observation network consists of 32 automatic weather stations (AWSs) and 34 manual stations. Figures 8 and 9 map out the FMS meteorological network.

Figure 8. Map of meteorological observation equipment.



Source: FMS internal documentation.

Figure 9. Automatic weather stations.



Source: FMS internal documentation.

In Fiji 28 AWSs and 4 automated weather observing systems (AWOS) for aviation are installed from four different manufacturers: NIWA, VAISALA, SUTRON and JICA. Below is the breakdown of the stations from different suppliers:

- NIWA: 22 AWS
- SUTRON: 5 AWS
- VAISALA: 4 AWOSs
- JICA: 1 AWS

The Data loggers used in different setup are as follows:

- NIWA: Unidata Data logger
- SUTRON: SUTRON Data logger 8310
- VAISALA: QML Loggers
- JICA: KPC-200

The current situation with the observation station network is very unsustainable for FMS due to the high number of different observation station manufacturers. The sensors and stations are incompatible with each other, rendering both maintenance and data collection difficult and fragmented. For example, it is not possible to replace Sutron station instruments with Vaisala instruments, and thus the spare part pool is expensive to maintain. In addition, it increases the costs of staff technical expertise and time dealing with multiple vendors and multiple incompatible technical systems.

The parameters measured using the above AWS stations as follows:

- Wind speed and direction
- Air temperature
- Relative humidity
- Atmospheric pressure
- Rainfall
- Solar radiation
- Cloud height (only Vaisala stations located at airports)
- Visibility (only Vaisala stations located at airports)
- Earth sensors
- Grass minimum
- Soil moisture

The AWSs communicate through BGAN and Iridium satellite and GPRS Vodafone networks. Data is transmitted on the hour to the servers located at FMS HQ, located in Nadi. This data is stored in the CLiDE database. The locations of the AWSs are shown in Figure 9.

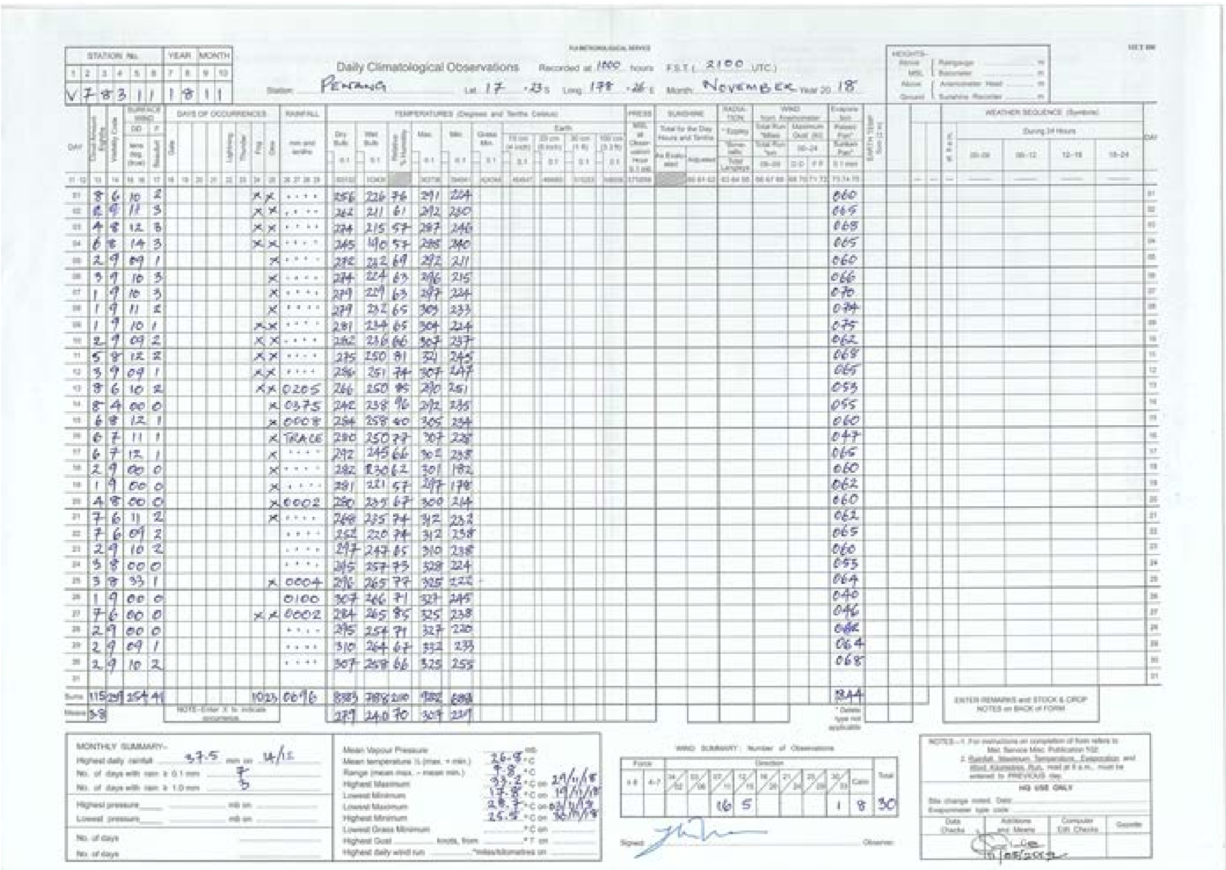
The 34 manual stations (Figure 11) observations are recorded manually in the field books, which are sent to FMS HQ at the end of each month. This data is then entered into the CLiDE database by climate division staff. Out of 34 stations, 15 are synoptic stations and 19 are climate stations that include three airports. The overall area of Fiji is 194,000 square kilometres, of which around 10 per cent is land, and the land-sea distribution sets relatively strict boundary conditions to the observation network and placing of the individual stations. Taking into account only its land area, Fiji is more densely populated with observation stations compared, for example, to Finland (land area 338,000 square kilometres and approx. 250 stations, mainly AWSs). **Thus, the issue with the observation network in Fiji is not the number of stations or the distribution between station types; mainly it is the heterogeneity of the equipment, reporting intervals and quality of the data.**

The meteorological parameters recorded by the manual stations are as follows:

- Maximum temperature
- Minimum temperature
- Dry bulb temperature
- Wet bulb temperature
- Rainfall (24-hr)
- Rate of evaporation
- Sunshine duration
- Earth temperature
- Grass minimum temperature
- Wind direction and speed

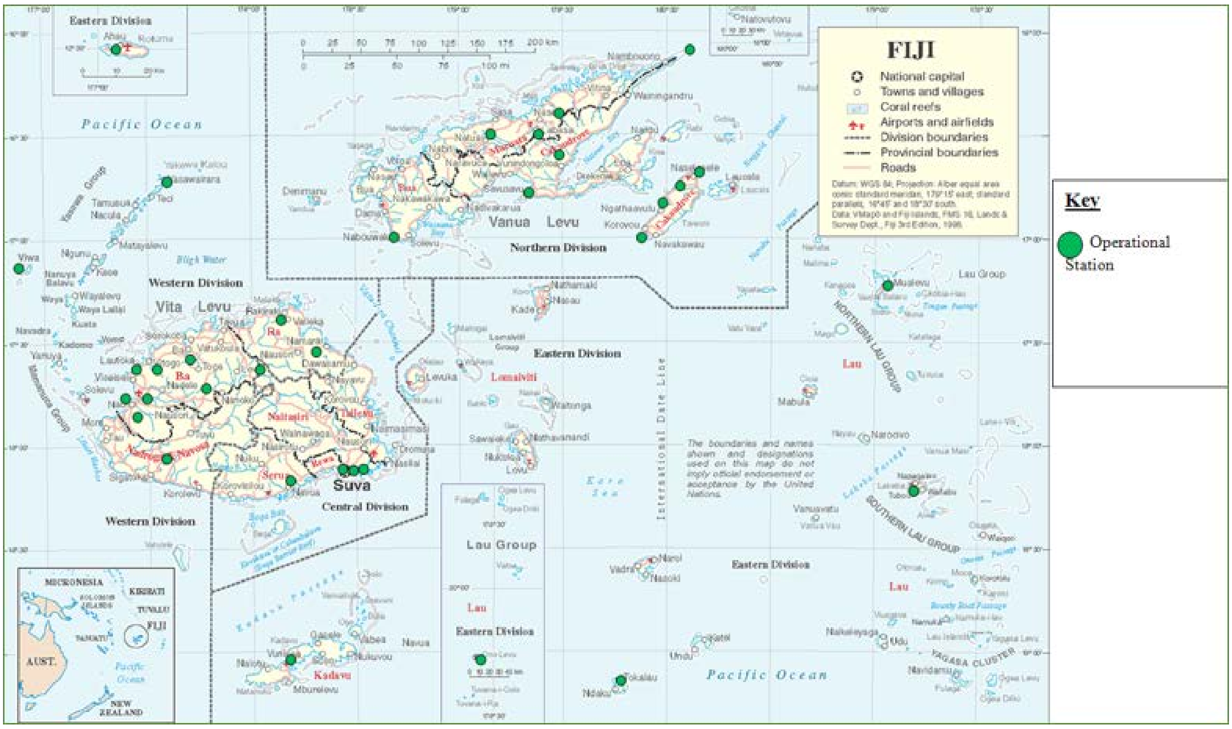
Figure 10 shows an example of a daily climatological observation report.

Figure 10. Daily climatological observation report.



Source: Authors.

Figure 11. FMS's Manual Climate and Synoptic stations.



Source: FMS internal documentation.

3.2 Hydrological Surface Observation Network

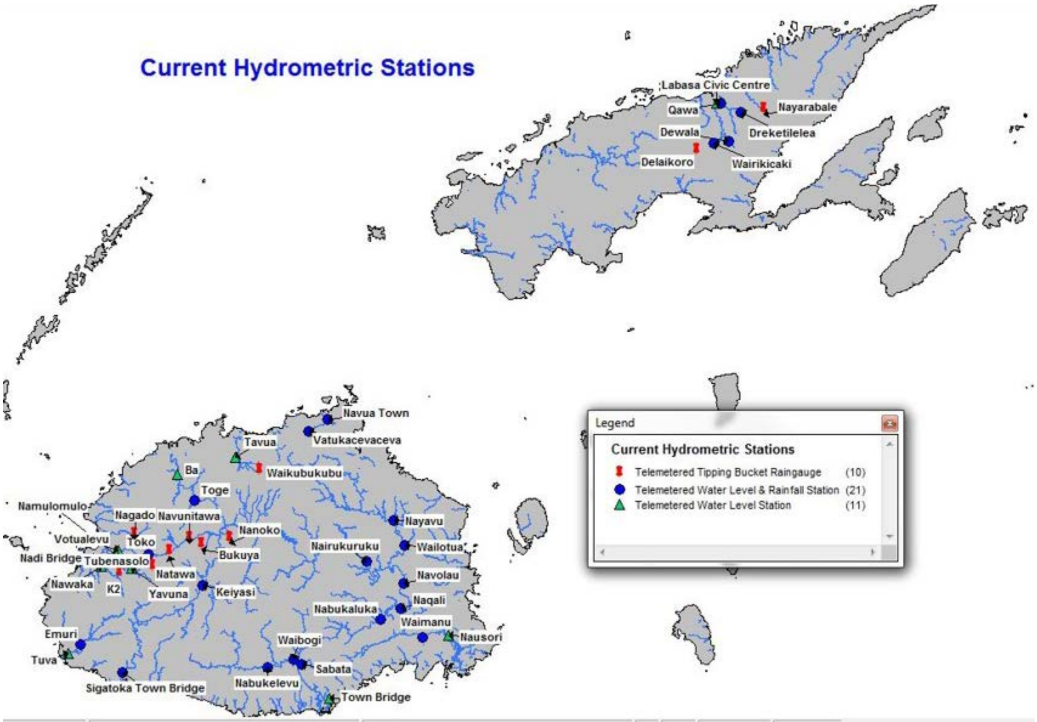
The FMS's Hydrological observation network consists of:

- **42 Telemetered stations** (see Figure 12), including:
  - 10 Rain Gauge NIWA TelemetricTB3 are reporting rainfall data in (mm)
  - 11 Water Level NIWA PumpPro 6150 are reporting water level data in (mm)
  - 21 water level and rainfall stations are reporting water level and rainfall data

  The telemetric stations communicate through the GPRS Vodafone network, and BGAN and Iridium Satellite. Every station transmits information in real time to the server located at FMS HQ. This, in turn, is linked to a server at the Water Authority of Fiji (WAF) Lautoka and a server in WAF Wailoku. Currently, the Hydrology section of WAF Lautoka utilizes the data for flood forecasting and monitoring. This data is stored in the database Tideda and Xconnect.

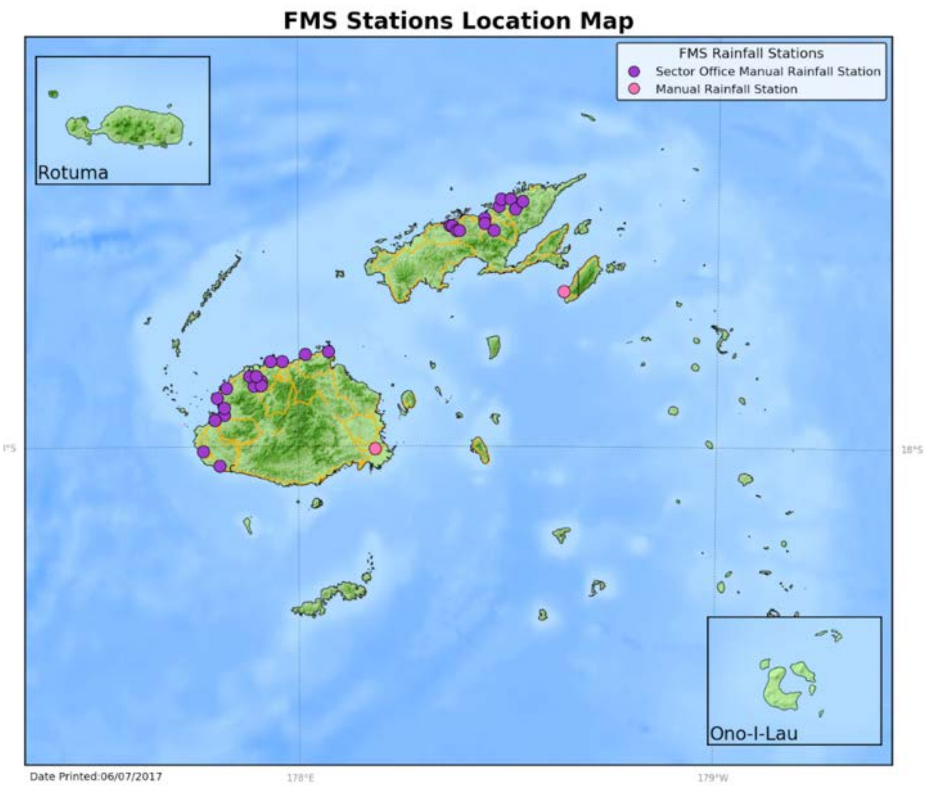
- **26 manual rainfall stations** (see Figure 13). The observations are recorded manually in the F20 forms, which are sent to FMS HQ at the end of each month. This data is then entered into the CLiDE database by the climate division staff.

Figure 12. FMS's Hydrological telemetered stations.



Source: FMS internal documentation.

Figure 13. FMS's manual rainfall stations.



Source: FMS internal documentation.

3.3 Calibration and Maintenance of the Instrumentation in the Observation Stations

It is critical that all meteorological and hydrological equipment and sensors be appropriately calibrated, maintained and replaced when needed for national and global applications.

FMS has a calibration laboratory, equipped with instrumentation donated by JICA, (Figure 14) that calibrates barometers, thermometers and relative humidity sensors. This laboratory is also used for assisting the other Pacific island meteorological organizations in calibrating their sensors to improve the data quality in the whole South Pacific region.

Instruments in FMS networks are inspected and calibrated annually. The FMS calibration laboratory reference instruments are also sent for calibration to the BoM's Regional Instruments Centre in Melbourne, Australia to maintain the laboratory's calibration certification. **Based on direct observation, it appears that the calibration room is congested with equipment and does not meet the standards for light and temperature conditions.**

There are a few pieces of equipment that are lacking from the (minimum required meteorological) calibration laboratory:

- **Rain gauge calibration rig**
- **Solar radiation verification/calibration**
- **Wind direction/speed verification kit**

Figure 14. FMS's calibration laboratory equipment.

Source: Authors.

