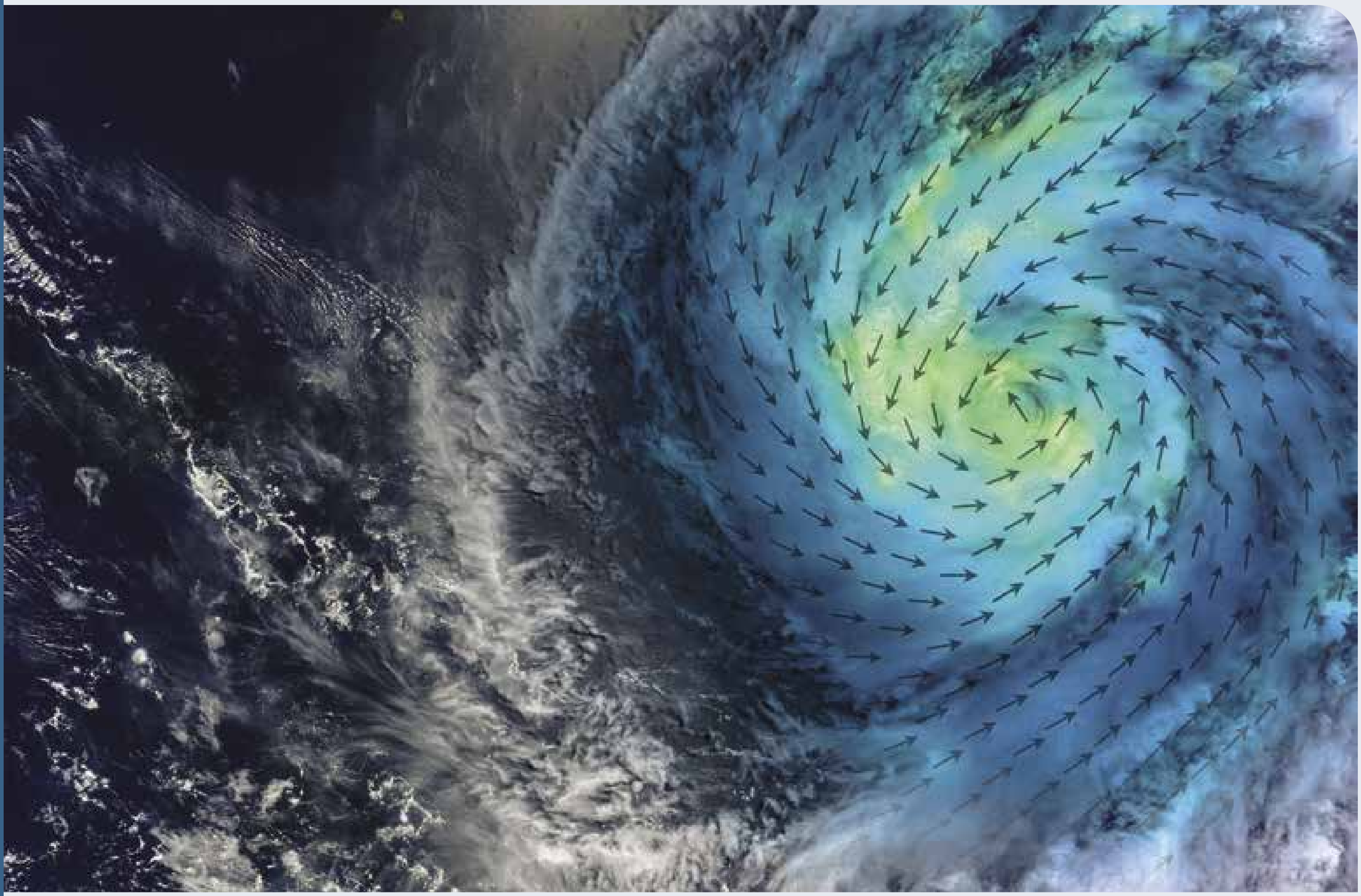
STRENGTHENING HYDROMET AND EARLY WARNING SYSTEMS



Weathering the Change

How to Improve Hydromet Services in Developing Countries

Authors
David P. Rogers
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Notes: Fiscal year (FY) runs from July 1 to June 30; the financial contributions and expenditures reported are reflected up to June 30, 2017; all dollar amounts are in US dollars ($) unless otherwise indicated.

Cover photo: Elen11.
Design: Miki Fernández/ULTRA Designs, Inc.

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Field training on snow and avalanche risk assessment for Central Asian specialists near Almaty, Kazakhstan. *Source:* M. Schaer, Swiss Institute for Snow and Avalanche Research (SLF), 2019.

Acknowledgements

The authors are grateful to the many institutions and individuals that have contributed to the improvement of national meteorological and hydrological services throughout middle- and low-income countries. We are especially grateful for the hard work and persistence of the many current and former World Bank staff who have led these efforts, including:

Greg Browder, Saurabh Dani, Tafadzwa Irvine Dube, Suranga Kahandawa, Ditte Fallesen, Haris Khan, Daryl Fields, Shelley McMillan, Poonam Pillai, Anil Pokhrel, Frederica Ranghieri, Claudia Sadoff, Prashant Singh, Lia Sieghart, Ulan Torobekov, Tolkun Jukusheva, Xiaolan Wang, Lucy Hancock, Naohisa Koide, Tetiana Shalkivska, Suiko Yoshijima, among many others.

We are also indebted to the many discussants at the GFDRR-sponsored event on the modernization of NMHSs, which was co-hosted by InterMET Asia 2018 in Singapore. In particular, we would like to recognize the insights of Patrick Benichou (Meteo France International), Mike Bergin, (Bureau of Meteorology), John McHenry (Baron), Marcel Marchand (Deltares), Khanmany Khoun Phonh (Director General of the Department of Meteorology and Hydrology, Lao PDR), Harri Pietarila (Finnish Meteorological Institute), Andi Sakya (Permanent Representative of Indonesia with WMO), Luc Randriamarolaza (Direction Générale de la Météorologie, Madagascar), Hanneke Schuurmans (HaskoningDHV), Govindarajalu Srinivasan (Regional Integrated Multi-Hazard Early Warning System for Africa and Asia), Michael Tanu (Permanent Representative of Ghana with the WMO), Moleni Tuuholoaki (Tonga Met Service).

The authors would like to thank the World Meteorological Organization, ECMWF, USAID, UK Met Office, National Weather Service, ZAMG (Austria), MeteoSwiss, Roshydromet, JMA, and other NMHSs for the collaboration in strengthening of the national meteorological and hydrological services.

The team would like to thank Yoko Kobayashi, Erika Vargas, David Tucker, and Laura Wallace for their help in the preparation of the book. The team thanks Julie Dana, Manager of the Global Facility for Disaster Reduction and Recovery as well as Francis Ghesquiere, former Manager of the GFDRR, who have supported this work.

List of Acronyms

ACAS	Agriculture and Climate Advisory Service
AFD	French Development Agency
AFDB	African Development Bank
AFR	Africa Region
AI	Artificial Intelligence
AMDAR	Aircraft Meteorological Data Relay
API	Application Programming Interface
ARSO	Slovenian Environment Agency
ASECNA	Agency for Aerial Navigation Safety in Africa and Madagascar
AWS	Automatic Weather Station
BMKG	Indonesia Meteorology, Climatology and Geophysical Agency
BOBER	Better Observation for Better Environmental Response
CAHMP	Central Asia Hydrometeorology Modernization Project
CAP	Common Alerting Protocol
CAREC	Central Asia Regional Economic Cooperation
CMA	China Meteorological Administration
CONOPS	Concept of Operations
CREWS	Climate Risk Early Warning Systems
DCRMP	Disaster and Climate Risk Management Project
DMH	Myanmar Department of Meteorology and Hydrology
DRM	Disaster Risk Management
EAP	East Asia and Pacific Region
ECA	Europe and Central Asia Region
ECMWF	European Centre for Medium-Range Weather Forecasts
ECOMET	Economic interest grouping of the National Meteorological Services of the European Economic Area
EPS	Ensemble Prediction System
EUMETNET	European Meteorological Services Network
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FIF	Financial Intermediary Fund
GCF	Green Climate Fund
G2B	Government-to-Business
G2G	Government-to-Government
G2P	Government-to-Public
GDP	Gross Domestic Product
GDPFS	Global Data-processing and Forecasting System
GFDRR	Global Facility for Disaster Reduction and Recovery
GFCS	Global Framework for Climate Services
GIS	Geographic Information System
GPC	Global Prediction Center
GPC	Global Production Center
GPS-RO	Global Positioning System – Radio Occultation
GTS	Global Telecommunication System
GWE	Global Weather Enterprise
HMEI	Association of Hydro-Meteorological Equipment Manufacturers
HPC	High Performance Computing
IA	International Advisor
IaaS	Infrastructure as a Service
IABM	International Association of Broadcast Meteorologists
IBRD	International Bank for Reconstruction and Development
ICAO	International Civil Aviation Organization
ICT	Information and Communication Technology
IDA	International Development Association

IMO	International Maritime Organization
IoT	Internet of Things
ISO	International Standards Organization
LAC	Latin America and Caribbean Region
LAM	Limited Area Model
LMIC	Low- and Middle-Income Countries
MENA	Middle East and North Africa Region
MoldATSA	Moldovan Air Traffic Services Authority
MOS	Model Output Statistics
MOU	Memorandum of Understanding
MTR	Mid-Term Review
NCEP	National Centers for Environmental Prediction
NFCS	National Framework of Climate Services
NHS	National Hydrological Service
NMA	Romania National Meteorological Administration
NMHS	National Meteorological and Hydrological Service
NMS	National Meteorological Service
NWS	National Weather Service
NWP	Numerical Weather Prediction
O&M	Operation and Maintenance
PMD	Pakistan Meteorological Department
PMU	Project Management Unit
PPCR	Pilot Program on Climate Resilience
PRIMET	Association of Private Meteorological Services
PWS	Public Weather Service
QA/QC	Quality Assurance/Quality Control
QCBS	Quality- and Cost-Based Selection
QMS	Quality Management System
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecast
QTF	Quantitative Temperature Forecast
RCC	Regional Climate Center
R&D	Research and Development
RSMC	Regional Specialized Meteorological Centre
RTC	Regional Training Center
SAR	South Asia Region
SAWS	South African Weather Services
SDG	Sustainable Development Goals
SHS	Moldova State Hydrometeorological Service
SI	Systems Integrator
SLA	Service-Level Agreement
SOLAS	Safety of Life at Sea
SWFDP	Severe Weather Forecasting Demonstration Project
UCAR	University Corporation for Atmospheric Research
UN	United Nations
UNDP	United Nations Development Program
UNISDR	United Nations Office for Disaster Risk Reduction
WB	World Bank
WBG	World Bank Group
WFP	World Food Program
WIS	WMO Information System
WMO	World Meteorological Organization
WRMA	Weather Risk Management Association
WWW	World Weather Watch
ZAMG	Austrian Central Institution for Meteorology and Geodynamics

A Guide to Key Terminology

Academic Sector: Public and private high education establishments and non-profit research institutions.

Business Plan: A roadmap for an organization outlining goals and how those goals will be achieved – it can be used to justify increased financing.

Business model: Describes how an organization creates, delivers and captures value.

Concept of Operations: A document describing the characteristics of a proposed system from the view point of an individual who will use that system.

Global Weather Enterprise: A term coined to describe the totality of activities by individuals and organizations to enable weather information to be created and provided to society. It encompasses the public, private and academic sectors.

Meteorology: The scientific study of the Earth's atmosphere as it relates to short-term weather and long-term climate variations.

Hydrology: The scientific study of the Earth's water system.

Impact-based Forecasts and warnings: Forecasts and warnings designed to express the expected impacts as a result of the expected weather. They require information on the hazard and the vulnerability of those affected.

Impact Forecast and Warnings: Forecasts and warnings designed to provide detailed information down to the individual, activity or community level. They require information on the hazard, and the vulnerability and exposure of those affected.

Meteorological and hydrological hazards: Flash floods, river floods, thunderstorms, tropical cyclones, and other extreme weather-related events, as well as slow-onset hazards, such as droughts.

Weather, climate, and water: A tag used frequently instead of meteorology and hydrology. Meteorology is inclusive of weather and climate, and these terms are interchangeable. Water refers to hydrology and occasionally to oceanography. The term meteorological embraces both meteorological and climatological phenomena.

NHMSs: An abbreviation that encompasses both National Meteorological Services (NMSs) and National Hydrological Services (NHSs). The abbreviation NMHS also refers to a national hydrometeorological service (if hydrology and meteorology are combined in a single institution).

Hydrometeorology: is a branch of meteorology and hydrology that studies the transfer of water and energy between the land surface and the lower atmosphere.

Objective Forecast: is one made without the personal judgement of the forecaster.

Operating model: Describes the underlying arrangements of people, processes, systems and information needed to execute the business model.

Private sector: Means that part of the economy run by individuals or groups.

Public Sector: means that part of the economy run by the state.

Strategic plan: A document that articulates the decisions made about an organization and the organization's goals and the ways it will achieve those goals.

World Meteorological Organization: An intergovernmental organization with 191 Member states and territories with the purpose of facilitating worldwide cooperation in the establishment of stations for making meteorological, hydrological and other geophysical observations; promoting the establishment and maintenance of systems for the rapid exchange or meteorological and related information;

promoting standards; furthering the application of meteorology to aviation, shipping, water problems, agriculture and other human activities; promoting activities in operational hydrology and close cooperation between meteorological and hydrological services; and encouraging research and training.

Forecasting: The application of science and technology to predict the state of the atmosphere for a given location on timescales of hours to years. Forecasts are often referred to as nowcasts (from 0 to 6 hours), very-short-range weather forecasts (up to 12 hours), short-range weather forecasts (from 12 to 72 hours), medium-range weather forecasts (from 3 to 10 days), extended-range weather forecasts (from 10 to 30 days), and long-range forecasts (from 30 days to 2 years). There are also monthly, trimonthly, and seasonal outlooks (covering, for example, December to February, March to May, June to August, or September to November) and longer term climate predictions (from years to centuries).

Synoptic meteorological network—a network of stations at which surface and upper-air observations (at locations that give meteorological data representation of the area in which they are situated, that could range many hundreds of kilometers) are made at standard times (i.e., main synoptic times: 0000, 0600, 1200, and 1800 UTC (Universal Time Coordinated); and intermediate synoptic hours: 0300, 0900, 1500, and 2100 UTC) for the purpose of presenting a comprehensive and nearly instantaneous picture of the state of the atmosphere

Mesoscale—in meteorology, it is the study of weather systems of horizontal resolutions generally ranging from around 5 km to several hundred kilometers, and temporal resolutions typically ranging from 1 hour to 1 day (WMO 1992). Examples of mesoscale weather systems are: sea breezes, squall lines, and large convective cells. Vertical velocity often equals or exceeds horizontal velocities in mesoscale weather systems due to non-hydrostatic processes such as buoyant acceleration of a rising thermal or acceleration through a narrow mountain pass.

Executive Summary

Climate change is impacting the lives and livelihoods of people everywhere. More people are vulnerable and exposed to the effects of extreme weather, especially through the impact of floods, landslides, droughts, heat waves and strong winds.

One way to cope is by reducing exposure to harm by providing more accurate, reliable, and actionable weather, climate, and hydrological information. This is amply demonstrated in high-income countries, where the impact of extreme weather events is mitigated by their ability to take early action based on meteorological and hydrological warnings. This is possible because these countries have invested in their publicly financed National Meteorological and Hydrological Services (NMHSs), encouraged the development of complementary private services, and invested heavily in research and development.

The gap between the most and least advanced meteorological and hydrological services is too large. Despite efforts to address the disparity between the more capable and less capable in the most vulnerable countries, a significant gap in the availability of reliable meteorological and hydrological information remains. Given the risks to lives and livelihoods, it is imperative that all countries have access to, and can use, the best available information wherever it originates. The World Meteorological Organization (WMO) encourages cooperation among its Members, which goes a long way to addressing the gaps. However, significant investment is still needed in many low- and middle-income countries (LMICs) to enable them to build on this cooperation by sustaining their own national monitoring, forecasting, and service delivery infrastructure.

Modernizing NMHSs. Equipping countries with the tools and techniques they need has been a pillar of World Bank strategy for many years. Considerable knowledge has been gained through this experience. In an earlier work, Rogers and Tsirkunov (2013a) introduced some of the basic concepts of how and why NMHSs function and the role of the WMO as the facilitator of worldwide cooperation. With that work as a starting point, this guide focuses on modernization of NMHSs with the aim of helping ensure the services are fit-for-purpose in the 21st century.

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 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 has to be useful to the users if it is to support appropriate behaviors, especially during extreme weather events.

Often, too great an 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) is central to a modern NMHS. It is the means by which all data are managed, and products and services generated. We cannot overestimate the importance of a central system for data management and the need for data policies, which require all suppliers of equipment, especially observing systems, to comply.

Investments must be sustainable. Many development projects focus on meeting the NMHSs' demands for more observations; however, sustaining this capability is difficult and the benefit of the investment often short-lived. Convincing governments to follow borrowing with investment to sustain their pubic services is a challenge—one for which there is no easy remedy. Convincing development partners that donating equipment without providing the resources to maintain that equipment is equally challenging.

The approach. A systematic approach is recommended. Preparation of complex projects requires considerable effort. 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 is a common understanding and support for the proposed operational system. The rigor 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 organization.

Reference material. Throughout the guide, we refer to many WMO publications that serve as foundation for the provision of meteorological and hydrological services worldwide. In addition to the referenced documents, teams are encouraged to access the many relevant WMO publications available through the WMO e-library.[1]

[1] https://library.wmo.int

Purpose of this guide

This guide aims to help World Bank task teams and development practitioners—as well as NMHSs, which are, or may be, involved in working with national governments—to improve the delivery of national meteorological and hydrological services to their citizens and economies. It touches on all actors involved in the production and delivery of these services, with an emphasis on the role of the public sector. The guide provides insights into how to improve the skill, efficiency, and cost-effectiveness of publicly funded NMHSs so that they can carry out their mandate to protect lives, livelihoods, and property, and are able to support economic development.

Overhead trolley at a hydrological post on the Djety-Oguz River, Kyrgyz Republic. Source: U. Torobekov, 2018.

Chapter 1
Backdrop for the Guide

Climate change is impacting the lives and livelihoods of people everywhere. More people are vulnerable and exposed to the effects of extreme weather, especially through the impact of floods, landslides, droughts, and winds.

- *Extreme weather, natural disasters, failure of climate mitigation and adaptation, and water crises are among the top five risks that will have the biggest impact on societies and economies in the next ten years.*
- *The Global Weather Enterprise (GWE)—comprising public, private, and academic sectors—is crucial for the provision of accurate and reliable weather information and services that save lives, protect infrastructure, and enhance economic output.*
- *It is recognized that meeting the challenges of a 21st century society—especially, the 2030 Agenda for Sustainable Development—now requires significant growth in all areas of the GWE.*
- *While much of the growth will be realized through the private sector, the public sector institutions—notably, National Meteorological and Hydrological Services (NMHSs)—are central to meeting each government's responsibility to warn and protect people from harm caused by extreme weather.*
- *Over the past decade, investments in NMHSs have been growing, but sustaining the improved services remains a big challenge, with many instances of equipment falling into disrepair.*

Introduction

The societal need for more accurate and reliable weather, climate, and hydrological information is growing fast as population density and migration increases and climate change takes place. Nowhere is this need more acutely felt than in low- and middle-income countries (LMICs). The Global Risk Perception Survey 2017–2018 (WEF 2018) lists extreme weather events, failure of climate change mitigation and adaptation, and water crises among the top five risks that will have the biggest impact in the next 10 years (**Figure 1.1**). The four environmental risks all have a higher-than-average likelihood of occurrence and are tangibly affecting human well-being, including health and economic prosperity.

Similarly, the World Economic Forum highlights the essential need to build a shared future that better predicts extreme risks and fosters the resilience required to mitigate these risks. More than 1 billion people have lifted themselves out of poverty in the past 15 years, but climate and disaster risks threaten these achievements (World Bank Group 2017). Global asset losses from disasters are now reaching an average of more than US$300 billion a year, which is more than the combined gross domestic product (GDP) of Sri Lanka, Ethiopia, Myanmar, and Costa Rica. A recent World Bank report finds that the impacts of disasters on well-being are equivalent to a US$520 billion drop in consumption—60 percent more than the asset losses usually reported—and force some 26 million people into poverty every year (Hallegatte et al. 2017).

How can these environmental risks be reduced, and losses avoided? Because weather, climate, and the water cycle know no national boundaries, international cooperation is essential for people and society to get timely access to high quality and actionable information to mitigate the threat of meteorological and hydrological hazards. This international cooperation takes place in what is called the Global Weather Enterprise (GWE)—a term coined to describe the totality of activities by individuals and organizations to enable weather information to be created and provided to society. The GWE is a supreme exemplar of the value of international cooperation, public-private management, and scientific technological know-how. But it now must be strengthened to match the needs of a 21st century society (Thorpe and Rogers 2018).

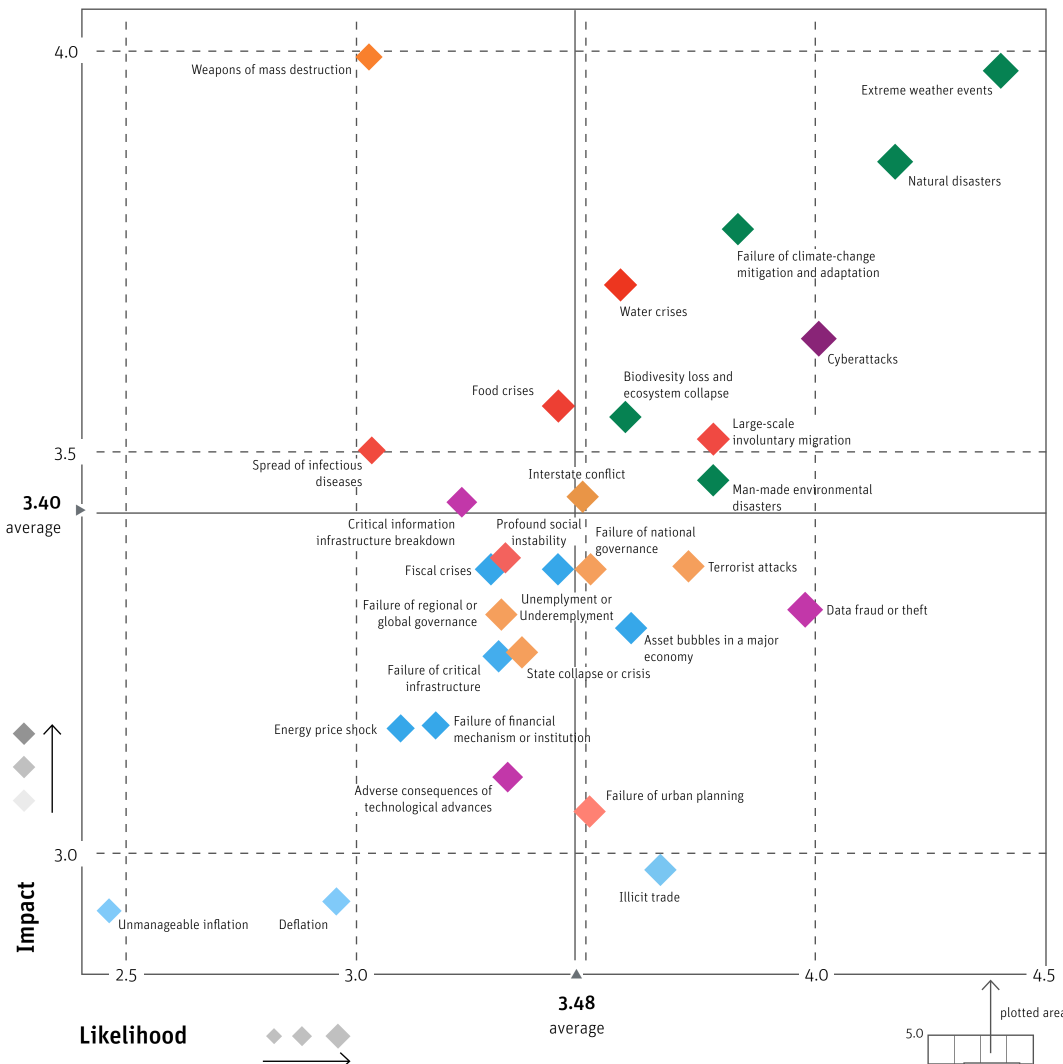
This chapter examines the current state of the GWE, the need for modernizing National Meteorological and Hydrological Services (NMHSs), and the difficulties of sustaining improvements once they occur. In effect, it sets up the rest of this report. Chapter 2 takes an in-depth look at NMHSs, highlighting the unacceptably big gap between the capabilities of the most and least advanced ones; Chapter 3 examines why NMHSs need to focus more on providing the services that their stakeholders need and want; and Chapter 4 provides detailed recommendations for modernizing NMHSs.

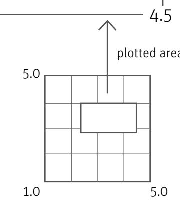
A Snapshot of the Global Weather Enterprise

What exactly is the GWE? It is an enabling environment fostering global engagement between public, private, and academic sectors that shares the common goal of providing accurate and reliable weather information and services that save lives, protect infrastructure, and enhance economic output. It includes the scientific research, technology, observations, modelling, forecasting, and forecast products that need to come together to reach this goal—a goal that is fully aligned with the requirements of the universally agreed Sustainable Development Goals (UN 2015a), the Sendai Framework for Disaster Risk Reduction (UNISDR 2015), and the Paris Agreement (UN 2015b).

So far, the GWE has been successful. But it now needs to shift into a higher gear with a better and more frequent dialogue and codesigned initiatives between the various actors in the public, private, and academic sectors (Thorpe and Rogers, 2018). Here, a key element will be a 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 sector could become the norm, instead of mutual cooperation—with significant implications for NMHSs' modernization projects.

FIGURE 1.1 Top Global Risks Include Major Environmental Issues
(The Global Risks Landscape, 2018)





Top 10 risks in terms of
Likelihood

1. Extreme weather events
2. Natural disasters
3. Cyberattacks
4. Data fraud or theft
5. Failure of climate-change mitigation and adaptation
6. Large-scale involuntary migration
7. Man-made environmental disasters
8. Terrorist attacks
9. Illicit trade
10. Asset bubbles in a major economy

Top 10 risks in terms of
Impact

1. Weapons of mass destrcution
2. Extreme weather events
3. Natural disasters
4. Faliure of climate-change mitigation and adaptation
5. Water crises
6. Cyberattacks
7. Food crises
8. Biodivesity loss and ecosystem collapse
9. Large-scale involuntary migration
10. Spread of infectious diseases

Categories

- Economic
- Environmental
- Geopolitical
- Societal
- Technological

Source: World Economic Forum Global Risks Perception Survey 2017–2018.

IMPACTS OF INCONSISTENT WEATHER WARNINGS ON PUBLIC BEHAVIOR

The coexistence of public and private weather providers can lead to a confusing multiplication of warnings, sometimes undermining the official public authority. In many countries the public can easily access inconsistent information—increasingly so on their mobile devices—that can negatively impact effective reactions and responses to warnings.

On a rainy day in November 2017, different weather information providers issued a variety of extreme weather warnings for the southernmost part of Switzerland around Lake Lugano. Warnings were issued by the national meteorological service (MeteoSwiss), the national broadcasting service (SRF Meteo), and two commercial providers (MeteoNews and Meteocentrale). They all had different visualizations (colors of warning levels), based also on different levels of forecasted rainfall. As compared to the ultimately observed rainfall, only the warning delivered by MeteoSwiss could be considered "correct."

Following the event, a survey was conducted to examine whether the inconsistency of the warnings made people doubt the whole information package (Weyrich et al. 2019). A simple matrix was developed to categorize the level of inconsistency across multiple warnings, considering both visual (warning colors) and text information. Four combinations were assessed: consistent warnings ("consistent"); inconsistent visual warnings ("inconsistent visual"); inconsistent textual warnings ("inconsistent text"); and inconsistent visual and textual warnings ("fully inconsistent").

The results showed that most people regularly consult weather information and do so from several weather providers. Half of the people who had received warnings from different providers for an event indicated that these were inconsistent. A further evaluation of warning quality and intended response actions in a decision scenario characterized by two severe rainfall warnings showed the negative impacts of these inconsistencies. Not surprisingly, consistent warnings were least confusing and fully inconsistent warnings were considered most confusing.

As Figure 1 shows, perceived warning quality and the likelihood to engage in risk minimizing behaviors were significantly higher for consistent warnings than for inconsistent warnings. There were no significant differences in the impacts of inconsistent textual information compared to inconsistent visual information on warning quality and intended actions. Enhanced cooperation between multiple weather providers is clearly warranted, in particular to agree on consistent delivery of information to incentivize risk mitigating behavior by the public.

Authors

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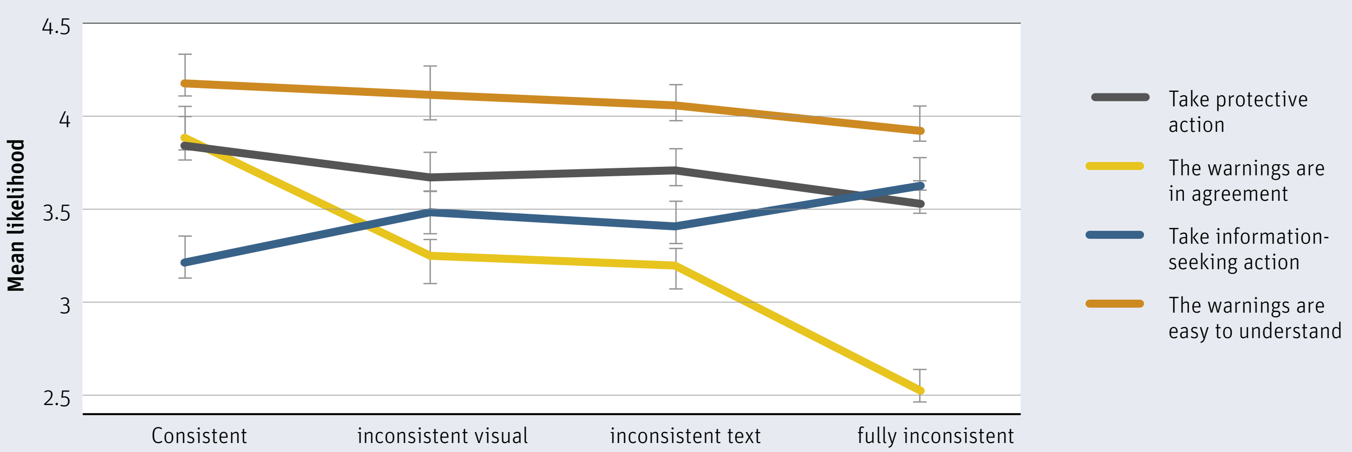
Reference

Weyrich, P., Scolobig, A., and Patt, A. 2019. Dealing with inconsistent weather warnings: Effects on warning quality and intended actions. Meteorological Applications, Doi: 10.1002/met.1785.

FIGURE 1 Intended actions and evaluation of warning quality



Note: Mean likelihood represents how much participants agreed or disagreed with each statement on a five-point Likert scale from 'not at all' to 'very'. Intended actions are represented by dark and blue lines. Warning quality variables are represented by yellow and orange lines. Error bars = 95% confidence intervals (CI).

World Bank Experience in Modernizing NMHSs

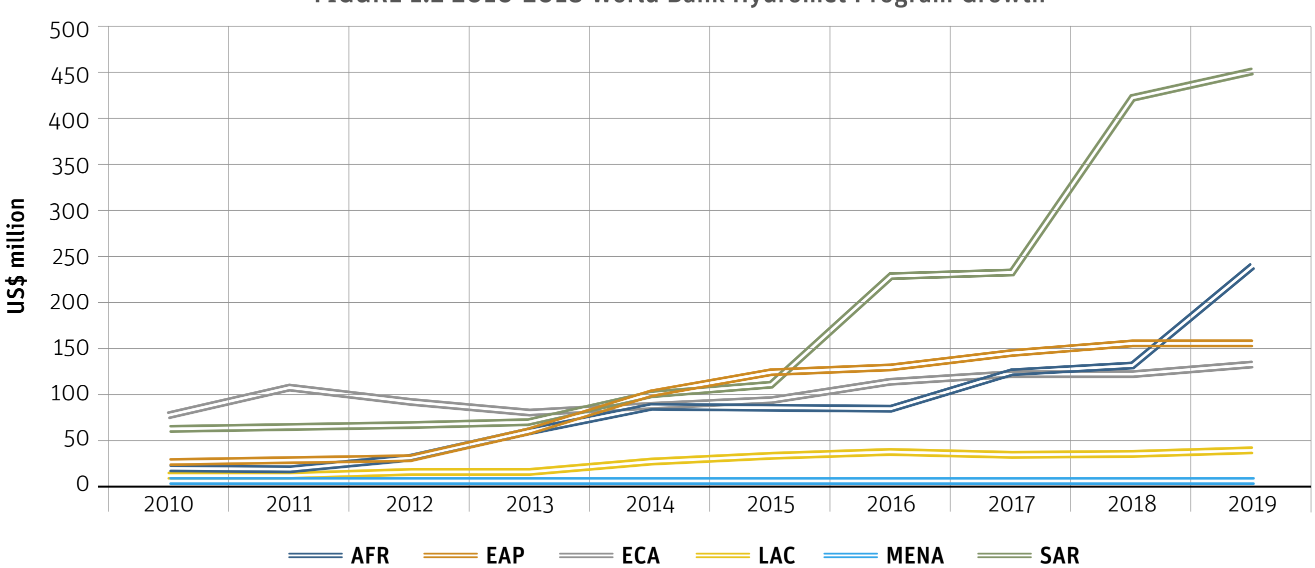
For the World Bank, modernizing NMHSs is a relatively new area of technical assistance and investment support. Until the mid-1990s, investments in NMHSs were structured as small-scale activities within water resource management, agriculture, or emergency operations—typically motivated by flooding and flood control (Hancock and Tsirkunov 2013). The aim was to improve forecasting for more than one user, but it did not address the needs of all users. The approach was fragmented, contributing to weather and climate services designed to serve a single sectoral user and partial systems. A systemic problem appears to have been the failure to integrate observations and forecasting into warning systems and services that benefit all weather-sensitive socioeconomic sectors.

In addition, a review by the World Bank Independent Evaluation Group indicates that the sustainability of hydrometeorological investments was an issue, especially for Africa, where the fragmented approach was more common until recently (Chomitz, Akhmetova, and Hutton 2012). It notes that in Africa, the network of hydrometeorological stations is sparse and deteriorating, hydrometeorological data are often spotty and inaccurate, and existing stations are often not functioning or fail to communicate with the global meteorological network. Only 4 of 12 completed African projects reported attention to maintenance, and only in the Senegal River Basin did the self-evaluation report consider sustainability to be likely (Chomitz, Akhmetova, and Hutton 2012).

Since the mid-1990s, there has been an overall rising trend in hydrometeorological investments and a gradual shift toward developing more complete systems—upgrades that serve all or many users and explicitly aim at being sustainable. In 2010, there were about 25 investment projects, or projects with components directed to hydrometeorological modernization, with total funding of US$197 million (50 percent of which was the Russia Hydromet Modernization Project). In 2018, these figures increased to almost 70 projects or components, with total funding of US$888 million—and for 2019, another US$147 million is in the pipeline. At the regional level, while Europe and Central Asia led at US$80 million in 2010, by 2018, South Asia was leading at US$453 million, followed by Africa at US$239 million (**Figure 1.2**).