3.4 Upper-Air Soundings

FMS has one upper-air observation located at Wailoaloa Nadi radar site. FMS uses a Vaisala DigiCora system to carry out upper-air observations, and the ground check system is installed at the HQ. Two balloon flights are released during the day. RS41-SG radiosondes are used for the observation. Data from the radiosondes is received through satellite communication. Figure 15 shows the FMS sounding system.

Weather balloons are filled with hydrogen gas produced by a hydrogen generator (electrolyzer) located on site. If issues arise, backup helium gas is used for the flights.

Figure 15. FMS's upper-air sounding.

Source: Authors.

3.5 Weather Radar Network

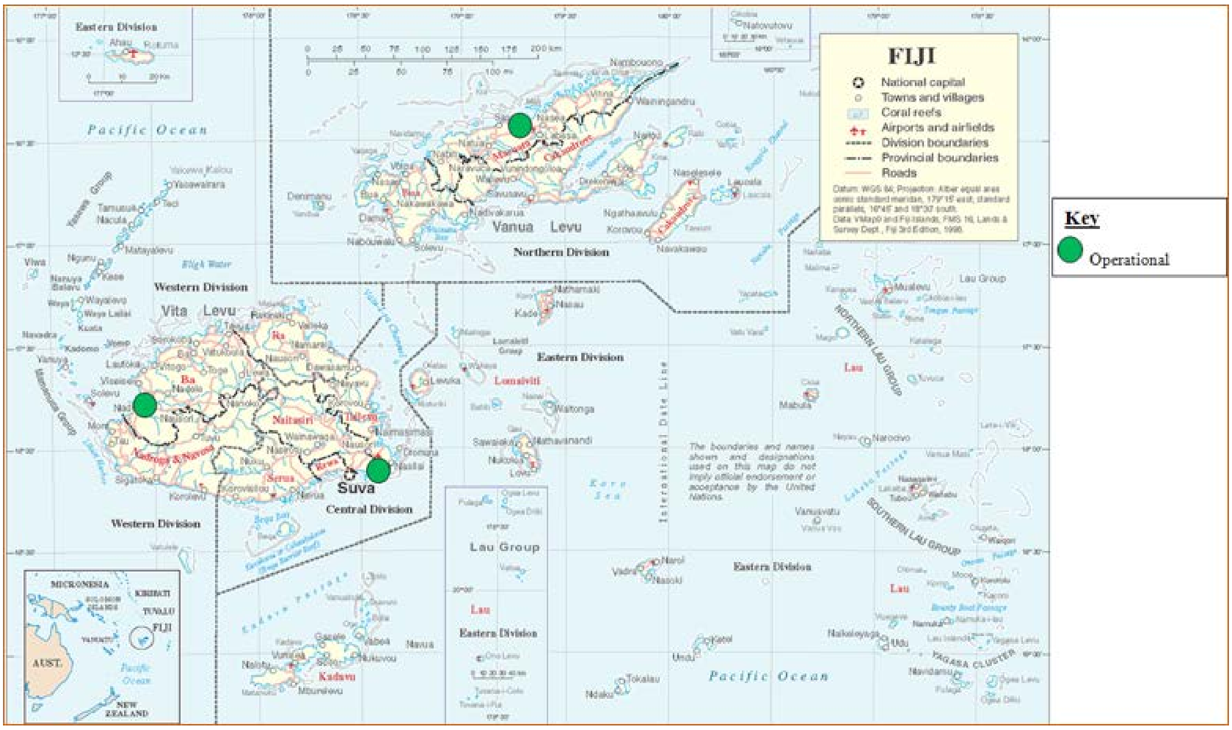
FMS has three Doppler weather radars located in Nadi, Nausori and Labasa (Figure 16). The Nadi radar was upgraded in August 2018 to full Vaisala Radar while Nausori and Labasa radar operates with Vaisala IRIS software and EEC mechanical components that were initially installed by the BoM. The weather radar in Nadi was recently upgraded; however, **the modern dual-pol feature is missing. The other two radars are more than 20 years old and thus at the end of their lifespan.** Table 2 along with Figures 17 and 18 show the radar equipment and forecaster end-user radar products.

Table 2. Details of the FMS's weather radars.

Location	Manufacturer	Radar band	Frequency	Status
Nadi	Vaisala	C Band	5.625 GHz	Operational
Nausori	EEC/Vaisala	S Band	2.282 GHz	Operational
Labasa	EEC/Vaisala	S Band	2.805 GHz	Operational

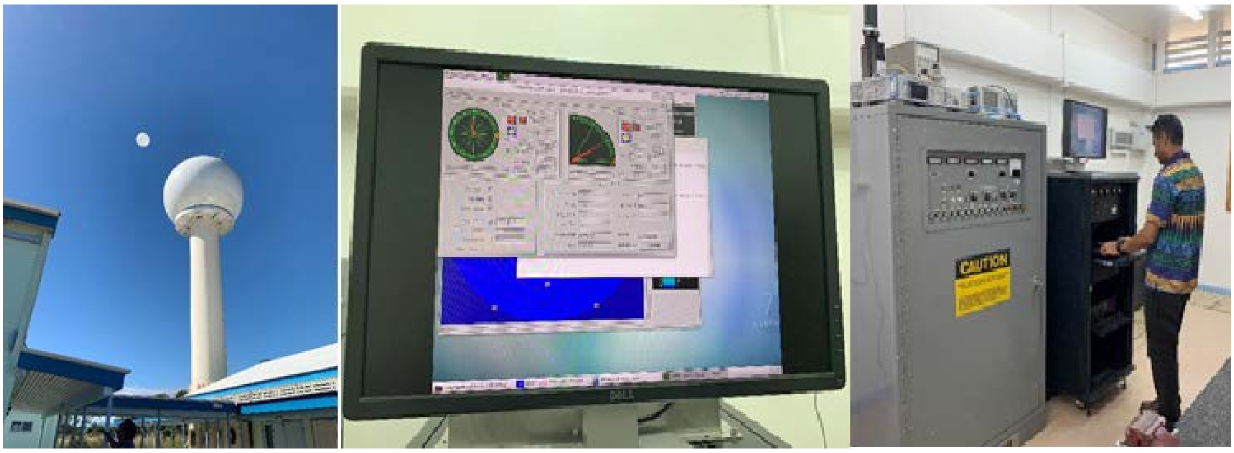
Source: FMS documentation.

Figure 16. FMS's weather radar network.



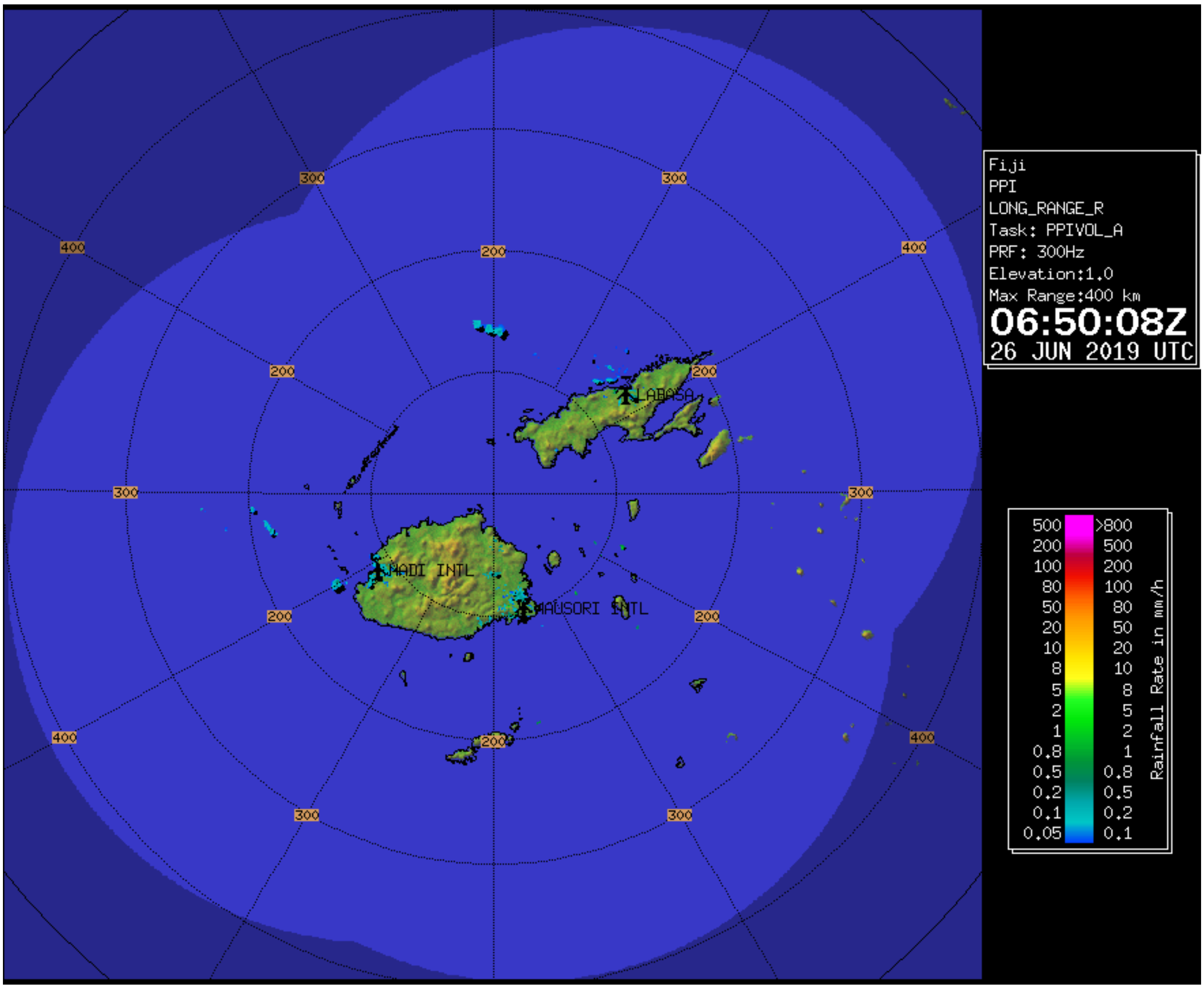
Source: FMS internal documentation.

Figure 17. FMS's Weather Radar Nadi.



Source: Authors.

Figure 18. Weather radar image (composite).



Source: Authors.

3.6 Lightning Detection Network

Lightning Detectors are located at:

- Nadi
- Rakiraki
- Labasa Airport
- Suva Met office

Data transmission is done through VSAT communication. Currently, the data processor is located at FMS HQ where all data from detectors is received and processed. The Vaisala Global lightning system is currently being tested by the forecasters and may be used in the near future as it requires a licence to have it fully operational.

3.7 Wind Profiler

JICA sponsored a wind profiler manufactured and installed by SUMITOMO Densetsu Co, Ltd, located at FMS HQ (Figure 19). The system is operational with the processing system based in Nadi. It operates at a frequency of 1357.4MHz. Data is sent from the JICA server to the FMS HQ.

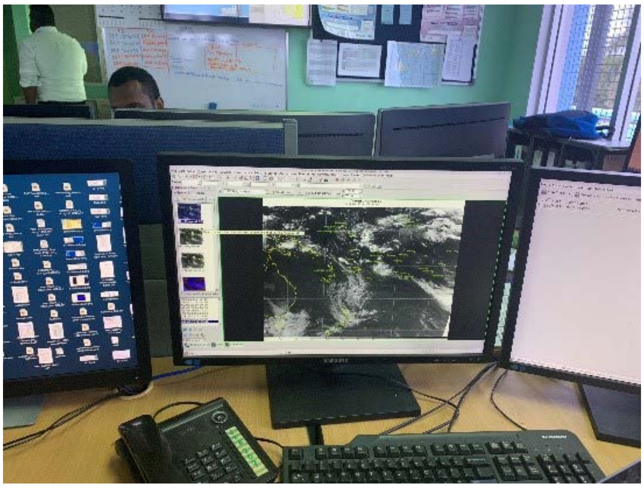
Figure 19. FMS's wind profiler.

Source: Authors.

3.8 Satellite Data

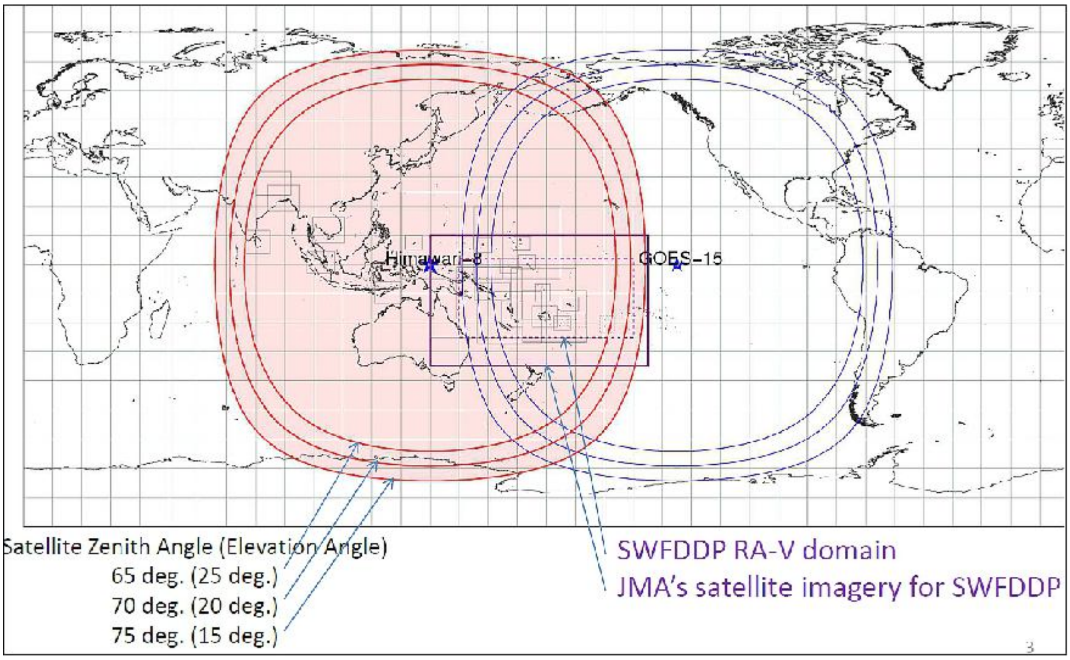
Satellite data gives precise information on the location of weather fronts, cyclones and clouds. The availability of satellite images is very important in helping forecasters for short- and long-term weather predictions. FMS uses geostationary Himawari-8 satellite data (Figures 20 and 21). It is also possible to receive polar-orbiting satellite data in Fiji, but FMS does not currently do this operationally. However, generally, the most important weather monitoring satellite data is from the geostationary satellites (mainly due to the constant updating of the data), while polar-orbiting satellites may add value for example in case of severe weather (by providing higher-resolution data at random intervals) and work as a redundant source of data. However, when taking into account the relatively high costs related to the data receiver and other more critical development needs in FMS, expanding satellite data receiving systems should not be prioritized. There is also redundancy available for the Fiji area from the GOES West satellite of the U.S. National Oceanographic and Atmospheric Administration (NOAA) through the internet or by acquiring an additional receiver as Fiji is inside the GOES West satellite coverage area (Figure 21).

Figure 20. Satellite data from Himawari-8.



Source: Authors.

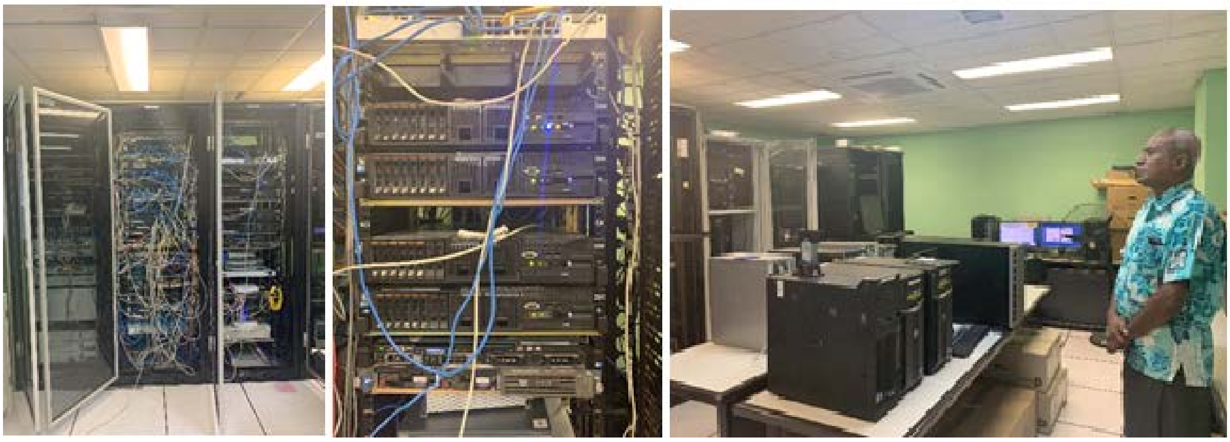
Figure 21. Coverage of Himawari-8/-9.



Source Koide, 2016.

3.9 Data Collection and Transmission

Figure 22. FMS's server room.



The computing and information systems division collects observational data directly from hydrometeorological stations network on the territory of Fiji through phone and mobile networks (SMS), email, fax and wireless communication networks (See Table 3). Since hydrometeorological data is mainly communicated through phone calls, SSB and FAX, frequent errors are inevitable due to human errors that occur when managing large amounts of data manually. Quality control (HQC) is also conducted manually, and the checked data is then entered into a CLiDE database. **Because the data is sent and collected mainly using antiquated systems, the observations cannot be used with confidence to support the forecasting.**

Potential upgrades will increase the amount of data flow and data, and thus place significant demands on communication and data management systems and capacity (current FMS IT facilities shown in Figure 22). These upgrades include:

- Increasing the number of automatic weather and hydrological stations
- Increasing the use of remote sensing (radars, satellite data, etc.)
- Implementing local area numerical weather forecasting models
- Automating the analyzing systems
- Increasing the number of hydrometeorological services and products

However, **currently, the FMS' communication facilities and IT infrastructure are deteriorated and obsolete. They fail to ensure reception and transmission of large data amounts that are required to produce modern information products.**

Table 3. Communication facilities used by the FMS,

Communication type	Communication status
Telecommunication service	Yes
• Maintenance	Yes
• Data collection	Yes
• Data dissemination	Yes
• Intranet	Yes
• Internet Mb/s	approx. 30
WMO GTS	Yes
Networking infrastructure	LAN, WLAN
DATA COMMUNICATION	
• Telephone	D, I, W
• Mobile phone SMS	D
• Telefax	D, I, W
• Dedicated leased lines	D, I
• UHF radio	D
• VSAT	D
• DCP	
• GTS	D, I
• MSG	
• Other satellite systems	D

Source: Authors.

(D = receive/send data, I = send/receive information, W = send/receive warnings)

3.10 Data Management

A database is an organized collection of (typically) digital data in which the data can be used by one or more users or systems. Database management systems are used for managing digital databases. They store database contents and enable data creation and maintenance, as well as searches.

Fluent data management and proper database functionality that can carry out the duties and support the operations of a modern weather service lies at the core of the modern operation of numerical weather prediction (NWP) and (automated) production and dissemination of products and services. It is critical to have the capacity to use or disseminate observation data to produce multiple analytical products as well as to integrate a variety of data in a very short delivery timeframe. But this is very difficult to implement if most of the hydrological and meteorological information is stored only on paper or hard copies, as is still the case in many developing countries. Digital climate databases are essential for the production of climate information, different climatological and applied studies and services, for research on climate variability and change, and for the production of hazard maps for the DRM.

The current data management system does not allow the use of much more real-time observations and handling of large amounts of data coming from NWPs, radar stations and others.

The automation of the observation network will bring more data for the FMS as well as for the users. The FMS must use standard and modern applications for telecommunication both for the preparation of outputs and for data archiving. The regular upgrading of telecommunication facilities and IT technologies would provide the basis for a continuously functional FMS.

It is standard practice to store the data received from automatic observation stations in climatological or hydrological databases for quality control and preparation of decadal to monthly bulletins. The same is true for the preparation of outputs for FMS web pages as graphs and maps. The first step is sending the data from automatic stations each hour to the database (MESSIR-COMM and CLiDE).

For a proper presentation of meteorological and hydrological data, FMS needs information on station metadata. Authorization for metadata preparation must be strictly defined to assure uniformity of names, elevations, coordinates, etc. The WMO is preparing the Manual on WIGOS (WMO Integrated Global Observing System) with a detailed description of metadata for meteorological observation.

The FMS should decide which of the existing versions of metadata will be used for meteorological and hydrological stations, which application archives it, and who is responsible for the actualization of the original version.

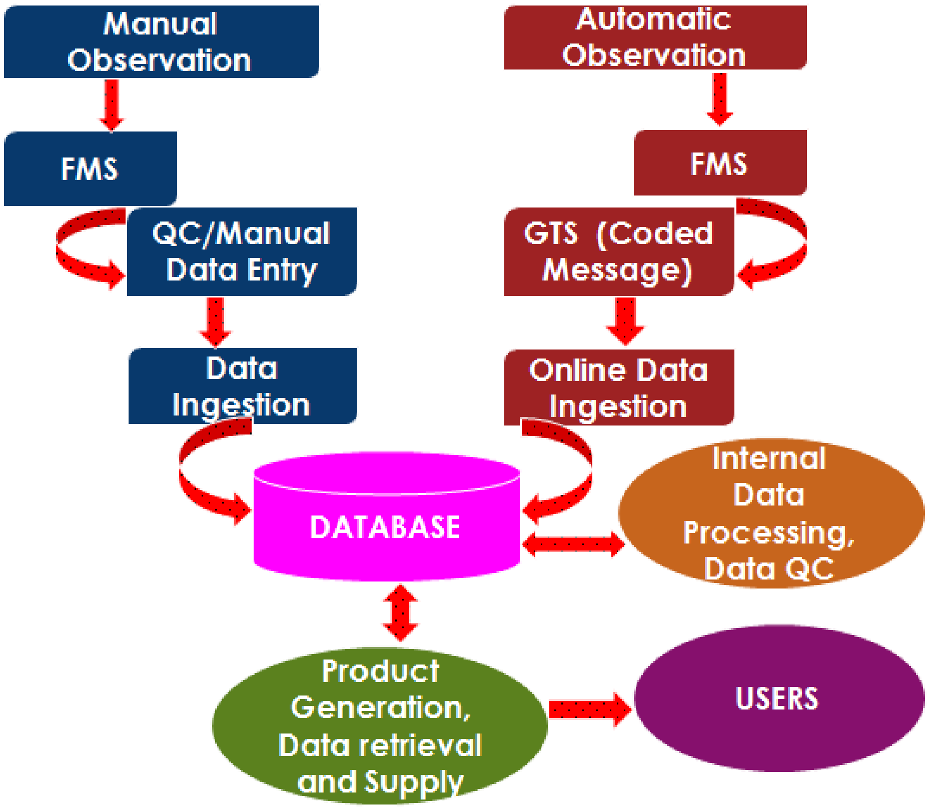
The FMS must use standard professional applications developed for meteorology or hydrology that are used in similar services globally. Interoperability between different applications within the FMS is critical (to transfer data and outputs automatically instead of manually) for end users.

A schematic description of integrated end-to-end observation and production system is shown in Figure 23; unfortunately, most of this process is not yet automated in Fiji.

3.10.1 Data Archiving

Paper data originates from manual meteorological stations, though the FMS is planning to change this to electronic data as soon as possible. Historical data and datasets are the greatest wealth of FMS. On the one hand, the government's expectations are that the FMS manages this wealth well; on the other hand, the government must create appropriate conditions for it. The FMS needs a reliable system for IT services (hardware, software, human resources) to allow for the timely managing of operational data and for reliable archiving of the historical data.

Figure 23. A schematic description of integrated end-to-end observation and production system,



Source: FMI, 2019.

3.10.2 Data Quality Control

The FMS is responsible for ensuring both the quality of the archived data in databases and the online data from automatic stations used in real time. Historical data may be used for quality control of actual data from automatic stations. The applications in the forecast office, the input to the forecast models and automatic preparations of outputs should recognize and omit erroneous data. Currently, the FMS does not perform any automated real-time quality control (QC) for the data due to the lack of such systems.

3.11 Summary of the Gaps in the Observation Network

Table 4 summarizes the biggest gaps found in the observation network of the Fiji Meteorological Services. Each gap has been evaluated according to its level of criticality (low = green, middle = yellow, high = red) to help identify which gaps are most urgent to fill.

Table 4. Biggest gaps found in the observation networks of the Fiji Meteorological services

Gaps in the FMS observation network	Criticality
Diversified observation network (multiple manufacturers)	**High**
Old radars in Nausori and Labasa, missing dual pol in Nadi	**High**
Lack of centralized and automated observation data management system	**High**
(Partly) manual observation collection	**High**
Lack of centralized observation database	**High**
High number of manual observation stations	**Middle - High**
Poorly designed calibration measures	**Middle**
Lack of certain calibration equipment	**Middle**
Lack of automated observation quality control	**Middle**
Lack of observation metadata	**Low - Middle**
Small number of internationally shared stations	**Low**

4.0 Current Situation and Gaps in FMS Services Provision

4.1 Numerical Weather Prediction

Currently, the FMS is not running any weather forecast models operatively. The model most likely to be run by the local forecast services in a country like Fiji is the Weather Research and Forecasting (WRF) Model, which is an American open-source weather model. It is relatively easy to install and does not require significant infrastructural investments (compared to the more sophisticated forecast models). However, parametrization of the model (i.e., tuning the model to local conditions) is time-consuming and requires expertise that the FMS currently does not have. Operative modeling also requires dedicated staff resources (IT, modelling etc.) and a stable infrastructure and environment.

Based on discussion with FMS staff, it appears that the use of the Australian Community Climate and Earth-System Simulator (ACCESS) weather models could be a reasonable and beneficial solution for weather prediction in Fiji. ACCESS weather models have been developed and tested by the BoM and are based on the UK Meteorological Office's Unified Model (BoM, n.d.).

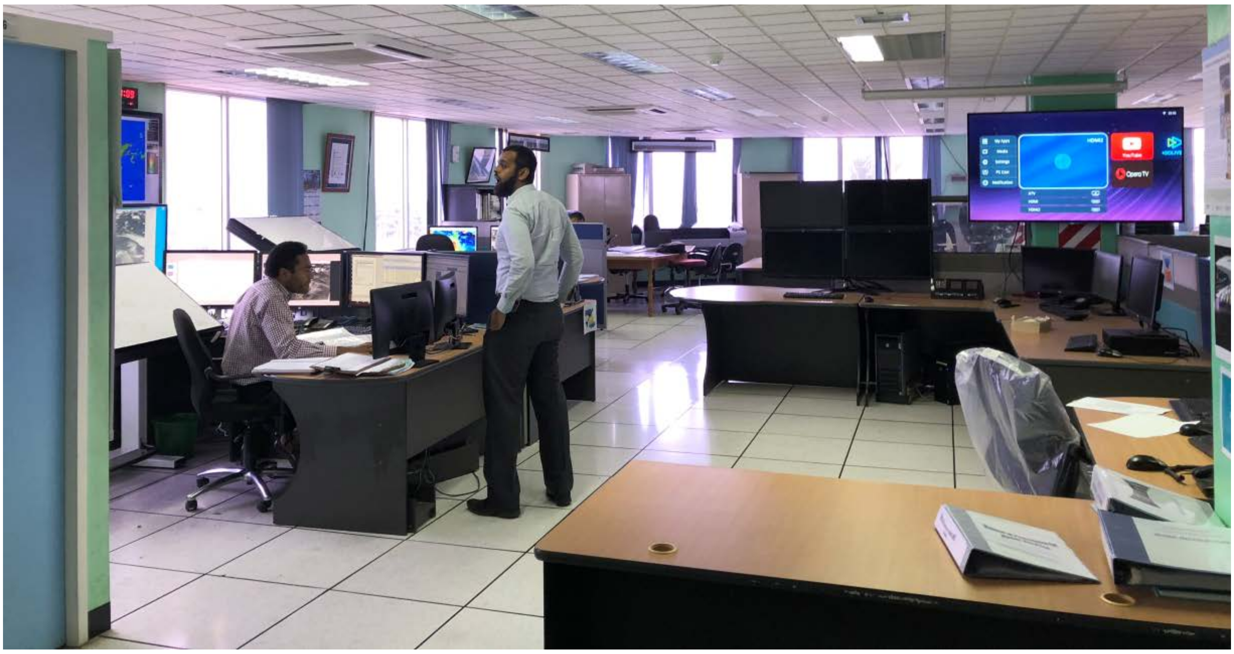
Depending on the version of ACCESS, the model can have a resolution of 25 km to 4 km, which is nearly the same as with the WRF model. However, due to its physics ACCESS is a much more sophisticated weather model—and is more likely to provide better forecasts in the Fiji region—than the WRF.

4.2 Forecast Services

FMS's NWFC (Figure 24) produces different services (weather forecast products and weather warnings) in the FMS. It is in the FMS headquarters building at the Nadi International Airport and is currently operating on a 24/7 basis.

The NWFC has a Quality Management system, which is also certified, and excellent documentation on different duties, products and activities. The NWFC is responsible for producing both "regular" weather services (marine and land area forecasts) and aviation weather forecast services. The forecaster duties are divided into two different shifts: a) marine and public weather services and b) aviation services. However, occasionally the same person may execute these shifts due to the unavailability of forecasting staff. It is recommended that these shifts be kept separate permanently to improve the service level for different customer groups. This would also be beneficial for calculating the costs of the aviation weather services for the cost-recovery mechanism (described later in this document).

Figure 24. NWFC premises in FMS,



Source: Authors.

4.2.1 NWFC Products and Services

The complete listing of the different forecast products made in NWFC is as follows:

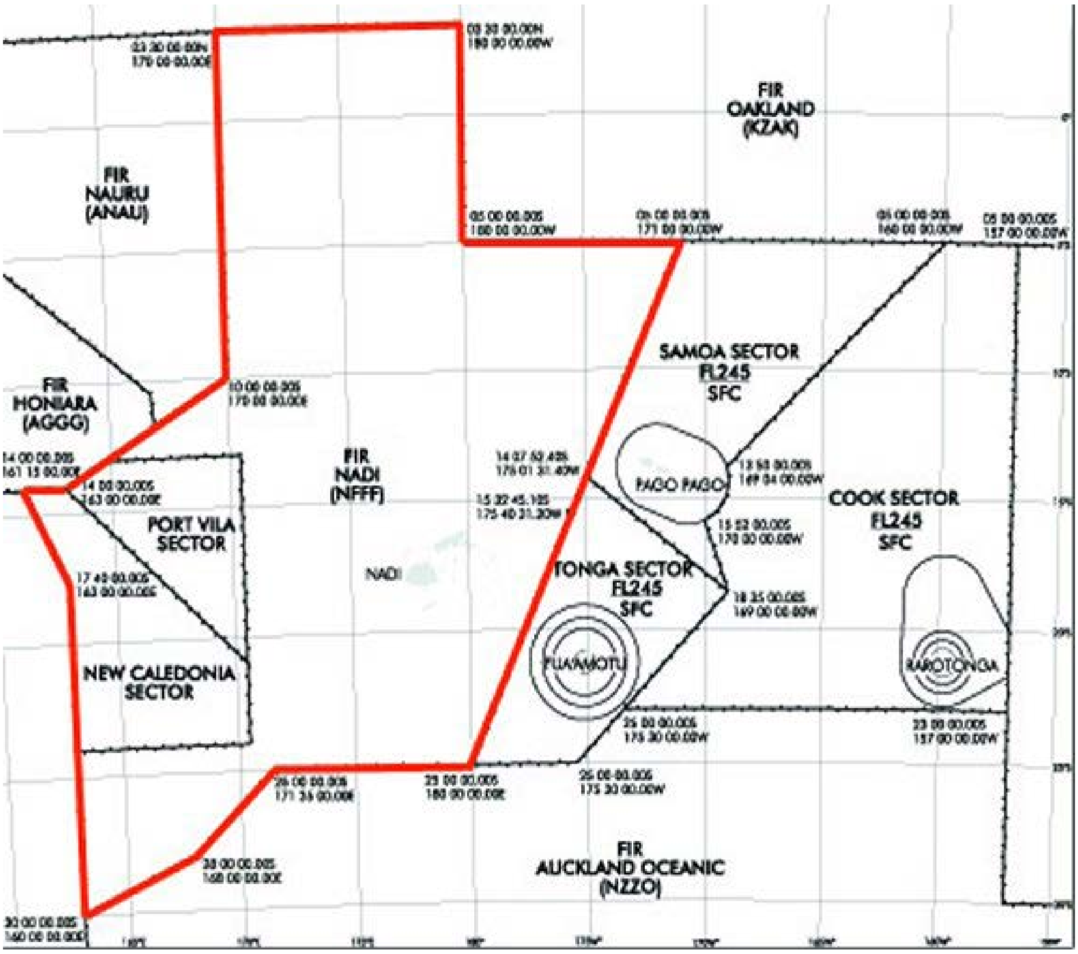
- Daily weather forecasts
- 7-day Outlook
- Heavy Rain Alert
- Heavy Rain Warning
- Tropical Cyclone (TC) Alerts & Warnings
    - 3-Day Tropical Cyclone Outlook
    - Tropical Disturbance Summary
    - Tropical Disturbance Advisory
    - TC Warnings
    - Special Weather Bulletins
    - TC Track & Uncertainty Maps
- Marine forecasts

4.2.2 Aviation Products

The FMS has an agreement with the International Civil Aviation Organization to act as the Meteorological Watch Office for the Nadi Flight Information Region (FIR) (Figure 25). The Nadi FIR extends from Southern Kiribati to Tuvalu, Fiji, Vanuatu, Wallis and Futuna and New Caledonia. In addition, the FMS provides some aviation forecast services to the Cook Islands and limited services for Christmas Island (Line Islands), Tokelau, Samoa, Niue and Tonga which are located outside the Nadi FIR area. The FMS provides the following products:

- Metars
- TAFs (Terminal Aerodrome Forecasts [3]) for 24 h: (10 airports)
- TAFS 9 hours: (three airports)
- TAF 12 hours: (four airports)
- TAFs also produced for the Cook Islands, Tonga, Samoa, Kiribati, Niue and Tuvalu
- SIGMET for the FIR (flight information region)
- Route forecasts
- AREA forecasts for the FIR
- Lightning warnings for airports

Figure 25. FIR of the Fiji Meteorological Service.