Some of the initial major systems projects, which are now complete, were implemented in Poland, Turkey, and Russia (**Table 1.1**). At the time, Russia's project was ranked as the World Bank's largest hydrometeorological modernization project at US$173 million (2005–13). But since this project could not address all problems accumulated during more than 20 years of underfunding, a second modernization program is now under way (**Box 1.2**). In Poland and Turkey, hydrometeorological modernization was triggered by a major disaster that convinced governments of the importance of a well-functioning NMHS for early-warning systems and mitigating natural hazard risks.

FIGURE 1.2 2010-2018 World Bank Hydromet Program Growth



Source: GFDRR Assessment.

TABLE 1.1 Examples of the World Bank Hydrometeorological Projects

Project title	Total Project Funding (US$)	Hydromet/EWS Funding (US$)	Description	Status (as of January 2019)
Mexico: Water Resources Management Project (1996–2002)	186.5 million	41.0 million	Overall modernization of meteorology and hydrology	Complete
Poland: Emergency Flood Recovery Project (1997–2006)	200.0 million	62.0 million	Observation networks, forecasting, service improvement	Complete
Peru: El Niño Emergency Assistance (1997–2002)	150.0 million	7.0 million	Forecasting	Complete
Dominican Republic: Hurricane Georges Emergency Recovery Project (1998–2002)	111.1 million	10.0 million	Observation networks and forecasting	Complete
Turkey: Emergency Flood and Earthquake Recovery Project (1998–2005)	369.0 million	26.0 million	Observation networks and forecasting	Complete
Russian Federation: Hydromet Modernization Project I (2005–2013)	173.0 million[2]	173.0 million	Institutional strengthening, observation networks forecasting, and service delivery	Complete
Albania: Disaster Risk Mitigation and Adaption Project (2008–2012)	9.16 million	1.8 million	Strengthening of hydrometeorological services	Complete
Moldova: Disaster and Climate Risk Management Project (2010–2016)	10.0 million	5.2 million	Observation networks, forecasting, and agrometeorology	Complete
Sri Lanka: Dam Safety and Water Resources Planning (2008–2018)	143.0 million	8.5 million	Observation networks (mostly hydrological) and forecasting	Complete
India: Bihar Koshi Basin Development Project (2011–2023)	250.0 million	30.0 million	Observation networks and flood forecasting	Under implementation
Afghanistan: Irrigation Restoration and Development Project (2011–2020)	219.7 million	28.9 million	Establishing hydromet service	Under implementation
Central Asia: Hydrometeorology Modernization Project (2011–2021)	39.2 million	39.2 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
Mozambique: Climate Resilience: Transforming Hydro-Meteorological Services (2013–2019)	21.0 million[3]	21.0 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
Nepal: Building Resilience to Climate-Related Hazards (2013–2019)	31.0 million	31.0 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
Second Russia Hydromet Modernization Project (2013–2021)	179.4 million[4]	179.4 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
DRC: Strengthening of Hydro-Meteorological and Climate Services (2017–2022)	8.0 million	8.0 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
Ayeyarwady Integrated River Basin Management (AIRBM) Project (2013-2020)	100.0 million	30.0 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
Bangladesh Weather and Climate Services Regional Project (2014-2022)	113.0 million	113.0 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation

[2] Including government counterpart funding
[3] Including co-financing
[4] Including government counterpart funding

TABLE 1.1 Examples of the World Bank Hydrometeorological Projects (cont.)

Project title	Total Project Funding (US$)	Hydromet/EWS Funding (US$)	Description	Status (as of January 2019)
Lao PDR Southeast Asia Disaster Risk Management Project (2016-2022)	31.0 million	10.0 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
Pakistan Hydromet Modernization and Climate DRM Services Project (2017-2023)	210.0 million	210.0 million	Institutional strengthening, observation networks and forecasting, and service delivery	Under implementation
Burkina Faso: Strengthening Climate Resilience (2018-2024)	31.0 million	31.0 million	Institutional strengthening, observation networks and forecasting, and service delivery country's hydro-meteorological, early warning and response systems and services in targeted areas.	Under implementation
Mali Hydrological and Meteorological Services Modernization Project	47.5 million	47.5 million	Institutional strengthening observation networks and forecasting, and service delivery	In preparation
Sri Lanka Climate Resilience Improvement Project	100.0 million	30.0 million	Institutional strengthening, observation networks and forecasting, service delivery	In preparation

Since 2012, a new wave of hydrometeorological modernization projects have been initiated in Mozambique, Nepal, Vietnam, the Republic of Yemen, Myanmar, Bangladesh, Bhutan, Sri Lanka, Pakistan, Laos, Tonga, Samoa, Mali, Burkina Faso, Niger, Democratic Republic of Congo, and Federated Republic of the Marshall Islands. Now many, albeit not all, of these projects are examples of an end-to-end approach, focusing on three key areas of activities—institutional strengthening, service delivery, and modernization of the observation and forecasting systems required to improve services (Rogers and Tsirkunov 2013a).

A big problem for many of these countries is retaining highly skilled employees, such as forecasters and information technology personnel. Competition with the private sector is substantial as economies develop, and the capacity and flexibility to reward is much higher in the private sector. In addition, there is government resistance to higher remuneration for those with high qualifications—often technical workers are paid at the same level as unskilled workers. Thus, innovative ways need to be found for staffing NMHSs in these countries. Such methods may include:

- Establishing special, higher remuneration categories of employment for technical posts in the public sector.
- Using contract personnel.
- Providing incentives through specialized training and establishment of career paths.
- Using public-private partnerships.
- Outsourcing functions.

Another systemic problem is ageing of qualified staff in the NMHSs. One of a few countries that found a solution to this issue is Indonesia, where the Meteorological, Climatological and Geophysical Agency (BMKG) provides targeted support and opportunities for growth for young qualified staff. The agency proudly reports that 70 percent of its workforce is younger than 40 years.

BOX 1.2 The Russian Federation's Roshydromet Modernization

In the mid-1980s, the capacity of Roshydromet to provide services to Russia and globally was steadily declining, mostly owing to inadequate funding, which was below 50 percent of the basic operational needs. The decline affected all elements of the system: (a) observation networks; (b) data transmission, archiving, and processing facilities; (c) forecasting; (d) research and development facilities; and (e) workforce quality. After more than 20 years of decline, the government recognized the challenge of modernizing such a complex hydrometeorological system and requested World Bank assistance in preparing and implementing a modernization project. This request was processed as the first self-standing and integrated hydrometeorological modernization project in the World Bank's portfolio.

The project's objective was to increase the accuracy of forecasts provided to the Russian people and economy by modernizing key elements of the technical base and strengthening Roshydromet's institutional arrangements. The project began in 2005 and was finished in 2013. At US$173 million, it was the World Bank's largest hydrometeorological modernization project. The project was a success, reaching or exceeding the main agreed performance indicators:

- Increased lead time and accuracy of global and regional forecasts.
- Improved data collection and transmission.
- Drastic reduction of response time for requests of archived data.
- Increased reliability of seasonal flow forecasts in the pilot river basins.
- Introduction of client satisfaction surveys in Roshydromet performance evaluation.
- Development and government approval of a long-term Roshydromet strategy, which led to a massive increase in government support to the agency—from US$76.6 million in 2003 to US$570 million in 2011.

The Second Hydromet Modernization project started right after the end of the first one in 2013 to ensure continuity of the modernization process. Its objective is to further enhance the capacity of the national hydromet to deliver reliable and timely weather, hydrological, and climate information to the Russian public and economic sector. The project amount is US$179.4 million, of which the International Bank for Reconstruction and Development (IBRD) loan accounts for US$60 million.

Several key activities are focused on hydrology and rehabilitation of the hydrological observation network along the Volga River. Russia has also upgraded the computing capacity by procuring a 1.2 petaflop supercomputer for the Main Computer Center of Roshydromet, along with smaller high-performing computers (HPCs) for regional centers and research facilities. And in addition to this significant infrastructure upgrade, the project supports the institutional strengthening and capacity building of Roshydromet institutions by helping to develop decision-making systems and methodological guidelines and bringing the experiences of advanced NMHSs.

Modernization Cannot Be Piecemeal

While there is no definitive methodology to modernizing NMHSs in LMICs, there is now a sufficient body of knowledge from the World Bank Group (WBG) hydrometeorological investment portfolio, along with diverse development partners, to understand the strengths and weaknesses of different approaches. It remains an axiom that modernizing NMHSs cannot be piecemeal (Rogers and Tsirkunov 2013a, Pilon and Asefa 2011). The process should be integrated and transformative, ensuring that NMHSs can deliver the services that their users and stakeholders expect within a landscape of multiple suppliers of information. Modernization efforts must account for a number of factors:

- Growing number of development partners' and donors' programs.
- Growing interest in the private sector to provide services.
- Typically limited financial and human resources and management skills at NMHSs.
- Challenges of applying World Bank and other development partners' processes for designing and implementing large-scale integrated modernization projects.

A big issue is what level of improvement is appropriate. Sometimes modernization efforts have focused more on the technical details and infrastructure without paying sufficient attention to the expected level of services or the absorption capacity of the recipient NMHSs. If NMHSs are to contribute to saving lives and increasing prosperity, modernization

LONG-TERM SUPPORT INCREASES IMPACT AND SUSTAINABILITY

In 2008, the World Bank published *Weather and Climate Services in Europe and Central Asia: A Regional Review*, which identified serious capacity deficiencies in many NMHSs, including those in Central Asia. It also identified the significant benefits that relatively modest but sustained investments in these NMHSs could deliver. This study initiated a strategic engagement of the World Bank with the Central Asian NMHSs that continues to deliver even more results to this day.

Following the above assessment and recognizing the need for a deeper understanding of the needs of Central Asian NMHSs, a more detailed analysis was undertaken in the Kyrgyz Republic, Tajikistan, and Turkmenistan in 2009, financed by GFDRR in support of the *Central Asia and Caucasus Regional Economic Cooperation Initiative on Disaster Risk Management*, coordinated by the World Bank, UNISDR, and WMO under the umbrella of the Central Asia Regional Economic Cooperation (CAREC). The assessment laid out clear economic arguments, strategies and investment scenarios for strengthening Central Asian NMHSs.

Informed by these assessments, the *Central Asia Hydrometeorology Modernization Project* (CAHMP) was developed and approved by the World Bank in 2011, constituting a US$27.7 million IDA and PPCR investment across a regional component and two national ones (Kyrgyz Republic and Tajikistan). This represented one of the first World Bank investments in hydrometeorological services that pursued a three-pronged approach at the national level: building institutional technical and management capacity; rehabilitating and modernizing observation networks and forecast production systems (ICT); and strengthening service delivery through improved engagement with users and product delivery. This is being supported by regional investments in strategic coordination, information exchange, regional forecasting systems, and a shared training system to support professional development through peer-to-peer exchanges.

After a somewhat challenging start, CAHMP began to produce results three to four years into the project. At the same time, it became clear that more "soft" capacity building support was required. As such, in 2016 the World Bank initiated the *Strengthening of Early Warning of Mountain Hazards in Central Asia* technical assistance project, financed by three GFDRR grants for a total of US$2.1 million. In addition to providing regional training and exchange, on-the-job coaching, improved access to global forecast products, study tours, and support to develop outreach strategies and materials for better engagement with users, the project helped integrate Turkmenistan better into regional efforts, which was not participating in CAHMP.

Field training on flash flood, mudflow and landslide assessment for Central Asian specialists near Almaty, Kazakhstan. *Source:* Y. Kubakov, Regional Center of Hydrology (RCH), 2018

By 2018 the benefits of investing in the NMHSs in Central Asia through this combined national and regional approach had become obvious to the involved governments and the World Bank. As such, additional financing of US$11.5 million was approved for CAHMP, with Turkmenistan now participating. Both CAHMP and the technical assistance project are currently scheduled to continue until 2021.

While the road to modernizing the NMHSs of Central Asia has not been without challenges, the ability for the World Bank to stay engaged for over a decade has ensured that issues could be solved in a thorough and sustainable manner. While there are always project timelines that need to be met, larger operational challenges could still be tackled in a more robust and strategic manner. In addition to this long-term engagement, partnership with many highly qualified and experienced institutions such as WMO, Roshydromet, ECMWF, and several other advanced NMHSs has meant that the NMHSs of Central Asia have always had expert support available to them. At the same time, coordination with parallel support from other World Bank projects, the Asian Development Bank, UN agencies, and bilateral donors such as Switzerland and Finland have ensured more holistic support.

Monitoring station on the Syr Darya River at Kairakum, Tajikistan, *Source:* GFDRR, 2018

projects should result in NMHSs being able to deliver the services their users require. How this is achieved is likely to vary from country to country. It could be accomplished by improving all of the functional systems within an NMHS, or by teaming up with other NMHSs, outsourcing, or engaging with the private sector.

Improving 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.[5] 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 societal and economic 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 in order to gain knowledge about users, the decisions they must make, and how weather-, climate-, water-, and environment-related information is applied to minimize risk and provide benefits, not only for specific user groups but also for society as a whole. With this knowledge, service providers are able to 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.

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[5] The WMO Strategy for Service Delivery and its Implementation Plan, WMO 2014a, WMO-No.1129.

CAN WE DO A BETTER JOB PREDICTING FLOODS AND MANAGING WATER RESOURCES?

Between 21 and 22 December 2018, parts of northern Sri Lanka received over 300 mm of rainfall, resulting in extensive flooding and flash floods. In Kilinochchi district, the flooding was exacerbated by spilled water from major and minor tanks. Nine of the sluice gates of the Iranamadu water tanks were opened, causing major water logging in the paddy fields downstream in the Kandawalai division (Figure 1). Overall, the flooding affected more than 45,000 people. Coordinated by the Disaster Management Center, more than 2,000 people were rescued by troops and sent to safety centers.

Why was the warning lead time so short? The meteorological forecast issued by the Department of Meteorology gave little indication of the severity of the situation. The summary of their forecast for December 22 issued at noon on 21 December stated "Showery condition is expected to enhance over the island (particularly during 21st and 22nd), especially in the Northern, North Central and Eastern provinces due to the low level atmospheric disturbance in the vicinity of Sri Lanka." It would be difficult to conclude from the summary that a major flood would occur. The synopsis mentioned up to 75 mm of rain.

Did the forecasters miss something? The European Centre for Medium-Range Weather Forecasts (ECMWF) model output issued on 17 December predicted heavy rains for the north of Sri Lanka between 21 and 22 December (Figure 2). However, these events are often associated with high dynamical instability in the atmosphere. This means that there was a large spread by the members of an ensemble forecast—i.e., a wide range of possible outcomes. Other members showed much lower rainfall amounts.

Without looking further, it might be reasonable to assume this event was improbable. However, inspecting the Extreme Forecast Index (EFI) and the Shift of Tails (SOT)—measures of the potential for extreme weather compared to climatology for a given location and time of year—indicated differently. A high EFI value indicated that an extreme event was more likely than usual, and the SOT provided information on how extreme the event could be. Specifically, it compares the tails of the distribution of the ensemble members (the extremes) and the model climatology (so-called M-climate distribution).

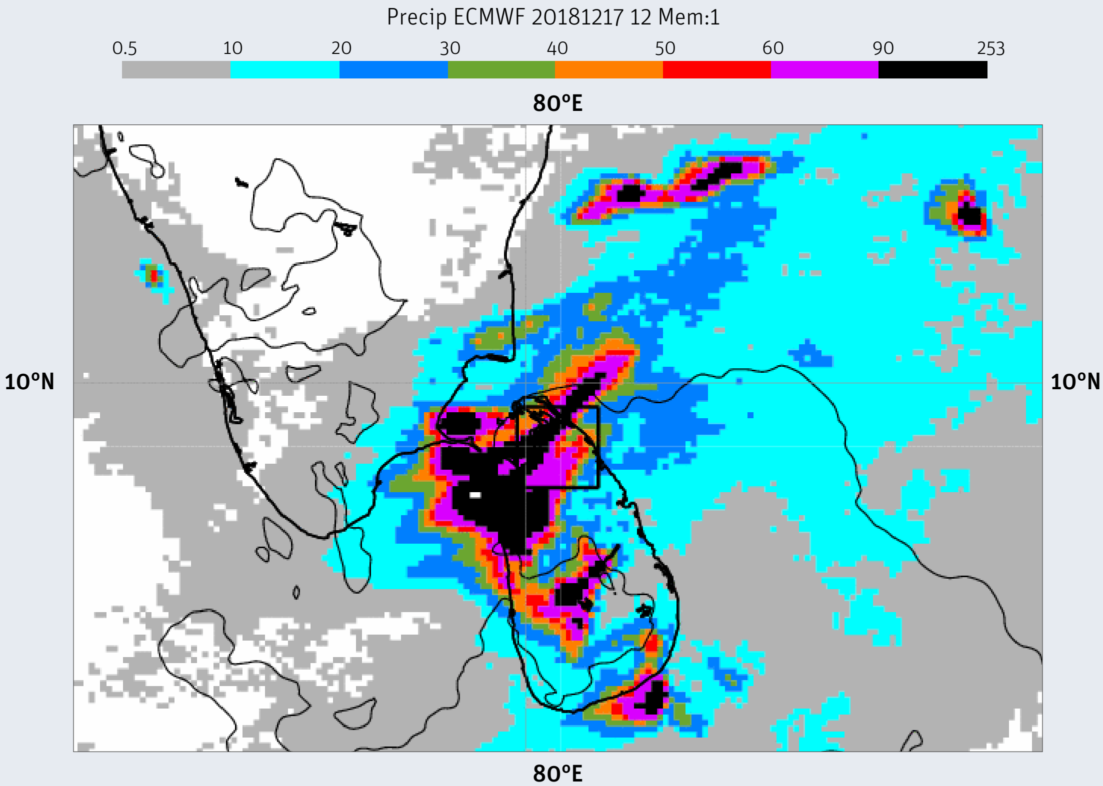
The EFI/SOT charts from 19 December showed that the EFI ranged from 0.5 to 0.7 in the northern part of Sri Lanka, which

FIGURE 1 Flood-affected paddy field in Kandawalai, Kilinochchi

Source: World Food Programme, Photo credit: Indu Abeyratne, WFP.

CAN WE DO A BETTER JOB PREDICTING FLOODS AND MANAGING WATER RESOURCES? (cont.)

FIGURE 2 Twenty-four hour accumulated precipitation 21 December 00UTC to 22 December 00UTC forecast on 17 December 12UTC



indicated that an extreme event was more likely than usual. Also, high SOT values started to appear from 18 December in the north of Sri Lanka, indicating that some members had extreme rainfall (Figure 3). This suggests that the possibility of this event should not be dismissed, and coupled with the potential for high impact, an alert of warning could have been issued as early as 19 December.

Combining the likelihood of a meteorological event happening with the impact of that event enables a risk matrix to be generated – an approach developed by the UK Met Office for warnings. This can be done for individual assets, for communities, at district levels, and so forth. In this case, we are focusing on the Kandawalai water tank. The tank was vulnerable because it was near capacity, and it would take several days to spill water safely without causing a downstream flood. Consequently, the impact would be rated as high in the matrix (Figure 4). A low likelihood coupled with a high impact would generate an amber/orange warning. This should be interpreted as recommending precautionary measures to reduce risk. In general, it is important to pay attention to medium and high impacts even when the likelihood is low or very low.

Use of the warning matrix would have enabled, permitting early action, or at the very least, raising awareness among decision makers and those at risk.

The situation highlights the importance of an integrated approach to forecasting and warnings of the impact of floods, landslides, and extreme weather. In Sri Lanka, this requires close cooperation among the Disaster Management Centre, the Department of Meteorology, the Irrigation Department, which is responsible for flood forecasting, and the National Building Research Organization, which is responsible for managing landslide risks.

A new initiative from the World Bank is helping the Sri Lankan government address these issues.

Acknowledgments

With thanks to Linus Magnusson at ECMWF for providing the ECMWF model images.

FIGURE 3 Extreme Forecast Index and Shift of Tails for total precipitation forecast on 19 December, valid 21–22 December (ECMWF)

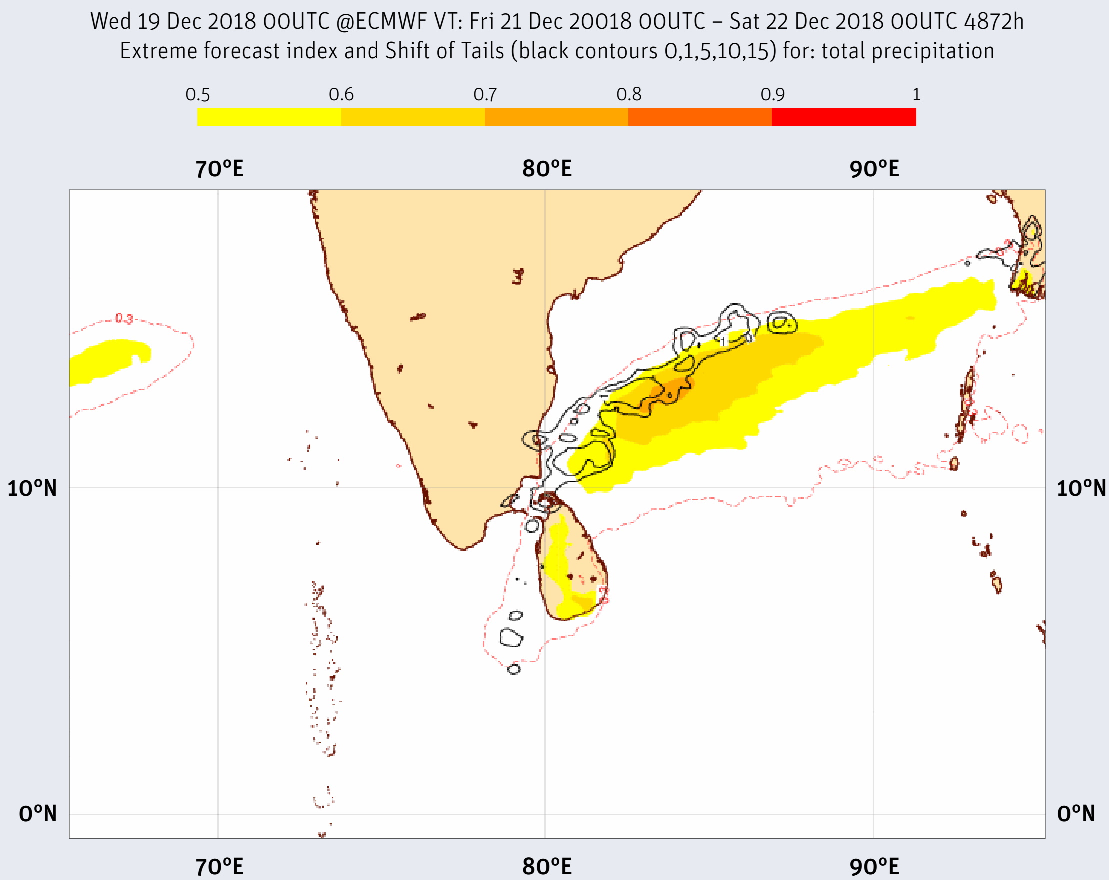
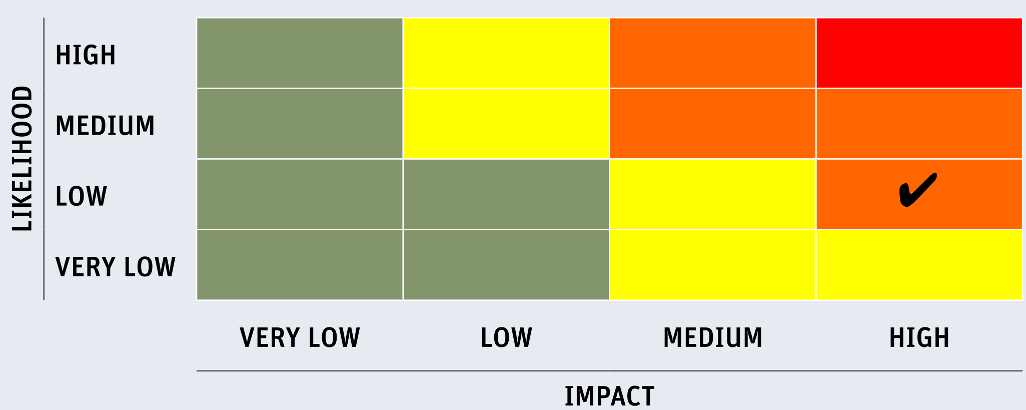


FIGURE 4 Using a warning risk matrix, the meteorological forecast indicates a low likelihood of an extreme precipitation event; the impact, however, on a dam that is near capacity would be high. Therefore, the warning would have been "amber/orange"



Doppler weather radar at the Chisinau International Airport, Moldova. Source: POPs Sustainable Management Office, 2015

Chapter 2
Meteorological and Hydrological Services

- *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.*
- *Effective service delivery is underpinned by a set of functions common to all meteorological and hydrological organizations, which we refer to as a "system of systems."*
- *These systems contribute to the overarching goal of improving services—each must reach an acceptable standard that meets all or, at least most, of the needs of users and stakeholders.*
- *Major challenges facing the public sector meteorological and hydrological services include operating and maintaining modern observing systems and embracing the advances in information and communication technologies (ICT).*

Introduction

Meteorological and hydrological services can be considered as a "system of systems," which are grouped in 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 (WMO 2014a). These are underpinned by support systems. One way to visualize this system of systems is illustrated in Figure 2.1, which shows a schematic using different colors. The categories and subcomponents are:

Delivery systems Comprising service delivery systems; and actions, services monitoring, and feedback systems.

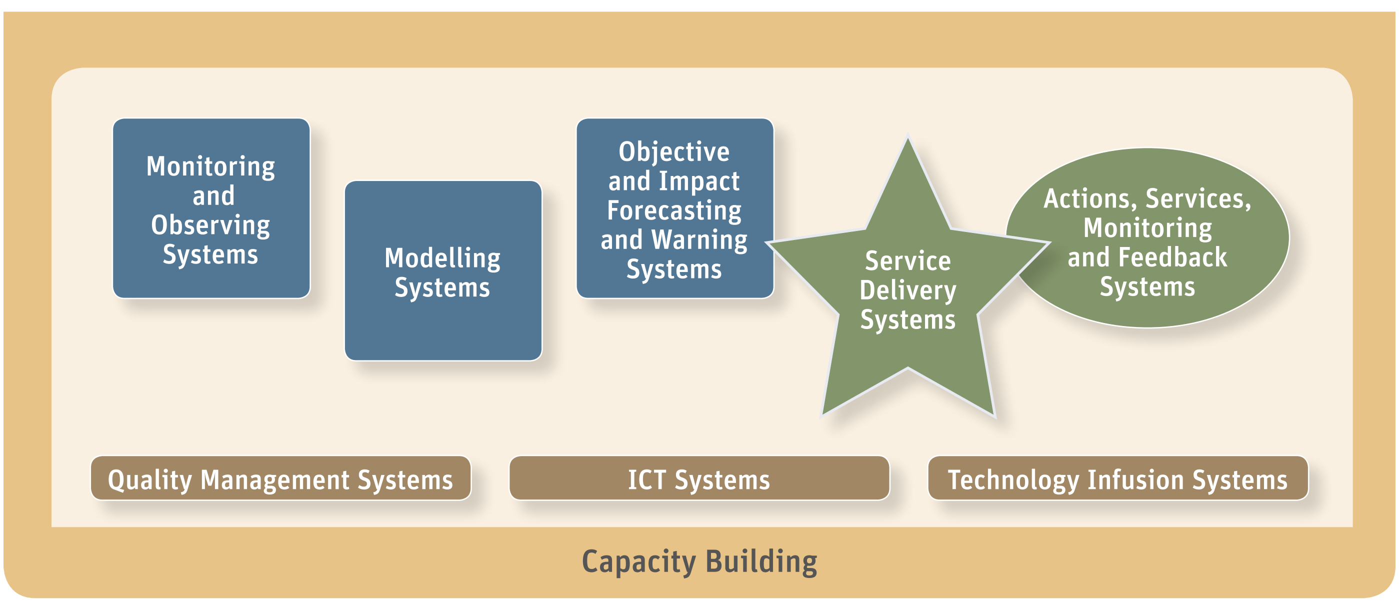
Production systems Comprising monitoring and observing systems; modelling systems; and objective and impact forecasting and warning systems.

Support systems Comprising ICT systems, quality management systems and technology infusion systems—along with capacity building.

Another way to visualize the system of systems is to view it as a matrix (**Figure 2.2**). Here services flow from left to right, cutting across the various product activities. This can be used to illustrate how more than one organization could cooperate. For example, three separate entities may provide meteorological, hydrological, and agricultural services—but they have the opportunity to share common observations, models, and means of delivering services. They could develop entirely separate systems or integrate their systems. This might include developing a common architecture for observations, common standards, and operating procedures—or even transferring responsibility for components of the observing networks to one of the entities. In the case of flood forecasting and warnings, it might be preferable to collocate the hydrologists and meteorologists that are involved in numerical prediction, and those involved in forecasting and warning preparation could collocate with disaster managers during an operational event.

This chapter takes an up-close look at the "system of systems"—and its main objective is effective service delivery. It also explores the major challenges facing the public sector, such as operating and maintaining modern observing systems and embracing the advances in information and communications technology (ICT).

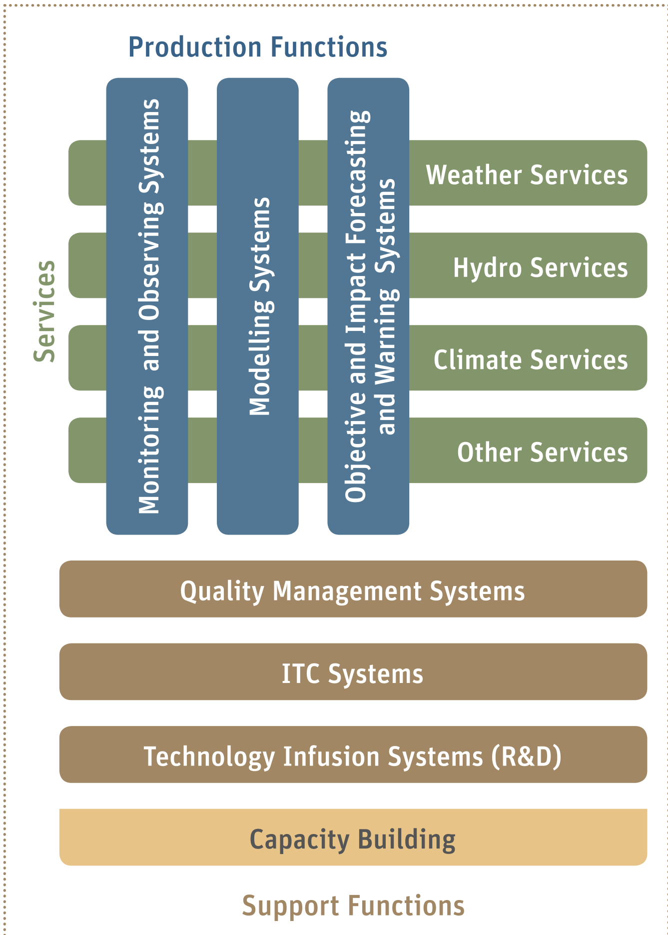
FIGURE 2.1 Schematic of an NMHS as a "System of Systems"



Note: Delivery services. Production systems. Support systems: and which underpin the delivery services and production systems.

Note: Green objects are delivery services; blue ones are production systems; items in bottom portion (brown and orange background) are support systems, which underpin the delivery services and production systems.

FIGURE 2.2 A Matrix of the "System of Systems"



Note: This matrix can apply to a single service organization or several separate entities, each having a common set of production systems and support functions.

Category 1: Delivery Systems

To understand service delivery, it is first necessary to provide a common definition of service and service delivery. *The WMO Strategy for Service Delivery and Its Implementation Plan* (herein referred to as "the Strategy") (WMO 2014a), defines service as "the delivered product and the activities associated with the people, process and information technology required to deliver it, or an activity carried out (advice, interpretation, etc.) in order to meet the needs of the user or which can be applied by a user." Service delivery is defined as "a continuous process for developing and delivering user-focused services, defined in terms of user engagement, service design and development, evaluation and improvement." To be effective, services should have the following attributes:

- **Available and timely:** at time and space scales that the user needs.
- **Dependable and reliable:** delivered on time to the required user specification.
- **Usable:** presented in user specific formats so that the client can fully understand.
- **Useful:** to respond appropriately to user needs and requirements.
- **Credible:** for the user to confidently apply to decision making.
- **Responsive and flexible:** to the evolving user needs and requirements.
- **Sustainable:** affordable and consistent over time.
- **Expandable:** to be applicable to different kinds of services.

Service delivery comprises seamless delivery of information in a tailored, interactive manner in an operational mode to the general public and specialized users. For NMHSs, service delivery takes on an emergency assistance role during extreme weather conditions to reduce disaster risk in weather-, climate-, water-, and environment-related events. Here, seamless implies integrated information relevant to the users across all appropriate timescales for their decisions.

It is useful to define some generic principles applicable to all types of services provided by NMHSs and private sector providers. In this way, service providers have the incentive to prove that their service is compliant with internationally agreed generic principles, namely: (i) science based; (ii) quality assured; (iii) user oriented; (iv) adding value to users; and (v) the best possible services that could be provided under the particular conditions of the NMHS or private sector provider.

To be "useful," services should be user driven. This means that services should be based on the requirements of users and produced and delivered in response to those requirements. However, sometimes services evolve around the research interests of service providers or have simply grown out of practices and traditions without consultation with the stakeholders or clients. Therefore, the first consideration needs to be, who are the users of the services prescribed by their programs and projects? The next most important considerations will be whether there is coherence and structure in the approach to service delivery, and whether those services possess the attributes and general principles cited above. If the responses to these questions are not overwhelmingly positive, this could be interpreted as a lack of consistent service culture among those programs.

Those NMHSs that provide commercial services involving contractual obligations are no doubt acutely aware of the need for high standards in service and service delivery, but high-quality delivery should also apply to weather-, climate-, water-, and environmental-related services that are provided to the public and to the government agencies and departments.

Good service delivery relies on the organization's internal processes, and thus those processes should be adjusted to match the service delivery systems' needs. Effective and efficient internal processes directly impact the quality of service delivery, the value of products and services, and the cost-effectiveness of an organization's day-to-day operations. The measurements of an organization's internal processes should be driven by the quality management system (QMS) used and the key processes defined therein.

The focus on understanding the users' value chain is vital because it provides knowledge about the users, the decisions they must make, and how weather-, climate-, water-, and environment-related information is applied to minimize risk and provide benefits—not only for specific user groups but also for society as a whole. With this knowledge, service providers are able to develop, produce, and deliver services that are useful, relevant, and responsive. Another important reason is that the public sector needs to ensure that the user requirements fall within the NMHSs' mission and that NMHSs have the capability to meet those requirements—in other words, that the services are "fit-for-purpose." Having a service "fit-for-purpose" implies that an agreement has been reached, either implicitly or explicitly, with users, providers, and partners. It should consider:

- Current and evolving user needs.
- Provider capabilities, including strengths and limitations.
- What services will be provided and how they will be provided.
- How services will be used.
- Expectations of acceptable outcomes and provider performance.
- Acceptable costs or levels of effort.
- Risks inherent in applying information to decision making.

If appropriate, NMHSs may want to explicitly outline the agreement reached with the user in a service-level agreement (SLA). The same principles also apply to the private-sector service providers.