Source: FMS Web page, Aviation Meteorological Services, n.d.a

[3] https://en.wikipedia.org/wiki/Terminal_aerodrome_forecast

4.2.3 Infrastructure and Tools in the NWFC

The NWFC has five different types of forecasting workstation software installed in the office:

1. Visual Weather made by the IBL. This is the latest acquisition by FMS. This software was first acquired by the BoM and Fiji followed shortly with their acquisition.
2. SmartMet, made by the Finnish Meteorological Institute. It was installed in 2014 for the Finnish Pacific Project (FINPAC) project
3. Messir Vision software, made by Corobor
4. McIDAS, made by Space Science and Engineering Center (SSEC) at the University of Wisconsin-Madison.
5. Australian Integrated Forecast System (AIFS), made by BoM.

The last three workstations are older and at the end of their lifetime.

In addition to forecaster workstation software, the NWFC has Vaisala IRIS radar data visualization software and JICA/JMA Sataid satellite data visualization software for HIMAWARI satellite data.

Currently, the NWFC can use GFS, GSM and GEM global weather forecast models and limited datasets from the European Centre for Medium-Range Weather Forecasts (ECMWF) and United Kingdom Meteorological Office (UKMO) global models.

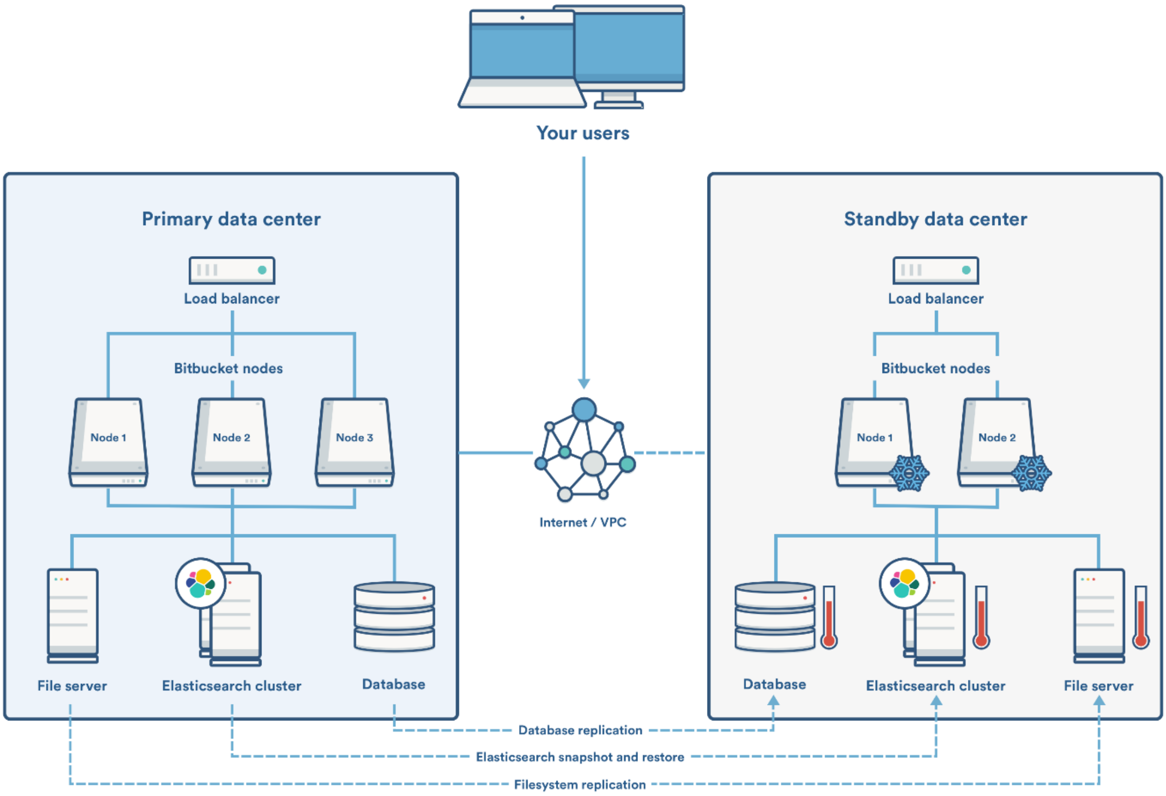
Access to the model data is fragmented between the different workstation software, and so a single workstation cannot view all models. **The current setup of five different workstation software versions is extremely unsustainable and costly to operate and maintain.** Each workstation software also has its own server and data ingesting systems, which increases the operational costs and overloads the internet connection of the FMS because the data is downloaded from external sources. **Currently, the main production tool is the AIFS, which is also at the end of its lifecycle and needs to be replaced.**

There are pros and cons to using different software. In general—and regardless of the software(s) selected—it is recommended that the FMS concentrates on only one (or at maximum, two) workstation software type. Selection of the software(s) should be made based on the sustainability and the production features reflecting the stakeholders' needs and business model. For example, the licence for IBL software costs roughly FJD 20,000 annually. However, it can currently provide aviation weather forecast production components (which also exist in AIFS). SmartMet, on the other hand, is open-source software and can be complemented with open-source aviation weather product components as well; however, expanding the software requires a one-time investment in installations. SmartMet also has a gridded forecast data production feature that enables unlimited expansion of the product portfolio and the provision of new formats of weather forecasts.

4.2.4 Current Forecast Workstation Upgrade Plan in FMS

FMS has a backup office (or "standby data centre") in Laucala Bay in Suva. It does not yet have forecast capabilities, but there is a plan to develop such a capability there as well. For redundancy purposes, such a backup office is an essential and reasonable investment. The plan is that the upgrade of the Laucala Bay office will host the disaster recovery system on a hyper-converged infrastructure (HCI) that will be a mirror of the forecasting system in Nadi HQ (Figure 26). This would allow the FMS to immediately shift operations to Laucala Bay online and continue with business either remotely or from the Laucala Bay office.

Figure 26. Schematic picture of the planned hyper-converged infrastructure.



Source: FMS internal documentation.

This backup system will be an exact duplicate of the forecasting system in HQ, and can also host a training environment on the HCI system to give trainees real-life experiences with real-time data and scenarios. In addition to the Laucala Bay office, FMS is also planning to offer virtual forecaster workstation services to neighbouring countries through the virtual environment.

The plan is modern and has many useful features; for example, the service is hosted within FMS' own premises and thus problems and issues may be solved by FMS staff (i.e., they are not reliant on a third-party provider). However, there are also some risks and challenges associated with it. Internet bandwidth between the two offices must be high enough to support the operation of the system. This may be an issue if the FMS is providing this service to neighbouring island countries that have even worse internet connection speeds than Fiji. Furthermore, maintaining the hardware and systems requires skilled IT staff, which is a notorious problem in developing countries in general. However, the FMS has planned to hire four more IT experts before the end of 2019, which would be sufficient. Some forecaster workstation software and production systems, like SmartMet, may also be run in external third-party cloud environments. It is recommended that the design and technical solution of the backup system be planned comprehensively.

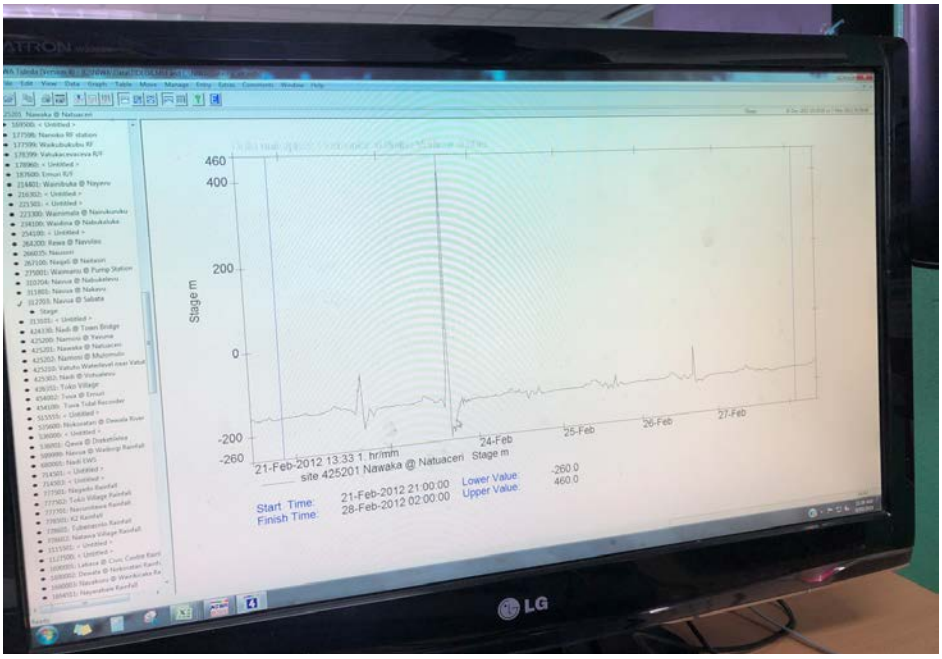
4.3 Hydrological Services

Hydrological services were embedded into the FMS seven years ago and currently share office space with the weather forecasting office. Current service provision is as follows:

- Flood alerts & warnings
- Hydrological data – river level & rainfall
- Intensity-Duration-Frequency Curve (IDF Curve)

In 2019, FMS does not do any hydrological modelling and the current flood forecasting services are based on monitoring the different hydrological observation stations (47 pieces). The main tools for the hydrological experts and forecasters are the Flosys and Tideda software made by NIWA, which is a versatile tool with quality control features (Figure 27). Hydrological forecasting duties are activated only when flooding is imminent (i.e., the services are not continuously produced).

Figure 27. Tideda software user interface. (poor quality of the observations may be seen as a spike in the left side of the curve).



Source: Authors.

Hydrological products are disseminated to the general public and disaster management office when available. However, the products are missing from the FMS home web page and the currently consist mainly of manually produced text-formatted products. The hydrological forecast service seems to be also working somewhat independently from the weather forecast service, although these two elements are highly linked. **For example, observed radar data should be part of hydrological forecasting, and forecasted rainfall data should also be considered. In addition, observation equipment maintenance and installation are not affiliated with the weather observation instrument maintenance services.**

The FMS is expanding its role to flood forecasting and planning to perform hydrological modelling as well. There are a few boundary conditions to be considered when planning modelling activities:

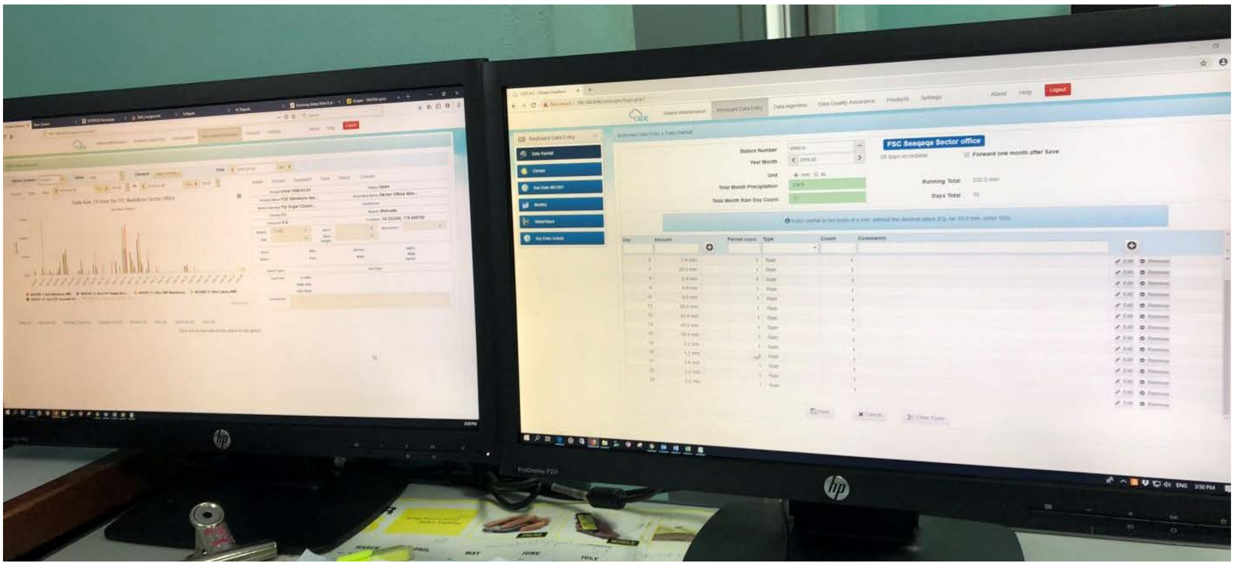
- Hydrological models typically work together with the weather models and require weather model data for the initial state. This should be considered in the FMS weather forecast production system.
- Hydrological modelling requires computing infrastructure investments and maintenance of the equipment.
- Hydrological modelling requires expert staff to configure the models, and research activities are almost mandatory to support the modelling and develop and localize the models into the local environment.

4.4 Climate Services

Climate services are also located within FMS' Nadi HQ and are responsible for operating the climate database and producing different (long-term) climate products. The main tool is the Australian-made CLiDE software (Figure 28), which has sophisticated features for climate service and forecast production.

The climate services produce different kinds of analysis and products from the observations as well as seasonal or climate forecast products either regularly or on demand. The product portfolio is rather comprehensive, and the main products are updated regularly and disseminated via the website http://www.met.gov.fj/index.php?page=climatedatalatest, which is publicly accessible. The products may consist of different elements such as text, analysis maps, tables, graphs etc. These are not limited to discussing or displaying strictly the weather or climate; some of them also include climate impact analysis, which is standard practice for modern climate services.

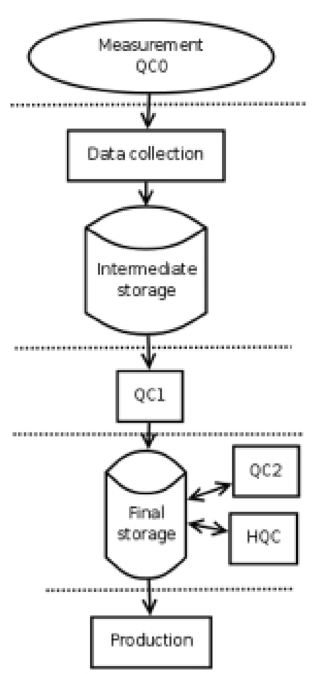
Figure 28. CLiDE software user interface.



Source: Authors.

The most significant gap in climate services is the absence of real-time data collection of part of the observations and manual procedures in data management. In modern weather services, all observations are entered into the database in real time, and an automatic quality control check is then made on arrival. This does not, however, remove the need for manual quality control; automatic quality control flags only suspicious observation values, and a final evaluation is made manually before entering the (suspicious) observations to the database. Nowadays, it has become nearly impossible to do manual quality control for all observations because the amount of observations has increased significantly. This is mainly due to the automation of the stations, which enables both shorter observation intervals and smaller increments at the observation stations. Typically, in modern weather services, data quality control is semi-automated and includes multiple layers where evidently false observations are automatically rejected, and these "flagged" observations are later checked manually. FMI's complete observation quality assurance process is shown in Figure 29.

Figure 29. Steps of the observation quality control process.



1. Components of the AWS and/or manual observation stations with possible initial Quality Control (QC0) based on logger and sensor indicators.
2. Data retrieval via satellite, GPRS, radio etc. and storage to intermediate raw database.
3. Automated Quality Control (QC1) based on logistic tests on data records.
4. Storage into "official" observation database (real-time & long-term data). Data quality is further screened and flagged by comparing with neighbouring station records or gridded data fields (QC2) (optional) and by human control (HQC).
5. Local processing & display (SmartMet, Web sites, customers), coding into BUFR, SYNOP, METAR etc. and sending to regional databases and to GTS.

Source: FMI, 2019.

4.5 End-User Service Production and Service Provision

Traditionally, the public sector has been the major customer and end-user group of hydrometeorological and environmental data and services. However, as the quality and local accuracy of weather forecasts have significantly improved, over the past few decades, the service demand for more end-user-specific and online products for public and different economic sectors has been strongly increasing, especially in developed countries. Due to their socioeconomic development, these countries (and their economic and leisure activities) have also become more weather- and climate-dependent. Weather forecasts have high priority (and interest) in media and especially different TV channels have several weather programs per day. The Internet has become a very important part of the dissemination system of weather and climate information, and weather forecasts and time series of national weather radar composite pictures and precipitation forecasts, as well as online lightning data, are shown not only on web pages of NHMSs but also on private weather services and media.

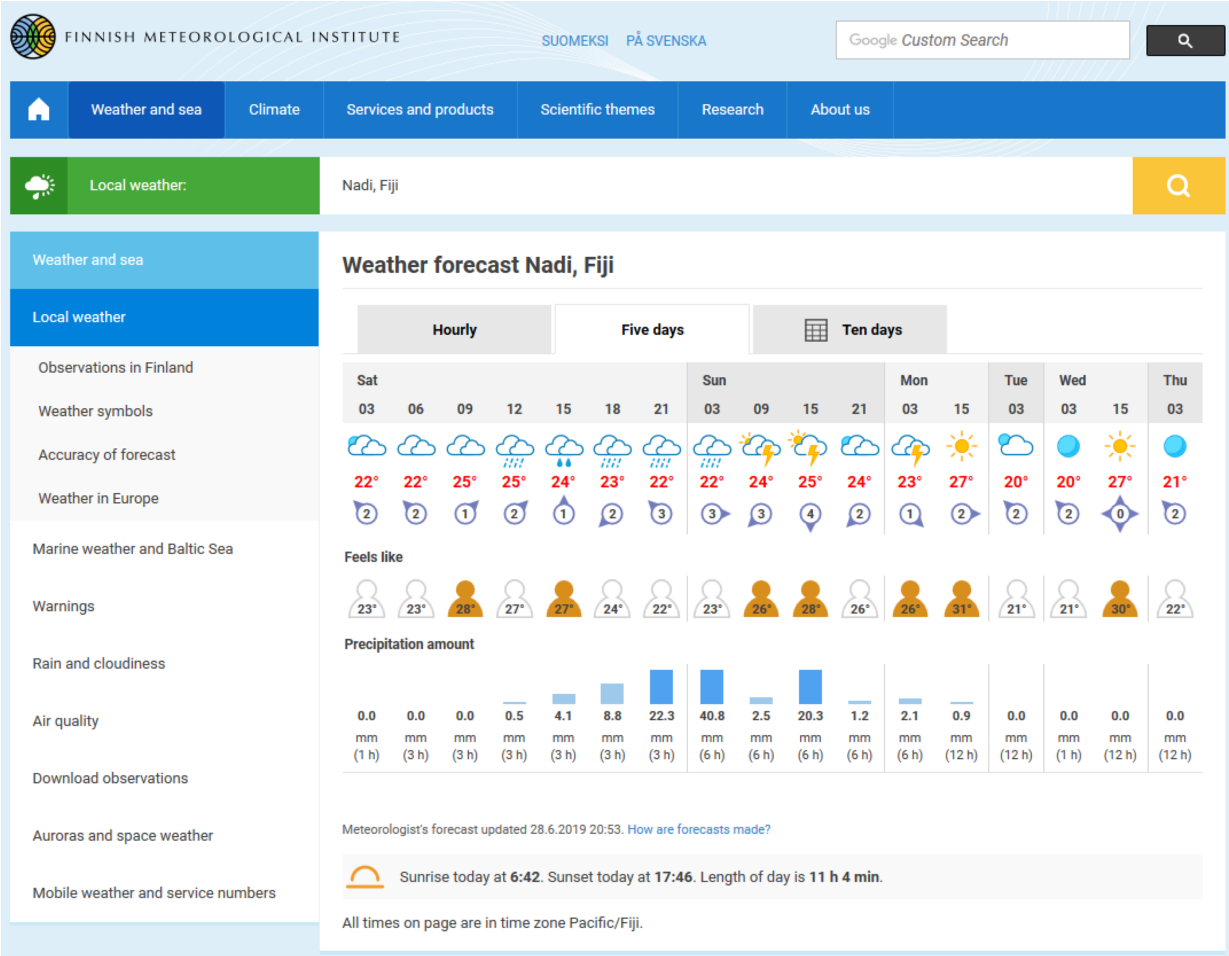
Examples from developed industrial countries with advanced NMHSs, and by World Bank, UNISDR, WMO and other country assessments show that different economic sectors and the national economy as a whole can benefit significantly from adequate hydrometeorological information. This requires that the information be delivered in a way that is understandable to the users, and that customers know how to use this information to support their decision making.

The biggest gap in FMS forecast production is related to inadequate and decentralized data management and production system. For this reason, forecaster tools are also decentralized and many duties, operations and forecast production are conducted manually in MSJ instead of being automatized as in modern weather services. This also limits FMS' end-user product portfolio, i.e., what kind of products it can offer, and the number of possible products it could make. For example, (modern) detailed graphical products are impossible to create manually and require automated forecast production systems. Figures 30 and 31 illustrate the different forecast production capabilities and end-user forecast products. Figure 30 shows a manually created product, while Figure 31 shows an automated graphic product. Basically, they both have the same content (weather forecast for a certain location) but present it in different formats.

Figure 30. Public weather forecast for different regions of Fiji.

Source: FMS web page, Public Weather, n.d.b

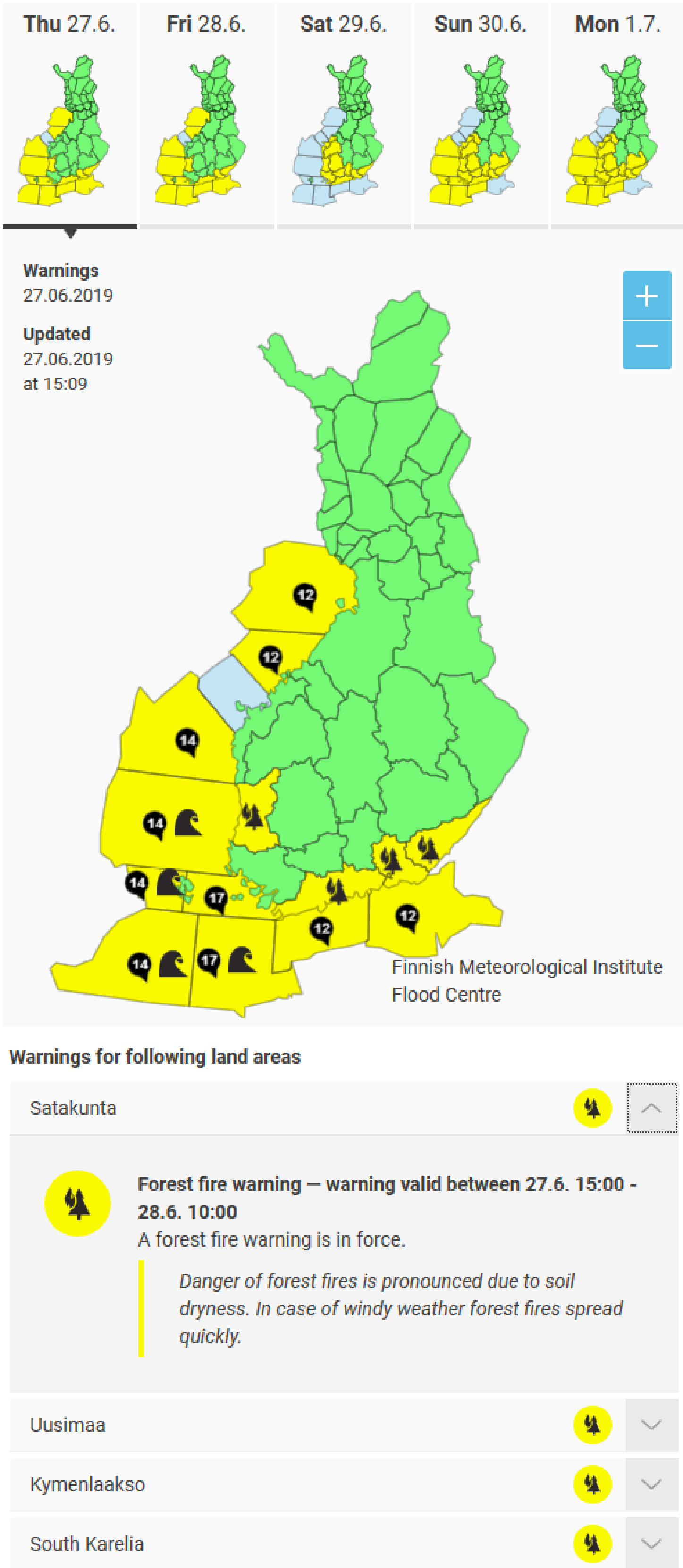
Figure 31. Hourly weather forecast for Nadi from FMI web page produced with SmartMet forecast production system.



Source: FMI web page, local weather, n.d.

The majority of the FMS' forecast products are created manually. **The main tool for weather forecast production is the AIFS system, which is outdated**. However, the latter is already under replacement with the IBL software. **Also, the weather warning information is currently produced manually in FMS and is disseminated only in text format.** This format can be somewhat informative but not very appealing or does not raise enough interest for large audiences and it is not in a suitable or optimal format for television and social media, which are the major modern information channels. Currently, modern weather services also distribute their warnings in map format, which is a more efficient way to reach the general public in case of a severe weather event (see example from FMI in Figure 32). FMS already has an open-source tool, SmartMet Alert, that enables such production, but it is not utilized at the moment due to inadequate training and lack of commitment of FMS during the installation phase. The system also supports WMO endorsed Common Alerting Protocol (CAP) format messages for warning dissemination, which can also be integrated easily to different stakeholders' and third-party systems. Utilizing SmartMet Alert would be the easiest way for the digitalization of weather warning information.

Figure 32. Example of graphical early warning products from Finland.



Source: FMI web page, Warnings, n.d.

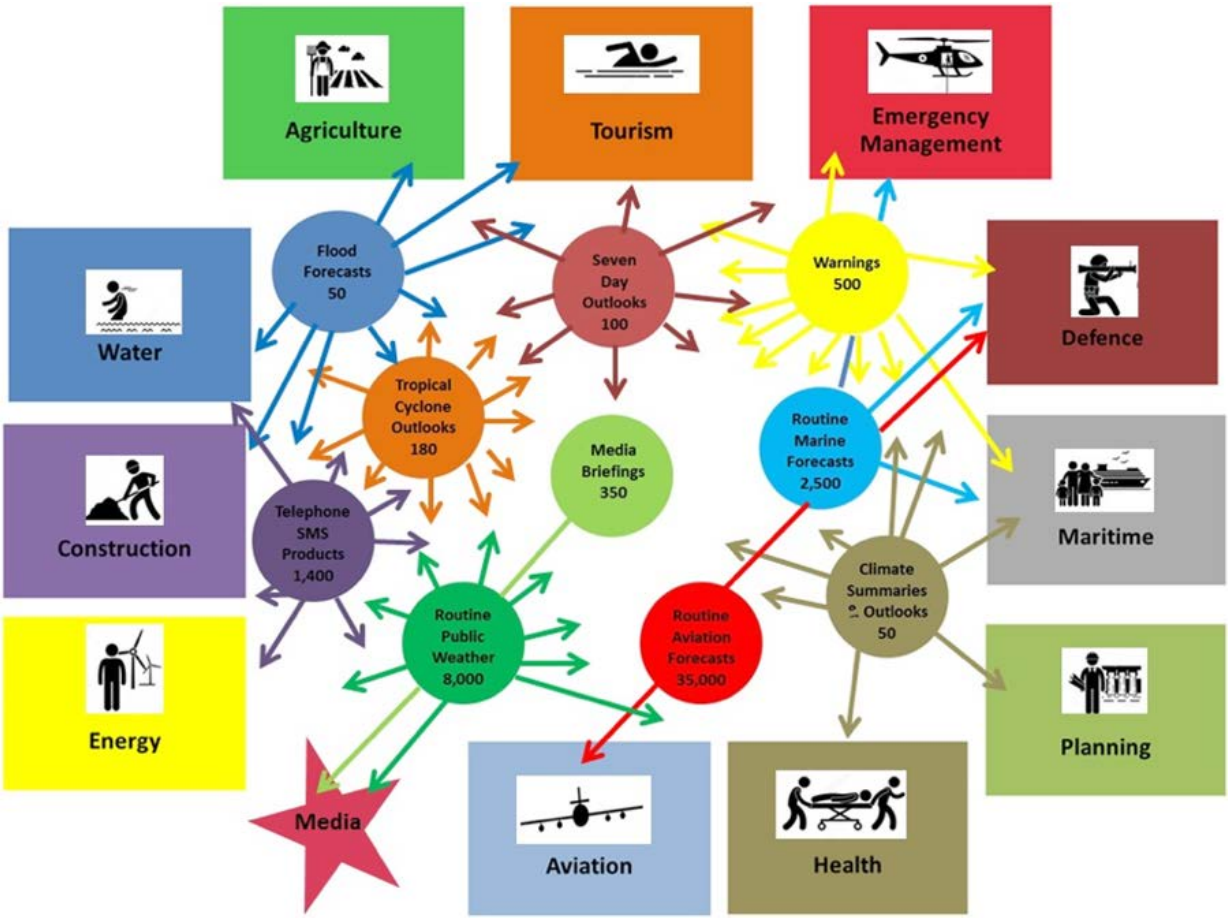
FMS is currently not doing impact-based forecasting. However, demand for such services is growing rapidly in developing countries.

The draft strategic plan of Fiji Meteorological Service (FMS, 2019, p.14) states:

> There is a broad and expanding base of users of our services and of the community of stakeholders who help support the FMD's operations. Perhaps the key challenge for the FMD over the next five years is to improve our ability to communicate with these service users and stakeholders. The list of service users and stakeholders is long, including Government Ministries, universities, the general public, operators of ships, aircraft and land transport, weather- and climate-sensitive industries, etc. Their voices are being heard and are reflected in this Strategic Plan. Furthermore, we undertake to improve how we communicate with users and stakeholders.
>
> [...] An expansion in the number of different products we issue would need to be achieved through automation of the production process as we are now working at close to the capacity of our existing staff of weather forecasters, climatologists and hydrologists.

The comments from the strategic plan indicate that the issues with the production system and model have already been identified by the FMS. The current numbers and types of products issued annually by the FMS to end users are represented in Figure 33.

Figure 33. Numbers and types of products issued annually by the FMS to service users in a range of sectors.



Source: FMS, 2019.

4.5.1 Customer Liaison and Satisfaction

The FMS's customer liaison activities are currently fragmented. Different experts from different units or divisions handle customer relations. This may not be a problem; however, the organized and unified customer relation process may be handled most effectively from a single unit concentrating solely on customer relations. In fact, the FMS's own development plans indicate that it is already seeking to establish a business development unit. It seems to be a logical place to also handle customer relations and satisfaction measurement duties. Centralized customer relations (along with system and product development) also make overseeing the implementation of the strategic plan easier for management.