In the public sector, countries benefit from a uniform and structured approach for service development and delivery, which builds upon and institutionalizes existing practices to strengthen service delivery aimed at protecting the public from harm. "The Strategy"— which draws heavily from the experiences of the WMO Public Weather Services (PWS) Programme—provides an adaptable tool and initial step for NMHSs. An emerging need is to introduce a service culture across the entire NMHSs' structures and projects through common applicable steps and activities to apply a joined-up approach, with the aim of creating a service discipline that is applicable to all programs. It is fully recognized that the content will remain the responsibility of the individual NMHSs' programs. A service-oriented culture requires the use of accuracy measures from the user's perspective, which differs from some of the accuracy measures widely applied, for example, within the Numerical Weather Prediction (NWP) community. A service-oriented organization should use forecast parameters that have a direct impact on the users' activities and operations.

Moving toward a Service Culture

What is behind the growing push for NMHSs to focus on effectively delivering the services that users and stakeholders want? The key drivers are many.

Shift toward open data. This shift in many countries stems from national or regional policies that open opportunities for service provision by different entities (such as public entities, private companies of different sizes, and research institutions). The resulting competition among public and private service providers is seen as a major driver to move toward providing high-quality services in a very efficient manner. A successful service provider should be able to demonstrate the benefits for the user through informed decision making, reliability, and cost efficiency. For NMHSs, this comes on top of their general mandate, which is related to reducing the risk to lives and adverse impacts on society.

Greater need for efficiency. A lack of public funds and competition with the private sector requires NMHSs to maximize their efficiency. Hence, a more streamlined approach is critical in the future work of NMHSs, especially service delivery.

This is an area where cooperation among the public and private sector has potential, with each exploiting the strengths and responsibilities of the other to provide cost-effective and efficient services tailored to the specific requirements of different user groups.

Social and technological changes. These pose broad challenges for NMHSs in terms of the ways in which people and activities are vulnerable to weather, climate, and water influences, along with how they use NMHS information to reduce risks and vulnerabilities and seize opportunities. Thus, the challenge for NMHSs is much more than mustering resources and achieving stable funding for infrastructure. They must also foresee and plan for a wide range of social and technological changes, including how these changes will affect their ability to provide services and enable users to realize the benefits. In many countries, the NMHSs face major hurdles in ensuring their capacity to meet the ever-growing demand for their services, while maintaining the integrity of the science that is the basis for these services—as well as providing authoritative information and advice for decision making.

The bottom line is that there needs to be major investments in many aspects of the operation of NMHSs in delivering services—such as effective tailoring of services to user needs; efficient public and private service delivery arrangements; improved methodologies and algorithms for use of meteorological, hydrological, and related information in decision making; and state -of-the-art ICT and computing facilities (**Box 2.1**).

Public-private engagement (PPE) arrangements could complement and enhance NMHS functions by developing cost-sharing and revenue-generating activities, or sales of value-added information. In agriculture, PPEs would be critical for the range and specificity of information products (like advisory services to farmers) and their market penetration. In ICT, the use of telecommunication masts for installing automatic weather stations could minimize the need for the NMHS to acquire land, and reduce O&M costs, vandalism, and other overheads.

Disaster risk reduction. Evolving national policies, legislation, and legal frameworks in areas like disaster risk reduction provide opportunities for a greater recognition of the NMHSs by governments and stakeholders. This could result in strengthened partnerships and increased resources and opportunities for providing products and services. However, it could also increase demand and liabilities for the provision of high-quality, reliable, and timely products and services to support disaster risk management (DRM) operations.

Cost-recovery services. In many instances, the NMHS is required to recover costs for its services. But the quality of those services may not have been established and, given the growth of the commercial sector, may not be the most competitive in terms of quality and cost. Faced with competition, the NMHS has a few options: one is to restrict access to data, thereby tilting the field in its favor; a second is to use legislation to delegitimize any competition. In an extreme case in one southeast Asian country, the meteorological law explicitly calls for destroying non-approved observation stations. Numerous studies have shown that restrictive data practices do not serve the national interest—and disempowering private sector providers and the ability of public and private businesses to choose their service providers, may damage economic performance. For example, if

BOX 2.1 A Major Role for ICT Developments

ICT developments in the last decade have brought enormous new opportunities in accessing data and products, and in communicating between providers and users. Traditional ways of disseminating information (like hard copy newspapers) are being rapidly replaced by web and mobile applications. Moreover, mobile devices are quickly becoming the main platform for delivering information to end-users (both corporate and individual).

As a result, the ICT capabilities of the service provider have become a key factor in the successful delivery of services. This is an area of direct competition with both national and international private sector service providers and other NMHSs that have developed sophisticated and user-friendly mobile applications. NMHSs are increasingly becoming aware of this competition, as well as recognizing that in today's fast pace of technological advances, the user/customer has many options to choose from and does not need to make the NMHS the first choice for service provision.

weather-sensitive business decisions cannot be made based on the best available analysis and forecasts, this is likely to impact profitability and consequently tax revenues.

A third option for NMHSs is to focus exclusively on their core public task—public weather services—and adopt the most efficient and effective business models. Met Norway, the Israel Meteorological Service, US National Weather Service and Japan Meteorological Agency have embraced this approach, making their data widely available and reusable[1]. The latter requires the government to adequately fund this task and to recognize that the activities of the public sector can enhance economic development by making their data openly available for reuse by others. At the same time, discipline is needed in the private sector to respect the government's decision on how to provide public services in the interests of safety of life. ECOMET, created by European NMHSs, focuses on maintaining a level playing field for commercial activities in Europe—such as operating and maintaining an administrative framework to increase and improve access to data and products, along with acting as advisors on the exchange of meteorological data and products. PRIMET is a pan-European trade association for meteorological services operating in the private sector. Together, these organizations try to constructively resolve problems that arise between public and private sectors within Europe.

New markets for services. In many areas, the users of the services of NMHSs may be driven by national policies, legislation, and mandates requiring delivery of services for certain applications. On the other hand, NMHSs may also be realizing other opportunities by identifying and developing other markets. Developing these services should be based on identification, segmentation, and prioritization of target user groups within and across sectors. It is important to understand the needs and requirements of the target users as they vary across the different user groups within a sectorial value chain. Thus, the types of products and services may range from basic over-the-counter services (products that meet the needs and requirements of a variety of users) to tailored services.

A Common Approach to Service Delivery

What is vital is that all services should be consistent and compliant with the attributes and general principles of services and related delivery methodology—recognizing by default NMHSs as the major service providers. Internal standardization of services, based on a standardization framework, will facilitate sharing and applying best practices among sectors, flexibility of staff use, and resource leveraging. It would also contribute to the branding of the service as an important part of market competitiveness.

Furthermore, this needs to be complemented with a products and service development and delivery process that would incorporate:

- Identifying and prioritizing the target users.
- Establishing working arrangements to understand the target users' needs and requirements.
- Developing products and technical support to meet the needs and requirements.
- Developing the proper service delivery model appropriate for this target user group.
- Delivering the service.
- Establishing feedback mechanisms for improving products and identifying new product opportunities with the target user.

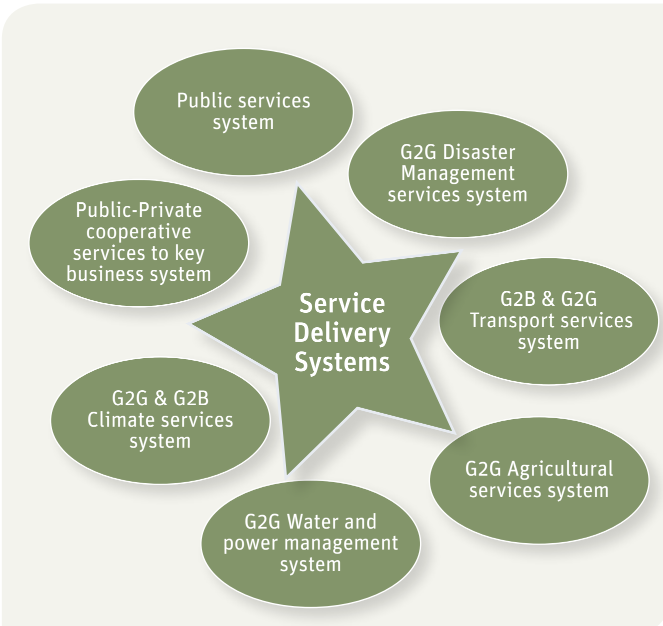
The expected benefits of such an approach for the NMHSs are: increased effectiveness and efficiency, increased competitiveness with other service providers, and sustaining and expanding their position as a public service provider. The benefits for the end-users are: receiving more quality and value, stronger focus on their primary needs, efficiency, and affordability.

In addition, there is a dynamic push now toward establishing a "user interface mechanism," instead of programs sticking to the traditional building blocks, which focus on a linear movement from data to information to services to users. In doing so, it is recognized that all programs and activities of NMHSs' systems are interdependent. Successful implementation of the user interface concept in service delivery requires much work, both on the side of technology and on the side of standardization. It is not going to be efficient and effective to develop individual user interfaces for each type of service (such as climate, weather, and water).

Thus, special efforts are needed to create a common concept and initiate work on setting up service standards that are flexible to cover different types of services. Key issues to

[1] MeteoWorld, 2016. NO.3 ISBM 1818-7137, September 2016, World Meteorological Organization, 4pp.

FIGURE 2.3 Service Delivery Systems



Note: This matrix can apply to a single service organization or several separate entities, each having a common set of production systems and support functions.

consider include the following:

- Weighing the necessity of all weather-, climate-, water-, and environment-related services to further develop mechanisms for interacting with users; identifying user requirements would be a first step.
- Establishing regular consultation and information sharing sessions among NMHSs' programs to better plan activities.
- Expanding the WMO Technical Regulations to cover generic aspects of service delivery, based on relevant standard operational procedures (SOP), in addition to the specific aspects covered by the existing regulations (like aviation).
- Improving services and service delivery through fast uptake of science and technology developments.
- Setting priorities for delivering weather-, climate-, water-, and environment-related services to meet the rapidly changing needs of society—including impact-based forecasts and warning services.
- Investing in training and capacity development—primarily for NMHS forecasters and managers, then extending the scope to cover users—based on the principles of service delivery and QMS.
- Setting competency requirements for the NMHSs to inform their staff development activities for optimum service delivery—like those developed by the WMO for aeronautical meteorological services, PWS, climate services, hydrology, and marine meteorology services.

As for the service delivery systems, these include: (a) public weather services; (b) government to government (G2G) disaster management services; (c) G2G agricultural services; (d) G2G water and power management services; (e) G2G and government to business (G2B) aviation services; (f) G2G and G2B climate services; and possibly (g) public-private cooperative services (**Figure 2.3**).

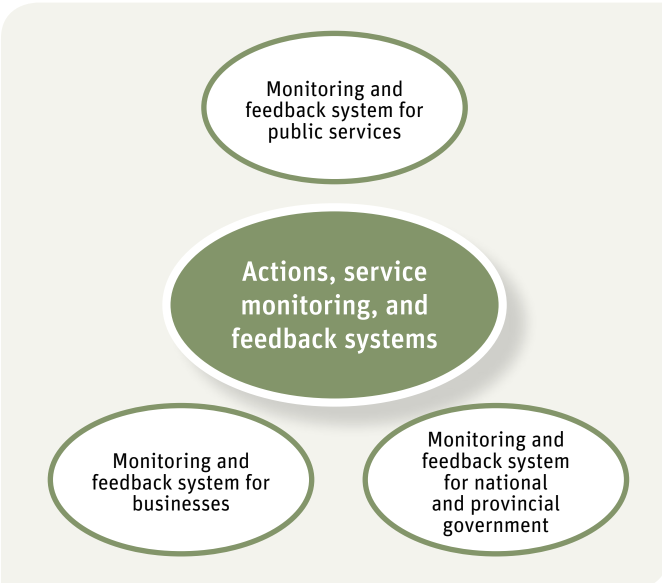
Who are the key users and stakeholders[2] of NMHSs? Certainly, water resources, agriculture and food security, and DRM services would top the list. Surveys in many countries have confirmed that:

- These sectors need real-time updates of forecasts, longer lead times, clear information (not vague), more accurate forecasts, information on impacts, and more site-specific information.
- Regular dialogue with the users and stakeholders is an essential step to develop awareness of user requirements.
- Color-coded messages are a better means of communicating warnings.
- The government is responsible for the safety and security of its citizens, and thus the provision of meteorological and hydrological warnings—the so-called authoritative voice or source.
- There is a general consensus that the conduit for these warnings is the NMHS—but views differ on whether the NMHS should do this alone, or it should be the conduit for collecting the best available data (public and private) to inform the warning services.

As for aviation and marine services, these are a somewhat special class of service because they are regulated, and the government must designate a meteorological authority, which may or may not be the NMHS. In some countries, aviation services are separate from the NMHS. In francophone

[2] A distinction is made between users, representing everyone who uses meteorological and hydrological services, and stakeholders, which may have a formal relationship with the service provider—in the case of an NMHS, this would include other government agencies. The stakeholder relationship may extend to a formal oversight role as representatives of a class of users.

FIGURE 2.4 Monitoring and Feedback Systems on Services



Note: Monitoring and feedback systems represent all of the actions, service monitoring, and feedback mechanisms from users and stakeholders to the service providers.

Africa, the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA), based in Senegal, is providing aviation services on behalf of its member governments. Regulations require that the service provider be supported by airport and overflight charges on the industry. But while this should be a significant source of revenue, many countries do not reimburse the NMHS directly for this service. The International Maritime Organization (IMO) is responsible for Safety of Life at Sea (SOLAS) regulations, which include marine meteorology. However, it does not have the same level of enforcement as the International Civil Aviation Organization (ICAO) Annex III (Meteorological Service for Air Navigation) and does not require payment from the maritime industry to support NMHSs marine forecasting operations.

Measuring customer or user satisfaction is both necessary and useful in assessing performance and areas for further development. In many NMHSs, there is no system in place to monitor the quality and delivery of services, which may be somewhat surprising given that this is the output of the organization (**Figure 2.4**). Thus, there needs to be a process to gather quantitative and qualitative information on performance from the users' perspective (**Technical Insight 2.1**). Survey tools have been developed by several NMHSs and are available to download via the WMO website. The WMO's survey of how NMHSs are performing (WMO 2015b) highlights the need for improvement—with smore than one-third reporting that they either did not have a service delivery strategy, or that it had just been initiated.[3] One area where such a strategy is required, as part of quality management, is civil aviation.

Issues related to service delivery should be considered with even more attention than is given to observing and forecasting systems. The profile of many NMHSs in LMICs as the main source of weather, climate, and water information is low among the public and stakeholders. This is attributed to a lack of active outreach and engagement with the user community, leading to insufficient awareness of user requirements. The limited capability of many NMHSs' to provide products and services required by stakeholders has contributed to lower levels of satisfaction by users.

Surveys are still the best means of measuring public satisfaction. Examples of indicators of user satisfaction are:

- Has the product fully met users' requirements?
- Is the format of the products appropriate (layout, colors, graphics, animation)?
- Is the means of dissemination and delivery adequate (easy to access, fast)?
- Is it easy to understand the content of products and services?
- Is the frequency of updates of the products sufficient?
- Are the phenomena and features shown on a forecast relevant (for example, use of isobars on a map, which may confuse people if no explanation is given and users do not see the relevance of such features to the weather's impact)?
- Is the wording used appropriate (too technical for some, or too simple for some others)?
- Are cultural norms observed in delivering the service (too formal for some cultures, or too casual for the liking of some others)?

Sectorial users' satisfaction with services is easier to determine and is usually done by personal contacts or relatively small workshops.

[3] https://www.wmo.int/pages/prog/amp/pwsp/documents/REPORT_SSD_SURVEY.pdf

What can be done to address the issues raised above and determine the current situation of NMHSs regarding service delivery? As a first step, the Service Delivery Progress Model of the Strategy (**Annex 1**) should be applied to map the existing service delivery capability of client countries' NMHSs. A next step would be to create an action plan, with short-, medium-, and long-term goals to address the weaknesses and decide on how to create the required capabilities. Allocating resources to implement the agreed actions will be essential. This would be followed by a review of the progress of activities against the action plan, and finally sharing best practices and knowledge with other NMHSs (perhaps through twinning or other collaborative activities).

TECHNICAL INSIGHT 2.1 Measuring User Satisfaction

Met Office User Satisfaction Surveys

The Met Office carries out annual and ad-hoc surveys to gain insight into the public's requirements and levels of satisfaction with our forecasts and severe weather warning services. These surveys are carried out for the Public Weather Service Customer Group (PWSCG) by independent market research companies to ensure they are unbiased and representative of the views of the UK public. They also help us to identify new requirements and ensure that the Met Office is providing services that meet public need.

Results

These are updated annually after a series of surveys are carried out.

National Severe Weather Warning Service (NSWWS) surveys

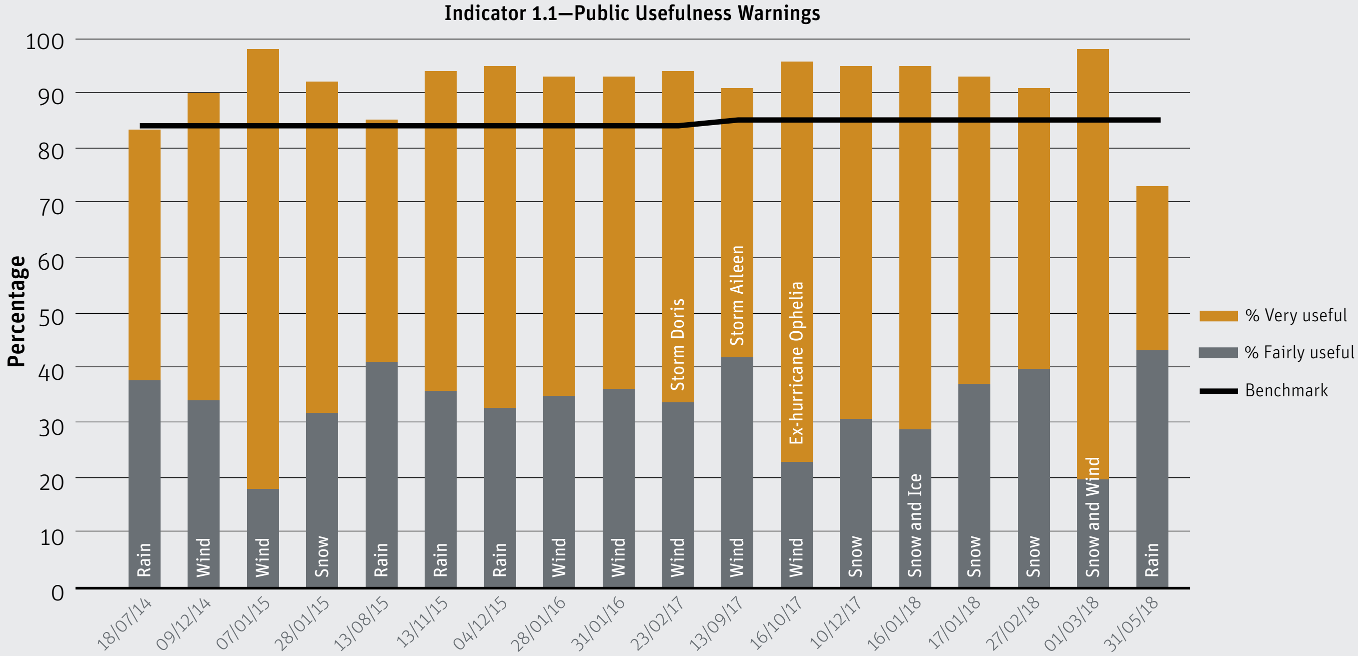
It is important to ensure that the warnings the Met Office issues reach the people who need them and that they find the warnings useful. The Met Office, therefore, carries out surveys following selected severe weather warnings.

- **Telephone interviews of 500 people in the affected area.**
- **Monitors awareness and usefulness of the warning against targets.**
- **At least six surveys are carried out each year.**
- **Conducted independently by DJS Research Ltd.**

Usefulness of warnings

- **Respondents are asked "Overall how useful would you have said this severe weather warning was?"**
- **Answers included: Very useful, fairly useful, not very useful, not at all useful, and don't know.**
- **92% of respondents found their warning very or fairly useful in 2015/16. Only five surveys were conducted during this period due to a smaller number of amber warnings being issued at times when it was appropriate to survey.**
- **The target for 2016/17 was 84% (average for at least six surveys).**

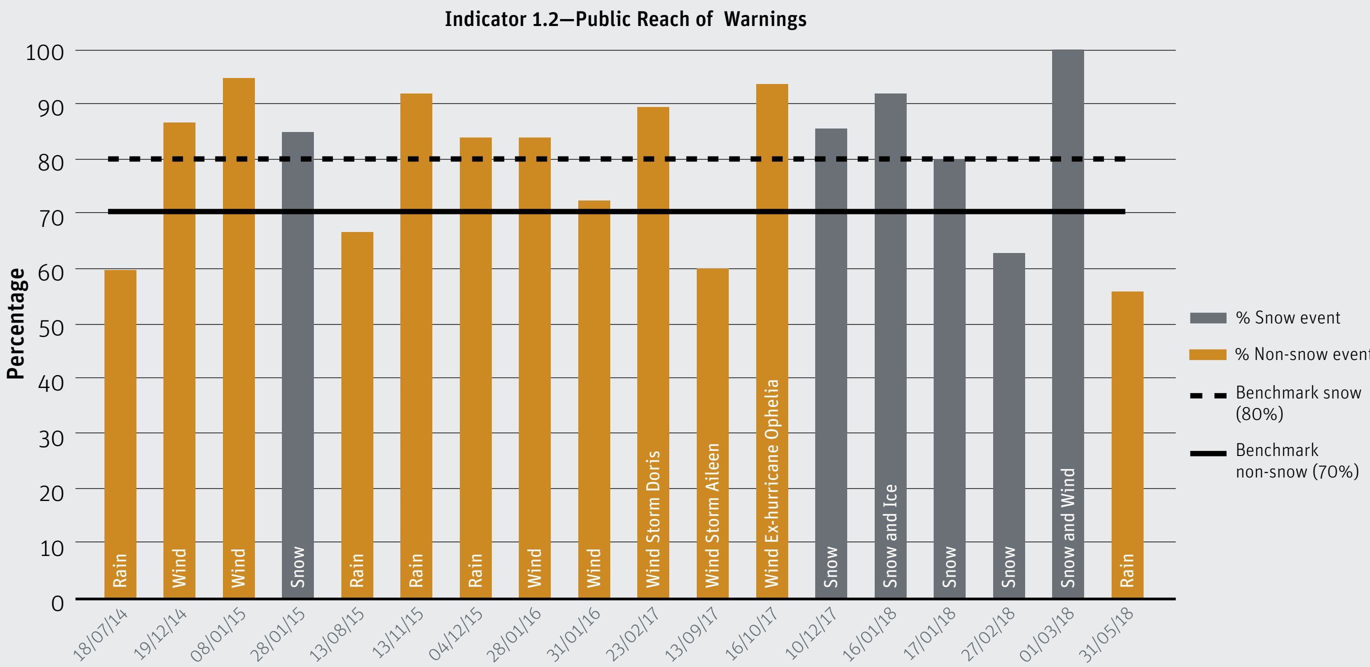
Indicator 1.1—Public Usefulness Warnings



TECHNICAL INSIGHT 2.1 Measuring User Satisfaction (cont.)

Reach of warnings

- Respondents were asked “Did you see or hear anything about this severe weather warning?”
- 80% of respondents had seen or heard their warning in 2015/16. Only five surveys were conducted during this period due to a smaller number of amber warnings being issued at times when it was appropriate to survey.
- The target for 2016/17 was 70% (average for at least six surveys).



Public perception survey

It is important to ensure that the forecasts the Met Office issues reach the people who need them and that they find the forecasts useful. It is also important that we know how people are accessing forecasts (e.g., mobile, television, internet, and where from). To do this we carry out a survey every year in the first week of October.

- In street, face to face, computer-assisted personal interviewing (CAPI) with 2,089 people across the UK.
- Monitors perceptions of accuracy and usefulness, plus frequency of use.
- Conducted independently by DJS Research Ltd.

Results

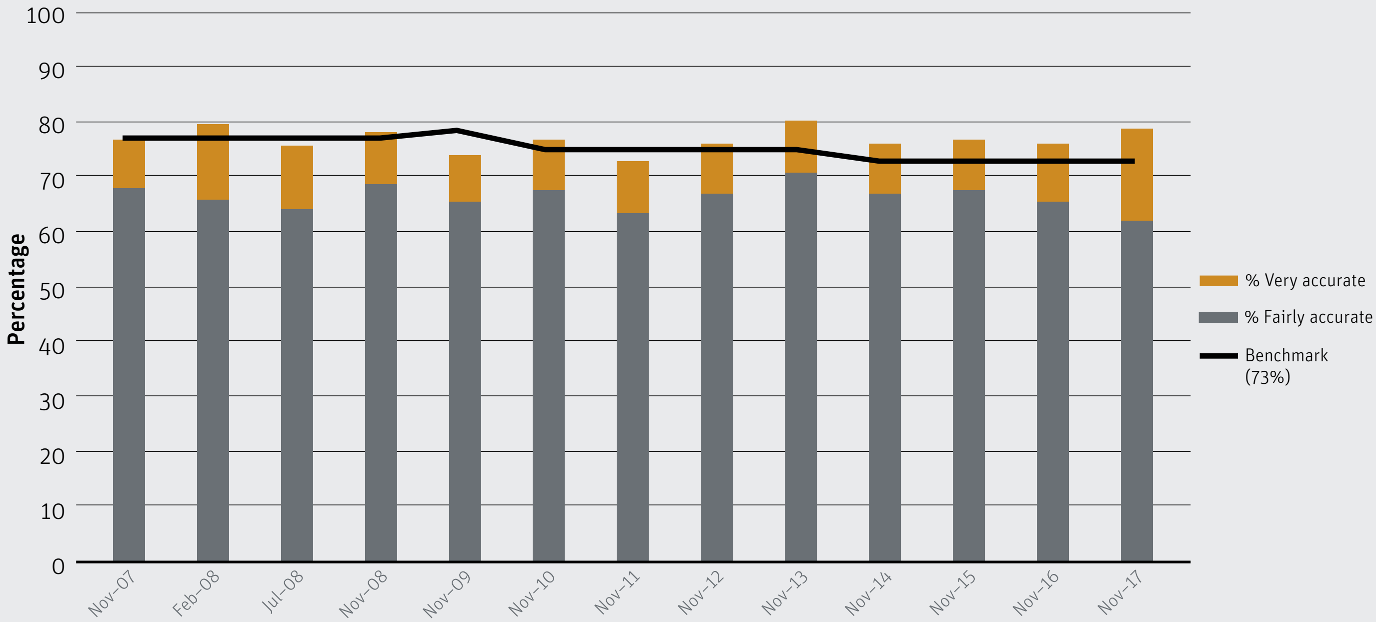
These are updated each year when the next survey is carried out.

Accuracy of forecasts

- Respondents are asked “Generally speaking, how accurate or inaccurate do you think most weather forecasts are?”
- Answers include very accurate, fairly accurate, neither accurate or inaccurate, fairly inaccurate, very inaccurate, or don’t know.
- 78% of respondents felt that forecasts were very or fairly accurate in 2017.
- The target for 2017 was set at 73%.

TECHNICAL INSIGHT 2.1 Measuring User Satisfaction (cont.)

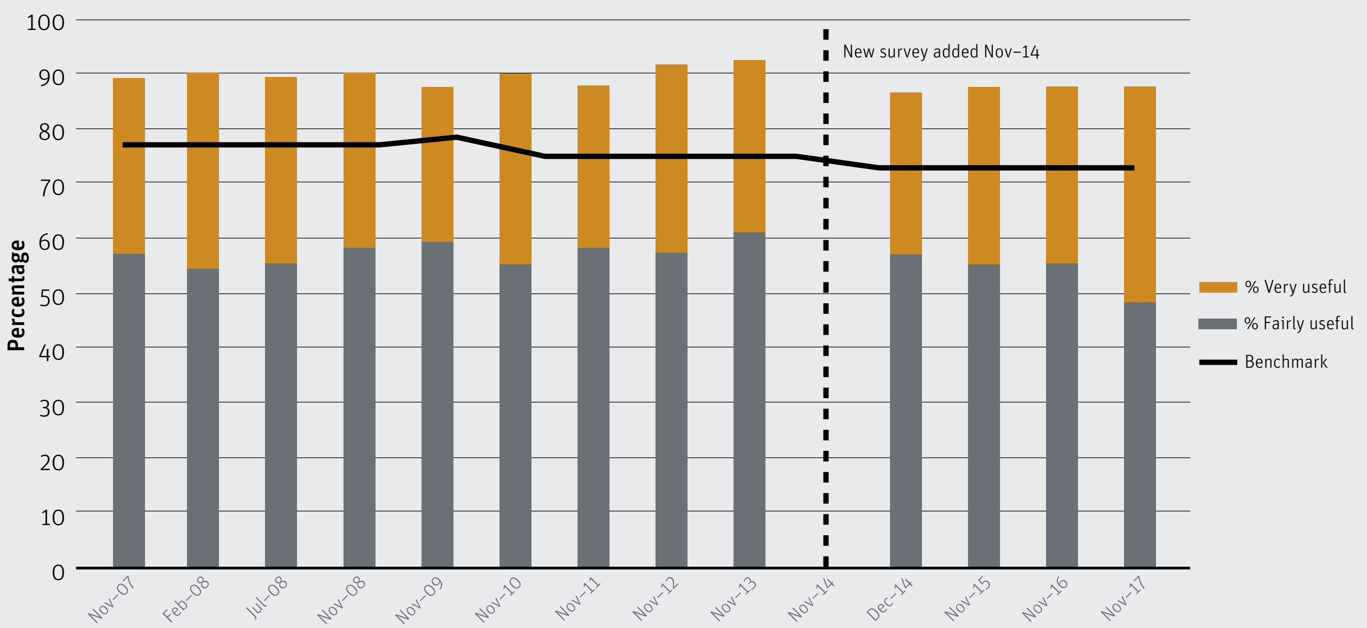
Theme 2a: Public Services—Direct Research
Indicator 4—Public Perceptions of Forecast Accuracy



Usefulness of forecasts

- **Respondents are asked "Overall how useful would you say weather forecasts are these days?"**
- **Answers include very useful, fairly useful, not very useful, not at all useful, and don't know.**
- **87% of respondents felt that forecasts were very or fairly useful in 2017.**
- **The target for 2017 was set at 80%.**

Theme 2c: Public Services—Products and Content
Indicator 16—Trends in Usefulness of Public Forecasts



Source: Met Office https://www.metoffice.gov.uk/about-us/who/accuracy/your-say

Category 2: Production Systems

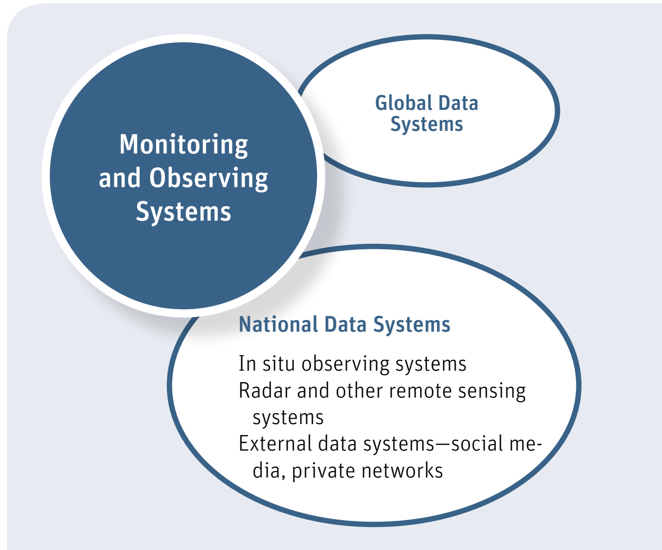
The second category of the system of systems centers on the production systems, which include: (i) monitoring and observing systems; (ii) modelling systems; and (iii) impact forecasting and warning systems.

Monitoring and Observing Systems

The monitoring and observing systems basically comprise two subsystems—the global data system and the national and subnational data system (**Figure 2.5**).

- *The global data system.* This includes all of the data available through the WMO Information System (WIS) and the global telecommunication system (GTS) that is accessible by the NMHS—including data from satellite systems available through systems such as CMACast or EUMETCast or any other GEONETCast for other satellite data providers.
- *The national data systems.* These comprise the data that are produced by, or on behalf of, the NMHS and any other national or local data supplied by other agencies or the private sector or academia or through crowdsourcing (Krennert et al. 2018a, 2018b).

FIGURE 2.5 Monitoring and Observing Systems



Note: Monitoring and observing systems have two distinct subsystems. The first is the global data system, which includes all of the information received via the WMO Information System or the Global Telecommunication System and data from unique sources, such as satellite products from specific providers. The second is national data, which is a combination of observations networks supported by different entities—public and private, and crowdsourced data associated with social networks—commonly associated with big data.

Increasingly big data[4] are being exploited—such as from social networks to improve warnings, or from drones for precision agriculture to maximize yields and minimize inputs of water and fertilizers. A typical national network may include synoptic stations (manual and automatic), radar, rainfall networks, lightning detection, river gauges, climate stations, and upper air and oceanographic stations. All of these stations need to be networked so that the data are available centrally within the NMHS for subsequent processing and use in analyses and forecasts. Automation of observing networks has the advantage of providing high fidelity and high temporal resolution (minutes rather than hours), which is critical for nowcasting and very short-range forecasting, along with rapid updates of the forecast environment. However, while automation can save costs in developed countries where the labor cost is high, it may come with a higher price tag in developing countries where labor is cheaper.

Making sure observation networks are fit for purpose. It is important to ensure, given the high cost of supporting observing networks, that they are fit for purpose, can be maintained, operated effectively, and are not acquired for the wrong reasons. Radar data, for example, are very useful for nowcasting and very short-range forecasting, which typically uses rapid refresh systems based on remote-sensed observations from radar or satellite, blended with NWP. They provide very high-resolution quantitative precipitation estimates (QPE), which are very relevant to rainstorm monitoring and flash flood forecasting. They can also contribute to 24 to 48 hour forecasts—if they are assimilated into convection[5]-permitting (~1 km or less) numerical models

[4] Data of a very large size such that its manipulation and management present significant logistical challenges and is too complex for processing by traditional data management tools. Big data often comprises structured and unstructured data from traditional and nontraditional sources. Size is less of an issue than the rate at which these data must be processed. For example, extracting meaningful information on the impact of a meteorological or hydrological hazard on a city by interpreting social media data.

[5] Convection—organized motions within a layer of air leading to the vertical transport of heat, momentum, etc. (WMO 1992), leading to thunderstorms, heavy precipitation, etc., typically within ~1 km or less horizontal resolution and timescale of ~1.5 days or less.

(Soares and Mylne 2013), which provide very high-resolution quantitative precipitation forecasts (QPF) that are critical for flood forecasting. However, attention to quality control is absolutely vital for any type of observational data, especially for radar data assimilation due to the effect of clutter and various non-meteorological sources of back-scatter. Another area where local observations are critical, but often overlooked, is forecast verification, which is an essential part of improving the forecast (including for model calibration, post-processing, and downscaling).

Forecast verification. This is done to monitor the quality of a forecast by measuring its accuracy and whether the forecast is improving over time; to discover what is wrong with the forecast; and to determine to what extent one forecasting system gives better forecasts than another.[6] Different types of forecasts require different verification methods—ranging from dichotomous for deterministic forecasts to ensemble methods for probabilistic forecasts. While the methodologies are mature, many NMHSs do not apply these methods consistently.

O&M of technical equipment. The addition of highly technical equipment to an institution that may be used to operating manual stations is likely to raise the operation and maintenance (O&M) costs significantly, and thus should be done with care and due diligence to avoid the situation where new equipment rapidly becomes nonfunctional, owing to lack of maintenance or access to spare parts (Lynch and Allsopp 2008). A contributor to the increased costs is the need to hire, train, and retain higher level technical expertise than traditional observers, which can be challenging in limited labor markets and with a not-so-flexible government pay scale. Quality control of all of the observational data is essential. In some circumstances, it may be more cost effective to supply data to the NMHS as a service. While many NMHSs may be reluctant to pursue this option, it may be more cost effective and could ensure continuity of data services.

Data sharing. As much of the available data as possible will need to be made available to the global prediction centers via the WIS/GTS or in some instances directly, if data restrictions prevent open access. Many countries share only a small fraction of the data they collect on the misunderstanding that because these data are not designated as essential within the meaning of WMO resolution 40 and WMO general regulations, they are not important to the global network. The high resolution of global models and the need for verification of model output makes all data valuable and essential to provide the best possible NWP and forecasts. Close attention must be paid to data redistribution rights if the NMHS pursues a data services option.

Monitoring and observing progress model. Similar to the service delivery model, a progress model for monitoring and observing can be adopted as a means of mapping the capabilities of a client country's NMHS to maintain or access meteorological, hydrological, and related observations (**Annex 2**). An approach, similar to service delivery, in terms of an action plan to address weaknesses in the monitoring and observing system could be implemented.

Meteorological and Hydrological Modelling Systems

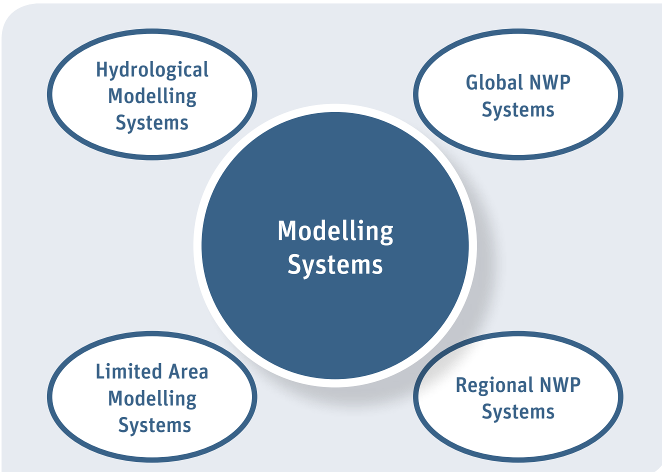
NWP is rapidly evolving—with the modelling systems now comprising global, regional, limited area, nowcasting, and hydrological models (**Figure 2.6**). Global models provide a wide range of products for the preparation of forecasts on timescales of hours to months. They are less and less seen as just low-frequency, low-resolution models providing a general large-scale outlook and boundary conditions for high resolution regional and national models. Frequently, NMHSs request support for their local limited area deterministic NWP efforts that use in-house high-performance computing. These NMHSs tend to run outdated versions of deterministic NWP models on workstations at spatial resolutions much lower than those currently available from the Global Production Centers (GPCs), and with no ability to assimilate local observational data into the models. Rarely is forecast verification, and model post-processing and calibration considered and operationalized.

Use of LAMs. In most instances, running a limited area modelling (LAM) is not the most optimal use of resources to quickly improve forecast capabilities, which should be one of the goals of most NMHSs. The level of skill and the resolution of global mesoscale[7] models are now so good that

6 See WWRP/WGNE Joint Working Group on Forecast Verification Research.

7 Mesoscale—in meteorology, it is the study of weather systems of horizontal resolutions generally ranging from around 5 km to several hundred kilometers, and temporal resolutions typically ranging from 1 hour to 1 day (WMO 1992). Examples of mesoscale weather systems are: sea breezes, squall lines, and large convective cells. Vertical velocity often equals or exceeds horizontal velocities in mesoscale weather systems due to non-hydrostatic processes such as buoyant

FIGURE 2.6 Modelling Systems



Note: Central to forecast production is the numerical modelling system, which comprises three main geographically dispersed elements—the global, regional, and local systems. Increasing the resolution of the global systems is reducing the need for separate regional and local modelling systems to provide basic meteorological predictions. The latter are used where they either provide very high resolution or unique data, which are assimilated at these scales. Hydrological modelling is highly dependent on local data and is almost always operated nationally with initial and boundary conditions provided by local observations and global or regional NWP. There is a growing preference for all models to be run as ensemble prediction systems, which enable risk to be better predicted.

these models can only be challenged by NMHSs with very high levels of investment and highly qualified experts. For example, the European Centre for Medium-Range Weather Forecasts (ECMWF) is currently running a global 9 km deterministic model and an ensemble prediction system at 18 km. And it aims to run a global high-resolution ensemble prediction system up to two weeks ahead with a horizontal resolution of about 5 km by 2025 (ECMWF 2016). While noting that lateral boundary conditions can be sourced from GPCs, the inherent errors introduced in passing data through a model boundary mean that a significant benefit is achieved only when the regional and local model can be run at substantially higher resolution than the global model. Initial conditions can also be sourced from GPCs for a pure downscaling approach, but the benefits will be limited without assimilation of high-quality local observations at high resolution. In addition, effective (operationally) running, maintaining, and updating locally of these LAMs requires a long-term commitment to continuing scientific and technical expertise—along with a complex infrastructure of high-level computing and telecommunications—both of which are major challenges for LMICs.

A lack of understanding of how to make full use of global and regional model guidance leads to an unwarranted use of LAMs. One argument given by NMHSs in LMICs for the local development of NWP is the cost of access to the full suite of digital products from GPCs, or lack of open access to these digital data. However, this is not a good reason for operating an inferior system. It is far more effective for NMHSs to make full use of the numerical guidance from GPCs. Where higher resolution is needed (such as hazardous-prone areas or over complex orographic regions), it is preferable to use the best available LAMs at the regional level (supported by WMO Regional Specialized Meteorological Centers (RSMCs) or by consortia (WMO 2017). This should be followed by forecast verification and feedback, model post-processing and calibration, model output interpretation, and delivery of services at the national level—the so-called "Cascading Forecasting Process." This approach has been introduced in many regions as a part of the WMO Severe Weather Forecasting Demonstration Project (SWFDP). It strengthens the links between the global NWP production centers, regional centers that interpret information from the global centers, and NMHSs (which are responsible for issuing alerts, advisories, and severe weather warnings). The SWFDP has been a particularly successful program, leading to the full operationalization of the concept in southern Africa and the expectation that the SWFDP in other regions will become fully operational once the skills are in place.

When would a LAM be appropriate? An NMHS should consider running very high-resolution (~1 km or less), convection-permitting numerical models over hazardous-prone areas or over complex orographic regions. But this should occur only if:

- Robust and reliable telecommunications infrastructure (to import the required volumes of data) and supercomputers are affordable to (i) support models of competitive resolution with optimal parameterizations of the physical processes; and (ii) address high-quality processing and full data assimilation, spin-up, and cycling issues.
- A large and expert staff of scientists and computer technicians are available to develop and maintain such a system 24 hours per day, 365 days per year, in an operational environment. Identification of high-risk areas is a prerequisite, which is not always available in many client countries.

acceleration of a rising thermal or acceleration through a narrow mountain pass.

In developed countries, many NMHSs are phasing out their local LAMs. Generally, the current freely available model codes have been conceived for training and research purposes only, lacking the optimal parameterizations of the physical processes, the configurations tuned for the regions of interest, and the developments required to keep them up-to-date in terms of science and technology. Thus, these codes are not well suited for operational use. The notion that lower-resolution, locally run models can be equivalent, or better, than the global mesoscale models is misguided.

For example, in the summary of the recent annual reports on the application and verification of ECMWF's forecast products (ECMWF 2017), most ECMWF Member and Co-operating States highlighted that overall the ECMWF deterministic model performance is as good as their LAMs' performance. For that reason, a number of ECMWF Member States (such as Switzerland, Norway, and Portugal) are phasing out their local LAM configurations at 7 to 12 km resolution, retaining only those LAM configurations at much higher resolutions (such as 2.5 km and less) with data assimilation. This illustrates that the current ECMWF model resolution has provided a direct cost savings for them. It also highlights that simply running a model without data assimilation serves little or no operational purpose.

Use of "ensemble prediction systems" (EPS). An important and continuing development for operational weather forecasting is the use of EPS, which are capable of providing uncertainty information, associated with NWP results. EPS are a powerful tool in predicting and early detection of severe weather events. For impact-based forecasting, the EPS may be used to help estimate the probability of weather hazards for use in the estimation of Risk (= Probability x Impact). The combined use of very high-resolution limited area deterministic NWP (and increasingly limited area ensemble systems) is relevant for short-range forecasting (typically up to 48–72 hours ahead)—in conjunction with global and regional guidance—which helps NMHSs at an early stage in severe weather forecasting.

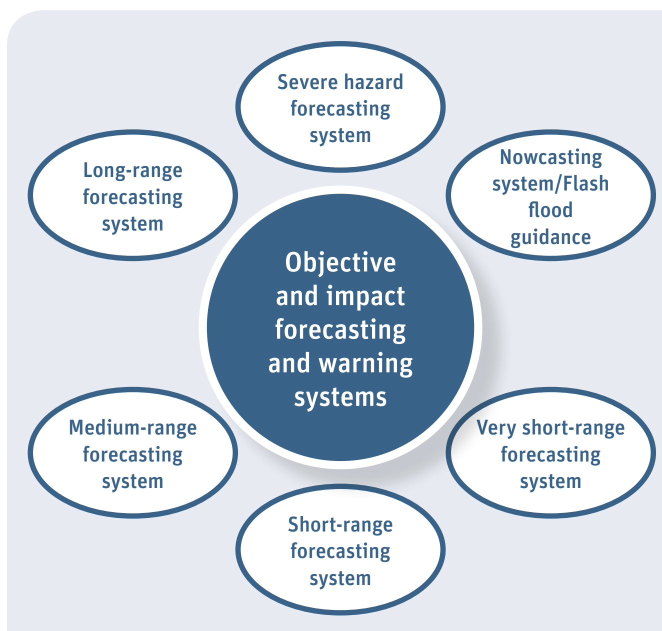
Forecasting and Warning Systems

Objective and impact forecasting and warning systems cover all timescales from the immediate to seasonal. This component includes: (i) meteorological and hydrological severe hazards; (ii) nowcasting; (iii) very short-range forecasts; (iv) short-range forecasts; (v) medium-range forecasts; and (vi) long-range forecasts (**Figure 2.7**). As the name implies, the severe hazard forecasting subsystem focuses on the extreme events within the NMHS's responsibility—such as tropical cyclones, thunderstorms, storm surges, high winds, extreme heat and cold, and rainfall and flooding. Nowcasting focuses on the immediate weather (nominally 0 to 6 hours); it is highly dependent on rapidly updated observations, usually from radar and satellites. Several advanced NMHSs have pioneered the development of these systems and made them available to the WMO community. Very short- and short-range forecasts cover up to 3 days ahead. Medium range extends the forecast up to 15 days, and long-range forecasts up to seasonal timescales.

Wherever possible, the forecasts should be based on ensemble predictions, which provide valuable information about the likelihood of an event, and coupled with information on the potential impacts, provide users with warnings of the severity risks (Fleming et al. 2015, Rogers et al. 2018).

Impact-based forecasts emphasize what the weather will *do* rather than what the weather will *be*. Impact-based forecasting and warning services focus on translating weather

FIGURE 2.7 Forecasting and Warning Systems



Note: Forecast and warning systems cover all timescales from the immediate (nowcasting) to climate timescales. Each range is often a specialization of a forecaster. For example, severe hazard forecasting may be the responsibility of flood forecasters, tropical cyclone forecasters, drought forecasters, or a combination of these and other expertise.

TECHNICAL INSIGHT 2.2 Putting the Focus on Weather Impacts

The WMO puts a high priority on impact-based forecasts and warning services as a way to increase NMHSs relevance and utility. What are impact-based forecasts? They focus on what the weather will do rather than what the weather will be—and by doing so, translate weather hazards into sector-specific impacts. The hope is that as a result, those exposed to a hazard will have a better understanding of the risk and will more likely take appropriate action (Fleming et al. 2015).

But using impact-based forecasts to boost the NMHSs output requires that NMHSs put a greater emphasis on service delivery. Already, WB- and GFDRR-supported modernization efforts emphasize service delivery. Moving beyond weather forecasting requires effective partnerships with many different government agencies. This is perhaps one of the most difficult things to achieve and where the WB has a role through its convening power to bring together many of the actors and stakeholders to help NMHSs create the necessary partnerships and data sharing arrangements, as well as encouraging other development partners to support this approach.

Impact-based forecasts

NMHSs must have access to the best available numerical guidance to generate timely, accurate, and specific meteorological and hydrological forecasts. This is often the most challenging part, but increasingly possible, as higher resolution numerical weather predictions become available from the WMO global production centers (GPCs) and WMO Regional Meteorological Specialized Centers (RSMCs). This can be taken a step further nationally if the country has the capacity and capability to run very high-resolution models (better than 2 km resolution), which incorporate assimilation of local data from radar and other observing systems. If this is not possible, reliance on the global and regional centers may be sufficient.

Establishing impact-based forecast and warning services can be done in two phases: the first focusing on developing a qualitative or subjective forecast that relies mostly on the experience of stakeholders to establish warning thresholds; and the second focusing on quantitative estimates of vulnerability and the use of tools to calculate impacts.

hazards into sector-specific impacts, and developing sectoral responses to mitigate those impacts (**Technical Insight 2.2**). By focusing on impacts, it is expected that those exposed to a particular hazard will have a better understanding of the risk and will more likely take appropriate action. While not essential for the successful implementation of impact-based forecast and warning services, it is highly desirable to develop a map-based warning system, which divides the country into a convenient grid and uses colors to represent warning levels within each of the grid boxes. This approach was initially developed by MétéoFrance and has been adopted Europe-wide through the MeteoAlarm system (see, for example Stepek et al. 2012). Other countries are following this example, which enables at-a-glance stakeholders to visualize the geographical extent and type of warning. Updated frequently, warnings evolve during the course of the event and in response to actions taken to mitigate risks. This tool can be used to display meteorological warnings and sector-specific impact warnings. It also highlights the importance of common color-coding for specific levels of risk regardless of the hazard, impact, or sector. This way a better "feeling" for risk is established across all sectors.

Modelling and forecasting progress model. The strategy for improving the use of high-resolution NWP and LAM, as a part of the overall forecasting processes, is based on the WMO Global Data-processing and Forecasting System (GDPFS) guidelines (WMO 2016a). Mapping current capabilities as a first step to identify weaknesses should be followed by developing and implementing an action plan to improve the overall forecasting system (**Annex 2**).

Category 3: Support Systems

The third category of the system of systems—the support systems—underpins the value chain of meteorological and hydrological services. It includes: (i) quality management systems; (ii) ICT systems; (iii) technology infusion systems; and (iv) capacity building.

Quality Management Systems

Quality management systems (QMSs) are an essential part of the normal operation of organizations—possibly making the difference in saving lives and property. Aviation requirements have forced most NMHSs to adopt ISO 9000 standards, but they have not been universally applied. As of November 2012, the International Civil Aviation Organization (ICAO) has required quality management systems for meteorology as a standard. However, few NMHSs have proper management systems to regulate their internal decision processes (**Figure 2.8**).

The overall management of the NMHS may be discussed in the context of a QMS, leading to an assessment of whether the current organizational structure of the institution is fit for purpose. ISO 9001 provides a rigorous management framework to enable NMHSs to identify and meet the requirements of their customers, monitor and measure their own performance, and identify opportunities to continually improve service delivery (WMO 2013). The adoption of a QMS is a strategic decision. If well planned, appropriately resourced, and efficiently implemented, it provides a cost-effective management system.

The ISO 9000 series consists of three standards on good quality management practices:

- ISO 9000:2005, Quality management systems—fundamentals and vocabulary. It describes the fundamentals of QMSs and the terminology used in the ISO 9000 family.
- ISO 9001:2008 (updated to ISO 9001:2015), Quality management systems—requirements. It can be applied to all types of organizations (public and private), regardless of size or industry group—enabling both product and service organizations to achieve standards of quality that are internationally recognized and respected. It is the only ISO standard against which organizations can be certified or registered through a third-party audit process.
- ISO 9004:2009, Managing for the sustained success of an organization—a quality management approach. It focuses on achieving sustainable success by meeting the needs and expectations of customers and other stakeholders. It promotes self-assessment as an important tool, which enables ongoing review of the level of maturity attained by the QMS. However self-assessment is not a substitute for a third-party audit process.

Corporate governance. Governance relates to the processes and structures that ensure an organization is directed, controlled, and held to account. It focuses on how an organization is managed, how risks are monitored, and how value is added for the community, government, and other stakeholders. The main components of a sound corporate governance framework are: (i) promoting and ensuring adherence to a code of conduct and values; (ii) risk management; (iii) continuity of service; (iv) occupational health and safety; (v) ongoing development of staff competencies; (vi) providing timely and accurate reports to senior/executive management; (vii) a published Service Charter that sets out the standards of service to the community; (viii) contributing to the organization's annual reports; and (ix) contributing to the strategic and operational planning process.

An ISO 9001 QMS is a management tool to measure the ongoing performance of the corporate governance activities of an organization. The WMO Guide to the implementation

FIGURE 2.8 Quality Management Systems

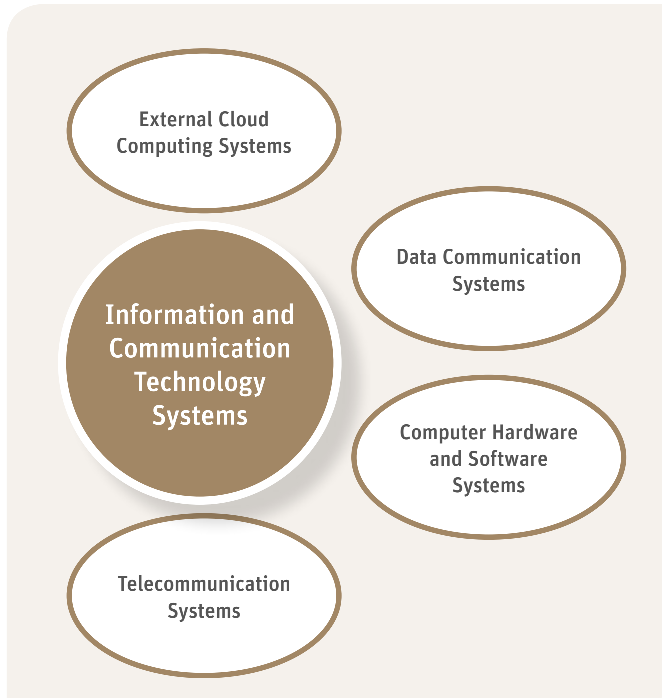
Note: Quality management systems, which are at the heart of well-run organizations, apply equally to operation of the various service delivery and production systems and the overall management of the organization.

of a QMS for NMHSs [8] is an essential starting point for introducing a QMS (WMO 2013).

Information and Communication Technology Systems

ICT systems are fundamental to the operation of a modern NMHS. They include data, computing hardware communication, and increasingly, managing access to cloud computing (**Figure 2.9**). An efficient organization has a central repository for data and information—including all observational data and numerical predictions (regardless of source), post-processing, and applications. This enables new services to be generated easily, and O&M of the ICT systems to be optimized. The current practice of each new observing or forecasting system setting up stand-alone servers should be discouraged. A key requirement is broad bandwidth access to the Internet to access very large data volumes on a daily basis from the global prediction centers, satellite- and ground-based remote sensing, and non-traditional national sources (like the Internet of Things (IoT) and crowdsourcing). This is an area where staff retention in an NMHS is often difficult because of highly paid opportunities in the private sector—raising the possibility of external national contracting.

FIGURE 2.9 Information and Communication Technology Systems



Note: ICT systems, which are central to a well-functioning NMHs, are increasingly a combination of internally supported systems and externally sourced services (such as Infrastructure as a Service (IaaS)), provided under contract by specialist IT firms.

Big data is motivating radical changes in the way ICT systems are being used in meteorological and hydrological services. Digital, gridded meteorological and hydrological data are increasingly being combined with data in multiple formats from other sources—like transportation networks, social media, and health services—in integrated maps to provide impact forecasts and targeted warnings. This requires the ability to gather, store, and manipulate data from these multiple, disparate sources, which, in turn, requires a centralized, flexible, extensible ICT architecture.

Cloud computing. As NMHSs access higher temporal and spatial resolution data from global centers, and integrate information from multiple national sources, higher performance will be required from computing systems, resource management, and networking (see for example Jiao 2016). A cloud-based approach is essential to achieve this. Infrastructure as a service (IaaS) is discussed in Chapter 3. While such a platform can be developed by an NMHS, it is more likely that smaller services will acquire this capability through commercial service providers. The balance between internal and external cloud services will depend on specific national circumstances, but the transition from traditional databases to distributed file systems is inevitable to match the need to maintain large amounts of useful data available online. A major benefit is less need to maintain many local operational systems in favor of a few online platforms.

Artificial Intelligence (AI). Another major ICT advance is the role of AI in forecasting. This is critical to mining big data and providing customized meteorological and hydrological services. This transition to so-called smart meteorological and hydrological services allows forecasts to be individualized and targeted to situations such as flooding, landslides, and storm surges. This hyperlocal service can be realized through mobile Internet by building user profiles based on mobility, demographics, and understanding specific real-time user scenarios. Cooperation with the private sector may be the best way to realize this potential.

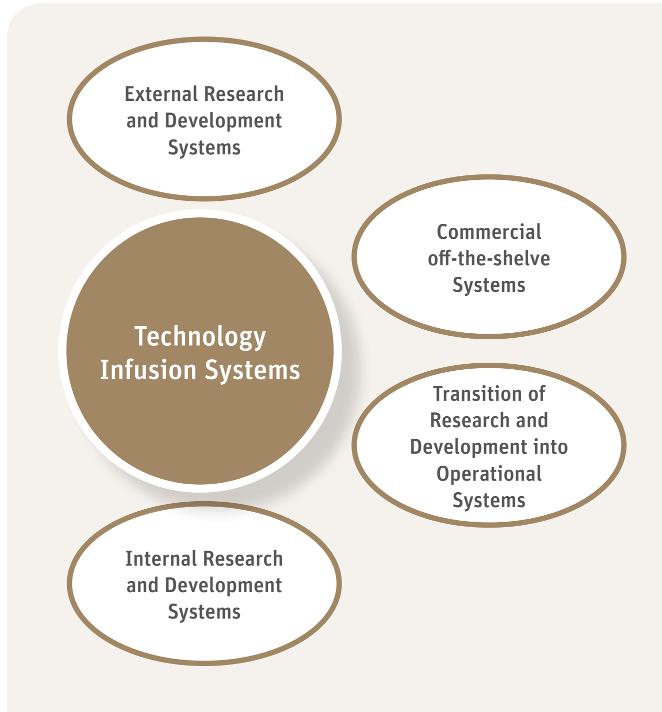
[8] https://library.wmo.int/pmb_ged/wmo_1100_en.pdf

Technology Infusion Systems

In most of the NMHSs in LMICs, the ability to further their own development is limited by the absence of a culture of research and development (including external research and development, internal research and development, and the transition of research to operations) (**Figure 2.10**). It also limits their participation in external research and development initiatives. The result is that the more advanced NMHSs and the private sector control the direction of the field. Thus, greater effort is needed to help NMHSs develop skills in verification methods, timeseries analysis, and downscaling techniques. Twinning arrangements with more advanced NMHSs and technical centers can go some way to addressing the lack of research and development in many low-income country NMHSs. Similarly, participation in WMO-led research initiatives and development projects (such as the SWFDP) can help build expertise. Traditional instruments used in the WB-funded projects are not well suited for providing support for research—underscoring the need for special efforts like targeted grant funded programs and twinning arrangements.

Adopting and implementing new ICT strategies is a key area for technology infusion. Exploiting AI, big data, and cloud computing technologies are critical to the future of any NMHS. This requires NMHSs to build or access the skills needed to implement these strategies.

FIGURE 2.10 Technology Infusion Systems



Note: Technology infusion systems refers to the combination of research and development, performed in-house or externally, that can be transitioned into operations—such as hardware or software or new forecasting techniques.

Capacity Building

Strengthening human capacity covers meteorological and hydrological training, business development, stakeholder training, and end-user training and outreach (**Figure 2.11**). This is an area where significant investment needs to occur to strengthen the human capacity within the NMHS. Based on feedback from many training events and NMHSs' management, it is clear that training should be concentrated on on-the-job training with external training focused mostly on building a cadre of trainers to conduct the national training. The piecemeal approach, focusing on one or two individuals, does not always work well unless their responsibility is to teach others.

Keeping up with rapidly evolving GWE skills. Training of NMHSs' management and technical staff is an integral and essential part of keeping pace with the evolving GWE. There are significant changes in education and training with greater emphasis on communication programming, big data statistics, and machine learning (Staudinger et al. 2018). These create greater challenges for LMICs, especially where training and sustaining a workforce is already difficult. A big problem is that public sector staff are often lost to private sector activities outside of the GWE, where remuneration for technical skills is often significantly higher. This is a challenging area in WB implementation projects that requires special attention. Management skills are often overlooked and should be a focus within WB modernization projects.

Core disciplines. The traditional skills in meteorological and hydrological sciences, which build on a foundation in mathematics and physics, continue to be the foundation of meteorological and hydrological services. However, these need to be expanded to include new skills without necessarily reducing the core disciplines.

ICT skills. Software engineers and meteorologists and hydrologists with programming and ICT skills are a critical component of modern services. The ability to utilize observations and prediction products requires the ability to manipulate and interpret big data. Communication skills are also essential. The ability to interpret scientific information

FIGURE 2.11 Capacity Building

Note: Capacity building underpins the human resources within the NMHS and within the main users and stakeholders.

and communicate it to the public, government agencies, and businesses is critical.

Social communication skills. The growing use of social media to exchange information requires its own particular set of skills—including writing, content design, communication, customer service, digital marketing, and analytics. The ability to measure the performance of social media posts, for example, is increasingly critical to understand how people respond to forecasts and warnings.

Business practices. Whether in a NMHS or in the private sector, knowledge of business practices is essential—including project management, business modelling, business planning, marketing, financial management, procurement, and risk management. The assumption by many NMHSs that business practices are the purview of only the private sector needs to be challenged.

On-the-job training. The most effective, cost-effective, and sustainable training is conducted on-site by experts using the systems and equipment available to the staff. This is especially useful for departments with many staff, such as forecasters and public weather service advisors. Individual trainers might be expected to do the following:

- Provide on-the-job training in the use and interpretation of model products from the GPCs, and introduce a forecasting process.
- Train forecasters in the interpretation of probabilistic forecasts into useful information for decision making by users.
- Train public weather service advisors (or staff tasked with public weather service duties) in developing and maintaining close relations with key stakeholders (notably, disaster managers and civil protection authorities), as well as assisting them to understand and make better use of probabilistic forecasts and warnings.

Typically, this training would involve several experts for about two weeks each, but due to the fast pace of development in forecasting and communication, it should be repeated at regular intervals. Such training took place at the Pakistan Meteorological Department during preparation of a modernization project (**Technical Insight 2.3**).

Training trainers. Specialized international training at WMO regional training centers (RTCs), for example, should be carefully selected for staff to be qualified as trainers of the other staff. These training opportunities should have specific objectives that can be tested and evaluated against staff performance. So-called south-south training can be particularly effective where staff from different LMICs agencies share their knowledge and experiences. It is also helpful to establish a formal process to measure the training's usefulness.

Twinning with advanced NMHSs. Well-defined standard operational procedures, including a checklist of activities for weather forecasting, are also required for improved quality forecasts that meet stakeholder and other end-user requirements and expectations. To address this, we recommend that twinning arrangements be made between the developing country NMHS and other NMHSs that can help provide guidance on forecasting techniques—including model post-processing and calibration, effective use of ensembles, and operational forecast guidance. This approach is practiced by the Met Office, the National Weather Service, and Météo-France, which provide twinning support to a number of developing countries. But it could also be provided by more advanced NMHSs within a region to share expertise as part of so-called south-south cooperation. Where there is a need for flood forecasting, the licensing of digital products from GPCs is recommended to provide quantitative precipitation forecasts as an input to locally executed flood models.

University education. Countries with university programs relevant to staff of NMHSs and related agencies usually have fewer problems recruiting staff than those countries that do not.

Summary of Services and Systems

The main purpose of NMHSs is the provision of services that meet the needs and requirements of users. This cannot be overemphasized. The era of data collection as the primary goal is past, and NMHSs need to focus on developing cost-effective and high-quality services for users. Further, given their limited budgets, the emphasis needs to shift from a heavy infrastructure-oriented approach to one that takes advantage of the range of available services external to the NMHS. The ability to manipulate and analyze data from multiple sources and provide hyper-local forecasts and warnings tailored to individuals' needs is at the heart of this service. The basic building blocks remain the same—deliver services and adjust those services based on feedback from users by: (i) monitoring and observing the natural and human environment, and (ii) modelling and predicting changes that impact the lives and livelihoods of people. The underpinning technologies and skills are challenging for even the most advanced NMHSs.

In the next chapter, we focus on key concepts for modernizing NMHSs.

TECHNICAL INSIGHT 2.3 Training Program to Strength Forecasting and Public Weather Services

Training is an integral part of developing and maintaining operational skills. Training can be conducted on-site by experts, usually in two week-long courses for each topic. The following is an example from the Pakistan Meteorological Department, addressing the following subjects:

Numerical weather prediction and forecasting

1. **Understanding the meaning of the Ensemble Prediction System (EPS) and the potential behind that technique, including in support of decision-making processes.**
2. **Guidance on the procedures to follow for a continuous and consistent operational weather forecasting process—including analysis, verification, use of deterministic versus probabilistic forecasts, and use of ensembles to estimate uncertainty.**
3. **Demonstration of capabilities of European Centre for Medium-Range Weather Forecasts (ECMWF) ecCharts, and how to build and use a Dashboard aligned with the operational weather forecasting process.**
4. **Forecast exercises, using case studies (monsoon and tropical cyclones applications).**
5. **On-the-job practical training on the above points, using (live) performance of the system (ecCharts) for weather forecasting.**

Public weather services

1. **How to meet the key stakeholders' specific requirements for hydromet information (including accuracy, timeliness, the use of nontechnical language, and agreed formats); how to handle uncertainty and how to get the message across about uncertainty and probabilities.**
2. **Guidance on the effective delivery and communication of forecasts and warnings to the end-users (like the general public, farmers, fishers, etc.), including the use of nontechnical language.**
3. **Guidance on preparing key messages for senior PMD management or government officials during severe weather events.**
4. **Guidance on working with the media (radio, TV, print) to deliver and communicate (both written and oral as applicable) forecasts and warnings in agreed formats and times.**
5. **How to interpret probabilistic forecasts and turn them into messages understandable to all the stakeholders, in support of decision making.**
6. **Simple call-to-action messages for end-users (especially the public), as part of forecasts and warnings of severe weather events (should be prepared in advance in consultation with the National Disaster Management Authorities (NDMAs) and Provincial Disaster Management Authorities (PDMAs)).**
7. **How meteorological services can contribute to the mitigation the impact of natural hazards.**
8. **On-the-job practical training on all of the above points, using the daily forecasts (and warnings if applicable).**

Modernized automatic weather station in Tajikistan. *Source:* GFDRR, 2018

Chapter 3
Key Considerations for Creating Effective NMHSs

- *Many NMHSs in low- and middle-income countries (LMICs) continue to follow a traditional business model—rooted in a culture of manual meteorological and hydrological observations—to support general forecasts and outlooks about a day ahead.*
- *The problem is that these NMHSs, which tend to be static, are often at a level that is too low to operate and maintain more than a basic level of services—on top of not paying much attention to their users.*
- *To be relevant, NMHSs, like all service organizations, should provide the services their users and stakeholders need and want. These needs far exceed the capability of most NMHSs in LMICs that are operating within a traditional business model.*
- *Thus, there is an urgent need for different business models—ones that can help improve the efficiency and effectiveness of NMHSs. Good planning and strategies are needed, along with the tools to design and test operational concepts prior to designing and implementing solutions.*

Introduction

The traditional business model of a national meteorological and hydrological service (NMHS)—relying on manual observations and trying to accomplish everything alone—needs to be urgently overhauled to deliver the services that users and stakeholders now need and want. What type of model would help transform weak agencies, especially in low- and middle-income countries (LMICs), into more robust ones?

This chapter explores the key considerations for creating effective NMHSs. It begins with the importance of business plans and business models, then looks at a growing recognition that more public-private sector engagement could help strengthen meteorological and hydrological services—before detailing the tools available to design and test operational concepts prior to designing and implementing solutions.

Business Plan

Why a business plan? The business plan of any organization, be it for profit, non-profit or government, describes what the organization does, its operational and financial goals, and how it intends to meet them. Many NMHSs consider business planning to be the domain of the private sector. But in practice, any organization that needs to demonstrate its value—ministries responsible for meteorological and hydrological services, ministries of planning, ministries of finance, and tax payers—must be able to articulate its business plan. The plan provides structure to the organization by explaining why it does what it does and what makes it successful. Without a business plan, it is difficult to assess the funding requirements for the organization and whether further investment is good value for money. In the case of an NMHS, it is an opportunity to capitalize on the government's investment in modernization to provide sustained, high-quality, value-for-money services.

Expansion financing. Business plans are usually targeted to a specific need and audience. In the case of an NMHS, which is going through a process of modernization, the plan explains: (i) what the improvements in capabilities will provide; (ii) its strategy to sustain these services; and (iii) the nature of the products and services. It can be used to help convince the government to increase its budget to cover the additional costs of operations and maintenance (O&M) associated with the new higher level of services. We refer to this as expansion financing. A different approach would be required if the plan has a different purpose.

Market, customers, clients, and users. The NMHS must understand the overall market and its structure. Vital questions are: How do people use information? Is government funding sufficient to discharge the public service responsibilities of the NMHS adequately? Is there a willingness to pay for services within the country's economic sectors? What are these sectors? Are sectors aware of how to use weather, climate, and hydrological information in their decisions? How do these sectors currently get information? What are the gaps that the NMHS can fill? How will new products and services be introduced? What are the areas for potential growth? Who else is likely to operate in this market? What is the NMHS' share of the total market? And what are the success factors and future developments for NMHS?

Competition. Inevitably, in a market that is growing and becoming increasingly important to economic sectors, there will be competition between the public and private sectors and among private sector providers of meteorological and hydrological services. Rather than being defensive, the NMHS needs to look at opportunities and consider its relationship with commercial providers. A first step is recognizing distinct roles and responsibilities for the public and private sectors. A second step is articulating the competitive advantage of the NMHS: (i) knowledge of meteorological and hydrological conditions of the country; (ii) close cooperation with government departments and communities; and (iii) its potential position as the national authority for meteorology and hydrology. By doing so, this provides the NMHS with a unique position as a partner for joint ventures with the private sector. Alternatively, it may choose to compete directly for commercial services. However, care should be taken to avoid distorting the market. Restricting private sector access to data, for example, limits competition and eventually reduces the interest of economic sectors in paying the market value for services—possibly resulting in an underdeveloped market, dominated by the NMHS but with a limited revenue stream.

Marketing. In countries where the NMHS is the dominant provider of services, there is little incentive to market its services. However, this often leads to a lack of awareness by the public and government of NMHS capabilities. Explaining what the NMHS has to offer is marketing. NMHSs may think they are in the public eye because of the kind of services they provide. However, they are often only visible to the public and the government during extreme events—and most often, when there is a failure in the system. Thus, a proactive approach is needed to maintain better awareness of NMHS capabilities. To use a marketing expression, the NMHS is the "brand" leader in the country.