Currently, customer satisfaction surveys are conducted annually for aviation weather service customers and stakeholders. These include the following:

- Fiji Airways
- Fiji Link
- Northern air
- Aviation Schools
- Nadi and Nausori briefing office
- Pacific Island Air

To develop stakeholder relations—and if the FMS wish to further expand its customer potential to commercial services—customer liaison measures should be given serious consideration, and measurements of customer satisfaction should be expanded into other sectors beyond aviation services. Attracting and acquiring new customers is demanding, requiring constant mapping and interaction with potential new customers and stakeholders. This can be done, for example, by arranging joint workshops or by contacting them directly. Forecasting and service production systems should be capable of producing the services that the customers need; the ability to customize products to the needs and priorities of different audiences is a key factor in attracting new customers.

4.5.2 Market Potential

New products and services may be marketed for the customers or stakeholders with two different pricing principles:

- **Cost-recovery mechanism:** The cost-recovery mechanism should be based on actual and transparent costs incurred by the FMS to develop and provide these services, including all social charges and administrative overhead, but no profit margin.

- **Commercial pricing:** For commercial services, a reasonable profit margin could be accepted. Services of a commercial nature cannot be provided under the actual value of service delivery so as not to bias the markets and provide indirect public support to selected private enterprises.

The legal status of the FMS enables it to produce commercial services and attract new customers. The FMS can, therefore, develop both cost-recovered and commercial services for interested customers and grow its external revenue (which is not the case in all countries).

The FMS does not currently have any commercial customers (apart from hydrology). But specific agreements should be explored in the following sectors:

- **Energy:** Fiji's National Development Plan (Fiji Ministry of Economy, 2017) for the next 5 and 20 years states: "Further investments in renewable energy will be undertaken to ensure that over 80 per cent of all electricity is generated from renewable sources by 2021." Three major hydro projects are currently being developed by the Fiji Electricity Authority (FEA). The significant planned investments into renewable energy create increased demand for more accurate and customized weather and hydrological services since energy production—especially with hydropower plants and windmills—is extremely weather-sensitive. It is important that FMS be ready to meet the growing demand for these services. In fact, the FEA is already a customer for hydrological services, and thus the relationship between the FMS and FEA is already established. It would be natural to also expand this relationship to weather services if suitable products can be created. Energy Fiji Limited is completely owned by the government of Fiji, which means that a cost-recovery mechanism (instead of a commercial contract) is likely the most suitable arrangement.

- **Water:** The National Development Plan also states the need for: "An integrated approach by the Water Authority of Fiji and Department of Water and Sewerage to develop a mechanism for detailed water resource monitoring and management in collaboration with Fiji Meteorological Services, Ministry of Waterways, FEA and other relevant agencies." This also creates the need for more detailed and customized hydrological/meteorological services for the above-mentioned authorities.

- **Tourism:** Tourism is a major source of revenue for Fiji, and there is significant—and most likely growing—demand for the provision of services for the sector, from marine weather for tourist boats to hotels and so on. It is likely that the greatest potential lies in marine services such as tourist boating, shipping and port activities, which are the most weather-sensitive activities in Fiji. One issue might be that daily weather forecasts for visitors can be obtained from several free international sources, and so making a large profit is difficult, although the FMS would have the best in quality in Fiji.

- **Agriculture:** Agriculture (including farming, fishing and forestry) still plays a significant role in the Fijian economy (13.5 per cent of GDP in 2017) (Central Intelligence Agency, 2019) and is also a potential source of additional revenue for the FMS. While the agricultural sector is already being served by the FMS especially with climate services, additional and more detailed information can be provided by updating the production model and systems. Weather services directly affect the efficiency of agricultural production, which is also mentioned in Fiji's National Development Plan.

4.6 Summary of the Biggest Gaps in Service Provision

Table 5 summarizes the biggest gaps found in the provision of services and weather forecasting by FMS. The gaps are also incorporated with the criticality (low – middle – high) to help to identify what gaps are most urgent to fill.

Table 5. Biggest gaps found in the service provision and weather forecasting of the Fiji Meteorological services.

Main gaps in services	Criticality
Fragmented software environment in the forecasting and forecast production	**High**
Centralized data management for observation and forecast data is missing	**High**
Automated forecast production system is missing	**High**
Weather warning production is manual	**High**
Lack of high-resolution forecast model data for Fiji area	**Middle - High**
Customer liaison and product development is fragmented	**Middle**
Hydrological modeling is missing	**Low**

PART 2: Roadmap of Actions

5.0 Priority Actions

5.1 Overview of Priority Actions

This review of the observational network, service provision, staff and organizational structures of the FMS—together with assessments of end-user needs of hydrometeorological data and products—shows that the FMS currently fails to meet the needs of Fiji's citizens.

The main gaps in the capacity of the FMS can be summarized according to four categories:

i) Weak communication systems for data collection and products dissemination

ii) Deficient data management and numerical modelling capacity

iii) Insufficient financing and poor cooperation with industry and end users

iv) Inadequate skills and training of staff to meet modern requirements

However, these four categories are not individual or separate packages—they are interlinked. In a functioning meteorological institute, all the categories need to be in order: if operations in one category fail, other categories will also suffer.

The following tables show the proposed actions by level of criticality and according to four different phases:

- **Level of criticality** refers to the urgency of the actions from high (red) to low (green).
- **Phases 1 to 4:** We identified four different phases to reflect the logical order of the actions (i.e., what needs to happen first, second, third and fourth). Phase 1 should be implemented first or at least started to be implemented first, followed by the later phases. For example, before investing in any new equipment or system, the funding base must be sustainable, maintenance costs need to be assured and maintenance plans need to be in place. It should be noted that some actions can be implemented in parallel.

Based on this analysis, the most important development need for FMS is to ensure that funding is sustainable and independent of external donors. Therefore, management-level activities and establishing cost-recovery mechanisms is a key priority.

The implementation timeframe of the roadmap depends on future resources and funding; however, in an optimal situation, the whole roadmap could be implemented in approximately 5 to 7 years. The overview tables below also provide an indication of the human resources needed from FMS, the necessary external partners and an estimated timeframe for completing the actions.

More detailed information on the priority actions is provided in the following sections.

Table 6. Phase 1 of the roadmap.

Gaps	Level of criticality	Proposed actions	Human resources and external partners needed	Estimated completion timeframe
Strategic planning incomplete	High	• Complete FMS' strategic plan	• Management • Ministry of Infrastructure	• Ongoing starting immediately • Updates of strategic plans annually
Aviation weather service cost-recovery mechanism missing	High	• Establish an aviation cost-recovery mechanism	• Management • *Fiji Airports Limited* • *Civil Aviation Authority of Fiji*	• One year, Revisions annually

Diversified observation network (multiple manufacturers)	High	• Homogenize the observation network by
		  • Better planning of acquisitions
		  • Reducing dependency on external funding and donors (first by developing and activating the aviation weather service cost-recovery mechanism and then by developing and activating other potential commercial and cost-recovered activities)
			• Management and procurement personnel
			• Observation personnel
				• Ongoing

Old radar technology in Labasa and Nausori & missing dual polarization feature in Nadi radar	High	• Complete modernization of the Nausori and Labasa radars • Acquire the dual polarization features for the Nadi radar.	• Management • Observation (radar) personnel	• Two years

Gaps	Level of criticality	Proposed actions	Human resources and external partners needed	Estimated completion timeframe
Lack of centralized and automated observation and forecast data management system	High	• Acquire and develop a fully integrated data management system for observation and forecast data • Improve the network environment for better data ingestion and sharing • Increase the number of IT experts in FMS with a minimum number of two to support the maintenance, development and operation of the system	• Management • NWFC • Climate Services • Computing and Systems information Division • Technical Systems Division	• Four years
(Partly) manual observation collection	High	• Include automated observation data collection in the data management system	• NWFC • Climate Services • Computing and Systems information Division • Technical Systems Division	• One year
Lack of automated observation quality control	Middle	• Include automated quality control of data in the data management system	• Climate Services • Computing and Systems information Division • Technical Systems Division	• Two years
Lack of centralized observation database	High	• Include centralized observation database in the data management system	• NWFC • Climate Services • Computing and Systems information Division • Technical Systems Division	• One year

Gaps	Level of criticality	Proposed actions	Human resources and external partners needed	Estimated completion timeframe
Lack of observation metadata	Low - Middle	• Include observation metadata in the data management system	• Climate Services • Computing and Systems information Division • Technical Systems Division	• Two years
Fragmented software environment in the forecasting and forecast production	High	• Select and invest in one weather forecast system (or a maximum of two) • Integrate the centralized data management system and high-resolution model data	• Management • Climate Services • Computing and Systems information Division • Technical Systems Division	• One year

Table 7. Phase 2 of the roadmap.

Gaps	Criticality in the gaps section	Proposed actions	Human resources and external partners needed	Estimated completion timeframe
Inadequate staff training and qualification	Middle – High	• Train staff, concentrating especially on: • Management level • Observation staff • Forecasters	• Management • Training Section • NWFC	• Ongoing, starting immediately • First training packages completed in one year
Inadequate training of hydrological staff	Middle – high	• Train hydrological staff (for example with WMO training packages)	• Management • Training Section • NWFC (hydrologists) • WMO	• Ongoing, starting immediately • WMO Basic Instruction Packages for Hydrological Services in one year
Incomplete business plan	Middle	• Complete the business plan	• Management • Customer and stakeholder portfolio of FMS	• Ongoing, business plan completed in 1.5 years with annual updates
Missing international agreements on the aviation weather services	High	• Establish international agreements on the services • Establish a cost-recovery mechanism also for the international. aviation weather services	• Management • Pacific Meteorological Council • Neighbouring Countries	• Two years, annual revisions
High number of manual observation stations	Middle – High	• Increase the number of automated observation stations	• Management • Observation personnel	• Ongoing, increasing the number of automated stations by 25% in two years
Missing automated forecast production system	High	• Acquire (or operationalize (SmartMet)) automated forecast production systems • Increase the number of automated forecast products	• Management • Computing and Systems information Division • Technical Systems Division	• Two years

Table 8. Phase 3 of the roadmap.

Gaps	Criticality in the gaps section	Proposed actions	Human resources and external partners needed	Estimated completion timeframe
Training of the staff mainly funded by external donors	Middle	• Reduce the dependency on external funding and donors (with actions in development of funding base) and aim for self-supported trainings	• Management • Training Section	• Ongoing
Poorly designed calibration measures	Middle	• Improve and design the calibration procedure • Beforehand scheduled calibrations • SOPs for the station maintenance and calibration	• Management • Observation personnel	• Three years

Lack of high-resolution forecast model data for Fiji area	Middle – High	• Select method for acquiring high-resolution data:
		  • Install WRF model or
		  • Acquire ACCESS model data from BoM
			• Management
			• Computing and Systems information Division
			• Technical Systems Division
			• NWFC
			• BoM
				• Two years

Relatively low number of forecasters and IT for the duties	Low – Middle	• Increase the number of forecasters and IT experts	• Management	• Three years
Weather warning production is manual	High	• Acquire (or operationalize [SmartMet Alert]) automated weather warning production system • Implement CAP (Common Alerting Protocol) formatted warning dissemination	• Management • Computing and Systems information Division • Technical Systems Division • NWFC	• 2.5 years
Fragmented customer liaison and product development	Middle	• Establish customer liaison unit • Improve customer liaison operations	• Management	• Two years

Table 9. Phase 4 of the roadmap.

Gaps	Criticality in the gaps section	Proposed actions	Human resources and external partners needed	Estimated completion timeframe
Research activities missing	Low	• Establish research unit • Start operational research activities	• Management • NWFC • Climate Services Division	• Five years
Small number of internationally shared stations	Low	• Increase the number of stations and amount of data shared internationally	• Management • Observation personnel • WMO	• Four years
Lack of certain calibration equipment	Middle	• Acquire missing calibration equipment	• Management • Observation personnel	• Four years
Hydrological modelling is missing	Low	• Establish hydrological modelling	• Management • NWFC (hydrologists)	• Five years

5.2 Recommended Priority Actions for Observations Networks

5.2.1 Meteorological and Hydrological Surface Observation Networks

The general guidance of observation network design and international data sharing is provided in the WMO's (2019) *Guide to the WMO Integrated Global Observing System*. Principle 1, "Serving Many Application Areas" (WMO, 2019, p. 29), states that "observing networks should be designed to meet the requirements of multiple application areas within WMO and WMO co-sponsored programs. Observing networks should be designed to address stated user requirements, in terms of the geophysical variables to be observed and the space-time resolution, uncertainty, timeliness and stability needed." Principle 2, "Responding to User Requirements (WMO, 2019, p. 30), states that "observing networks designed to meet national needs should also consider the needs of WMO at the regional and global levels."

Recommendations:

- Increasing the number of Regional Basic Synoptic Network (RBSN)[4] nominated stations to reflect the size of Fiji and its complex geography will fulfil this design principle more completely. *(Phase 4)*
- Improving observations to support understanding of climate variability and climate change impacts on all appropriate Application Areas in Fiji. *(Ongoing)*

Generally, AWSs from different manufacturers can be used in the same online system if they have their own collection systems that can use (i.e., send the data to) any common database. Of course, the measurements must be close enough to make them comparable. It is inadvisable to keep the equipment of many manufacturers as it will make the system very expensive, laborious and difficult to maintain. As a general rule, having two generations or manufacturers of AWS is manageable to avoid a situation where all devices age out at the same time without having replacement instruments for all different stations. Three are still manageable, but four are starting to be too much.

Recommendations:

- Standardize the equipment in the observation network immediately. This includes formalizing a development plan for the observation network and selecting the equipment to be used. Automated weather stations should be prioritized. *(Phase 1)*

The modernization of observation systems does not automatically mean that the FMS is becoming a modern hydrometeorological service. It is imperative to recognize the financial needs for promoting sustainable development. This means that investments cannot be made separately—in general, it can be estimated that annual operating costs will increase by 15

[4] RBSN = WMO network of weather observation stations that fulfil the minimum regional requirements and enables the members to fulfil their responsibilities within WMO World Weather Watch programme.

per cent for each investment in technology, and each investment requires adequate staff to maintain and develop the system. It is imperative that modernization actions are planned well and account for the maintenance and operation costs.

Recommendations:

- Take action to ensure financial sustainability via (for example) aviation weather service cost recovery and allocating sufficient staff resources to meet the needs of the automated observation network. *(Phases 1-2)*
- It can be estimated that operating a fully automated observation network would require at least two more maintenance experts for the FMS.

5.2.2 Upper-Air Sounding Station(s)

The FMS has one upper-air sounding station in Nadi. The optimal site area for one sounding station should be approximately 40,000 km^2 (WMO, 2015c). Therefore, this is sufficient for Fiji. At this moment, and given the financial situation of FMS, there is no need to plan for additional stations. However, FMS has issues with the gas generator for the soundings, whose measurements are critical for the global community in weather modelling.

Recommendation:

- Pay due attention to the maintenance of the station (particularly the gas generator) and keep the sounding operational continuously. *(Ongoing)*

5.2.3 Weather Radar(s)

In order to promote nowcasting (weather predicting on a very short timescale of up to two hours) and early warning, all the radars should be fully operational continuously and measuring correctly, all the data sent to the FMS and high-quality data goes to the customers. High-speed internet and undisturbed electricity supply must be guaranteed. Currently, three radars cover the territory of Fiji well and there are no expansion recommendations for the radar network. In the future, the FMS could add one radar to the network. However, the Nausori and Labasa stations require immediate update or renewal since they are at the end of their lifespans. These should be equipped (along with the Nadi radar) with dual-polarization features to support severe weather forecasting.

Recommendations:

- Maintain the radars according to international standards and manufacturer's guidance.
- Modernize the Nausori and Labasa radars and equip all radars (including Nadi) with the dual-polarization features *(Phase 1)*. The estimated investment cost is around USD 5-10 million.

5.2.4 Lightning Detection Network

The lightning detection network is operational and does not need urgent attention.

Recommendation:

- Maintain the lightning detection network according to international standards and manufacturer's guidance. (Phases 1–4)

5.2.5 Observation Quality Management System

The backbone of the operations of modern meteorological institutes is a functional quality management system that includes observation services. The advantages of a well-planned, implemented and managed observation system are as follows:

- The condition of every single station is known, making it easy to assess the quality of observations and scheduling maintenance.
- Unnecessary work can be avoided, leading to cost savings.
- Quality can be demonstrated if required.

The processes should be audited regularly (e.g., once every two years) either internally or by an external expert (the latter especially if the quality management system is certified). The person responsible for quality insurance needs to check the actual performance of the process against the operations and procedure manuals and make corrections to the process and/or manual as required. In addition, manuals should be updated after auditing, and the latest version should always be available wherever the corresponding process is performed. In a quality management system, there should be a manual for every process in the production of observations. For example:

- Site selection and criteria
- Installation of a station
- Operating a station
- Regular onsite maintenance
- Fault case maintenance
- Onsite calibrations
- Central maintenance
- Laboratory calibrations
- Traceability processes for the laboratory standards and transfer standards
- Handling and transport of critical parts (e.g., sensors)
- Quality control of the observation data
- Action in faulty and "poor-quality data" cases

All processes should be performed in conformity with their manuals. The manuals should also include a list of elements to be documented in the processes.