"In Belarus the public obtains forecasts from all sorts of different apps and social media sites, generally never caring about the sources of the forecasts. But when these forecasts are wrong, they blame Belhydromet. So we have had to establish a presence on all social media channels to deliver good information and protect our reputation." —Mr. Roman Labaznov, Head of Belhydromet

Production and delivery. The NMHS should provide an overview of its modernized systems from production through service delivery (the value chain). How the NMHS goes about its business is important from the perspective of understanding its efficiency and effectiveness.

Research and development (R&D). Infusing new technologies is a critical element of maintaining the relevance of the NMHS in an ever-changing economy (see chapter 2). But in developing economies, R&D is often not part of NMHSs. However, this can be addressed by working with regional partners and participating in WMO research activities, thereby showing that the NMHS is actively benefitting from developments within the worldwide meteorological and hydrological community.

Management and organization. Change management is a critical component of the modernization process to ensure that not only is the technology fit for purpose but also the staff are adapting to their evolving roles. The business plan should describe the skills of the NMHS workforce and provide confidence that there is a capable management team.

Risk analysis. It is critical that NMHSs identify, assess, and manage operational and business risks. Doing this effectively increases confidence—including by the responsible government ministry—that the NMHS is well managed and can anticipate and deal with institutional problems.

Finances. Financial planning should focus on worst-case and best-case scenarios—for example, a worst-case scenario would be what will happen in five years if there is no budget uplift to support O&M. It should anticipate information failures that may contribute to turning a hazard into a disaster and use a variety of economic tools to determine the NMHS' financing needs.

Business Models

The business model is central to the business plan, focusing on how the NMHS operates. It is a conceptual structure that supports the viability of a product or organization and includes the purpose and goals of the organization and how it intends to achieve them. It covers all the business processes and policies that an organization adopts and follows. And it is supposed to answer who is your consumer, what value you can create or add for the consumer, and how you can do that at reasonable costs. Like most businesses, an NMHS has both external and internal consumers.

Cost centers. Each of the "systems" (or in some cases the "subsystems") comprising an NMHS can be treated as an individual cost center. How each is operated can be analyzed to determine the most cost-effective and efficient way to provide the services required of, or by, these systems. Each of the systems is a production center with a well-defined set of consumers. For example, the monitoring and observing system's outputs are consumed by: (i) the modelling system, and (ii) the objective and impact forecasting and warning system (**Figure 2.6**).

Staff limitations often compromise the effectiveness of each of the systems—particularly in the observing networks, modelling, ICT, and service delivery systems—and absent access to external research, the ability to infuse new technologies is limited or nonexistent. Few LMICs address staff shortages by outsourcing. In many instances (especially with ICT and service delivery), the private sector has the capacity to provide contract services—such as maintaining computing systems, hosting servers, staffing, web-based services, and mobile applications. In the Middle East, it is common practice to hire contract staff. Currently, the Kuwait Meteorological Service has four Kuwaiti nationals on its staff and about 150 contract staff, mostly from Egypt. These are hired individually, but it would also be possible to contract a firm to provide these staff—as is done by the U.S. National Weather Service to provide technical support staff to the National Centers for Environmental Prediction (NCEP). In the latter case, this is a business decision based on government rules that limit the hiring of full-time civil servants.

Traditionally, as government departments, NMHSs in LMICs are obliged to follow a simplistic and often inefficient approach to budgeting. A fixed amount of money is spent mostly on salaries of civil servants. A limited O&M budget supports the observing networks and the rest of the organization's infrastructure. Thus, investment depends largely (and sometimes, completely) on external support from development partners. Increasingly, however, governments are moving organizations, such as NMHSs, from a departmental to an agency operating model in some regions like Africa (Rogers and Tsirkunov 2013a). This switch forces the NMHSs to look more carefully at efficiency and effectiveness to meet the demands of the customers and justify additional investment. It is often accompanied by an expectation on the part of ministries of finance or treasuries that there will be a return on capital employed. As a result, many NMHSs are forced to focus heavily on selling services, mostly data services. But because they often lack the capability to improve these services, they resort to protectionism through legislation to maintain their monopolies. This is an increasingly untenable position as more users of meteorological and hydrological services have access to the Internet and multiple sources of information.

Thus, NMHSs operating with an agency model must look at their overall business model and restructure themselves to remain relevant. The various models used to deliver the overall services were discussed by Rogers and Tsirkunov (2013a) and are the subject of ongoing studies supported by GFDRR. One of these studies is looking at different models of public and private engagement in the hydrometeorological sector and comparing performance against good public-private practices in other sectors.

The main areas where different models can be effectively employed are in support of the service delivery systems; the monitoring and observing systems; ICT systems (like data services and cloud computing); modelling systems; and capacity building (like training). The outsourcing or privatization of an entire NMHS could be a future option, but it is not considered here. National observations are a core responsibility of all NMHSs—and are often a key component of efforts to improve NMHSs, because existing systems have become obsolete or nonfunctional, owing to lack of investment. They also absorb a considerable number of staff, which are themselves part of the observing network. There are a number of potential options for observation and data services:

1) **Own and operate:** In this model—which is almost exclusively used in NMHSs of developing countries—the NMHS owns, maintains, and operates its own equipment. Equipment is often operated well beyond its depreciated life and replaced when capital is available through national budgets or development partners. The NMHS maintains a large field staff. The advantage of this approach is the certainty that the data are restricted to the NMHS, which has control over how they are used, sold, or distributed. Also, some degree of continuity is assumed, providing the equipment is properly maintained. But the disadvantage is that it requires significant capital investment to renew the system periodically. Rarely is a capital expenditure budget available for the routine upgrade of equipment and most operate until they fail. Over time, the quality of the network may decline as equipment ages.

2) **Observational networks as a service:** In this model, the NMHS contracts with another party to meet its observational requirements. It may involve outsourcing the entire network with the contractor providing all of the equipment, maintaining it, and providing the NMHS with quality-controlled data that is ready for use in analysis and forecasting, and may be sold to third parties. An advantage of this model is that there should be a fixed cost, or at least a known annual cost, for service provision. This would mean no significant capital expenditure during the lifetime of the contract, and the contractor would be expected to meet NMHS requirements for quality and quantity of data supplied by the network. Depending on the contract, the NMHS may retain some right to the equipment installed on its property—partially mitigating the risk of the contractor failing to perform to the requirement. In effect, the contractor is pledging the equipment as collateral against performance. Having different contractors provide different aspects of the observing network might be an advantage. A short-term but important downside of this model may be the need to redeploy or make redundant significant staff; in general, redeployment should be an option, but there is some operational risk. Another issue may be variations in contractual arrangements.

Mexico tried this model in 2018 when it planned to award a contract for a public-private partnership to provide data collection, transmission, processing, and delivery services as part of modernizing its national weather service. This contract included providing: (i) automatic weather stations, radiosondes, radar, hydrometeorological stations, and lightning detection; (ii) collection, integration, distribution, and storage of observation network information; and (iii) O&M of the equipment. The period of the contract was 20 years, with transfer of intellectual property for any products and information produced. But the intended outsourcing faced practical logistical and implementation challenges, resulting in the cancellation of the initial bid. Despite this setback, the market for such services is growing, encouraging competition among potential suppliers of observational networks as a service.

3) **Data as a service:** In this model, the observational network, or part of it, is maintained and operated by a third party, which provides a data service to the NMHS. This model differs from the previous one, in that it is assumed that the vendor retains its rights to resell the data. It may take the form of a public-private partnership, where the NMHS and the vendor cooperate and play complementary roles. For example, the NMHS may restrict itself to specific uses that would not impinge on the vendor's business. Similar arrangements already exist, such as lightning detection, which has high commercial value, and are the subject of discussion for emerging global data sets. The right to reuse these data beyond the immediate needs of the NMHSs would depend on the type of contract. In practice this should be a low-cost option, but with some significant disadvantages—notably, the NMHS would have restricted data rights, which may limit its options to develop its own external business prospects. Alternatively, the NMHS may partner with the vendor, or others, or both, to develop new business opportunities, where additional value is added by other NMHS activities. Contractually, if part of the data set were considered essential (as defined by WMO resolution 40), they would be made available through the WMO Information System without restriction.

In practice, some variant on each of these models is likely to create the optimal solution—depending on the specific circumstances of each country.

Numerical prediction. There are serious questions about whether NMHSs should run a local limited area model (LAM)—as opposed to drawing on global or regional models (see Chapter 2)—pointing to the need for a business case to justify which path should be taken. The options, which are not necessarily exclusive to each other, include:

1) **Own and operate LAMs locally.** This option would be justified if: (i) the model's resolution is sufficiently high (higher resolution than global and regional models); (ii) data not available to the global and regional models are assimilated; and (iii) the LAM performs better than the global model and others. But justification is often anecdotal and not backed by rigorous analysis of model performance—leading to unsubstantiated, exaggerated claims of the benefits. The costs of maintaining the computational infrastructure and model codes are significant, with impacts on other cost centers. However, for hydrological forecasting, where the models are specific to a river basin, these models must be run locally.

2) **Outsource NWP services.** Reliance on regional and global centers for NWP guidance is a form of outsourcing. Some centers provide these data without charge, while others require a license fee to access their full set of digital products. The European model is a good example of countries collaborating to provide a very high level of NWP capability by pooling resources in a single center. Another solution is bilateral arrangements between countries with advanced NWP and neighboring countries that lack this capacity.

Choosing between options 1 and 2 is a matter of cost, quality, and reliability. Note these options are not necessarily mutually exclusive to each other as locally owned and operated LAMs still require global NWP outputs as boundary conditions.

Outsource ICT functions. The ICT system, which underpins all of the functions of a modern NMHS, lends itself most obviously to outsourcing. After all, most NMHSs cannot hire or retain sufficiently qualified staff in this area, where there are competing (and often more attractive) demands for this expertise, and where the technology is changing so rapidly. Not only do many developing countries want to run their own numerical models but they also want to own and operate high-performance computing (HPC) systems. At the same time, more advanced services are pooling their numerical prediction expertise in regional centers, or outsourcing their computing needs,[1] or both.

The European Centre for Medium-Range Weather Forecasts (ECMWF) is one of the best global modelling centers, and its computing requirements are substantial. However, its high-performance computing facility is operated under

[1] https://www.meteoswiss.admin.ch/home/latest-news/news.subpage.html/en/data/news/2015/9/meteoswiss-and-cscs-pave-the-way-for-more-detailed-weather-forecasts.html

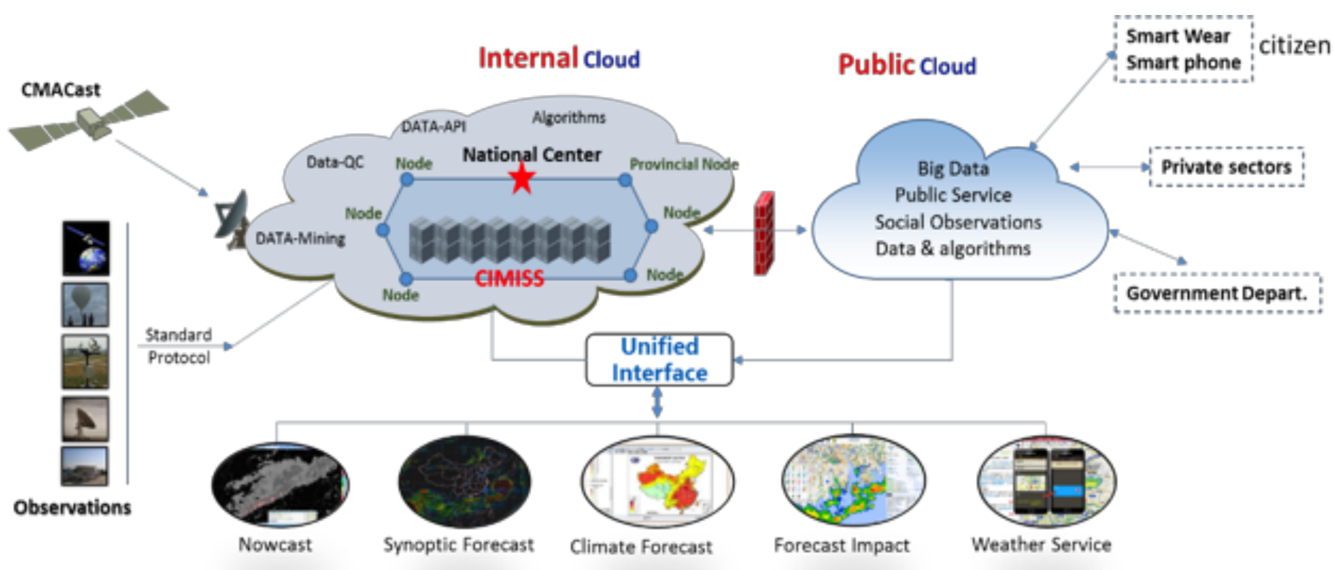
a service level contract to a high-performance computer vendor with the requirement to provide a certain level of processing capability, memory, and storage. In effect, they do not own the computers on which their models run. Amendments to the contract allow upgrades to the main systems and extend the contract support period. Most of the supporting technicians are provided by the supplier, with only a few staff employed by ECMWF. This approach ensures ECMWF has access to the newest technologies within a fixed annual operating budget.

Infrastructure as a service (IaaS). This platform is a form of cloud computing that provides virtual computing resources over the Internet. It is one of three main categories of cloud computing services; the others being software as a service and platform as a service. IaaS is a way to integrate and centralize data and information. The goal is to improve processing and delivery of data and remove the need for developers to move data between environments, and with the use of advanced APIs, data can be better shared with consumers (Jiao 2016). This approach is also readily adapted to new sources of weather observation data from nontraditional data sources. In addition, data can be readily shared with the NMHS from external sources, which improves the quality of impact-based forecasts that rely heavily on vulnerability, exposure, and the response of those at risk.

In China, the China Meteorological Administration's (CMA's) operational hybrid cloud (**Figure 3.1**) highlights how internal cloud and public cloud systems are used to host and deliver meteorological services and host NWP products and observational data. The public cloud has broad bandwidth and flexible resource allocation to support a diverse database and network protocols. CMA has demonstrated that cloud-based operations, based on a big data platform, save energy, provide faster data sharing, quicker deployment of new systems, easier maintenance, and better support for scientific experiments (Jiao 2016). This type of platform may be developed internally by the NMHS or accessed commercially through commodity cloud services. Although not readily applicable to NWP, commodity cloud services are increasingly being used by advanced centers, such as the U.S. National Weather Service and the UK Met Office (Dodds et al. 2017) for data management and access.

Application of ICT. Rapid adoption of Application Programming Interface (API) technology and IaaS by private sector weather services means that these services are readily accessible. The widespread use of smartphones in developed and developing countries alike enables citizens to find and use weather data from a variety of private and public sources, not necessarily their own national providers, which makes the monopolistic tendencies of some NMHSs untenable. Common

FIGURE 3.1 China Meteorological Administration (CMA) Switches Operations to a Hybrid Model



From 2015, CMA started to build an internal cloud computing platform (IaaS, Infrastructure as a Service)—which consists of 1 national center and 31 provincial nodes to integrate meteorological data and application for centralized monitoring and management. A public resource is also employed in a CMA cloud, not only to deliver meteorological service but also to host numerical weather prediction products with real-time verification and NWP interpretations, as well as the satellite data of long time-series analysis. Source: Jiao 2016.

business models of NMHSs include: (i) government to government (G2G), where meteorological and hydrological services are provided to other government departments (such as disaster management, water resources, and agriculture), either as part of the agencies funded responsibilities or through intra-governmental financial transfers; (ii) government to public (G2P), where the NMHS provides public weather and public hydrological services as part of its funded mandate; and (iii) government to business (G2B), where the NMHS provides a fee for service to private clients.

Governments have often perceived their NMHS as a cost recovery vehicle, which can boost its operating budget by selling services to the private sector and directly charging other government departments for data and services. While this may appear attractive, it tends to incentivize behaviors, which have an overall detrimental effect on the quality of services available from the NMHS. It should also be noted that cost recovery of many NMHS in developing countries is marginal at present due to the limitations of the market and challenges related to the quality of service being offered. Governments need to accept that the value of the NMHS is in the provision of public goods services, especially to support warnings to protect life, property, and livelihoods. The fee-for-service model inevitably puts the NMHS in direct competition with the private sector in areas where the private sector is often the more skilled.

Switch to service-oriented models. The move from infrastructure to services is a challenge for development partners and some client countries that are not well aligned with these business and technical shifts, and who need to adapt their procurement practices and operational models. There is a tendency to reinforce the developing countries' "own and operate model" which, rather than sustaining development, may contribute to expanding the technological gaps that are already present between the more and less advanced NMHSs and the private sector. In practice, this switch is not an option, but essential if NMHSs are to remain viable services.

Public and private sector engagement. The nature of the relationship between the public and private sectors is changing and will inevitably affect the public sector's business models. Any effort to improve public services must explicitly consider the role of the private sector throughout the value chain—from the delivery of observations to the provision of services to end-user customers and clients. Working with partners, the World Bank Group (WBG) is helping LMICs expand their range of options and solutions to sustainably grow their economies, reduce poverty, and expand opportunities. While countries have unique needs, the WBG is helping find the right mix of public and private funding to meet their objectives.[2]

The 17th World Meteorological Congress in 2015 gave a new perspective to partnerships by acknowledging the growing involvement of entities belonging to the "private sector" (private companies, citizen's associations, bloggers, etc.) in weather, climate, water, and related environmental matters). Since then the WMO Members highlighted the different, and at times, complementary roles and responsibilities of NMHSs, academic institutions, research and technological agencies, and the private sector. They felt that closer interactions between the public and private sectors would stimulate innovation and facilitate cross-fertilization, benefitting the society. But they also recognized that such activities could lead to the proliferation of weather and climate information of various nature and quality—which could challenge the NMHSs mandate to disseminate authoritative weather information and warnings to the public and disaster management authorities as well as the rest of the enterprise in delivering on their missions.[3]

The World Bank's support to the hydromet sector fully supported the efforts of the WMO to expand cooperation between the various stakeholders participating in the Global Weather Enterprise (GWE) in line with the UN Sustainable Development Agenda 2020, which emphasizes the need for more partnerships between public and private actors as a necessity for achieving the ambitious Sustainable Development Goals (SDGs). SDG 17 calls for strengthening the means of implementation and revitalizing the Global Partnership for Sustainable Development. In 2018, the WMO adopted a Policy Framework on Public-Private Engagement (**Box 3.1**). The topic of the public and private engagement in weather, climate and water related services is present in the program of the 18th World Meteorological Congress (June 2019).

[2] http://www.worldbank.org/en/about/partners/maximizing-finance-for-development

[3] EC 70 Doc 12.2 Public-Private Engagement.

Box 3.1 WMO and the Private Sector

The WMO's Policy Framework on Public-Private Engagement is intended to guide global, regional, and national action by the WMO to promote active engagement between the public, private, and academic sectors, and with other stakeholders to manage and participate in the GWE. An all-inclusive weather-enterprise approach aims at maximizing the benefits to citizens. It aims to build understanding and enhance cooperation, strengthen opportunities for WMO Members, their NMHSs, and the private sector, on the basis of ethical behavior to ensure a level playing field, enable efficiency and innovation, and utilize an inclusive approach to funding basic infrastructure and research. There is considerable opportunity to improve the efficacy and reach of warnings, forecasts, and other services through more cooperative relationships among the sectors.

People-first. WMO has adopted a "people-first" approach to public-private engagement, which is widely accepted as a vehicle to achieve the UN SDGs. This implies that the focus of GWE should be on improving public safety and the quality of life. Partnerships should, therefore, help increase access to essential, affordable, and fit-for-purpose products and services, which eliminate vulnerabilities and exposure to weather, climate, and hydrological impacts.

Shared Values. It should be recognized that the public, academic, and private sectors coexist and benefit mutually from their engagement in the GWE. Both the private and public sectors recognize the opportunities for innovation and growth, based on science and technological advances. Shared value is created by promoting data sharing, accelerating the uptake of research and technology developments into operations, and stimulating the creation of new services. The sustainability of the GWE is a matter for joint action and can be best achieved by assuming complementary roles, which minimize overlap and unnecessary competition, and where the strengthens of each sector are reinforced.

Standards and recommended practices. The WMO facilitates worldwide cooperation in meteorology and hydrology. It sets standards and provides recommended practices to enable a unified global exchange of data in weather, climate, hydrology, and related fields, a harmonized data processing and forecasting system, and that services are provided with an acceptable level of quality and standard to specific economic sectors and the public. It is important that both the public and private sector meteorological and hydrological services adhere to these standards, particularly in the areas of observations and forecasting, to ensure the public and economic sectors' confidence in the GWE. Quality assurance is an ongoing issue for both public and private sectors with greater emphasis being placed on verification and validation of all aspects of the value chain.

Strategic Planning

Given the rapidly changing landscape of the GWE, strategic planning is an essential building block for the effective development of the NMHS. A relatively simple but effective approach is promoted by the WMO,[4,5] and it is recommended that this be followed at the earliest stage of any effort to modernize or improve an NMHS.

Strategic goals. In many instances, there is a rush to invest in an NMHS without fully understanding the strategic goals of the organization, which may be poorly articulated or nonexistent. For a public facing body, the NMHS must ensure that it is set up to meet the needs of those it serves—its users, customers, or clients (the exact nomenclature depends on the specific country circumstances), which are the external end-user of the services whose decisions and actions are informed by the NMHS. These external stakeholders are not always considered at the outset of the strategic planning process, but it is essential to understand their current and future requirements of the NMHS and to develop the planning process around these requirements.

The South African Weather Service's vision is an exemplar of a user-oriented organization—"The South African Weather Service (SAWS) . . . has a vision of "A weather SMART Nation"—where citizens and institutions are able to use quality and reliable weather- and climate-related data provided by the organization to enhance the quality of their lives and build resilience to extreme weather events and mitigate climate change impacts. ". . . SAWS will achieve this vision by evolving into a Weather and Climate Centre of Excellence that provides innovative solutions to achieve a Weather-smart (WeatherSMART) region, sustainable development

4 World Meteorological Organization—Strategic Plan Template.

5 WMO Integrated Strategic Planning Guide.

and economic growth through leadership in meteorological, climatological and other related sciences, the development of relevant and innovative applications and products utilizing cutting-edge technology and establishing and leveraging collaborative partnerships."

Planning process. The strategic planning process helps to align the organization's goals to fulfil its mission and achieve its vision. The main output of the process is a plan, which is used to communicate with internal and external stakeholders the goals and actions required to achieve those goals. The basic rationales are to:

- Agree on a common purpose.
- Build consensus around goals, objectives, and priorities.
- Increase effectiveness.
- Increase efficiency.
- Provide the basis for resource allocations and ensure value for money.
- Understand, predict, and adjust to changing circumstances.
- Improve decision making.
- Improve organizational abilities.
- Improve communication.
- Assess performance.

There are several different approaches to strategic planning. The World Bank's ten-step guide is to:[6]

- Agree on the process.
- Carry out an environmental scan—how the organization relates to its external environment.
- Identify key issues, questions, and choices.
- Define or review and update the organization's values, mission, and vision.
- Develop a shared vision—where the organization wants to be in five years.
- Develop a series of goals.
- Agree on key strategies to achieve goals.
- Develop an action plan (Concept of Operations) that addresses goals, objectives, and work on an annual basis.
- Write the strategic plan.
- Monitor and modify based on changes in the external environment of the organization.

Theory of change. Variations on this model include issue-based planning, alignment, scenario planning, self-organizing planning, real-time planning, theory of change, and balanced scorecard (WMO 2016a). Each of these models is adapted to specific needs, but in essence all are intended to achieve the goals of organization, efficiently and effectively. WMO favors the theory of change model because of its emphasis on results-based management. This model first identifies the desired long-term goals and then works back to identify all of the conditions that must be in place, and how these are casually related, for the goals to occur. These are all mapped in an outcomes framework or logic model that provides the basis for identifying what type of activity or intervention will lead to the outcomes identified as preconditions for achieving the long-term goal. This way the link between activities and the achievement of the long-term goals is more fully understood.[7]

Concept of Operations (CONOPS)

The services provided by NMHSs can be considered a complex, dynamic "system of systems" that deliver a spectrum of meteorological and hydrological services to a variety of users—from public guidance and warnings to specialized services for other government agencies. They may also play a role in the provision of bespoke, commercially oriented services. The purpose of the CONOPS is to ensure that: (i) there is a consensus among all stakeholders so that every partner understands and supports the proposed operational system; (ii) risks are reduced by ensuring every aspect of the system is determined before it is procured or implemented; and (iii) quality improvement is built in by taking every opportunity to leverage existing and new infrastructure to increase system performance.

The CONOPS is a document that describes the scope and characteristics of the proposed system and the way the system (or system of systems) will be used (**Technical Insight 3.1**). It must consider all stakeholders, ensuring that the CONOPS is readable and relevant to high-level decision makers and systems operators (UCAR 2010). And it is built on the strategic plan, business modelling, and stakeholders'

[6] https://siteresources.worldbank.org/INTAFRREGTOPTEIA/Resources/mosaica_10_steps.pdf
[7] Center for Theory of Change.

TECHNICAL INSIGHT 3.1 A Sample CONOPS

The CONOPS may include the following:

- Why the system is needed and an overview of the system itself—for example, a severe weather forecasting platform.
- The full system life cycle from deployment to decommissioning.
- Different aspects of the system—operations, maintenance, support, and decommissioning.
- The different groups of users—for example, end-users of the system, forecasters, technicians, public weather advisers, and their different skills and limitations.
- The physical environment and locations in which the system is used and supported.
- The relationship between the system and other systems.
- When the system will be used, and under what circumstances.
- How and how well the needed capability is currently being met.
- How the system will be used, including operations, maintenance, and support.
- Scenarios illustrating specific operational activities involving the use of the system.

The CONOPS should answer the following questions:

- Who are the stakeholders involved with the system?
- When will the activities be performed?
- Where are the geographical and physical locations of the system?
- Why does the NMHS require this system?
- What are the known elements and the high-level capabilities of the system?
- How will the system be resourced, designed, built, and maintained?

It is recommended that the CONOPS addresses the following issues

1. Scope
   a. Vision for the system
   b. Outline of the contents of the document
   c. Purpose for implementing the system
   d. Intended audience/beneficiaries
   e. Limitations of content covered
2. Knowledge references
   a. Discussions with stakeholders and experts
   b. Studies of systems from other countries
   c. Analysis of mission requirements and operational needs
   d. Recommendations offered by vendors and product manuals
3. Operational description
   a. Summary of each user's role and activities
   b. Clarification of the order of user operations
   c. Summary of the operational process procedures
   d. Description and flow diagrams associated with organizational decision-making and management structures
4. System overview
   a. Specific goals and objectives that are measurable and time bound
   b. Interdependencies between subsystems
   c. Confirmation that the system's capabilities will satisfy its mission
5. Operational and support environments
   a. Facilities
   b. Equipment
   c. Hardware
   d. Software
   e. Personnel
   f. Operational procedures
   g. Maintenance, training, and support requirements
6. Operational scenarios
   a. A range of stakeholders' perspectives
   b. A range of stress/failure scenarios (both typical and extreme circumstances)

Note: A sample Concept of Operations for modernizing and operating an NMHS is based mostly on the approach taken by the COMET program of the University Corporation for Atmospheric Research in developing a flash flood early warning guidance system.

Source: UCAR 2010.

requirements. The system of systems approach shown in Figure 2.1 provides the basic building blocks of the CONOPS. It can be used to identify the current status of any NMHS and to visualize investments, component by component, in each of the systems and subsystems to achieve a particular level of improvement. The complexity of each system and its subsystems varies depending on the size, level of development, and resources of an individual NMHS. A pre-requisite of each of the individual systems is access to sufficient staff with the capacity to understand and operate a particular system. At the same time, access to various systems within the observing systems block is essential for the rest of the systems to function and produce various products for delivery to the users—and eventual establishment of a monitoring and feedback loop to the users. All associated equipment, facilities, material, software, hardware, policy and technical documentations, services, training, and personnel required for operations and support of the NMHS are included as part of each subsystem. How each system is supported depends on the choice of business model.

The CONOPS should evolve with the system. It is a vehicle to communicate high-level quantitative and qualitative characteristics of the system to the user, developer, operator, and other stakeholders. The CONOPS addresses the challenges involved in ensuring the NMHS is fit for purpose. It is intended to be a structured document with an architecture defined by the 1362-1998 IEEE guide for information technology system definition Concept of Operations (CONOPS) document.[8] This formality services several purposes: a common understanding of the systems requirements, a common format to test and exchange information among projects within the NMHS community and with others, and proven approach to development of operational systems. The CONOPS has 10 sections.

- Section 1 describes the approach used to develop the CONOPS.
- Section 2 provides a list of reference documentation used in the creation of the CONOPS.
- Section 3 describes the current NMHS systems.
- Section 4 discusses the justification and nature of changes based on the most current information.
- Section 5 provides information on proposed system concepts.
- Section 6 describes operational scenarios.
- Section 7 summarizes operational, organizational, and other impacts during development.
- Section 8 analyzes the proposed system.
- Section 9 includes abbreviations and acronyms.
- Section 10 includes annexes.

An annotated table of contents of a CONOPS is shown in **Annex 4**. This can be used as a template for preparing a CONOPS document. Because this follows an IEEE standard, it is important to adhere to the structure of the document as closely as possible for the document to be considered a CONOPS. The rest of this chapter looks at **Sections 1–8**, and **Box 3.2** cites some common mistakes to avoid in drafting the CONOPS.

Section 1: Scope

Section 1 describes the approach used to develop the CONOPS. Given that the primary mission of NMHSs is to serve the needs of the public and government, the CONOPS should be based on an assessment of user requirements, which should be derived from a series of stakeholder workshops—including an element of user education, since many users do not understand what can be expected from an "ideally" functioning NMHS.

The initial approach to preparing the CONOPS may use concept analysis—which is the process of analyzing a problem domain and an operational environment—for specifying the characteristics of the proposed system from the users' perspective. This approach helps to clarify and resolve vague and sometimes conflicting needs, wants, and opinions by reconciling divergent views. The goal is to minimize the potential for designing a system in which each individual function meets its specifications, but the system, as a whole, fails to meet the users' needs.

Section 2: Referenced Documents

Section 2 summarizes the documents used in the preparation of the CONOPS. It should reference the following WMO standard and guidelines, at a minimum:

[8] http://sse.tno.nl/IEEE_STDS/SESC/1362-1998.pdf

- WMO, 2014. The WMO Strategy for Service Delivery, WMO-No. 1129. Geneva, Switzerland. http://www.wmo.int/pages/prog/amp/pwsp/documents/WMO-SSD-1129_en.pdf
- WMO, 2016. WMO Technical Regulations: General Meteorological Standards and Recommended Practices. WMO-No. 49, Volume I. Geneva, Switzerland.
- WMO, 2016. WMO Technical Regulations Meteorological Services for Air Navigation. WMO-No. 49, Volume II. Geneva, Switzerland.
- WMO, 2006. WMO Technical Regulations: Hydrology. WMO-No. 49, Volume III. Geneva, Switzerland.
- WMO, 2013. WMO Technical Regulations: Quality Management. WMO-No. 49, Volume IV. Geneva, Switzerland.
- WMO, 2011. Manual on Flood Forecasting and Warning. WMO-No. 1072.
- WMO, 2006. Guidelines on the Role, Operation and Management of National Hydrological Services, WMO-No. 1003.
- WMO, 2017. Manual on the Global Data-processing and Forecasting System (GDPFS). WMO-No. 485, 2017 edition, Geneva, Switzerland.
- http://www.wmo.int/pages/prog/www/WIS/manuals_guides_techregulations_en.html (the link to all Technical Regulations above).

These should be supplemented by certain NMHS documents, including:

- The statutory authority of the NMHS, which states its mandates and legal responsibilities.
- User requirements—these would be acquired during any strategic planning process, but, in any case should be frequently updated and will drive continuous improvements in the NMHS to remain responsive to these requirements.
- The Strategic Plan of the NMHS.
- An analysis of alternative approaches, which could be employed to meet the strategic objectives of the NMHS.
- Any other documents, which may include project appraisal documents, project descriptions, government data sharing policies, and any other information that may influence the operations of the NMHS.

BOX 3.2 Avoiding Common Mistakes

Several common mistakes can be made when developing CONOPS (UCAR 2010). These include:

1. **The NMHS expecting its system vendors, contractors, or other external partners to develop the CONOPS, as a part of the other deliverables.**

   The NMHS must ensure that its staff is responsible for the development of its CONOPS, albeit with external expert assistance.

2. **Postponing CONOPS development until after the system has been designed and delivered.**

   A CONOPS is a document that must be drafted before a system design is finalized and kept continuously up-to-date as systems requirements change.

3. **Allocating inadequate staff resources for CONOPS development.**

   The process of conceptualizing NMHSs' systems is complex, tedious, and time consuming. It requires study tours to learn about current practices in CONOPS development from other leading NMHSs.

4. **Assigning unqualified staff for CONOPS development.**

   Adequate representation by personnel with experience in the organization's strategic, operational, technical, administrative, financial, and communication programs is essential.

5. **Adopting another organization's CONOPS.**

   Borrowing another organization's plan is likely to ensure that mistakes of others will be repeated. Worse, stakeholders will have a much weaker commitment than if they are given the opportunity to contribute to the development of their own CONOPS.

6. **Neglecting to update a CONOPS while the new system is being implemented and once it becomes operations.**

   The CONOPS should reflect the actual system design, mission requirements, and operational vision. It should be reviewed and updated regularly to remain relevant.

Section 3: Current System

Section 3 of the CONOPS describes and assesses the current operational system. This includes: (i) background, objectives, and scope of the current system and its subsystems; (ii) operational policies or constraints; (iii) the details of the current system and subsystems; (iv) modes of operation for the current system; (v) users of the services provided by the NMHS; and (vi) staff and the support environment.

Possible approaches. Based on the current status, the analysis should propose different approaches to developing the NMHS. This might include: (i) maintenance of the current business model, (ii) privatization of some or all functions, (iii) partnerships with external public and private entities, and (iv) outsourcing of some functions. The analysis should also consider the activities of other development partners, which may be actively investing or proposing to invest in the NMHS. Frequently these efforts are limited in scope, but they can have a significant bearing on modernizing the NMHS—if those efforts encompass key components of the system or require a particular business model to be sustainable. It is not uncommon that one project results in unplanned delays in another, as a result of incomplete exchange of technical information.

Very often the proposed investment is made because the NMHS's process for monitoring and observing, modelling, forecasting, and service delivery rely largely on outmoded systems. A motivation for modernization includes: (i) the acquisition of new observational capabilities (such as fully exploiting new radar technologies required for nowcasting and very short-range forecasting); and (ii) access to, and best use of, high resolution global and regional model outputs—for generating tailored products for users and operating the latest technologies for dissemination and delivery of forecasts and warnings.

NMHSs tend to pay more attention to modernizing monitoring networks and instruments, usually the most expensive part of the program, which has a high risk of being unsustainable. Modern observation methods are typically based on as much automation as possible, because automation increases the frequency and spatial coverage of the observations. While the advantage of the greater density of the network and frequency of observation is apparent, most developing countries' NMHSs are not able to take advantage of the high volume of observations, owing to their lack of the ability to assimilate these data in nowcasting systems and very short-range forecasting models. Also, automation does not necessarily mean instruments should be left unattended, given that in extreme environmental conditions, instruments need to be inspected.

Automation versus manual systems. The transition from entirely manual to even quasi-automation is a difficult, relatively long-term (two to four years), and costly step in all countries—especially countries that rely on unskilled or semiskilled labor and that might be uncertain about future employment (Lynch and Allsopp 2008). NMHS management often overlooks the fact that introducing automatic systems requires fundamentally changing data collection routines and operating procedures. This process is costly because it requires extensive staff training, significant technical support, and parallel manual and automatic observations for at least one year at all climatic and other stations with significant historical records.

Much more effort is needed to exploit the benefits of an automated network than is done in most modernization projects. In many instances, automatic stations are viewed as supplemental to manual stations, and no effort is made to transition the network to fully integrated automatic stations—which is why it is important to engage all staff members, including field observers, so that they fully understand the benefits. Vandalism is also a generic problem in most developing countries, especially where solar panels are used. Experience suggests that where the local community is engaged and can access the data directly from the station, vandalism is less of a problem. Over time, the number of observers at the automatic weather station sites should be gradually reduced, and their duties should be transformed from pure observers to technicians, station guards, or community climate extension workers.[9]

Upper-air measurements. These are particularly important for forecasts, but many of the poorest countries have stopped taking such measurements because of the cost of the expendables. Continuing to take upper-air measurements requires the government to commit to the additional O&M costs that accompany the new capabilities. In the case of upper-air stations that are critical for global forecasts, development agencies or the WMO might want to allocate special long-term funding.

[9] Creating a cadre of climate extension workers from existing observers could help improve the community's response to hazardous weather and increase local knowledge on climate resilience.

The rapid development of Global Positioning System–Radio Occultation (GPS-RO) technology means that atmospheric profiles of temperature and humidity may be derived from satellite observations at virtually any point. This means that models can be initialized with data at every grid point. However, this does not eliminate the need for radiosondes to provide direct measurements of temperature, humidity, and winds aloft, and as a reference network for calibration.

Overall system goals. In order to meet the NMHS's strategic goals, the proposed system typically should be able to accomplish the following:

- Affordable and easy to maintain observing networks.
- Effective and efficient data transmission, archiving, and management, including rigorous quality assurance/quality control (QA/QC) of data.
- Access to and effective use of NWP ensembles.
- Reliable forecasting system, including impact-based.
- Robust dissemination and communication.

Section 4: Justification for and Nature of Changes

Section 4 describes the rational for the proposed system. Most NMHSs have a long history of providing meteorological and hydrological services to their countries. Continuing growth in the weather- and climate-dependent economic sectors—and in the increasing exposure of a growing population to weather and climate extremes—makes it an imperative to improve the quality and level of services provided by the NMHSs and other service providers to protect lives, livelihoods, and economic development.

One of the purposes of a modernization program is to increase the number of services that can be provided by the NMHS to meet the growing needs of their users. There is an increasing demand from users for more accurate, timely, and useful forecasts and warnings. Advances in knowledge and technology have increased the accuracy of meteorological predictions that help save lives, protect livelihoods, and improve economic performance. Most modernization efforts are initiated because the NMHS has not kept pace with these requirements or developments. It is critical to improve the quality of weather, climate, and hydrological information and services—and their accessibility and use by the stakeholders and end-users—by building on technological advances to reduce the economic impact of disasters of meteorological and hydrological origin, and to improve climate resilience.

What are the attributes of the system? From the overall system perspective, the proposed modernization of an NMHS should possess the following attributes:

- Infrastructure independence: an architecture that allows the NMHS to operate under all circumstances, including during extreme hazards.
- Scalability: the capability to accommodate growth and evolving technologies without requiring a complete replacement of the systems.
- Flexibility: the ability to tailor services to users' future requirements. The system should be flexible enough to interface with other agencies' evolving systems.
- Comprehensiveness: the system should be able to meet all anticipated needs.
- Extensibility: the ability to handle new types of observations, numerical models, and forecasting systems.

What should an NMHS be able to do? To meet strategic objectives, the NMHS needs to integrate its systems and subsystems, along with incorporating legacy systems and new systems provided by other development partners. Increasingly, parts of the system may be provided by others as a contract or within a partnership with shared responsibility. In any case, the NMHS, or its contractors/partners, or both should be able to:

- Receive observational data from a variety of international and national sources and use these data in the forecasting system.
- Apply quality control to observational data.
- Ingest, preserve, and provide access to observational data.
- Store observational data in a manner that is independent of any particular hardware and software over long periods.
- Retrieve NWP/EPS data from global and regional centers and use these data in the forecasting and service delivery systems.
- Carry out verification of NWP/EPS forecasts and apply post-processing techniques (that is, statistic downscaling), such as Model Output Statistics (MOS), for calibrating models throughout the country.

- Apply and use dynamic downscaling for improved understanding of regional and local weather phenomena and fine-tuning of forecasts.
- Produce user-tailored numerical products for specific users.
- Use EPS techniques for impact-based forecasting.
- Scale up in order to store and preserve observational and forecasting data.
- Code and decode observational and forecasting data using international standards.
- Organize and maintain an adequate metadata repository and asset management—including inventory register of the contents of the systems, their conditions, maintenance, and replacement/calibration/upgrade schedules.
- Provide electronic access to weather, climate, and hydrological observational and forecasting data and information for all users based on established user rights and privileges to ensure that users are able to access all of those electronic data and information to which they are entitled.
- Provide access to weather, climate, and hydrological observational and forecasting data and information in a manner consistent with current technology and the changing expectations of diverse users.
- Adapt to changing technology in order to provide the level of services desired by the users.
- Exploit current knowledge and technology to provide the optimum level of quality services expected by the users.

Section 5: Concepts of the Proposed System

Section 5 describes the proposed system. The proposed system would be derived from the analysis of the existing system of systems, new and evolving user requirements, and any constraints imposed by the government and financial instruments. Ideally, the proposed system follows the system of systems architecture proposed above.

Monitoring and Observing Systems. More frequent, high-quality meteorological and hydrological data would improve short-range forecasts. A detailed network design would be required to determine optimum impact. If the existing synoptic network is not dense enough, this should be expanded using automated stations where feasible—for example, augmentation would allow better agricultural services. Upper-air stations and radar are costly, but beneficial. Upper-air stations are particularly useful to improve the local and downstream forecasts, if these data are assimilated in the global models. Radar would improve thunderstorm detection and quantitative precipitation estimates, in turn improving nowcasting and very short-range forecasts. A significant investment in data servers would be required. The modelling and forecasting system would provide a data service to the modelling systems, the objective and impact forecasting and warning systems, and to end-users that require validated observational data.

Modelling systems. All NMHSs should be able to exploit the available global and regional prediction centers' products at the highest resolution available. The architecture of the modelling system, therefore, should be based on access to digital data from these centers, including the purchase of licences, if required. The choice of the NWP system should be in close consultation with the relevant staff and management to ensure due consideration of the continuity in usage of known models—preferably those with higher resolutions and established mechanisms to provide direct technical support from global and regional center(s) running such models. Model selection also requires knowledge of how to apply each model to particular physical situations, which requires an extensive objective verification program. The use of EPS digital data would enable the application of impact-based forecasting techniques, as well as the provision of the forecast uncertainty for decision making. Statistic downscaling (such as Model Output Statistics) should be implemented for the calibration of both deterministic and probabilistic forecasts from ensembles. Dynamic downscaling should be considered for hazardous-prone areas to fine-tune and refine forecasts. To support application areas, including hydrology and agrometeorology, manipulation of digital data (that is, coding and decoding) should be implemented. Introducing LAM should be done with caution, taking into consideration the points made earlier.

Hydrological modelling systems should be flexible to allow a wide range of forecasting models and should provide an interface with meteorological models to use quantitative precipitation forecast data. It is also important to consider the affordability of the models, if they are not open source. Model selection requires knowledge of how to apply each model to a particular physical situation. This necessitates not only an understanding of the model and its use but also the physical setting—including a detailed understanding of the underlying vegetation, topography, soils, geology, and climate. This system can be used to specify the type of hydrological models that are most favorable for forecasting purposes and appropriate to the available database and spatial and temporal boundary conditions of modelling. The system should provide for ensemble-based flood forecasting to add a probabilistic component by using inputs from multiple NWP models—which, in turn, would require a data ingest process. For example, ECMWF ensemble NWP fields of QPF and QTF and an efficient hydrological observation network would be required to automatically generate hydrological forecast ensembles at all forecast locations. Hydrological forecasting based on an ensemble of NWP models would permit the modelling of the complete river basins (including snow modelling and reservoir simulation modelling) to produce monthly to seasonal hydrologic outlooks for water resources planning and management purposes.

The primary user of the modelling systems products and services would be the forecasters running the objective and impact forecasting and warnings systems, and other agencies. If hydrological modelling is done elsewhere, the modelling system would be expected to provide a feed of model data.

Objective and impact forecasting and warning systems. The architecture of a modern forecasting system is based on the implementation of real-time forecasting processes—which consist of (i) quality-controlled data services from the monitoring and observing system; and (ii) verified, post-processed, and calibrated NWP data and statistic and dynamic downscaling from the modelling system. The forecasting systems would include: (i) interpretation and communication of products; (ii) visualization and processing tools to enable integration, overlaying, and manipulation of observational and NWP/EPS data for nowcasting and very short-range forecasting, short- to medium-range forecasting, and seasonal forecasting; (iii) real-time forecast monitoring and verification; and (iv) impact-based forecasting. It would also require a quality management system and standard operational procedures. Probabilistic forecasting is an important tool that should be implemented as a part of any modern forecasting system. Capacity building of staff would be critical to understand and use these new products.

Modernization of hydrological forecasting should be expected to provide:

- An integrated modelling environment within a single forecast system.
- Significantly enhanced data and hydrologic modelling visualization.
- A framework to expand modelling and forecast capabilities from major rivers to minor tributaries, and flash flood–prone areas.
- Extended forecast lead times to several days and hydrological outlooks to weekly, monthly, and seasonally (based on remote sensing and snow modelling).
- The capability for both short lead time and extended (seasonal) probabilistic hydrologic forecasts, using ensemble NWP outputs (primarily, precipitation, and temperature fields) as hydrological model inputs.
- Forecast verification, which would aid forecasters to identify strengths and weaknesses in the forecast process to guide model and forecast process improvements.

The hydrological forecasting system should provide: (i) access to global hydrological products; (ii) implementation of real-time forecast evaluation, model verification, calibration, and post-processing systems; and (iii) visualization tools to allow data from rain gauges, radars, and satellites to be overlaid seamlessly into single multisensory fields on an hourly basis.

Service delivery systems. The service delivery system should fully engage the users, and it should include the introduction of public weather and hydrological services for major sectors (such as DRM, water resources, agriculture, civil aviation, transport, energy, and health). The system should support: (i) developing and enhancing new and existing user-tailored products and services; (ii) the Common Alerting Protocol (CAP)[10] capability; (iii) improving dissemination mechanisms to all communities (particularly remote areas)—including mobile applications (for warnings, food security), FM radios, SMS, and web-based services, on top of traditional media; and (iv) developing mechanisms for evaluation of forecast utility and user satisfaction.

The system should specifically address developing and operationalizing impact-based forecast and warning services, and include a post-event review and assessment process. In addition, the system could include an Agriculture and Climate Advisory Service (ACAS) (including drought monitoring) and satellite assessment of crop condition. A National

[10] http://www.wmo.int/pages/prog/amp/pwsp/CommonAlertingProtocol_en.html

Framework of Climate Services (NFCS) is also recommended to be included in the system—and as part of climate service delivery or the latter, it should contribute to the NCFS if this is developed outside of the NMHS. Also, a digital library of climate-relevant information should be developed to digitize original data (data rescue), quality control the historical data, and create a centralized and standardized database (including metadata).

ICT systems. A modern data management, communication, and ICT system should be part of any NMHS. The modernization and expansion of an NMHS's observation network system and improvement in forecasting and service delivery systems require comparable improvements in ICT infrastructure and data integration capacity. The systems should be fully redundant, enabling continuous operations during extreme events. A critical, and sometimes overlooked, component is access to high speed Internet—which, if not available, should be introduced as soon as possible in the project.

Capacity building. For a strong and effective NMHS it is essential to have continuous access to new skills for new and existing staff, provision of short- and long-term courses, and on-the-job training. Some of these skills could be provided by universities and technical institutes. Generally, a steady supply of meteorologists, hydrologists, and related specialists (at the B.Sc., M.Sc., and Ph.D. levels) are required to replace retiring staff. These new staff would need to be equipped with the skills and abilities to perform at the required skill levels, in line with the proposed advances in forecasting and observing systems, and service delivery practices. Most NMSs and NHSs develop cooperative relations with local universities, so that the latter can provide qualified staff to the operational services that match current needs.

Technical- and service-related expertise will change as new meteorological and hydrological products become available. Such changes would require review and upgrading of skills and responsibilities of staff and a long-term plan for staffing, to be defined in the context of the technical upgrades and service delivery strategy. Technical training should be offered to main stakeholders to facilitate the smooth operational processes to the benefit of all concerned.

Training requirements for capacity building. The NMHS should consider developing a plan (initial and ongoing), which addresses all capacity building needs prior to starting any new operations and activities. Areas where training is usually required include:

- Project management.
- Management training.
- Financial management.
- Quality management and QMS.
- Technical skills to support meteorological and hydrological observing networks.
- Instruments and detectors for maintenance and engineering.
- Enhanced skills in weather forecasting using numerical models on all timescales from nowcasting to long-range forecasting.
- Enhanced skills in weather forecasting based on remote sensing.
- Enhanced skills in hydrological forecasting using numerical models.
- Understating of the end-to-end early warning production and delivery, including coordination with disaster management authorities.
- Impact-based forecasting and warning services.
- Mesoscale meteorology.
- Verification and statistics methods, including big data methods.
- Database management.
- IT management skills.
- Skills in Public Weather Services (PWS) and service delivery—including user/stakeholder consultation, communication, negotiation, and feedback gathering.
- Knowledge of social, environmental, and economic sectors sufficient to provide consulting services to their users.
- Enhanced skill in climate prediction using numerical methods.
- Public education and outreach.

Leadership and management training should be conducted as a priority to facilitate the rapid development of high-quality management processes near the start of the project. Team building workshops to build strong team performance in the NMHS should also be conducted (for example, through leadership coaching). The capacity building system should support retraining of current technical staff, and recruitment of new staff, as required, to suit the modernized environment. An important component of capacity building relates to training support for the main stakeholders and end-users to understand and be able to apply the NMHS' information and services in their decision-making processes. It would also be important to conduct outreach and public education activities for communities. Service monitoring and feedback systems should be established to gather crowdsourced data from trained volunteers, as well as evaluation of user satisfaction. Relations and collaboration with local universities should be established or strengthened.

Section 6: Operational Scenarios

Section 6 of the CONOPS document expresses what users want and envision. Scenarios convey these needs in a nontechnical language. Overlap exists between different scenarios as a result of interaction between different users or due to similarity between different activities. For example, the document might include scenarios for disaster managers, agriculture extension workers, farmers, and the general public.

A scenario is a step-by-step description of how the NMHS should operate and interact with both its users and external interfaces under a given set of circumstances. Scenarios should enable readers to walk through them and gain an understanding of how all principal parts of an NMHS functions and interacts.

For example, the following scenario for DRM highlights how an NMHS would support emergency operations prior to, during, and after a major event:

- The NMHS provides long lead time outlooks ahead of the monsoon season, based on numerical model guidance, with regular updates (such as monthly).
- The NMHS provides long lead time outlooks on developing adverse weather situation, up to 10 days ahead, based on numerical model guidance.
- The NMHS enables emergency operations to begin initial preparation.
- Guidance provided by the NMHS is updated daily—and closer to the severe weather event and associated impacts and briefings are given on a frequent basis.
- Severe weather forecasters must relocate to emergency operations center.
- Warnings are issued via the emergency operations center, and directly through the media and other communication channels.

Section 7: Summary of Impacts

Section 7 describes the operational, organizational, and implementation impacts of the modernization program. These should be documented and addressed, including:

- Changes in the operational budget.
- Changes in the operational risks.
- Changes in the maintenance budget.
- Changes in the maintenance risks.
- New modes of operations, based on new forecasting techniques.
- Changes in the quantity, type, and timing of data to be input into the system.
- Uses of new data sources.
- Changes in procedures.
- Numbers and skill levels of personnel needed for contingency operation.
- Changes in the number of personnel, skill levels, position identifiers, or location of personnel.
- Revision of position descriptions to reflect changes in business practices.
- Commitment of resources to the new system.
- The need for cross-functional, interdisciplinary staff teams.
- The development of education and increased training for both NMHS staff and users.
- Improved opportunities for career development for NMHS staff.
- Relationship between the NMHS and external partners.
- Articulation of business rules, templates, and other controls needed for operational implementation.
- Development of training for staff.
- Consideration of parallel operations of the new and existing systems.
- Operational impacts during system testing and transition of the proposed system.

Section 8: Analysis of the Proposed System

Section 8 considers various improvements, disadvantages and limitations, and alternatives and trade-offs. Some of the benefits would likely include:

- More accurate and timely forecasts, based on full use of the high-resolution ensembles provided by advanced numerical prediction centers, such as ECMWF.
- More confidence in warnings issued with greater understanding of risk and the ability to improve decisions in low probability, high impact extreme weather events.
- More detailed shorter range forecasts.
- Nowcasts and very short-range weather forecasts.
- Dynamic, ensemble-based flood forecasts.
- Impact-based forecasts and warnings.

Some of the potential disadvantages include:

- High development costs.
- Staff anxiety brought about by new responsibilities.
- Poor staff morale without proactive change management.
- Higher operating and maintenance costs.
- Unrealistic expectations of users and stakeholders.

By adhering to this approach, it is possible to assess the impact on the operational system of any change. It should be updated frequently and whenever there is a material change in the system, which may affect any aspect of the operations from operational costs to the delivery of services.

Summary of Changing Roles

NMHSs and their private sector counterparts can complement each other in their efforts to provide levels of service to protect lives, livelihoods, and property in an era of increasing meteorological and hydrological hazards. NMHSs need to evolve quickly, not because of the threat of competition from the private sector, but rather because society needs to be able to make informed decisions. The changing requirements of users, in response to growing threats, is the main driver for change. Services must be and must remain fit-for-purpose. Therefore, they need to evolve as the information requirements of their users change.

The traditional model of an NMHS doing everything alone is no longer tenable from either an economic or technical viewpoint. New business models are needed that can help the public sector deliver what is required. Few of these models have been tested, and efforts are under way to determine the most effective ones under a variety of national conditions. Static organizations cannot meet the changing needs of their users and customers. Strategies must change and tools to evaluate and test new directions are needed. The Concept of Operations (CONOPS) is a powerful tool to help design and evolve an operational system. To be useful, it must be kept up-to-date as users' requirements and technical opportunities change.

This chapter has emphasized the role of public and private sectors. There is growing recognition that creating resilient societies depends on harnessing the capabilities of both—something that needs to be kept in mind in any effort to help a country strengthen its meteorological and hydrological services.

In the next chapter, the focus is on practical approaches to modernizing NMHSs.

Specialists from MeteoRwanda checking soil temperature in Kigali. Source: D. Kull, World Bank Group, 2015.

Chapter 4
Recommendations on Modernizing NMHSs

- *Although there is no definitive approach to designing NMHS modernization projects in low-and middle-income countries, because of many various country specific elements—such as institutional setups, NMHS capacity, natural conditions, cultural context, and project objectives—a lot has been learned over the past decade that can contribute to more successful outcomes.*
- *A key problem is that the goals of the NMHSs are often not well articulated and not supported by an effective and evolving planning process, making it difficult for proposed investments to respond to these goals.*
- *Thus, the starting point for a modernization project should be a strategic plan, which lays out the NMHSs' goals and the means to achieve them. It should include the adoption of appropriate business plans and models and the implementation of the strategy within an operational plan—that is, a concept of operations or CONOPS.*
- *The aim of the CONOPS is to explore the entire operational system from the perspective of users and stakeholders—enabling various options to be tested theoretically to determine what is critical to achieving the goals.*

Introduction

Despite the evident benefits of strengthening weather, climate, and water information systems and services, and modernizing NMHSs, considerable efforts are needed just to convince governments and World Bank (WB) teams to proceed with project preparation and commit resources for preparing and implementing complex, and often relatively small, hydromet modernization activities. And once the preparation is done, there is implementation—and importantly, steps to make the improved services sustainable, given the many instances of improved services in low-and middle-income countries (LMICs) not holding up over time.

What is the best approach to NMHS modernization? Although there is no definitive approach to designing these projects, a lot has been learned over the past decade that can contribute to more successful outcomes. This chapter begins with recommendations on the preparatory phase before moving on to those for implementation and sustainability. A key message is a need for NMHSs to articulate their goals and lay out a strategy early on for how to meet them.

How to Carry Out NMHS Modernization Programs

The first step in the preparation process is for the project team to concentrate on matching the needs for modernizing the NMHS with opportunities. This can take the form of identifying champions in the country and within the WB; identifying potential public and private sector partners; and identifying funding commensurable to the task (**see Box 4.1**). A key element is developing the concept of operations (CONOPS), which explores the entire operational system from the perspective of users and stakeholders—enabling various options to be tested theoretically to determine what is critical to achieving the goal.

As for implementation, so far in this report, we have discussed the operation of an NMHS within the framework of a system of systems (**see Chapter 2**). But now it is useful to map the systems into four larger components: (1) institutional strengthening, which comprises the quality management systems, capacity building, and technology infusion systems; (2) improving service delivery, which comprises service delivery systems and feedback systems; (3) modernizing infrastructure, which includes monitoring and observing systems, modelling systems, forecasting systems, and ICT systems; and (4) improving all aspects of project management, which includes support for the project management unit, and potentially international advisors and a systems integrator, if they have responsibilities spanning more than one project component.

Component 1: Institutional Strengthening

This objective of Component 1 is to: (a) strengthen the legal and regulatory framework of agencies involved in the modernization project (including the NMHS, disaster management, water resources, and agriculture); (b) improve the NMHS's institutional performance as the main provider of weather, climate, and hydrological information; (c) build capacity of its personnel and management; (d) ensure operability of future networks and systems; and (e) support project implementation. This approach applies to the NMHSs and may extend to other agencies. Where the NMSs and NHSs are separate organizations, ensuring close collaboration is vital to enable flood forecasting and management. Some of the subcomponents—such as strategic planning, business modelling, and the preliminary CONOPS—help ready the project plan for implementation. The main subcomponents are:

Road mapping. This includes: (a) mapping all the relevant paths that can be taken to meet end-users' needs (route, actions, and milestones); and (b) holding workshops with major stakeholders and users of the NMHS's products and services (including development partners and ministries responsible for planning and budgeting).

Strategic planning. This includes: (a) holding joint workshops with the major users of the NMHS's products and services (such as agriculture, emergency, health, water resource management, energy, and transportation); (b) holding internal workshops with agency staff; and (c) writing the strategic plan.

Business modelling. This includes assessing the applicability of different business models to achieve strategic objectives, which would feed into developing the CONOPS.

Development of a concept of operations (CONOPS). This includes: (a) holding workshops with development partners to incorporate their activities; (b) conducting a review of institutions' operations and management (such as observing and forecast system requirements; and (c) drafting of CONOPS version used as the guide for designing the modernized systems.

INVESTING IN HUMAN CAPITAL REQUIRES A LONG-TERM APPROACH

With financial support from the World Bank's Central Asia Hydrometeorology Modernization Project (CAHMP) and the World Meteorological Organization (WMO), Kyrgyzhydromet sent five promising students to Russia to study hydrometeorology. Having completed their studies at the Russian State Hydrometeorological University in Saint Petersburg and the Moscow Hydrometeorological College, all returned to join Kyrgzhydromet as staff, with some receiving additional operational training under CAHMP in Germany, Russia, and Uzbekistan. One young expert, who at the age of 26 attained a PhD in atmospheric physics from the Russian State Hydrometeorological University, is now working in the forecasting department, integrating modern technologies and approaches, and accelerating the institution's transformation into a modern hydrometeorological service. His skills and therefore Kyrgyzhydromet are increasingly recognized regionally and globally for progressive expertise in forecasting; the expert has even been accepted as a hydrodynamic model developer for the Weather Research and Forecasting (WRF) Model by the US National Center for Atmospheric Research (NCAR).

As part of the agreement to sponsor his studies, the expert committed to working for Kyrgyzhydromet following attainment of his degree. The expert is also personally committed to contributing to the development of his country and the modernization of Kyrgyzhydromet, further serving on the Council for Science, Innovation and New Technologies under the prime minister of the Kyrgyz Republic. While his contributions are and will continue to be impressive and significant, their sustainability may however be challenged. Although personally dedicated to supporting Kyrgyzhydromet, the limited employment packages Kyrgyzhydromet is able to offer can strain staff and the families they support. As NMHSs around the world continue to struggle to hire, train, and retain high-quality staff, modernization projects need to include long-term human resource development strategies

Kyrgyzhydromet specialist maintaining manual equipment under extreme climate conditions. *Source:* U. Torobekov, 2016.

BOX 4.1 Initial Steps to Match NMHS Modernization Needs with Opportunities

Seeking government and NMHSs commitment. **The commitment to modernize NMHSs should include socioeconomic assessments (WMO 2015a) and building partnerships with project beneficiaries (such as disaster risk management, agriculture, and water resource management).**

Introducing the modernization agenda. **This agenda should appear in country assistance strategies and country partnership strategies, usually through disaster risk management, climate adaptation, food security, water resource management, and other significant sectoral programs and projects.**

Identifying funding sources. **The focus should be on financial sources for preparation (such as the Global Facility for Disaster Relief and Recovery (GFDRR) and Climate Risk Early Warning Systems (CREWS)) and for implementation (such as the International Bank for Reconstruction and Development (IBRD), International Development Association (IDA), and the Green Climate Fund (GCF)). These development partners will have to coordinate to extend the lifetime of projects from the usual five years to a more realistic timeline of seven to eight years. GFDRR is proving to be instrumental in supporting these initial stages with technical assistance and economic and sector work, using grant and trust fund resources. The GCF also supports modernization efforts where there is a clear and strong link to climate adaptation.**

Crafting a strategy. **The focus should be on encouraging the NMHS management to formulate and articulate a clear role for the future of their services (10–20 years ahead) and a clear strategy on how to get there as part of the modernization plan—with input from major stakeholders and service beneficiaries.**

Identifying potential opportunities. **The focus should be on engagement with private sector service providers and understanding broader developments in the country (such as in telecommunications, social media, and information technology).**

Motivating staff ownership. **This is important (especially for often disincentivized NMHS staff) for tasks such as developing the concept of operations (CONOPS), which will determine the scope and direction of the modernization project, along with a sense of pride in achieving success.**

Scoping modernization activities. **This should be based on: (a) natural risks and vulnerability assessment (types of natural hazards, frequency, and exposure); (b) weather dependence of economy and user needs assessment; (c) evaluation of NMHSs status and high-priority modernization needs; (d) cost-benefit analysis of the potential modernization scenario; and (e) government commitment to sustain proposed modernization.**

Ensuring a substantial preparatory phase. **This would include, besides the above scoping activities, developing a strategy/roadmap and an initial CONOPS—and if time and funds allow, identifying key procurement packages (systems integrator, integrated ICT, design, and build or DBO/T).**

Developing a business plan. **This should be based on the social and economic benefits of the new services to attract government financing for the additional operations and maintenance costs.**

Institutional bolstering. This includes: (a) developing a legal and regulatory framework for the NMS, NHS, and disaster management operations (such as assessing new business models and enhancing public-private engagement); (b) twinning support between the NMHS and one or more advanced NMHSs for operational forecast and service guidance; and (c) developing and operationalizing standard operating procedures.

Capacity building. This includes: (a) conducting NMHS staff training, retraining, and professional development; (b) supporting the professional orientation of the NMHS senior management; (c) providing educational support for staff; (d) offering training for key users and stakeholders (may include media and communities); and (e) strengthening national training and educational institutions.

Design and implementation support. This includes: (a) providing a detailed systems design for the NMHS and other agencies, based on the CONOPS (for example, observation and monitoring networks, and forecast and service delivery systems) and implementation support through a systems integrator; and (b) procuring and integrating systems.

Engagement with the private sector. This includes exploring potential business relations with the private sector as part of a pilot project. In most instances, it would be difficult to make firm partnership agreements for private sector engagement with the public sector within the value chain of meteorological and hydrological services without some no-regrets evaluation of the potential benefits. The

CREATING AN ENABLING ENVIRONMENT FOR HYDROMETEOROLOGICAL MODERNIZATION PROJECTS

From 2010–2015, the Slovenian Environment Agency (ARSO) implemented the national modernization project Better Observation for Better Environmental Response (BOBER), financed 85 percent by the EU Cohesion Fund and 15 percent by the Slovenian government from the national budget. Costing EUR 33 million, BOBER upgraded the meteorological (including radar), avalanche, and hydrological monitoring networks; established flood forecasting, drought monitoring, water quality monitoring and marine monitoring and forecasting systems; upgraded ICT systems including a new high-performance computer; and strengthened calibration facilities.

While the idea for the project started already in 2005, activities to create an enabling environment were needed to get it off the ground. For example, during preparation of the project, the Slovenian government recognized its importance and included it in the Operational Programme for Environmental and Transport Infrastructure Development 2007–2013 under the priority guideline Reduction of damage caused by water. This program was also adopted by the European Union in 2007. Further, ARSO discussed in detail the content and priorities of project outputs with internal and external users, including the relevant civil protection and rescue agencies, national authorities for water and environmental management, and the private sector, such as the hydropower industry. This led to a project design aiming to deliver comprehensive solutions suitable for most users, thereby building support.

Floods in September 2007 in northern and western Slovenia caused significant economic damage and the loss of several lives, particularly in the town of Železniki, which experienced flooding beyond the 100-year return period. Following this disaster, the government recognized BOBER as a very important non-structural flood prevention measure and fully backed it, further stressing that the upgraded information systems would also inform the design of better performing future structural flood control measures.

Recognizing the inherent challenges of maintaining a modern observation network, ARSO developed its own distributed real-time monitoring system. Utilizing inexpensive bulk-produced electronic parts and Linux run by embedded computers, every sensor at every station can be accessed and controlled from the central office, with software upgrades also performed centrally. This approach ensured that no significant increases in financial and human resources for maintenance of the upgraded observation system were needed. In addition, project implementation was performed almost entirely utilizing existing human resources. More than 50 ARSO employees were involved, some of them full time, and only a few additional staff were hired.

Commissioning of a oceanographic monitoring buoy in the Gulf of Trieste, Adriatic Sea. *Source:* L. Ravnik, ARSO, 2014.

In the middle of the project in 2013, the government supported a proposed amendment to the National Regulation on the classification of construction with regards to complexity, thereby minimizing the required paperwork for construction at observation sites and enabling ARSO to successfully complete the project according to plan.

Before and during BOBER, ARSO and its supporters in the Slovenian government made sure that there was an enabling environment at both the policy and operational levels to ensure the project could be successfully financed and implemented. While the requirements and possibilities for pursuing supporting factors will vary from context to context, without the relevant policy and financial support mechanisms in place, as well as plans for sustainable operation of modernized systems, projects are destined for failure. And like the 2007 floods in Slovenia, hydrometeorological disasters often provide windows of opportunity to help establish such an enabling environment, at least in terms of political will.

Acknowledgments

Gregor Sluga, Acting Director General and project leader, ARSO and Klemen Bergant, Director of Meteorology and Hydrology Office, ARSO.

framework for such engagement would be developed as a part of this component and implemented within Components 2 and 3, if the right conditions exist.

Business planning. This includes developing a sound financial plan for the NMHS's future operation based on all of the forgoing activities. It could be part of the results framework as a business plan to support higher operations and maintenance costs.

Component 2: Enhancement of the Service Delivery System

The objective of Component 2 is to enhance the service delivery system by creating or strengthening the public weather service—including developing new information products for vulnerable communities and the main weather-dependent sectors of the economy. The main subcomponents are:

Introducing or strengthening the public weather service (PWS).[1] This covers services related to disaster risk management, agriculture, the media, civil aviation, health, energy, and water resources—which are essential for delivering the benefits of the modernized program. It includes:

- *Developing a service delivery strategy*. The PWS will function as the principal interface between the technical provider of products and the users. It should be responsible for developing and implementing standard operating procedures with authorities (such as civil protection), as part of disaster risk management and service quality management.
- *Developing a PWS platform to provide impact-based forecast and warning services*. Such a platform provides forecasts and warnings of the weather's impact, based on information available from the forecasters, combined with geographic information system (GIS) vulnerability and exposure data to provide risk assessments. It requires forecaster workstations for producing decision support information tailored to each of the PWS sectors. These systems can be turnkey or built to suit.
- *Installing media equipment*. Such media equipment enables the NMHS to create broadcast-quality bulletins, as well as being used for conducting interviews, and education and public outreach activities.
- *Installing computer visualization systems*. Such systems should be installed for user-defined locations (like civil protection offices and NMHS regional offices). Each system should be tailored to the stakeholder's specific requirements.
- *Implementing early-warning system pilots*. Such pilots are particularly important if the NMHS has little or no experience with developing and using warning systems.

Greater use of mobile telephone–based applications. Although such applications are optional, it is becoming increasingly important to exploit the advances in mobile technology in even the poorest and most vulnerable communities to reach the population during severe weather events.

Creating a national framework for climate services. This framework is intended to transform the traditional climatological role of an NMHS and other climate service providers to a full user-oriented service and to increase opportunities for NMHSs to provide relevant climate information to government decision makers and the World Meteorological Organization. Tasks may include: (a) application of a digital library of all climate-relevant information from all sectors; and (b) application of a national framework for climate services (linked to the Global Framework for Climate Services) by engaging all climate-sensitive sectors.

Component 3: Modernization of Observation and Telecommunication Infrastructures, Modelling, and Forecasting Systems

The objective of Component 3 is to: (a) modernize the observation network systems, communications system, and ICT system of the NMHSs and possibly related organizations (such as disaster management agencies), based on the business models and CONOPS developed in Component 1; (b) improve the meteorological and hydrological forecasting system; and (c) refurbish offices and facilities. The main subcomponents are:

Technical modernization of observation networks. This includes: (a) rehabilitating and reequipping meteorological, hydrological, and other networks as required;[2] (b) introducing ground-based remote sensing systems for nowcasting and very short-range weather forecasting (for example, radar

[1] The PWS provides a model for the delivery of all services, including climate services. Its principal function is to focus on (a) translating and interpreting meteorological and hydrometeorological forecasts into impact-based forecasts and information; and (b) communicating this information to all sectors, including the public.

[2] This task may also support aviation, agriculture, or other sector-specific networks, depending on the NMHS's responsibility.

DELIVERING LOCAL BENEFITS YIELDS PUBLIC SUPPORT

During the partial modernization of Kyrgyzhydromet's observation network under the World Bank's Central Asia Hydrometeorology Modernization Project (CAHMP), a hydrological post on the Djety-Oguz River (among many others) was rehabilitated in 2016. At first, however, there was local opposition to this investment. Having been dysfunctional for many years, neighboring residents were resentful that Kyrgyzhydromet had for years kept prime riverfront land without delivering benefits to the community.

Following rehabilitation of the station, Kyrgyzhydromet was able to deliver higher quality and more timely river stage and flow information and forecasts to the community. Local residents now appreciate the services that the hydrological post helps deliver, and actively support its operation and maintenance by ensuring it is not vandalized. It is clear that improving service delivery incentivizes support and resources far more effectively than simply asking for support.

weather surveillance equipment, wind profilers, and lightning detection networks);[3] (c) upper-air measurements using radiosondes, although temperature soundings may also be available from commercial aircraft as a part of the AMDAR (Aircraft Meteorological Data Relay) system; and (d) strengthening quality control by setting up calibration facilities.

Access to GIS data. This includes: (a) digital elevation data (like for flood modelling); (b) demographic data for vulnerability mapping; and (c) exposure data for critical infrastructure.