Recommendations:

- Initiate and include the development of manuals and documentation on the observation equipment maintenance installation and data management into FMS' existing quality system as early as possible, starting with the first few stations *(Phase 3)*. Ensuring the quality at a later stage becomes more difficult when the network has grown and got older.

5.2.6 Observation Support Activities and Structures: Maintenance and calibration of sensors

The quality of observations from AWSs and manual observations has suffered due to a lack of proper calibration systems at the FMS. The calibration laboratory needs to have a special room that complies with the following requirements (WMO, 2010):

- Constant temperature (e.g., 20–25°C)
- Preferably no windows because solar radiation causes uncontrollable temperature effects
- Laboratory security standards i.e., instruments and documents should be stored safely.

Currently, FMS's calibration room is congested with equipment and does not meet light and temperature standards.

Recommendations:

- Modify the calibration facilities to meet the above-mentioned requirements. *(Phase 3)*

Some important calibration equipment is also missing from the calibration facilities, including:

- Rain gauge calibration rig
- Solar radiation verification/calibration
- Wind direction/speed verification kit

To support the recommended improvements to the observing networks, it will be necessary to improve the supporting infrastructure.

Recommendations:

- Establish a calibration centre to support the increased number of technical staff, equipment and spares that will be necessary to support the observing networks. *(Phase 3)*
- Ensure that the following are in place: testing facilities for new observational equipment, calibration laboratory, repair facility and secured equipment storage. *(Phase 3)*

Efficiencies can be gained in the infrastructure by combining the above-mentioned facilities in one location. The combination of several technical observational aspects will result in a critical mass of staff working in a central observation location. This will facilitate staff training and development and encourage cross-team working.

Recommendations:

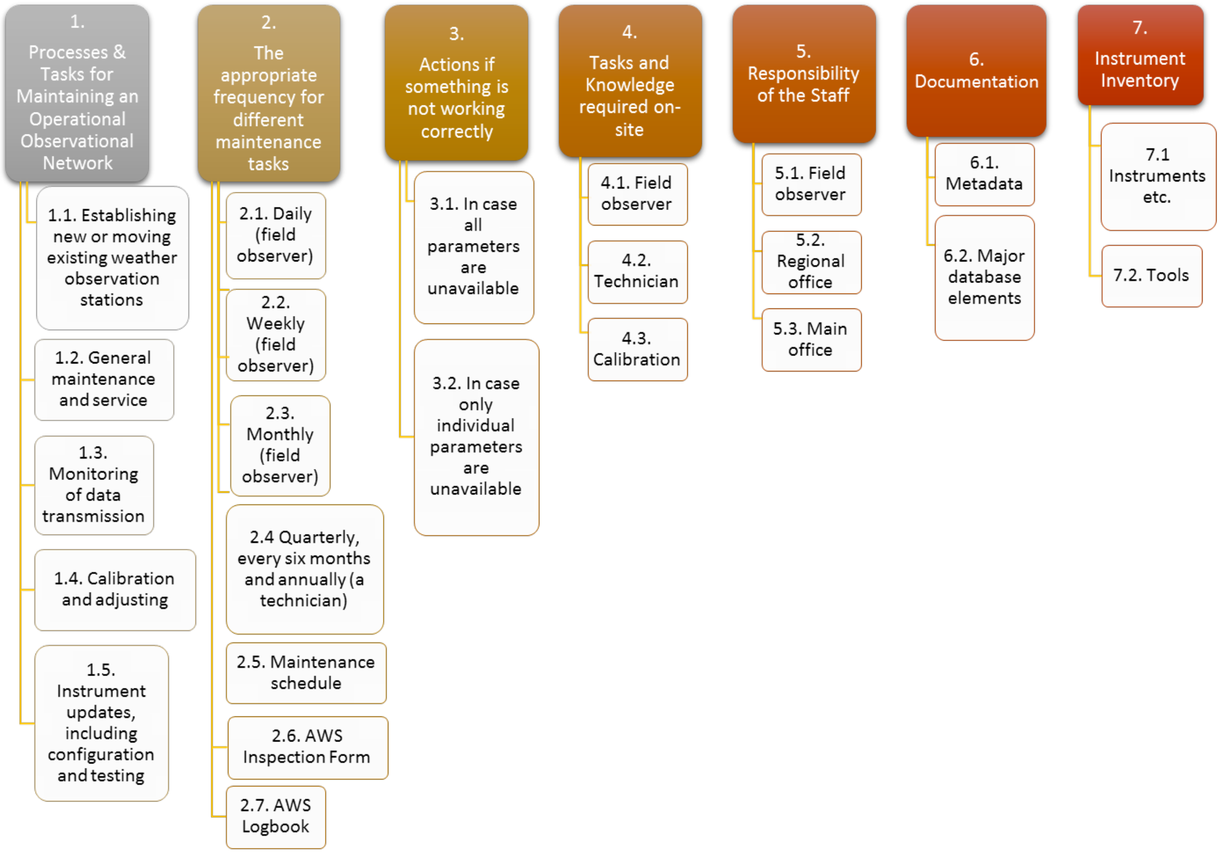
- Continuously maintain several spare sensors and systems in the FMS premises to ensure timely recovery from any system faults and the effective replacement of sensors as part of a systematic sensor calibration program. *(Phase 3)*

To reap the long-term benefits associated with the increased number of automatic meteorological and hydrological stations, station maintenance and instrument calibration must be guaranteed and the FMS must be prepared for station malfunction.

Recommendations *(Phase 3)*:

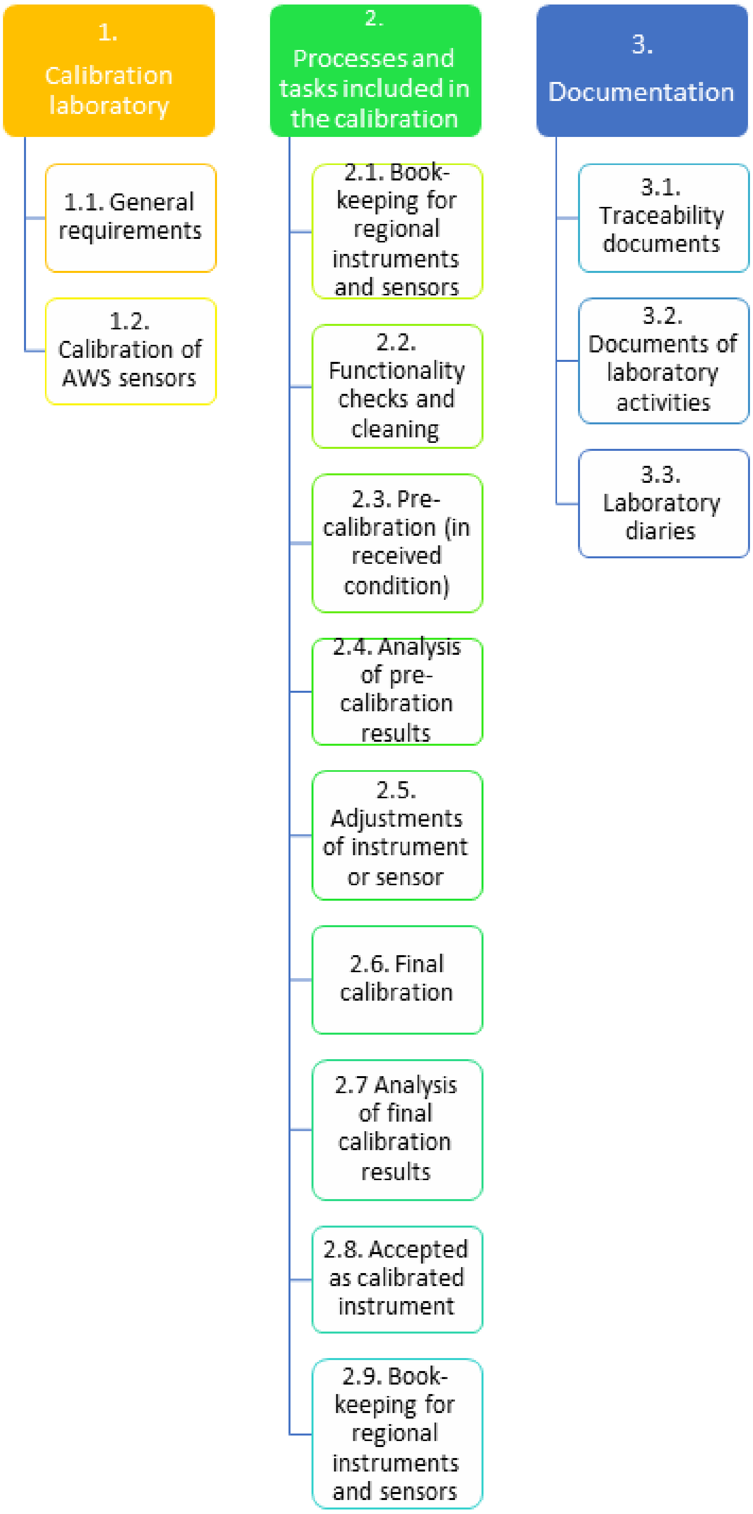
- A yearly maintenance visit to each station by FMS observation maintenance personnel.
- Develop and implement a preparedness plan for situations of station malfunction.
- Regular (dependent on the instrument) calibration of the instruments must be ensured by purchasing required equipment or alternatively, preparing for the cost of sending the instruments elsewhere for calibration.
- Increase the number of maintenance staff for yearly maintenance and malfunctions, ideally a minimum of two maintenance and calibration experts.
- A set of standard operational procedures (SOPs) needs to be developed for each observational system. Examples of SOPs for AWS, calibration and radar are given below (Figures 34, 35 and 36).

Figure 34. Content of SOP for AWSs in the table.



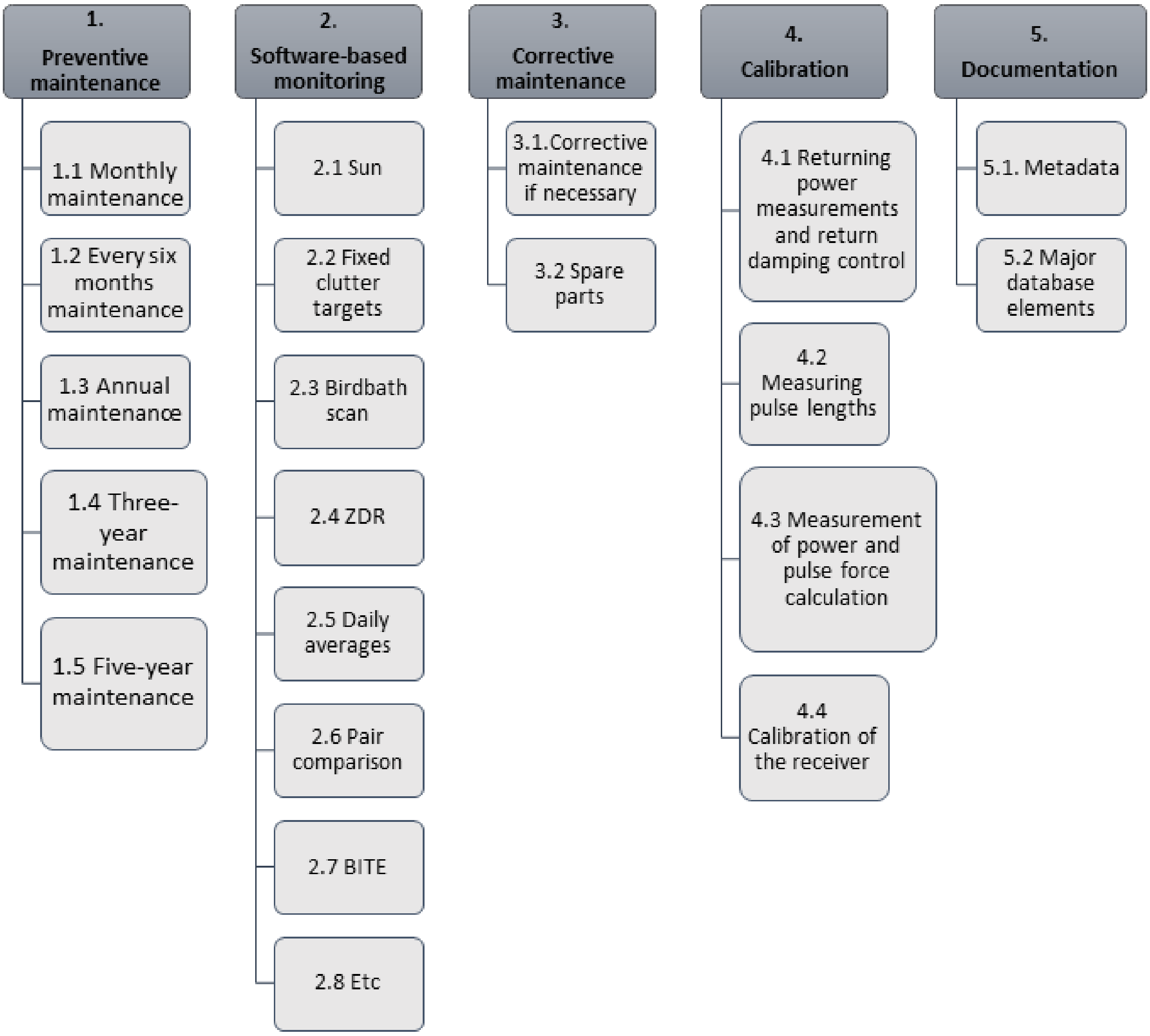
Source: FMI, 2019.

Figure 35. Content of SOP for Calibration in the table.



Source: FMI, 2019.

Figure 36. Content of SOP for radar maintenance in the table.



Source: FMI, 2019.

5.3 Priority Actions for Forecasting and Service Production

5.3.1 Aeronautical Services

ICAO's policies on charges (ICAO, 2012, see Section I, paragraph 5) recommend that, where economically viable and in the best interest of air navigation service providers (ANSPs) and users, states consider establishing autonomous entities to operate their air navigation services.

Recommendations (once the charges policy is in place):

- Develop a comprehensive description of the free public good, the costs recovered and the commercial services it would provide under the new arrangements.
- Develop a costing model considering the direct costs, the overhead (support) costs and the capital (equipment outlay or depreciation) costs appropriate for each cost recovered and commercial service.
- Establish a small standing committee to periodically review the charging and costing policies and advise FMD staff on how any proposed new services should be categorized for charging policy and costing purposes.

5.3.1.1 COST RECOVERY FOR AERONAUTICAL METEOROLOGICAL SERVICES

The requirements of international air navigation for aeronautical meteorological service provision have remained relatively stable for decades. But the sector is subject to see many changes in the coming decades with the introduction of the ICAO Aviation System Block Upgrades (ASBUs) and the ICAO Weather Information Exchange Model (IWXXM). Airspace users will demand more real-time and high-quality automated data provision to support their operations.

Cost recovery is not currently in place for the aeronautical meteorological services, and this should be the key priority for the FMS and Fijian society. Currently, the costs borne by providing the required services are underpaid leading to a situation where the Fijian government and taxpayers are subsidizing the aviation business in Fiji, with ultimately the airlines and passengers (mostly international) as the final beneficiaries.

Cost recovery, as defined by ICAO, shall follow the four key charging principles of non-discrimination, cost-relatedness, transparency and consultation with users in the national legislation, regulation and air service agreements. The cost to be allocated is the full cost of providing the aeronautical meteorological service, including appropriate amounts for cost of capital and depreciation of assets, as well as the costs of maintenance, operation, management and administration (ICAO, 2012 – see Doc 9082, Section III, paragraph 3i).

Moreover, according to ICAO, good relations between regulators, ANSPs and users are important for the proper development of air transport. Consultation and cooperation lead to increased mutual understanding between ANSPs and users, thereby improving efficiency and cost-effectiveness in the provision and operation of air navigation services, with all the parties striving to move in the same direction. Consultation with users covers all aspects referred to in ICAO Doc 9082 (ICAO, 2012), namely, changes in charging systems or levels of charges, air navigation services planning (capacity development and investment plans), performance management, service quality and pre-funding of projects.