Modernization of the NMHS's communication and ICT systems. This includes:

- Consider creating a data center, which would support all information needs and simplify ICT procurement.
- Increasing access to sufficient Internet bandwidth to access global and regional data and products. This should be addressed early on, preferably during preparation, using grant funds to enable NMHS access to the country's telecommunication infrastructure. Experience suggests that in most countries broadband communication exists, but it is not always exploited effectively by the public-sector services.
- Introducing new communication equipment that meets WMO Information System (WIS) standards.
- Developing archiving, database management, and digitizing capabilities.
- Providing computers and software to access and use numerical weather predictions (NWPs) and climate models.[4]
- Consider exploring the potential role of public-private partnerships or other alternatives to own and operate within the NMHS, if the capacity to develop these skills internally is very weak.

Improvement of the hydrometeorological forecasting system. This includes: (a) introducing modern computer equipment for processing observational data from in situ surface networks, satellites, upper-air stations, radar, and other in situ remote sensing systems (for example, radar, wind profilers, and lightning networks); and (b) forecaster workstations to integrate observations and numerical weather prediction guidance to prepare forecasts and warnings. A significant amount of effort should be spent on NWP model verification, calibration, and post-processing, as well as on how to effectively use ensemble prediction systems (like probabilistic forecasting techniques).

Refurbishment of NMHS's offices and facilities. This includes updating office spaces and, in some instances, new buildings to accommodate new ICT systems and provide a modern working environment for operational staff.

3 Generally, all these ground-based remote sensing technologies are complex. If the NMHS staff has little or no experience with these technologies, they should be introduced with sufficient long-term technical support. It is also important to weigh alternative technologies that can partly fill the role of these in situ systems (such as satellite-based imagery that can be blended with rapid refresh systems for nowcasting), which are freely available to WMO members. Here outsourcing, or data as a service, may be a viable alternative to owning and operating the system entirely within the NMHS.

4 The CONOPS should, among other things, clearly determine the type of NWP support required. It should be based on a cascading forecasting process with reliance on the global mesoscale NWP and climate models' data and products, followed by regional products; and finally, model verification, calibration, and post-processing at the national level. Only if clearly justified, national investment in dynamic downscaling of NWP and climate models should be considered. The latter is a last step, not the first one.

Experience shows that facilities that have deteriorated and are in a poor state of repair contribute to poor staff working conditions and motivation—besides being unable to house modern equipment.

Component 4: Project Management

The objective of Component 4 is to support the NMHS' technical team to fully engage on project management, development, oversight, and implementation—with assistance from national and international advisors and a systems integrator. Another critical element is a highly qualified project management unit, adequately staffed with procurement and other specialists knowledgeable about the complexity of NMHS modernization projects.

Project Managers. An essential element for success of a modernization program is a robust project management and implementation support team, which should include an NMHS project management team—comprising a Project Management Unit (PMU), a specialized technical support team, and a qualified World Bank supervision and implementation support team.

Systems Integrator. This is a firm, typically a consortium of key technical providers, including experts from advanced meteorological and hydrological services. Their tasks include designing the new system, developing implementation plans, supporting procurement, and making sure the procured systems work together to support the optimal operation of the NMHS. When it was first envisaged, the system integrator was also responsible for developing a training program, organizing workshops with stakeholders to develop the initial strategic and operational concepts, developing new tools, and providing ongoing operational guidance.

But the contracts for large-scale modernization are typically multi-million dollars and take much longer to procure than is desirable for projects that typically last five years (the system integrator is normally hired at the implementation stage of the project, although selection can be done earlier). In some instances, because high-level approvals within government are required, the system integrator hiring process can take up to 18 months. This invariably means that the project's start-up is quite slow and some of the tasks (like procurement) are started without system integrator support, which may lead to substandard technical design of the systems.

International Advisors. The "soft" functions—such as strategic planning, assessment of business models, development of the CONOPS, design of training programs, and stakeholder workshops—can be done through separate contracts to individual highly qualified international experts that have the client's trust and can take the time to advise the client on transforming services. Critical to the success of this approach is (a) the availability of a pool of qualified experts with experience in integrated hydrometeorological modernization in developing counties; (b) the experts' level of expertise; (c) the amount of time they can devote to the client; (d) excellent communication skills; and (e) support from the NMHS management and PMU. There should also be enough flexibility for them to call on other experts if new needs arise.

The drawback is that this approach increases the administrative workload and requires a qualified team to coordinate input and monitor performance of multiple international advisors (IAs). Thus, there is still the advantage of enabling projects to start up quickly and make sufficient progress prior to contracting the system integrator. In practice, the service delivery strategy and the CONOPS would be developed through workshops with stakeholders and the client's staff (with the international advisors' help), and the system integrator would develop the design and implementation plan to achieve the CONOPS. Another approach would be to start hiring the system integrator earlier and include the international advisors at the project preparation phase, using financing available for technical assistance.

How to Make Modernization Programs Sustainable

It is preferable to develop modernization projects in two phases: (a) design, which focuses on service delivery strategic planning, business modelling, and the CONOPS; and (b) implementation, which focuses on acquiring assets and introducing new operational capabilities and services.

The design phase can be developed through technical assistance projects and/or the hiring of individual advisors. It typically lasts at least 12 months, which ideally should be initiated in parallel with the project preparation and funded by grant resources. Bank projects are usually five years, but increasingly this is recognized as too short for complex projects that involve strengthening weak institutions. Obviously, the overall budget for the project needs to be established and robust estimates of costs made. However, this does not preclude a range of solutions, including engagement with the private sector, which by its nature should be in the form of a partnership and thus a joint financial venture. In 2018, the WB and WMO signed an agreement that permits governments to use WB financing to obtain WMO technical assistance[5]—which is particularly useful for basic training, setting up twinning arrangements, and accessing WMO regional technical centers.

Operations and Maintenance (O&M). One of the key factors in defining the project's affordability is assessing the O&M costs of the future system, which should be done as part of preparing the CONOPS. In developing countries with very limited funding for NMHSs, any modernization effort will generally increase the annual O&M costs. Thus, the government must agree up front to the incremental cost of running the NMHS, or the project will be difficult, if not impossible, to sustain beyond the lifetime of the project investment. Experience suggests that the incremental O&M costs are equivalent to about 10 to 15 percent of the investment budget. Many donor-driven projects, which have focused on providing observation equipment, have failed because the NMS or NHS did not have the staff or resources to maintain the new observation capability.

Staffing. Most developed countries' modernization efforts have also included costs for staff reductions because employees are often the largest operational expense—which raises the possibility of introducing automation as a cost-reducing strategy. However, this strategy is ineffective in most LMICs, where staffing costs are relatively low. In those countries, relatively few qualified technical personnel are available, and more are usually needed to maintain modern observation, telecommunication, and forecasting systems.

Mitigating Risks. NMHS modernization projects are usually high-risk, high-reward efforts because they require significant cultural changes within institutions—and introduce technically complex information and communication technologies—but have the potential to provide substantial benefits to weather- and climate-sensitive sectors of society. The risks of problems can be mitigated by a set of interlinked activities, including the following:

- Building government (ministries of finance, economy, and planning) understanding of the NMHS's importance through business planning, in hopes of a legally binding commitment fixed in credit or a grant agreement to increase budget support and allocations for O&M costs.
- Developing a CONOPS and project design that is more likely to be affordable and implementable by involving NMHS staff in the process.
- Introducing a quality management system in the entire NMHS and developing standard operating systems to provide a uniform structure and process across the whole organization.
- Preparing national strategic plans.
- Mounting training programs on service provision.
- Organizing media workshops.
- Building capacity and retaining qualified staff members, including developing additional incentives.
- Testing new business models to strengthen sustainability.
- Building partnerships with national and international stakeholders, such as twinning arrangements for more advanced and developing NMHSs (see **Technical Insight 4.1**).
- Setting up user and policy committees.
- Building the membership of WMO technical commissions.
- Creating a modernization leadership team composed of NMHS management, the project management unit, and a special modernization team (including international advisors and system integrators).
- Carefully assessing absorption capacity and ensuring that the investment is scaled accordingly.
- Ensuring close supervision, especially during the initial phase of project implementation; also often helpful is mobilizing additional Bank-executed trust funds.

Procurement issues. Procurement is complicated, owing to the need to buy and install numerous and relatively small packages of various specialized interrelated hardware and software products—often high-performance computers and communication equipment—and to arrange delivery and installation of equipment in multiple and often remote locations. A detailed design of networks and systems is expensive and time consuming, and it is often unavailable at the time of appraisal. Consequently, many projects have shifted the

5 Standard Form of Agreement for use by World Bank Borrowers. Provision of Technical Assistance by WMO under Bank-Financed Projects V.1 (October 12, 2018).

WORLD BANK HYDROMET INVESTMENTS
RESULTS FRAMEWORK AND INDICATORS –RECURRENT CHALLENGES

From 2005 to the present, the Bank has undertaken hydromet modernization investments in about 30 countries. Their success was measured according to results frameworks developed individually for each project. The experience that has accumulated for these past fifteen years allows for analysis of some recurrent issues regarding how results frameworks are setup, as well as to identify approaches that allows for more effective use of results frameworks as tools for project management.

Analysis revealed that altogether around 150 different indicators were used in the results frameworks of hydromet projects. They can be roughly grouped by objective/outcome as follows: (i) Institutional strengthening; (ii) Strengthening weather forecasting: and (iii) Tailoring user services.

By assessing project implementation reports including progress on indicators and achieving targets, the following recurrent issues were identified:

- Most indicators show no change from the baseline until mid-year 3 or year 4 of project implementation. Progress is then achieved in a rush in the last year or two of the project lifecycle. This pattern is seen as a weakness in the design of the results framework as project indicators are intended to support project monitoring, and to guide task teams to identify implementation weaknesses.
- Baselines are rarely prepared during project preparation. Sometimes baselines are not set in place for several years during project implementation. Often, the lack of the crucial baseline is represented by a "zero", which leads to incorrect reflections of project progress (i.e. when the baseline is eventually prepared, and it is some number greater than "zero", it appears significant results have been delivered, which may or may not be the case.)
- When user satisfaction is used as an indicator, the results framework often promises annual updates, but in many cases only one survey is undertaken during implementation – the baseline survey that tends to occur somewhere around the mid-term review (MTR). While a survey at the project end is planned, it often does not occur.
- Measures of the technical quality of forecasting (accuracy, skill and timeliness) are commonly used as indicators, but are often not described precisely, which leads to differences in interpretation and monitoring approaches. For such indicators to be useful, the NMHS needs to have a reliable verification system in place, and the parameter and lead-time of the forecast to be monitored needs to be clearly defined.
- In some cases, when accuracy of the forecast is used as an indicator, it rises and then falls and then rises again, suggesting that the chosen indicator does well or poorly by chance and does not measure underlying capacity growth. It must be recognized that depending on the instability and/or complexity of the weather occurring in a particular reporting period, forecast accuracy can also display some inconsistency; changes in forecast accuracy and skill should therefore be viewed as trends rather than individual points.
- For the projects that involve system integrators, indicators are worded so that progress does not formally exist until the system integrator has devised a plan that is approved so that the progress can be assured to be aligned with that plan.
- Some indicators simply do not measure what they say they do. I.e., reliability of climate projections may not be measured by their downscaling. The existence of an authoritative public weather service may not be measured by a user satisfaction survey.

detailed design of networks to the project implementation phase and included them as the first phase of the integrator assignment. The integrator assignment also includes developing most procurement packages (technical specifications and bid documents) and implementing support to NMSs, NHSs, and project implementation units. Hiring an integrator is a high priority and selecting the consultant through quality- and cost-based selection (QCBS) should be initiated well in advance, given that the project's implementation will strongly depend on the consultant's success. Thus, it is important to develop a well thought through CONOPS before entering the design and implementation phase.

Turnkey systems. An alternative approach involves using a turnkey contract for modernization, under which most tasks would be outsourced to a consulting firm to design-build-operate or design-build-operate-transfer. But such contracts in the hydromet sector have never been arranged in the WB, and rarely by other development partners. Particular attention has to be paid in the design-build to include legacy systems and those supported by other development partners. Thus, it will take some time and significant efforts to properly structure, test, and define safe areas of application for such innovative contracting. There are an increasing number of firms and joint ventures with the ability to provide turnkey solutions.

Setting project performance indicators. Realistically, it is hard to determine indicators for the results effective framework, given that hydromet modernization projects are technically complex and their results are broad and multi-sectoral. That said, we believe that the indicators need to combine quantitative measures related to forecast accuracy and qualitative measures related to services and benefits, which adhere closely to the service delivery progress model (**Annex 1**), observation, telecommunication and forecasting progress model (**Annex 2**), and, and the climate services progress model (**Annex 3**). Measuring performance during the execution of a project is essential to ensuring that a project achieves its objectives. Metrics must be realistic, measurable, and useful—enabling project managers to make corrections during project implementation. Ideally the project metrics should align with or be identical to the key performance metrics of the organization.

Public facing entities, such as NMHSs, should focus on satisfying their users' needs. Any service has two components—one focused on user satisfaction and another on technical aspects. For example, a warning service is most useful if it is in time, at the right location and intensity. **Figure 4.1**. through 4.8 show the scoring used by the UK Met Office derived from first responders to a situation as well as from the public affected.

TECHNICAL INSIGHT 4.1 Types of Twinning Arrangements

It is difficult to realize the full benefit of a modernization program within an institution that does not have a full complement of staff or that lacks training and experience in modern forecasting techniques. National meteorological and hydrological services (NMHSs), however, do not operate in isolation and can benefit from the capacity and capabilities of more advanced services.

Most WMO regions contain both advanced and developing NMHSs. More advantage could be taken of the capacity of the most advanced NMHSs to provide operational support to the weakest. This assistance is provided in some regions, but it is not universal, and it cannot be readily sustained without financial support.

A useful example is the Cascading Forecasting Process implemented in southern Africa. It provides global and regional NWP guidance to 16 countries through the WMO Regional Specialized Meteorological Centre (RSMC) Pretoria, which is hosted and operated by the South African Weather Service.

Arrangements for pairing NMHSs are best managed through the WMO, which has the capacity to monitor these activities and, where necessary, can facilitate financial support. Ideally, the WMO regional centers would play a leading role in this process, because most (but not all) are located within the more advanced NMHSs. The pairing arrangement would provide operational backup for forecasters, enabling them to receive guidance on complex weather situations. This guidance could be in the form of bulletins or, in the case of life-threatening situations, through direct video or voice contact—much the way that a central forecasting office works with regional offices within large countries.

Frequent training is essential to increase and maintain the skills of an NMHS's staff. Such training should be viewed as a continuous process in which all staff members are involved in a long-term program to improve their skills.

FIGURE 4.1

Purpose	Parameter	Range of scores	Satisfactory score
Measure the accuracy of public warnings	Impact level	0–3	More than 72% of warnings score > 6
	Impact timing	0–3	
	Impact location	0–3	

The "satisfactory score" can be used to measure year-on-year progress, increasing from an agreed baseline to something in the range of 72 percent. The relatively large uncertainty reflects the nature of predicting risk.

The aim is to target only those at risk, rather than the entire population. Making warnings available to everyone results in over-warning, which should be avoided. The desired outcome is to persuade people at risk of a high impact of an event to take action on the relatively low probability of occurrence. The purpose of impact-based forecasting is the ability to forecast the probability of an event happening, based on a forecast of a hazard and the vulnerability of those at risk to the impact of that hazard. The public is encouraged to understand their exposure to risk and to act accordingly. However, the response depends on people's appetite for risk; it is therefore impossible to expect that everyone deemed at risk will take appropriate action (**Figure 4.2**). From the perspective of disaster management, the more people taking appropriate action in response to a warning is a useful metric.

FIGURE 4.2

Purpose	Indicator	Satisfactory score
Measure the effectiveness of public warnings	Number of people who take action as a percentage of the population at risk receiving a warning	>75%

Measurement of the public's satisfaction with forecasts and warnings is also an approach used by many NMHSs to assess year-on-year changes in the quality of their services. Since not all people will take action, it is useful to measure people's perception of a severe weather warning by sampling a statistically significant number of those expected to have received it. Questionnaires have been developed by some NMHSs and can be adapted to most situations. Questions might include those shown in **Figure 4.3**.

FIGURE 4.3

Survey questions	Purpose
Did you see or hear anything about this severe weather warning?	This helps to assess the effectiveness of the communication systems used to deliver the warning.
Generally speaking how accurate do you think most weather/flood forecasts and warnings are?	This would assess people's perceptions of the accuracy of the information received. A low score, despite significant quantitative improvement in the forecasts, would indicate the need to improve public awareness.
Overall how useful would you say the weather/flood forecasts and warnings are these days?	This would assess whether people are able to understand the information.

The survey questions and the measurement of the effectiveness of warnings can be disaggregated by gender and other demographic indicators. They can also be turned into a satisfaction index. Again, it would be reasonable to expect more than 75 percent of the population affected being satisfied with the services provided by the end of the project. An initial baseline survey would be indicative of the gap between the current and proposed services.

Frequent false positive (false alarms) and false negative (missed) warnings are the primary cause of lack of compliance to subsequent warnings. Consequently, an important aspect of a forecast improvement project is the reduction on both false positive and false negative warnings and the use of probabilistic forecasts. It has been demonstrated that the use of probability estimates increases compliance, trust, and decision quality (LeClerc and Joslyn 2015) and is more important than reducing false alarms, because the cost of a bad decision is usually much greater than that of a false alarm. Hence the focus is on the use and improvement of impact-based forecasts and warnings. The introduction of an impact-based forecast and warning system is a binary measure of project improvement (**Figure 4.4**).

FIGURE 4.4

Activity	Purpose
Operational use of an impact-based forecast and warning system	Probabilistic forecasts and warnings, which reflect the likely impact of a severe weather event, are issued. Aligned with CONOPS

Subsequent improvement in the system depends on technical improvements in meteorological and hydrological forecasts and access to vulnerability and other data, which can be measured independently.

From the perspective of the forecasting process, timely access to high-quality observations from various sources—international and national—is important. International observations are available via the GTS or WIS, and not much can be done to improve on the observations except to ensure high reliability of the communication links. National observing networks are most useful if most of these data are shared within the global meteorological and hydrological community since the local application of a global model is improved by any data assimilated from that location. Metrics for national observations may include any or all of those shown in **Figure 4.5**.

FIGURE 4.5

Activity	Purpose	Indicator
Number of meteorological and hydrological stations installed and operating to international standards or standard operating procedures	A measure of the procurement and deployment of equipment such as automated weather stations, river gauging stations, upper-air stations, and radar	Number, aligned with CONOPS
Amount of data available to the forecasters via a central database	A measure of how well the individual observations are integrated into the overall data management system and how well each of the individual sensors operate	Gbytes of data available to the forecasters expressed as a percentage of the total amount of data that should be available from all of the national networks. The amount should be well over 90%.
Utilization of the observations in the analysis and forecasting process	This measures how much of the available data is actually useful in the forecasting process. It reflects on the quality of the data as well as the maturity of the forecasting system	Percentage of new data used in the forecasting process
Data shared with the international community	Overall forecast improvement will occur if data are shared with global modelling centers in a timely manner. Withholding should be considered adversely	Percentage of national data shared via WIS/GTS with the global modelling centers. Ideally, this number should include all basic meteorological and hydrological parameters, but not necessarily very high-volume data.

In addition to the external measures of the forecast and warning systems, the basic forecasting processes, can be assessed as in **Figure 4.6**.

FIGURE 4.6

Activity	Purpose	Indicator
Forecast of basic meteorological and hydrological parameters	Demonstrate year-on-year improvement in the basic forecasting system, applying standard methods used by the international community. Regional variation will indicate where additional effort is needed to improve forecasts, e.g., urban areas, extra urban, mountainous terrain, coastal areas	At a set of locations for which measurements are available: Daily maximum temperature Daily minimum temperature Daily accumulated rainfall Daily water levels Each compared with the forecasts at the same locations for days 1, 2, and 3 to generate a matrix of skill scores (0–1) and monthly composite scores for temperature, rainfall, and river levels
Numerical weather prediction	Evaluate the quality of local numerical predictions (without forecaster intervention). The comparison would be against local observations and NWP from other centers.	The same as above, but comparing raw model products with these data and with model data from other centers for the same locations for days 1, 2, and 3

These are relatively straightforward verification methods and appropriate for performance measures that can be shared with the public. One limitation is the need for about three years of meteorological and hydrological data to create the baseline. Since this may not be available, these metrics should not be given too much prominence in the early stages of the project but can become key performance metrics for the organization in the latter part and beyond. More complex verification is appropriate for forecast departments to gauge improvements in different aspects of the system.

A critical aspect of modernization is the introduction of new ICT capabilities, which are required to be fully operational during the first part of the project to support other components. It is useful for project implementation, therefore, to monitor progress in the design, procurement, installation and operation of the ICT system (**Figure 4.7**).

FIGURE 4.7

Activity	Purpose	Indicator
Installation and operation of ICT system	Measure progress in design, procurement, installation, and operation of the ICT system. Identify problems that could slow the implementation of the overall modernization program and may require revision of the CONOPS	Number of subcomponents completed and aligned with CONOPS

Modernization brings with it the need for significant organizational change—new working methods, new skills, and some restructuring of departments to align with the introduction of new services. Change management is often overlooked—a measurable facet of the modernization process. It is suggested to consider the activities shown in **Figure 4.8**.

FIGURE 4.8

Activity	Purpose	Indicator
Number of staff (at all levels) participating in change management seminars and courses	Provide all staff with the tools to cope with the necessary adjustments to meet the objectives of the future organization	Number of staff. The goal is to educate and train all.
Leadership courses for all senior managers	Provide all managers with the tools to manage their staff through a change process. The aim is to minimize resistance to change and encourage the full participation of all staff	Number of managers. The goal is to educate and train all.
Align departments with new functions	Ensure all departments are fit for purpose within the future organization	An organogram aligned with strategy and CONOPS
Technical training	Provide staff with skills required to carry out new functions in all departments	Number of staff, aligned with CONOPS

Internal development of, or external access to, production systems. The overall expectation should be that the modernized NMHS can provide a full level of services and that these are sufficient to meet the population's needs. In the past we would have expected that the NMHS would develop its own production systems to attain a sufficient level of capability to be able to deliver this high level of public services, based on building and operating its own systems. However, it is more realistic to support the notion that the NMHS should have access to sufficiently high-level production systems—meaning that they could achieve this level by accessing the required systems through twinning with other NMHSs, engaging with the private sector, or some combination of internal development and external opportunities. Thus, they should either have, or have access to, production systems that underpin the required public services. Either way, the results framework is not altered since the NMHS is ultimately responsible for the outputs of the production system, which are measured as performance indicators.

Safeguards. Environmental and social risks of NMHS modernization projects are typically small. Moreover, the hydromet projects usually provide environmental benefits, given that they support lowering risks associated with floods, drought and fire, winds, extreme weather events, and even industrial accidents. Project activities are usually implemented within available hydromet sites and involve a minor installation of observation equipment with no or minimal environmental disturbance. Specific attention should be given to the safe handling and disposal of equipment containing mercury (such as thermometers). Procuring larger equipment (such as Doppler radar) or constructing

MULTIFACETED CAPACITY SUPPORT TO ADOPT NEW TECHNOLOGIES

Training of radar specialists and forecasters of the State Hydrometeorological Service of Moldova. *Source:* R. Keene, Enterprise Electronics Corporation (EEC), 2018.

The Moldova State Hydrometeorological Services (SHS) received significant investments under the World Bank Disaster and Climate Risk Management Project (DCRMP), including the procurement and installation of a modern Doppler weather radar at the Chisinau International Airport in 2014. The radar is jointly operated under a Memorandum of Understanding (MOU) between the SHS and Moldovan Air Traffic Services Authority (MoldATSA). This MOU provides, inter alia, that while the SHS owns the radar, MoldATSA is tasked with its operation and contribution to maintenance. This approach was pursued to help support the sustainability of radar operations, where both agencies benefit from the real-time data it produces.

Unfortunately, by 2017 the radar had stopped functioning properly, the warranty had expired (due to financial constraints, a very limited warranty had been purchased), and the Moldovan authorities were not able to fix the radar on their own. Despite the MOU, SHS and MoldATSA could also not agree on the best course of action. It was therefore decided to contract the radar manufacturer to fix the radar under the World Bank/GFDRR Reinforcing Weather and Climate Services in Moldova technical assistance project. During their work, the manufacturer also identified several shortcomings in how the radar was being maintained and operated.

To further support the full leveraging and sustainability of the radar, under the same project, the radar manufacturer was further contracted to provide significant technical training on radar operations and maintenance. In addition, experts from the Romania National Meteorological Administration (NMA) were tasked to provide coaching to SHS on the:

- Development of standard operating procedures on effective operation and use of the radar;
- Optimal utilization of radar products by forecasters;
- Development of a methodology for estimating the budget needs for delivering radar products; and
- Integration of the SHS radar data/products into the common radar system of the NMA.

Romania and Moldova share a common language, and the NMA experts were already supporting SHS to strengthen their forecasting verification and Quality Management System (QMS), so this twinning approach was welcomed by both sides.

The experience clearly illustrates the need to ensure that NMHSs adopting new technologies (this is the first and only weather radar in Moldova) have sufficient capacity to fully leverage and sustain them. While the original DCRMP project should have better prepared the SHS to receive the radar, the follow-on technical assistance project was able to rectify any shortcomings.

In addition, financed by UNDP and GFDRR, the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) helped SHS qualify for and join certain operational programs of the European Meteorological Services Network (EUMETNET) including MeteoAlarm, aiming to enhance the quality of meteorological information through the existing European meteorological infrastructure. This included integration and use of radar products. Strong partnerships that provide complementary technical assistance and support should be leveraged to strengthen the sustainability of resilience investments.

buildings will require a more detailed evaluation of the public health and environmental safety aspects, which should be carefully documented in the environmental and social management framework. A potential staff reduction during a large-scale replacement of manual observations by automatic instruments should be carefully evaluated within the framework's scope and will require extensive consultations with key stakeholders. That said, so far no hydromet modernization projects in developing countries have triggered any incremental staff reductions.

Coordination with development partners. Nowadays, there is a crowded and competitive space among development partners—underscoring the need for coordinating activities to ensure that the NMHSs really benefit and reduce the risk of overlapping and potentially conflicted interests. That is why WB/GFDRR and WMO have encouraged cooperation among partners through engagement at both the international and national levels. Progress has been made through the First and Second Global Development Partners Conferences[6,7], the emerging Alliance for Hydromet Development[8], and national NMHSs' efforts to create more complementary projects. In recent years, several international development partners conferences have been organized by WMO, WB/GFDRR, and other partners. And it is becoming common practice to encourage clients to organize national events, especially when a large WB supported investment is being proposed or is under way.

One example of the effective coordination of development partners' support to an NMHS is Myanmar's Department of Meteorology and Hydrology (DMH). At the national level, led by DMH with support from WMO, the focus is on technical issues and firming up commitments from partners[9] to carry out specific activities and to identify any financial and technical gaps. Priorities include introducing flash flood guidance, sharing radar data, and reconciling existing activities with new initiatives.

But the different approaches of development partners can be confusing for clients. For the WB, there is an expectation that the client would take full responsibility for the investment, with the WB playing an implementation support role, along with ensuring compliance with agreed provisions of grants or credits. However, many other partners do not actively encourage the client to participate in the implementation or supervision of a project. Consequently, there is a tendency to hand-over a finished product to the client, who may have little incentive to continue its operation. Conversely, the NMHSs, which have little experience in managing their own projects, expect others to deliver the solutions with little engagement on their part. An attitude of "we pay them, so they should do the all of the work", misses the point that the NMHS is the beneficiary and thus should retain the responsibility for delivering the investment's benefits.

International initiatives. A key one is the Regional Framework Program to Improve Hydrometeorological Services in Sub-Saharan Africa (Africa Hydromet)—a joint effort of the African Development Bank (AFDB), WMO, United Nations Development Programme (UNDP), World Food Programme (WFP), French Development Agency (AFD), WBG, and GFDRR. It aims to address the deficiencies highlighted above by supporting the improvement of hydromet services on the national, regional, and continental levels. At the national level, the program seeks to modernize or build infrastructure and strengthen service delivery. Sub-regional efforts include standardizing procedures to promote trans-boundary collaboration, while Africa-wide efforts will ensure that hydromet services across the continent are linked to regional and global centers, thereby improving data availability and sharing and promoting partnerships.

The Climate Risk and Early-Warning Systems (CREWS) Initiative is another example of development partners collaborating toward building stronger people-centered, multi-hazard, early warning systems. It was launched in 2015 as part of the COP21 Solutions Agenda. It aims to raise US$100 million by 2020. The WBG serves as the trustee (it is a Financial Intermediary Fund (FIF)), and there are three Implementing Partners—the World Bank/Global Facility for Disaster Reduction and Recovery (GFDRR), the World Meteorological Organization (WMO), and the UN Office for Disaster Risk Reduction (UNISDR).

6 https://www.gfdrr.org/en/publication/meeting-summary-development-partners-roundtable
7 https://www.gfdrr.org/en/event/second-hydromet-development-partners-conference-beyond-business-usual-closing-capacity-gap
8 https://public.wmo.int/en/media/news/world-bank-and-wmo-announce-hydromet-development-alliance-commitment
9 The partners include WMO; WB; Japan Meteorological Agency (JMA); Japan International Cooperation Agency (JICA); Korean Meteorological Administration and its partners; China Meteorological Administration; USAID; Met Norway; Met Office; Asian Disaster Preparation Centre (ADPC); the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES); Bureau of Meteorology (BoM), Australia; Hong Kong Observatory (HKO); and Indian Meteorological Department (IMD), among numerous other international and national actors.

Small-scale investments and technical assistance projects. Despite the recommendation that modernization projects should be transformative, large-scale investments may not be practical. In this case, the emphasis should be on improving the delivery of services by increasing the efficiency and efficacy of the existing systems.

In Armenia, for example, the first step was to develop a roadmap with three scenarios of increasing complexity and cost—offering a phased approach based on the availability of resources[10] (Kootval et al. 2018). In the low-cost, technical assistance scenario, grant funds of about US$350,000 are proposed to: (a) improve short-range weather forecasting by learning to utilize fully NWP products from GPCs; (b) improve monthly and seasonal forecasts through training to apply regional climate downscaling methods; and (c) improve hydrological forecasting by training staff on data management, use of statistics, hydrological modelling, and the visualization of geospatial data sets—and purchasing low-cost, high-priority communication and computer equipment and software. The expectation is that this limited intervention should produce better weather and hydrological forecasts, improve access to forecasts by the public and government stakeholders, and better support the early warning system.

Conclusion

When it comes to developing a modernization project, it is essential to hire a skilled team to assist the client in the initial planning stages—which include strategic planning, business modelling, and a preliminary operational concept (CONOPS). Moreover, implementing these activities early has the added advantage of building knowledge and trust with the client. It is important that the project is developed by them and not for them, although care must be exercised to avoid infrastructure-heavy projects. In this way, ownership is achieved at the outset. This is important, given that most development projects are implemented by the development partner, often with only perfunctory engagement of the client. While expedient, it does not impart any skills in project management to the client.

In addition, engaging with other partners is critical, and projects need to be sufficiently flexible so that they can adapt to the changing circumstances, which will include new donor-assisted activities. The CONOPS is designed to take these factors into account. By maintaining its currency, it provides the NMHS with a tool to assess the impact of any changes that will affect the NMHS' operations.

[10] http://documents.worldbank.org/curated/en/684751548347371395/Modernizing-Weather-Climate-and-Hydrological-Services-A-Road-Map-for-Armenia

ANNEX 1

Progress Model for Service Delivery

The Service Delivery Progress Model is adapted from WMO No. 1129—The WMO Strategy for Service Delivery and its Implementation Plan. The model can be used as a tool for assessing the level of development of NMHSs and creating an action plan to improve service delivery.

Full details can be found at http://www.wmo.int/pages/prog/amp/pwsp/documents/WMO-SSD-1129_en.pdf.

STRATEGY ELEMENT 1 **Evaluate user needs and decisions**

Undeveloped	Development initiated	Development in progress	Developed	Advanced
The users and their requirements for products or services are not known.	Users are known, but no process for user engagement exists. User requirements for service delivery are not well defined.	Users are able to contact NMHSs and their feedback is recorded. There are some formal processes for integrating the feedback received into the development of services. User requirements are defined with limited documentation.	NMHSs seek input on an ad hoc basis from users to facilitate the development of services. Requirements are defined in documents agreed upon with the customer but are not routinely updated.	An ongoing dialogue is maintained with users regarding their needs and the services they receive. Requirements are defined in documents agreed upon with the customer and routinely updated using feedback from users.

STRATEGY ELEMENT 2 **Link service development and delivery to user needs**

Undeveloped	Development initiated	Development in progress	Developed	Advanced
No concept of service exists; products are simply issued.	Services do not adapt to changing user needs and new technology. Products are documented with limited descriptive information.	Services are developed and changed as technology allows, but engagement with users is ad hoc. Products and services are documented, and the information is used to inform management of changes.	User feedback is used to inform management of changes and developments to services. Products and services are consistently documented. SLAs are defined.	Users are consulted to facilitate development of products and services. The service defined in the SLA is agreed upon with the customer based on user consultation.

STRATEGY ELEMENT 3 **Evaluate and monitor service performance and outcomes**

Undeveloped	Development initiated	Development in progress	Developed	Advanced
No measures are in place for assessing performance, either in terms of accuracy or service delivery.	Some measures of development are in place. The verification of accuracy and/or service delivery takes place, but no systematic process exists to use this information to improve the service.	Measures of verification and service delivery are in place but are not informed by user requirements.	User requirements are used as data for performance measures. Findings are used to identify areas for improvement. Subsequent actions are taken in an ad hoc manner.	Measures of performance are based on user needs, which are regularly reported and consistently used to inform decisions on improvements.

STRATEGY ELEMENT 4 **Sustain improved service delivery**

Undeveloped	Development initiated	Development in progress	Developed	Advanced
No concept exists of service delivery principles.	The concept of service delivery has been introduced, and an assessment of current status has been undertaken.	An action plan has been created to improve the current level of service delivery, and resources have been identified to implement it.	The action plan is being implemented to improve service delivery; the outcomes are being monitored.	The status of service delivery is reviewed on a regular basis. The action plan evolves in response to the outcome of the reviews.

STRATEGY ELEMENT 5 **Develop skills needed to sustain service delivery**

Undeveloped	Development initiated	Development in progress	Developed	Advanced
No concept or communication of service delivery principles exist.	No formal training in service delivery is provided, though service delivery principles are Informally communicated.	Most members of NMHSs are aware of the importance of service delivery. Some formal training is provided.	All members of staff are fully aware. Formal training is provided. There is an ad hoc process for staff to offer ideas for improvements to service delivery.	There is a culture of providing best possible service delivery. Innovative ideas are routinely integrated into the continual service improvement process.

STRATEGY ELEMENT 6 **Share best practices and knowledge**

Undeveloped	Development initiated	Development in progress	Developed	Advanced
NMHSs are encouraged to share best practices in service delivery through formal training, twinning, mentoring, and other methods.				

ANNEX 2

Progress Model for Observations, Telecommunications, and Forecasting

OBSERVATIONS AND TELECOMMUNICATIONS				
Undeveloped	**Development initiated**	**Development in progress**	**Developed**	**Advanced**
The NMHS has very few manual synoptic stations and hydrological stations. It does not share these data on the Global Telecommunication System (GTS).	The NMHS has the capacity to support a synoptic meteorological network[1] and hydrological network. It shares these data on the GTS. The NMHS has sufficient staff to maintain its observing networks.	Automation of observing networks with quality control is routine. The NHMS accesses satellite data with, e.g., the capacity to derive precipitation estimates. The observing network is sustainable with a sufficient budget for operations and maintenance. The vertical structure of the atmosphere may be routinely measured.	Observations extend to smaller scales and include ground-based remote sensing techniques, such as radar. The NMHS may be able to take and integrate observations from other parties. It may access observations by outsourcing its observing requirements.	The NMHS conducts research, introducing new observational technologies and techniques as needed. The observing network is comprehensive, is sufficient to meet main user needs, and incorporates external observations from other suppliers, for example, agro-meteorological networks operated by a Ministry of Agriculture or hydrological network operated by a Ministry of Energy or Water Resources.

1 Synoptic meteorological network—a network of stations at which surface and upper-air observations (at locations that give meteorological data representation of the area in which they are situated, that could range many hundreds of kilometers) are made at *standard times* (i.e., main synoptic times: 0000, 0600, 1200, and 1800 UTC (Universal Time Coordinated); and intermediate synoptic hours: 0300, 0900, 1500, and 2100 UTC) for the purpose of presenting a comprehensive and nearly instantaneous picture of the state of the atmosphere (WMO, 2015c).

FORECASTING SYSTEMS				
Undeveloped	**Development initiated**	**Development in progress**	**Developed**	**Advanced**
The NMHS provides up to two-days deterministic forecast based on graphical forecast products retrieved from different web sources. There is no verification of forecasts. The NMHS does not operate forecasting on a 24-hour, seven-days-a-week basis, and warnings are not issued.	The NMHS can provide at least three-days deterministic forecasts based on access to global and regional numerical weather prediction data and products available on the GTS and/or graphical products available from WMO RSMCs. The NMHS monitors the current weather and hydrological system. The NMHS has basic data-processing and archiving systems. It carries out subjective forecast verification. There is no research and development, and the quality management system is rudimentary. The NMHS may not operate forecasting on a 24-hour, seven-days-a-week basis. Warnings are limited.	The NMHS can provide 0 to 5 days forecasts using global and regional deterministic NWP and EPS data and products from GPCs; issues nowcasts and very short-range forecasts up to 12 hours based on extrapolating NWP and blending remote-sensing observations; is able to monitor major rivers and generate short-term flow and flood forecasts; has protocols for emergencies, backup of data and products, and offsite storage facilities; carries out verification, and post-processing; has some R&D and a QMS. The NMHS operates forecasting on a 24-hour, seven-days-a-week basis.	LAM systems are available locally or through regional centers. Using local data assimilation, high-resolution short-time scale forecasts are produced with emphasis on 0–6 hours for extreme events. The forecasting system extends from 0 to at least 7 days based on a combination of global, regional, and national deterministic NWP and EPS data and products. The NMHS has the capacity to manipulate digital data and to tailor forecasts to specific users. A multi-hazard warning system exists. It is able to generate seasonal stream flow outlooks, and specialized hydrology products; and has full R&D capability. There are well-established relationships with partner agencies.	The NMHS has an extensive research program and introduces new forecasting technologies and techniques; has the capacity to support requirements of other NMHSs; is able to run global, regional, and national NWP and EPS systems. Forecasts of weather and hydrological impacts on specific sectors are routine and generally developed with users of these forecasts. The NMHS has a well-developed education and training unit.

ANNEX 3
Progress Model for Climate Services

CLIMATE SERVICES				
Undeveloped	**Development initiated**	**Development in progress**	**Developed**	**Advanced**
The NMHS may operate a limited national climate observing system; collect data in paper form; retrieve climate data from different sources to generate national climate products; participate in regional climate outlooks; and have very limited or no interaction with users. Typically, the NMHS does not have staff dedicated to carry out climate services.	The NMHS designs, operates, and maintains national climate observing systems; manages data including QA/QC; develops and maintains data archives; monitors climate; oversees climate standards; performs climate diagnostics, climate analysis, and climate assessment; disseminates climate products; participates in regional climate outlooks; and interacts with users. The NMHS performs the functions of a national climate center providing basic climate services. Staff are proficient in climate statistics, homogeneity testing techniques, and quality assurance techniques.	The NMHS has the capacity to develop and/or provide monthly and longer climate predictions, including seasonal climate outlooks, both statistical and model-based; conduct or participate in regional and national climate outlook forums; interact with users in various sectors; add value from national perspectives on the products received from RCCs and in some cases GPCs for long-range forecasts; conduct climate watch programs; and disseminate early warnings. Staff are proficient in developing and interpreting climate prediction products, and in assisting users in the uptake of these products.	The NMHS generates sub-seasonal to seasonal forecast products, develops specialized climate products; downscales long-term climate projections as well as interprets annual to decadal climate predictions; covers all the elements of climate risk management, from risk identification, risk assessment, planning and prevention, services for response and recovery from hazards, information relevant to climate variability and change, and information and advice related to adaptation; builds societal awareness to climate change issues and provides information relevant to policy development and a national action plan. Staff have knowledge in climate modelling and methods for downscaling/calibration, risk and risk management and financial tools for risk transfer.	The NMHS has research capacities and runs global and regional climate models (sub-seasonal to decadal and longer); and works with sector-based research teams and develops application models and develops software and products suites for customized climate products. Staff have multi-disciplinary modelling and statistical expertise and can downscale/calibrate global scale information to regional and national levels. The NMHS is able to receive and respond to user requirements for new products.

ANNEX 4
Progress Model for Hydrological Services

HYDROLOGICAL SERVICES				
Undeveloped	**Development initiated**	**Development in progress**	**Developed**	**Advanced**
The NHS may operate and maintain a very small hydrological observation network; collect data in paper format; and have very limited or no interaction with users. Typically, staff of NHSs in this category are not trained in hydrology.	Functions of NHS may include operation and maintenance of a small hydrological observation network; hydrological data management, with basic hydrological data-processing, archiving and communication system; little or no back-up / offsite storage; and some interaction with users of hydrology data and products. There is no research and development, and rudimentary quality management system. There are no relationships with partner agencies.	The NHS is able to operate and maintain a hydrological observational network to monitor major rivers, and take and integrate some hydrological observations from other parties. The NHS operates an interoperable hydrological data management system; and have well-established protocols for emergencies, backup of hydrological data and minimum offsite facilities. The NHS carries out water level and flow monitoring, and is able to generate short-term flow forecasts (low flows), flood forecasting, and hydrological data products for design and operation of water supply structures. There is a small research and development unit; and a quality management system. There are some relationships with partner agencies.	The NHS operates and maintain a comprehensive hydrological observational network to monitor major and some smaller rivers, and takes and integrates most of the hydrological observations from other parties. The NHS operates a well-developed interoperable hydrological data management system; and has well-established protocols for emergencies, backup of hydrological data and offsite facilities. The NHS carries out water level and flow monitoring, and is able to generate short-term flow forecasts (low flows), flood forecasting, and hydrological data products for design and operation of water supply structures. The NHS is also able to generate seasonal stream flow outlooks, and specialized hydrology products. There is a research and development unit; and a well-established quality management system. There are well-established relationships with partner agencies.	In addition to the foregoing capabilities, the NHS has an extensive research and development program; and strong relationships with partner agencies, taking a leading role in the advice and decision support. NHSs have the ability to generate customized hydrological products, and to develop hydrological application tools.

ANNEX 5
Annotated Concept of Operations

Concept of Operations (CONOPS)

(Document #)

for the

{Name of the National Meteorological or Hydrological Service (NMHS}

{Date}

Prepared by:

{Preparer}

{Contact information}

Concept of Operations (CONOPS)

Signature Page

Document Change Control Sheet

Document Title: Concept of Operations (CONOPS)

Date	File name/version #	Author	Revision description

Table of Contents

PREFACE

The NMHS {provide mission statement}

{Statement about what will be possible after the completion of the modernization project}

The CONOPS document provides a conceptual overview of the proposed system and sub-systems. The CONOPS is intended to support the evolution of a fully integrated, modernized and functional NMHS, which provides the level of services required by its users and stakeholders. The CONOPS is a living document and will be coordinated in a collaborative manner with users and stakeholders to ensure the viability of the concepts presented.

CONCEPT OF OPERATIONS (CONOPS)

1.0 Scope

The CONOPS document describes the desired characteristics of the NMHS's system from the users' viewpoint. The sections below identify the proposed system, provide a document overview and the approach used to generate the document, and provide a brief overview of the system.

1.1 Identification

The proposed system will include all of the associated subsystems (**Figure 1-1, Components of the Proposed NMHS System**) that comprise the NMHS, including all associated equipment, facilities, material, software, hardware, policy, technical documentation, services, training and personnel required for operations and support of the NMHS. The CONOPS is built on a user requirements document, which was prepared separately and included as an annex to the CONOPS document in **Section 10**.

1.2 Document Overview

The CONOPS is a vehicle to communicate high-level quantitative and qualitative characteristics of the system to the user, developer, operator, and other stakeholders. The CONOPS addresses the challenges involved in ensuring the NMHS is fit for purpose.

- Section 1 describes the approach used to develop the CONOPS;
- Section 2 provides a list of reference documentation used in the creation of the CONOPs;
- Section 3 describes the current NMHS systems;
- Section 4 discusses the justification and nature of changes based on the most current information;
- Section 5 provides information on proposed system concepts;
- Section 6 describes operational scenarios;
- Section 7 summarizes operational, organizational, and other impacts during development;
- Section 8 analyzes the proposed system;
- Section 9 provides additional information;
- Section 10 is for annexes; and
- Section 11 provides a glossary of terms.

1.2.1 Approach

The initial approach taken by the NMHS technical team (TT) to develop this document used concept analysis, the process of analyzing a problem domain and an operational environment for the purpose of specifying the characteristics of the proposed system from the perspective of users. This helped to clarify and resolve vague and sometimes conflicting needs, wants, and opinions by reconciling divergent views. Using this approach, the potential for designing a system in which each individual function meets its specifications, but the system as a whole fails to meet the users' needs, was minimized.

This version of the CONOPS document is the initial version based on extensive consultation with users, staff of the NMHS, and external technical experts.

In order to meet users' requirements, a complete reexamination of all subsystems was required.

1.2.2 IEEE Standard

{If appropriate cite IEEE Std. 1362-1998 guide for information technology system definition—Concept of Operations (CONOPS) document}

1.3 System Overview

{Describe the current structure of the NMHS; how it operates, etc. This should be based on a separate assessment of the organization, which should be referenced.}

2.0 Referenced Documents

The standards, guidelines, and NMHS documentation used to develop the CONOPS are described in the sections that follow.

2.1 Standards and Guidelines

The standards and guidelines used in preparation of this document are listed below.

2.2 NMHS Documentation

The following NMHS document was used to support the generation of this document

- {statutory authority of NMHS}
- Review of NMHS
- ….

NMHS Project Management Documentation

- {Results of stakeholder workshop}
- {User requirements document}
- {Early version of CONOPS, if any}
- {Analysis of alternatives}
- {Project management plan}
- {Project appraisal document}
- {Project description document}

2.3 Other Documentation

Other documentation used to support the generation of this document. *{May include government directives on data sharing, for example.}*

3.0 Current System

The following subsections describe the background, objectives, and scope of the current system and its subsystems; operational policies or constraints; the current system and subsystems; modes of operation for the current system; users of the services provided by the NMHS; and staff and the support environment.

3.1 Background, Objectives, and Scope

{Describe how well or otherwise the current system meets the mission needs.}

Currently, the NMHS's infrastructure consists of manual observing systems, daily forecasts, etc., that do not meet the mission needs, or effectively address the emerging requirements of the NMHS's key users. *{Describe briefly the history of the organization.} {Weather and climate dependence of all sectors of the economy are increasing, and the risk to lives and livelihood of citizens is growing as more people are exposed to severe weather and flooding.}*

3.1.1 Analysis of the Current Systems/ Subsystems

The NMHS's systems are nearly obsolete, incapable of providing the breadth and depth of services that the proposed system will provide. Currently no single system or group of systems exists *{i.e., no turnkey solution}* that will provide the capabilities envisioned for the proposed modernized NMHS system. To support this assertion analyses were performed on alternatives.

3.1.1.1 First Analysis of Alternative Findings

{If there are alternatives for the modernization of the NMHS' systems and subsystems, they should be described here in terms of whether those alternatives met the requirements of the users. Scoring the current system against a complete or partial modernization with respect to mission tasks accompanied by a technical and cost analysis is used to justify the new system.}

In the initial analysis, several alternatives for the development of the NMHS were identified by the *Analysis of Alternatives Team and examined {for example, the privatization of the NMHS; creating a commercial arm of the NMHS; partnerships with the private sector; and focusing the NMHS exclusively on public sector services, etc.}*. The *Analysis of Alternatives Team* rated the alternatives and selected the alternative that would best meet the goals and objections of the NMHS mission.

In the first step, the *Analysis of Alternatives Team* identified a number of basic criteria from existing NMHS needs and laws that each alternative would have to meet. Through their analysis, the Analysis of Alternatives Team eliminated the alternative of *privatizing the NMHS, for example,* as this alternative would be unable to comply with current laws and regulations.

In the second step, the remaining alternatives were scored against the mission tasks, measures of effectiveness, and the requirements of the NMHS. *{Each of these needs to be identified enabling a numerical score to be created. Measures of effectiveness might include proficiency in providing warnings to disaster managers, for example.}*

Lastly a technical and cost analysis with respect to the development of a new system/subsystems was performed. *{This should guide and support the alternative selected for the new system and provide a strong argument based on its cost-effectiveness to deliver the mission tasks.}*

3.1.1.2 Second Analysis of Alternative Findings

{If additional analysis is done it would be described here. This might include a separate risk analysis. It might also be used to evaluate new offers as alternatives to the preferred approach, for example, from a new vendor of turnkey systems that had not been considered during the first analysis of alternatives.}

3.1.1.3 Legacy Evaluation Findings

{This would include an evaluation of systems that have been provided by other development partners and need to be included in the final modernized NMHS. These legacy requirements might be included as a table.}

3.1.2 Motivation for a New System/ Subsystems

{Describe the factors that motivate the need for a new system. This will include new observational technologies that will improve nowcasting, very short and short-range weather forecasting and service delivery, etc.}

The NMHS's process for monitoring and observing, analyzing and forecasting, and dissemination rely largely on manual systems. The NMHS needs a system capable of meeting the needs of users, which requires the ability to provide timely, accurate, and relevant impact-based forecasts and warnings tailored to the specific needs of different groups.

{A motivation for modernization might include the acquisition of new observational capabilities; for example, to exploit fully new radar technologies requires nowcasting and very short-range forecasting capability, access to high resolution models, etc.}

In order to meet the NMHS's strategic goals, the proposed system should be able to accomplish the following goals:

- *{Service-related goals}*
- *{Reliability of forecasting system}* …
- *{Access and effective use of NWP ensembles}* …
- *{Affordable and easy to maintain observing network}*
- *{Etc.}*

3.1.3 Modes of Operation of the Current System

Modes of operation of the current systems are provided in **Section 3.4, Modes of Operation for Current System.**

3.1.4 Classes of Users

Classes of users for the current systems are identified in **Section 3.5, User Classes and Other Involved Personnel.**

3.2 Operational Policies and Constraints

{This might include interagency agreements on data sharing, commercial sales of data, etc.}

There are no other constraints beyond those mentioned in previous sections and in **Section 4.0, Justification for and Nature of Changes.** Limitations of a number of the subsystems that comprise the current environment are discussed in **Section 3.3, Description of the Current System/ Subsystems,** and appropriate subsections.

3.3 Description of the Current System/ Subsystems

The NMHS's current operating environment consists of a number of subsystems that do not adequately fulfil its mission needs. *{This section should provide an overview of the whole system and how it performs currently. The details of each subsystem would be discussed in sub-sections.}*

3.3.1 Description and Capabilities of Existing Systems/Subsystems

The following subsections provide a functional description of each subsystem and include any known limitations. A summarization of the high-level functionality of these systems is also provided.

3.3.1.1 Monitoring and observing systems

{Function and current limitations}

3.3.1.2 Modelling systems

{Function and current limitations}

3.3.1.3 Objective and impact forecasting and warning systems

{Function and current limitations}

3.3.1.4 Service delivery systems

{Function and current limitations}

3.3.1.5 Actions, service monitoring, and feedback systems

{Function and current limitations}

3.3.1.6 Quality management systems

{Function and current limitations}

3.3.1.7 ITC systems

{Function and current limitations}

3.3.1.8 Technology infusion systems

{Function and current limitations}

3.3.1.9 Capacity building

{Function and current limitations}

A summary of the high-level functionality/capability of each subsystem is provided in **Table 3.1.**

TABLE 3.1 Systems/Subsystems High-Level Functionality Summary

System/Subsystem	Functional area/high-level functionality	Point of contact

3.4 Modes of Operations for Current System

{Describe why the current system is inadequate.}

The current modes of operation provide forecasting capabilities limited to *{describe briefly}*.

3.5 User Classes and Other Involved Personnel

{Summarize how people interact with the current system. A later section (5.5) will describe this in detail.}

Users, stakeholders, and other involved personnel are provided in **Table 3.2**.

TABLE 3.2: System Users

System	Number and Type of Users/Providers
Services (actions, etc.)	There are a total of {XX} user groups comprising public sector, businesses, and government stakeholders.
Service delivery systems	Staff:
Observing systems	The observing system is supported by {XX} field technicians. Internal users comprise the modelling and forecasting staff.
Modelling systems	The modelling system is supported by {XX} technical staff. Internal users comprise {XX} forecasters.
Forecasting systems	
QMS	Staff:
ITC	Staff:
Technology infusion systems	Staff:
Capacity building	

3.5.1 Organizational Structure

{Organograms of how the NMHSs serve its public users and government stakeholders, and how the NMHS is organized internally.}

3.5.2 Profiles of User Classes

Profiles of the user classes for the current situation identified above are the same as those addressed in **Section 5.5.2, Profiles of User Classes. Please refer to this section for detailed information.**

3.5.3 Interactions among User Classes

Interaction among the user classes for the current situation identified above are the same as those addressed in **Section 5.5.3, Interactions among User Classes. Please refer to this section for detailed information**.

3.5.4 Other Involved Personnel

Responsible points of contact for the systems/subsystems are provided in **Table 3.1, Systems/subsystems High-Level Functionality Summary.**

3.6 Support Environment

{How are the various systems/subsystems supported and maintained?}

The current systems are supported entirely by in-house government support.

4.0 Justification for and Nature of Changes

{General description of the need for change, followed by brief description of subsections that follow.}

Over the last {XX} years, the NMHS has been responsible for providing meteorological and or hydrological services to the country. Continuing growth in the weather- and climate-dependent economic sectors and in the increasing exposure of a growing population to weather and climate extremes make it an imperative to improve the quality and level of services provided by the NMHS to protect lives, livelihoods, and economic development.

Currently the NMHS can provide only a limited number of services that do not meet the growing needs of users adequately.

The following subsections describe the proposed system in terms of the justification of changes, a description of the desired changes, priorities among changes, changes considered but not included, and assumptions and constraints of building the new system.

4.1 Justification of Changes

Advances in knowledge and technology have increased the accuracy of meteorological predictions that help save lives and improve economic performance. The NMHS has not kept pace with these developments.

4.2 Description of Desired Changes

The following subsections list the proposed system attributes, capabilities, and interfaces.

4.2.1 Proposed System Attributes

From the overall system perspective, the proposed modernization of the NMHS should possess the following attributes:

- Infrastructure independence: an architecture that allows the NMHS to operate under all circumstances including during extreme hazards
- Scalability: the capability to accommodate growth and evolving technologies without requiring a complete replacement of the systems
- Flexibility: the ability to tailor services to users' future requirements. The system should be flexible enough to interface with other agencies' evolving systems
- Comprehensiveness: the system should be able to meet all anticipated needs
- Extensibility: the ability to handle new type of observations, numerical models, and forecasting systems

4.2.2 Proposed System Capabilities

To meet strategic objectives, the NMHS must integrate its systems and subsystems and incorporate legacy systems and new systems provide by other development partners. To meet the challenges of today and the future, the proposed NMHS system should provide the following capabilities.

- Capability to receive data from a variety of international and national sources and use these data in the forecasting system
- Capability to ingest, preserve, and provide access to data

- Capability to store data in a manner that is independent of any particular hardware and software over long periods
- Capability to scale in order to store and preserve data
- Capability to provide electronic access to data and information for all users based on established user rights and privileges to ensure that its users are able to access all of the electronic data and information to which they are entitled
- Capability to provide access to data and information in a manner consistent with current technology and the changing expectations of its diverse users
- Capability to adapt to changing technology in order to provide the level of services desired by the users
- Capability to fully exploit current knowledge and technology to provide the optimum level of quality services expected by the users

4.2.3 Proposed System Interfaces

The proposed system will operate within the framework of the national government, and be capable of interfacing with other government systems, enabling the seamless transfer of data and information. The volume and diversity of input and output data, and the expected heavy use of the system, will have considerable impact on the NMHS computing environment.

Interfaces with other government agency systems will be accommodated by the proposed NMHS system. Other systems the proposed NMHS system will interface with are provided below with additional detail in **Section 5.3.2, Interfaces to External Systems or Producers.**

- WMO information System
- ECMWF
- WMO Regional Specialized Meteorological Center
- NCEP
- Etc.

4.3 Priorities among Changes

This section describes the functionality by increment that the proposed NMHS system is expected to satisfy. *{This may be developed in a separate document if necessary.}*

4.4 Changes Considered but Not Included

There are no changes to the proposed NMHS system that were considered but not included in the proposed list of NMHS system attributes, capabilities, or system interfaces identified in **Sections 4.2.1** through and including **Section 4.2.3**. Changes to the items provided in those sections will not be known until completion of the systems analysis and design phase of the NMHS modernization program. Moreover, changes that may result in newly identified requirements and/or changes to requirements cannot be considered until cost estimations have been provided.

4.5 Assumptions and Constraints

This section identifies assumptions and constraints that may impact the system architecture or specific components of the proposed system.

4.5.1 Assumptions

The proposed NMHS system relies on a set of assumptions that is derived from the NMHS's operational policies or are inherent in its operational environment. The proposed NMHS system assumes that:

- For the next several years, data inputs will be in standard and familiar format enabling full integration into the system without requiring any reengineering;
- Expect the volume, variety, and complexity of data will continue to grow throughout the period of the NMHS modernization;
- Expect the numerical weather prediction technology available from the international community to evolve significantly throughout the period of the NMHS modernization and beyond; and
- Expect the operations and maintenance budget for the NMHS to keep pace with the technological improvements throughout the period of NMHS modernization and beyond.

4.5.2 Constraints

Constraints that may impact the system architecture or specific components of the proposed system are provided in **Section 5.2, Operational Policies and Constraints**.

4.6 Adverse Effects

The risk of not proceeding with the development of the proposed system are many and include the following:

- The NMHS will not be able to achieve its mission
- The public will not receive information that could protect their lives and livelihoods
- The weather- and climate-dependent sectors will not receive information relevant to protecting their business activities
- Emergency management of weather-related hazards will be compromised
- The NMHS will not be positioned to provide adequate guidance, assistance, or services to agencies to manage their weather and climate risks
- The NMHS's role as the single authoritative voice for weather warnings would be increasingly reduced
- The nation's long-term climate records would be adversely affected if these data will not be stored properly

5.0 Concepts of the Proposed System

The following subsections describe the concepts of the proposed system with respect to the background, objectives, and scope of the proposed system; operational policies and constraints that apply to the new system; description of the proposed system; users, stakeholders, and other involved personnel; and the support environment.

5.1 Background, Objectives, and Scope

A high-level system overview has been provided in **Section 1.3, System Overview**. Goals of the proposed NMHS system and the motivation for the new system are discussed in **Section 3.1.2, Motivation for a New System/Subsystems**.

{Here follows a detailed description of the proposed system.}

5.2 Operational Policies and Constraints

The proposed NMHS system is required to adhere to government policies for the provision and exchange of data. It is mandated by *{here cite any legal arrangements that govern the operation of the NMHS and its relations with users, private sector providers, etc.}*

Constraints as currently known that may impact system architecture or major system components are provided below.

- World Bank procurement rules;
- NMHS system design and implementation is flexible and adaptable to changes in hardware, software, communication technology, policy, personnel, locations, etc.;
- The NMHS system design is a balance of Commercial Off The Shelf (COTS) and developed software; and
- The NMHS system implementation is within the specified budget and time frame.

5.3 Description of Proposed System

The proposed NMHS system described herein incorporates the information from user surveys, user workshops, requirements documents, NMHS reviews, and recommendations from other reviewers on necessary and desired characteristics, as well as those learned from ongoing activities and other development partners' activities. The design and development of the proposed NMHS system currently does not exist.

Section 4.6 provides a bulleted list of risks in the event the NMHS system is not designed and developed.

5.3.1 Major System Components

Proposed architectural characteristics/concepts are provided in *{this might include review of NMHS with specific recommendations; workshops on NWP and forecasting, etc.}*. Additionally, details on major components are presented in the **Section 6.0, Operational Scenarios**.

5.3.2 Interface to External Systems and Data Flow

The external interfaces include the observations ingested from the WMO information system; access to proprietary and nonproprietary numerical weather prediction data; and non-NMHS national and local sources of observations and non-weather data. There are also external interfaces with users, which can provide feedback on the utility of the information they receive. This is also a crowdsourcing interface to improve impact-based forecasts and warnings. **Figure 5.1, External Interfaces Context Diagram** depicts external interfaces along with associated data flows. The data flows are high-level, i.e., not broken down into individual elements.

5.3.3 Capabilities or Functions of the Proposed System

Capabilities of the proposed NMHS system are listed in **Section 4.2** *{they may also be expounded on in additional documentation}*. NMHS capabilities by user class are provided in **Section 5.5.3., Users' Capabilities.**

5.3.4 Continuity of Operations

The proposed NMHS system is intended to be able to survive and operate during hazardous events. Therefore, the ability to operate critical infrastructure and services away from the main operations center needs to be considered. Different approaches will vary in terms of complexity and cost.

5.4 Modes of Operation

The modes of operation for the proposed system as currently known are:

- Nominal
- Degraded
- Maintenance
  - Remedial maintenance
  - Preventative maintenance
- Upgrades
- Alternative site

Nominal mode of operation describes the system when working at the optimum, i.e., the system is operational and working as intended.

Degraded mode and maintenance mode of operation describe operations in times when the system or subsystems are working using a reduced strength of operations. For example, the system is in maintenance mode if the radar system is off-line. Forecasters may need additional backup from remote centers or use satellite data under these circumstances.

Alternative site mode of operation can be described as occurring when the main operational center is out of action due to the Impact of a hazard requiring operations to be conducted from an alternate site.

Standard operating procedures should be established for the different modes of operations and the expected level of services that can be provided in the different modes.

5.5 User Classes and Other Involved Personnel

The following sections describe the organizational structure and classes of users, including user capabilities that are associated with the proposed NMHS system.

5.5.1 Organizational Structure

The following organizational chart, **Figure 5.2, Organizational Interfaces**, portrays the structure of the NMHS.

5.5.2 Profiles of Users Classes

A user is anyone who uses the services of the NMHS. A user class is determined by the way in which the user interacts with the NMHS system. The major user classes identified for the proposed NMHS system include the following:

- End-user—receives forecasts and warnings and acts on those warnings. An end-user is generally the public or a community. An end-user may also apply to a business that does not receive specially tailored products and services from the NMHS.
- Government stakeholders—receive forecasts and warnings from the NMHS usually in advance of any release to the public. This information may be automatically transferred from the NMHS and may be incorporated in decision-support tools; for example, for emergency operations. For non-collocated hydrological services, this information would enable flood forecasts to be computed at a remote location.
- Customers—these are users or stakeholders that receive forecasts, warnings, guidance, etc., as a fee-for-service. Generally, this would apply to commercial users, who by agreement may repackage information for their clients or use the information in commercial decision-making systems.
- Etc.

5.5.3 Users' Capabilities

- The NMHS services correspond to users' capabilities, needs, and desires for the proposed system. These capabilities are organized according to user class, but some capabilities cross user class boundaries and may be employed by users in more than one user class.

End-user

- Receives forecasts and warnings through traditional or social media
- NMHS may provide apps to assist the end-user access information through smartphones and the Internet
- Provides NMHS with feedback through crowdsourcing tools where available, which provides feedback on the quality of the service and the actions taken by end-users to minimize their exposure to hazards following receipt of a warning
- Etc.

Government stakeholders

- Emergency managers may be responsible for transmitting warnings to the public and others
- Emergency operations centers may collocate the NMHS extreme weather forecast desk to enable forecasters to interact directly with emergency managers
- Hydrological service may collocate with the NMHS forecasting office to enable flood forecasts to interact directly with weather forecasters
- Water resource managers and dam operators access critical weather and hydrological information to manage water levels
- Etc.

Customers

- May have varying degrees of capability depending on their operations, ranging from guidance based on forecasts to ingesting data into their own decision support systems or combining the NMHS products with their own to generate ensembles and new forecast products for their clients.
- Etc.

5.5.4 Interactions among Users and Stakeholders

The proposed NMHS system described here is an overall conceptual workflow model that depicts where user classes should interact within the system and with each other. **Figure 5.3 NMHS User classes**, illustrates this conceptual model.

5.5.5 Other Involved Personnel

Figure 5.4, NMHS Modernization Project Oversight Structure depicts the organizational structure that is overseeing the overall execution of the project. This organizational structure includes the following elements:

- The Director General of the NMHS is the decision authority
- {Can be populated by the Project Appraisal Document or Terms of Reference of System Integrator (SI)}
- Etc.

5.6 Support Environment

The support environment will not be determined until the conclusion of the system analysis and design phase of the modernization program.

6.0 Operational Scenarios

The CONOPS document expresses what users want and envision. Scenarios convey these needs in nontechnical language. Overlap exists between different scenarios as a result of interaction between different users or due to similarity between different activities. For example, the document might include scenarios for disaster managers, agriculture extension workers, farmers, and the general public.

A scenario is a step-by-step description of how the NMHS should operate and interact with both its users and external interfaces under a given set of circumstances. Scenarios should enable readers to walk through them and gain an understanding of how all principal parts of the NMHS function and interact.

6.1 Disaster Management Scenario

This scenario represents one example of how the NMHS will support the emergency operations prior to, during, and after a major event.

- NMHS provides a long lead-time outlook on a developing adverse weather situation, up to 10 days ahead based on numerical model guidance;
- Enables emergency operations to begin initial preparation;
- Guidance is updated daily, and closer to the event horizon briefings are given on a frequent basis;

- Severe weather forecasters may relocate to emergency operations centers; and
- Warnings are issued via the emergency operations center.
- Etc.

6.2 Water Resources Management Scenario

This scenario represents one example of how the NMHS will support water resources management.

- NMHS provides seasonal and longer lead-time forecasts to hydrologists to predict long-term availability of water and the risk of meteorological drought.
- Etc.

6.3 Public Weather Services Scenario

This scenario represents one example of how the NMHS will support public weather services.

- NMHS provides daily forecasts up to 10 days ahead to the general public via traditional and social media;
- NMHS provides public weather information via smartphone apps;
- Warnings of severe weather are issued via the emergency operations center; and
- Impact-based forecasts are provided routinely.
- Etc.

6.4 Farming Community Scenario

This scenario represents one example of how the NMHS will support farmers.

- In addition to the routine public weather services, farmers receive special bulletins related to planting, harvesting, and protection of crops and livestock. These impact-based forecasts enable farmers to manage inputs and maximize yields.
- Etc.

6.5 Facilities

Facilities' requirements will be based on the future design of the system.

7.0 Summary of Impacts

7.2 Operational Impacts

Until the modernization program undergoes systems analysis and design, operational impacts of the proposed modernization are not known; therefore, impacts to the following have been omitted:

- Changes in the operational budget
- Changes in the operational risks
- Changes in the maintenance budget
- Changes in the maintenance risks
- New modes of operations based on new forecasting techniques
- Changes in the quantity, type, and timing of data to be input into the system
- Uses of new data sources
- Changes in procedures

However, it is anticipated that the NMHS will have to implement changes to the ways it conducts business in order to achieve the agency's mission, goals, and objectives. The proposed NMHS system will facilitate this endeavor.

7.2 Organizational Impacts

The NMHS is examining current policies and business practices and may have to develop and/or modify policies and business practices as necessary. The depth and breadth of the organizational impact is unknown at this time. Information with respect to the following has not been provided for this reason.

- Numbers and skill levels of personnel needed for contingency operation
- Changes in the number of personnel, skill levels, position identifiers, or location of personnel
- Revision of position descriptions to reflect changes in business practices
- Commitment of resources to the new forecasting system
- The need for cross-functional, interdisciplinary staff teams
- The development of education and increased training for both NMHS staff and users

- Improved opportunities for career development for NMHS staff
- Relationship between the NMHS and external partners

7.3 Impacts during Development

The full extent of impacts during development will not be known until completion of the system analysis and design phase and as such has not been provided; however, impacts considered thus far including the following:

- Articulation of business rules, templates, and other controls needed for operational implementation;
- Development of training for staff;
- Consideration of parallel operation of the new and existing systems; and
- Operational impacts during system testing of the proposed system.

8.0 Analysis of the Proposed System

Various improvements, disadvantages and limitations, alternatives and trade-offs considered are covered in this section.

8.1 Summary of Improvements

The proposed NMHS system, when implemented, will subsume and enhance the existing functionality provided by the current system identified in **Section 3.3.1**; however, the proposed NMHS system will provide new sets of capabilities as offered in **Section 4.2.2**. The full extent of the capabilities to be provided by the proposed NMHS system will not be known until completion of the systems analysis and design phase of the program and will be addressed at that time as required. It is anticipated, however, that the proposed NMHS system will offer numerous benefits to users and may include the following:

- More accurate and timely forecasts based on full use of the high-resolution ensembles provided by advanced numerical prediction centers, such as ECMWF;
- More confidence in warnings issued with greater understanding of risk and the ability to improve decisions in low probability, high impact extreme weather events;
- More detailed shorter range forecasts;
- Nowcasts and very short-range weather forecasts;
- Dynamic, ensemble-based flood forecasts; and
- Impact-based forecasts and warnings.

8.2 Disadvantages and Limitations

Potential disadvantages or limitations of the proposed NMHS system include:

- High development costs;
- Staff anxiety brought about by new responsibilities;
- Poor staff morale with proactive change management;
- Higher operating and maintenance costs; and
- Unrealistic expectations of users and stakeholders.

Alternatives and Trade-offs Considered

{May be documented elsewhere in support of the analysis of alternatives.}

9.0 Notes

The technical terms used in this document are defined below. **Table 9.1** provides a list of acronyms used herein.

TABLE 9.1: Acronyms

Acronym	Definition
CONOPS	Concept of Operations
NMHS	National Meteorological and Hydrological Service
WMO	World Meteorological Organization

10.0 Appendices

11.0 Glossary

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Weathering the Change: How to Improve Hydromet Services in Developing Countries

Climate change is impacting the lives and livelihoods of people everywhere. More people are vulnerable and exposed to the effects of extreme weather, especially through the impact of floods, landslides, drought, and winds. One way to cope is by reducing exposure to harm by providing more accurate, reliable, and actionable weather, climate, and hydrological information. This is amply demonstrated in high-income countries, where the impact of extreme weather events is mitigated by their ability to take early action based on meteorological and hydrological warnings. This is possible because these countries have invested in their publicly financed National Meteorological and Hydrological Services (NMHSs), encouraged the development of complementary private services, and invested heavily in research and development.

GFDRR Global Facility for Disaster Reduction and Recovery

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The Global Facility for Disaster Reduction and Recovery (GFDRR) is a global partnership that helps developing countries better understand and reduce their vulnerabilities to natural hazards and adapt to climate change. Working with over 400 local, national, regional, and international partners, GFDRR provides grant financing, technical assistance, training, and knowledge sharing activities to mainstream disaster and climate risk management in policies and strategies. Managed by the World Bank, GFDRR is supported by 37 countries and 11 international organizations.