The advantages of transforming the FMS into a government-owned autonomous entity that is self-financing, charges for its services, funds operating expenses and finances capital expenditure using revenues from these charges while applying commercial accounting standards and practices are the following:

a) Ensures revenue generated using air navigation and other resources are transparently reinvested in operating and developing the facilities.

b) Ensures that the users of air navigation and other services contribute directly to the running, maintenance and development of the facilities that they use (the "user pays" principle).

c) Reduces the government financing burden.

d) Encourages development in business orientation and culture (for example, better monitoring of revenues and expenses, faster decisions and more responsive actions, and good governance), leading to increased efficiency and improved service quality.

e) Greater open access to private capital markets. This, however, requires larger legislative and organizational changes due to public sector borrowing restrictions.

f) Unequivocal division of the functions to regulate and operate.

The framework typically used for defining the proportion of the national meteorological service costs to be allocated to civil aviation is as follows. Guidance is provided by ICAO and WMO, which includes an inventory list of services or products that can be attached to civil aviation services. However, it is open to some interpretation, since the guidance material of WMO and ICAO is nonbinding. In addition, there are multiple methods of estimating and calculating the proportion of meteorological costs to be recovered through aeronautical navigation service charges. To establish the aeronautical meteorological cost base, the national meteorological costs are usually divided into (Eurocontrol, 2004):

- Direct costs for aeronautical meteorological services
- Direct costs relating to other industries
- Core costs for services that provide the underpinning infrastructure to enable the delivery of the product to individual industries.

Table 10 is a calculation of possible total meteorological service costs to be recovered as part of air navigation costs in Fiji (Fiji Airports Limited, 2012–2016). The latest available annual report by Fiji Airports limited was from 2016: the calculations in the table assume growth of at least +2% p.a. in air traffic movements since then. The assumption seems rather conservative since the increment rate between the years 2012 and 2016 (last reported) has been significantly higher on average.

Table 10. Estimated recovered costs from civil aviation weather services. 2012–2016 reported air traffic movements and fees, 2017–2021 estimated.

	2012	2013	2014	2015	2016
Total landings	78,409	78,380	91,691	89,179	97,507
Air navigation service units	2,984,252	3,155,313	3,192,107	3,488,516	3,808,559
AIR NAVIGATION FEES					
Landing and parking fees	USD 11,900,000	USD 12,100,000	USD 11,900,000	USD 18,200,000	USD 21,600,000
Air navigation charges	USD 10,300,000	USD 11,000,000	USD 11,100,000	USD 19,200,000	USD 21,900,000
Total	**USD 22,200,000**	**USD 2,310,000**	**USD 23,000,000**	**USD 37,400,000**	**USD 43,500,000**
Approx. Met costs of air navigation and landing charges	3%	3%	3%	3%	3%
FMS Recovered aviation costs (est.)	**USD 666,000**	**USD 693,000**	**USD 690,000**	**USD 1,122,000**	**USD 1,305,000**
	2017	**2018**	**2019**	**2020**	**2021**
Total landings	99,457	101,446	103,475	105,545	107,656
Air navigation service units	3,884,730	3,962,425	4,041,673	4,122,507	4,204,957
AIR NAVIGATION FEES					
Landing and parking fees	USD 22,032,000	USD 22,472,640	USD 22,922,093	USD 23,380,535	USD 23,848,145
Air navigation charges	USD 22,338,000	USD 22,784,760	USD 23,240,455	USD 23,705,264	USD 24,179,370
Total	**USD 44,370,000**	**USD 45,257,400**	**USD 46,162,548**	**USD 47,085,799**	**USD 48,027,515**
Approx. Met costs of air navigation and landing charges	3%	3%	3%	3%	3%
FMS Recovered aviation costs (est.)	**USD 1,331,100**	**USD 1,357,722**	**USD 1,384,876**	**USD 1,412,574**	**USD 1,440,825**

Source: Fiji Airports Limited, 2012–2016 (reported), Authors (estimated).

Establishing a cost-recovery mechanism is always a political decision and needs to be accepted by the responsible ministries. It must be noted that implementing a cost-recovery mechanism can be rather simple, but consultation by external and/or international experts may be needed to support the cost analysis on meteorological services since FMS is relatively inexperienced in this area.

Recommendations:

- Invest in the necessary technology and human resources to ensure its position as the designated service provider for aeronautical meteorological services *(Phase 1)*.
- Take the following steps toward cost recovery *(Phase 1):*
    1. Discussions and agreement with responsible ministries
    2. Discussions and agreement on the outlines of the cost-recovery mechanism with civil aviation authorities
    3. Development of the model for the cost recovery and detailed, transparent mapping of the costs related to the aviation weather service
    4. Separation of aviation weather forecaster duties and other forecasting duties into separate shifts in the weather forecast office
    5. Formalizing an annual process for monitoring and reporting of the costs and duties
- Take the following additional steps toward cost recovery *(Phase 2):*
    6. Negotiations on the agreement on services provided outside Fiji
    7. Signing of MoU (or similar) with countries' authorities
    8. Service-level agreement with different authorities on the services and products to be provided

5.3.2 Cost Recovery for Other Services

The principles for cost recovery for the aeronautical weather services also apply to other services provided by the FMS. Currently, the best potential lies with hydrological and weather services for hydroelectricity and with government-owned Energy Fiji Limited.

Recommendation:

- Move hydrological and weather services for hydroelectricity under a cost-recovery mechanism if possible. *(Phase 4)*

5.3.3 Climate Services

As previously stated, the most significant gaps in climate services are the lack of real-time collection of part of the observations alongside the use of manual procedures in data management.

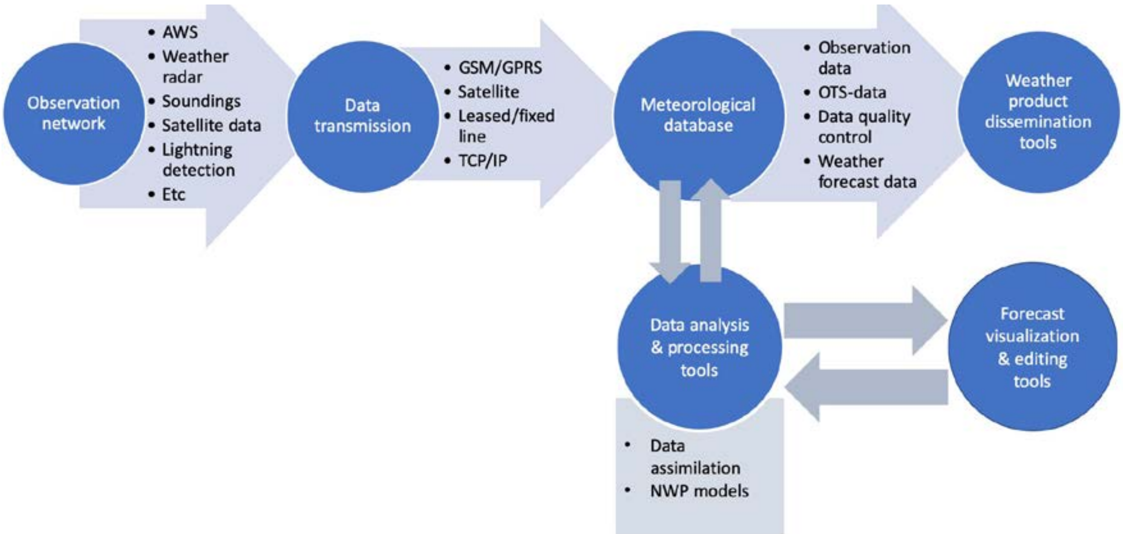
Ensuring real-time data acquisition is a critical issue, and it should be considered when renewing or acquiring new observation stations. Modern weather services no longer separate weather observation databases and climate observation databases. Observations are stored in a single database, which is used by both weather and climate services.

To operate successfully, a modern meteorological data management system requires all the elements shown in Figure 37. The whole chain of the data management process becomes useless if there are missing or dysfunctional components. The technical level—and the size of the investment—required for each component depends on the products and planned activities.

Recommendations:

- Modernize and centralize the data management system *(Phase 1)*. This includes:
  - Collecting and storing the observations in real time and build in potential for automatic quality control
  - Include (or have a direct link to) a production system that enables automatized production of different end-user products such as maps, graphs etc. (For example, modern climate services produce automatically daily and monthly map images and graphs on the climate variables such as mean temperatures or precipitation etc.)
  - Include automated data quality control measures and procedures
  - Include station and observation metadata information
- Modernize the data management system to serve both the meteorological centre and climate service in the FSM. *(Phase 1)*

Figure 37. Schematic presentation of a data management system.



AWS = Automated Observation Station

GSM /GPRS = Global System for Mobile Communications / General Packet Radio Services

TCP/IP = Transmission Control Protocol/Internet Protocol

OTS = Observation Time Series

NWP = Numerical Weather Prediction

Source: FMI, 2019.

5.3.3.1 DATABASE IN AN INTEGRATED DATA MANAGEMENT SYSTEM

Databases are a critical part of any data management system, and there are several engines or platforms available. The particular engine in any NHMS environment is not necessarily relevant; however, the detailed design (including the structure of the database tables) is important. Also, the staff operating the database need to have knowledge of the system and the database design and platform.

Open-source systems have multiple benefits and the value or importance of some of these benefits is even magnified in developing countries. These include, among others:

- No licence commitment or fees
- Good interoperability with other systems
- Minimal risk of depreciation
- Active community of users

However, technical support needs may require separate contractor selection. Also, security and usability might be issues in some open-source solutions.

The climate services (as well as other operational services in FSM) would need research activities to support and develop service provision and climate forecast model downscaling activities. (Phase 4). These are described in Chapter 5.4.

Recommendation:

- Use an integrated database for observations using open-source solutions such as PostgreSQL or My SQL. *(Phase 1)*

5.3.4 Weather Forecasting, Forecast Systems and Service Provision

At the time of this analysis, FMS appears to be in a difficult technical situation with fragmented weather forecasting infrastructure. Using five different weather forecasters and forecast production software setups is unsustainable, laborious and costly to operate and maintain. It is critical that the FMS choose one (or at most two systems) for future forecasting work and service provision. The most modern ones are the IBL and SmartMet software, which makes them the most natural choices. Open-source programs should also be favoured to reduce costs and to avoid falling into a trap of recurring licence fees. IBL is a licensed, while SmartMet is open-source. It is also essential that the production model (together with the tools) is brought up to date, thus enabling digitalized forecast production with modern forecast formats. This should be made reflecting the needs of the Fijian society, stakeholders and customers. Enabling customization of the services and products with up-to-date tools also enhances the opportunities for getting new customers.

Recommendations:

- Follow a 10-step process for developing the forecast services and forecast production :
    1. Clear selection of the forecast production tools and limiting the number of systems to a reasonable number. *(Phase 1)*
    2. Creation of business model and business plan. *(Phase 2)*
    3. Developing the business and marketing aspects by establishing separate customer relations and business units and concentrating those operations there. *(Phase 3)*
    4. Operationalizing forecast production with the IBL (and possibly with SmartMet) and moving from a completely manual production model into automated or semi-automated forecast production. *(Phase 1-2)*
    5. Start forecast production in digital (gridded) format. *(Phase 2)*
    6. Operationalizing the weather warning services using digital formats and Common Alerting Protocol (CAP). *(Phase 2)*
    7. Development of the impact-based forecasting services following WMO guidelines (WMO, 2015a). *(Phase 3)*
    8. Establish an integrated data management system for observations and (digital) forecast products together with the climate services. *(Phase 1)*
    9. Start forecast verification for forecast quality monitoring and development. *(Phase 4)*
    10. Development of the plan for the mesoscale numerical weather prediction in Fiji, either with its own (WRF) model or in cooperation with BoM using their model. *(Phase 3)*

Some of these steps are extremely laborious and time-consuming, and it is essential to progress step-by-step toward an integrated entity. For example, establishing an integrated data management system typically takes at least a few years and requires a completely dedicated project.

Regarding the mesoscale numerical weather prediction, if FMS choose to adopt ACCESS weather models, the following should be considered:

1. The operational version should be ACCESS-C+ to reach a resolution similar to the WRF (4 km).
2. The whole dataset for the model (including all model surface parameters and vertical level parameters) should be available for the FMS in a gridded format for the workstations and production system.

5.4 Priority Actions for FMS' Organization and Management

The organization of the FMS does not fully support its future activities and actions and the priority actions identified in this analysis. As already mentioned, meteorological services around the world are currently asked to act more and more as service provision institutes. With the increasing uncertainties associated with the impacts of climate change, societies require more customized and dedicated services to support decision making. Customer liaison is an extremely important function of a modern weather service, and mapping stakeholder needs—and developing products to meet those needs—should be an ongoing process. The required services and products are becoming increasingly complex and need a lot of preparation work. Development plans must also not only consider the investment needs in technology and software but also the investment needs in buildings and new staff. The scientific level of staff at the FMS is presently not optimal for very rapid modernization and improvement of services. The necessary meteorological background associated with some services may be very complex and require scientific research activities. For example, impact-based forecasting is based on the research of the effects of weather events on different sectors or activities in the society and requires cross-sectoral research activities from the meteorological services and sectors affected.

Recommendations (by order of action):

- Create a business model and plan (Phase 2)
- Establish a separate business unit for customer relations and liaison activities (Phase 3)
- Establish research activities to support the business model and plan (Phase 4) including:
    - Provision of climate services and product development
    - Impact-based forecast and warning services
    - Numerical weather prediction activities
    - Weather forecast product development
    - Hydrological forecast services
- To support the above, establish a dedicated research unit inside FMS (Phase 4).

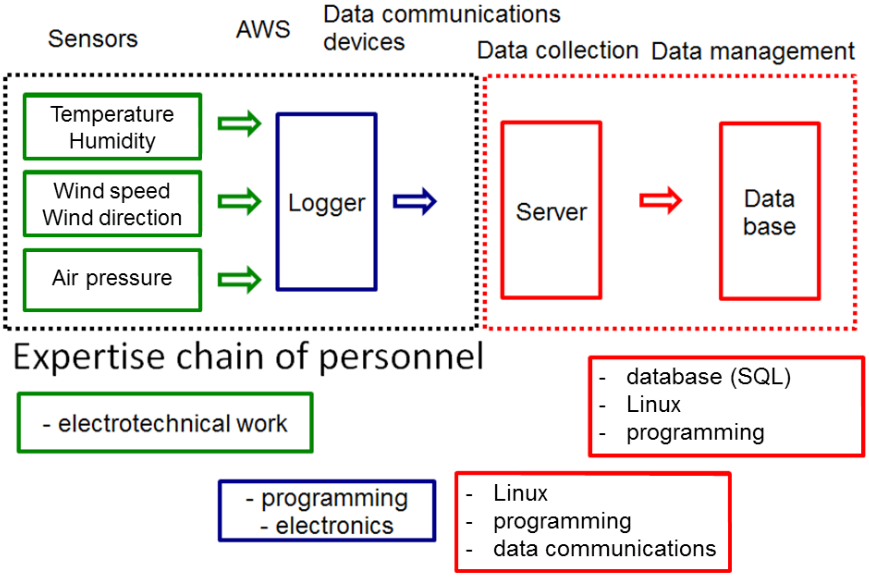
5.5 Priority Actions for Training and Education

Modern NHMSs must provide state-of-the-art services and the best possible weather forecasts to community and different economic sectors. The scientific and technical staff at the FMS (along with managers) need to be properly equipped. The FMS need to start rolling out a training component to raise the awareness of all staff.

Recommendations *(Phase 2):*

- Train directors, middle management and experts of general management in areas ranging from:
    - Vision/strategy and annual activity planning
    - Leadership skills
    - Human resources management
    - Raising funding
    - International cooperation and research programs
    - Regional cooperation
    - Operation of a modern NHMS
    - Technical possibilities, including remote sensing systems, communication & information
    - Cooperation with customer and end-user sectors
    - Dissemination of information
- Train IT staff on modern weather observation forecast systems and software environment. The exact contents depend on the chosen technologies; however, topics on Linux, PHP, SQL, Python and network configurations should be considered.
- Train medium-range personnel for modern meteorological forecasting services.
- Train experts on modern meteorological services, cooperation with customers, tailored products, modern software.
- Conduct further training of the hydrological staff. A good starting point would be, for example, adding Basic Instruction Packages for Hydrological Services (BIP –HWR, BIP-HWIMT, etc.) of WMO to the training program of FMS.
- Train technical staff to use AWSs. For example, the skills needed for AWS -operations are shown in Figure 38.

Figure 38. Skills needed for AWS operations



Source: FMI, 2019.

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Rerevaka na Kalou ka doka na Tui