Modernizing Weather, Water, and Climate Services:

A Road Map for Bhutan

Prepared in Collaboration between the
Royal Government of Bhutan and the World Bank

WORLD BANK GROUP

WATER
PARTNERSHIP
PROGRAM

SAWI SOUTH ASIA WATER INITIATIVE

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Airport, Paro, Bhutan Photo. Photo: © Nyiragongo70 | Dreamstime.com

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Acronyms

AIT	Asian Institute of Technology
AMS	Aviation Meteorology Section
AWLS	automatic water level stations
AWOS	automated weather observing system
AWS	automatic weather station
BMD	Bangladesh Meteorology Department
COMET	Cooperative Program for Operational Meteorology, Education and Training
CWC	Central Water Commission
DCA	Department of Civil Aviation
DDM	Department of Disaster Management
DES	Department of Engineering Services
DFPS	Department of Forests and Park Services
DGM	Department of Geology and Mines
DHMS	Department of Hydromet Services
DHPS	Department of Hydropower and Power Systems
DoA	Department of Agriculture
DoE	Department of Energy
DoP	Department of Power
DoR	Department of Roads
DRE	Department of Renewable Energy
EWS	early warning system
FWS	Flood Warning Section (DHMS)
GDP	gross domestic product
GEF	Global Environment Facility
GFCS	Global Framework for Climate Services
GFS	Global Forecast System
GIS	geographic information system
GLOF	glacial lake outburst flood
GoI	Government of India
GSB	Geological Survey of Bhutan
HD	Hydrology Division (DHMS)
HYCOS	Hindu Kush Himalayan Region Hydrological Cycle Observing System
HMSD	Hydromet Services Division
ICIMOD	International Centre for Integrated Mountain Development
IMD	Indian Meteorology Department

IPR	Ice Penetrating Radar
IT	information technology
JAXA	Japan Aerospace Exploration Agency
JICA	Japan International Cooperation Agency
MD	Meteorology Division (DHMS)
MoEA	Ministry of Economic Affairs
MoH	Ministry of Health
MoHCA	Ministry of Home and Cultural Affairs
MoWHS	Ministry of Works and Human Settlement
NAPA	National Adaptation Programme of Action (INDIA)
NCMRWF	National Centre for Medium Range Weather Forecasting
NEC	National Environment Commission
NMHS	National Meteorological and Hydrological Service
NORAD	Norwegian Agency for Development Cooperation
NWFFWC	National Weather and Flood Forecastimg and Warning Center
O&M	operation and maintenance
QPF	quantitative precipitation forecast
PCRD	Planning Coordination and Research Division (DHMS)
R&D	research and development
RGoB	Royal Government of Bhutan
RIMES	Regional Integrated Multi-Hazard Early Warning
RSTA	Road Safety and Transportation Authority
SASCOF	South Asian Climate Outlook Forum
SGD	Snow and Glacier Division (DHMS)
TA	technical assistance
UNDP	United Nations Development Programme
WIS	WMO Information System
WMD	Watershed Management Division
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting Model

Executive Summary


Raphstreng Lake
Thorthormi Lake
Pho Cho River
Luggye Lake

Bhutan is a mountainous country and highly prone to a range of hydrometeorological hazards, including glacial lake outburst floods (GLOFs), flash floods, riverine floods, landslides, landslide dam outburst floods, cloudbursts, windstorms, and river erosion. It ranks fourth highest in South Asia in terms of relative exposure to flood risks, with 1.7 percent of the total population at risk. With climate change, the frequency and intensity of extreme events are expected to increase. Most of the infrastructure, fertile agricultural land, and over 70 percent of the settlements are located along the main drainage basins and are therefore at high risk, especially during the monsoon season. In the mid-mountains, landslides triggered by cloudbursts are frequent, and recent occurrences of landslide dam bursts have caused major destruction in low-lying areas, including the Thimphu Valley. Bhutan is also at risk for tropical cyclones. Flash floods are a recurrent phenomenon, with the eastern and southern regions being the most vulnerable.

Key sectors supporting the economy are highly dependent on and affected by weather and climate hazards. Hydropower is a key sector both in terms of its contribution to the economy and as a source of foreign currency revenues. This sector is highly exposed to floods and climatic risks. Another major contributor to the economy is agriculture. Unpredictability in the timing of monsoons and prolonged drought have long-term implications for agricultural productivity and food security. Farmers relying mainly on rain-fed agriculture are among the most vulnerable.

Improved monitoring and forecasting is key to strengthening disaster-related early warning systems (EWSs) and adapting to climate change and variability over the long run. Despite its importance, however, at present there is no comprehensive analysis of the existing status of the hydromet observation network, forecasting and early warning systems in Bhutan. Nor has there been an assessment of user needs or how monitoring and forecasting can be strengthened to meet those needs.

The Royal Government of Bhutan (RGoB) has identified addressing hydrometeorological hazards and strengthening climate resilience as priority issues. It is in the process of modernizing its hydromet observation network, improving weather and flood forecasting capacity, and strengthening community-based early warning systems. The Department of Hydromet Services (DHMS) aims to transform itself from primarily a "data collection agency" to a "reliable and credible hydromet service provider." It is within this context and in response to a request from the Ministry of Finance that this Technical Assistance (TA) supported by the World Bank was initiated.

Study Objective

The main objective of this TA is to provide recommendations to the RGoB for modernizing its hydrometeorological services, including capacity strengthening for disaster-related early warning systems (EWSs). The DHMS does not have a national hydromet services policy but is in the process of preparing a strategic document to guide its modernization and institutional reform process. This TA contributes to this process and proposes a road map for transforming the DHMS into a modern service delivery agency.

Approach and Process

The report starts with an assessment of user needs and how DHMS services can be strengthened to respond to them. The monitoring and forecasting capacities, institutional setup, and organizational capacity of the DHMS were studied in depth in view of its mandate to deliver the country's hydrometeorological services and to work with other user sectors. The analysis is based

Facing page: Thorthormi Glacier Lake, Bhutan. NASA Earth Observatory image by Robert Simmon.

on extensive consultation with various government agencies, development partners, and stakeholders. A draft version of this report was presented at a stakeholder workshop held on August 12, 2014, in Thimphu. Feedback and comments received have been incorporated in this study.

Strengthening hydrometeorological services is a challenging task that cuts across multiple agencies. The focus here is limited to assessment of the DHMS's capacity for provision of services. It does not focus on broader aspects of disaster risk management such as risk assessment, reduction, financing, mitigation, and response-related activities. Follow-up studies are being initiated to assess how sector-specific services such as agrometeorological services and end-to-end disaster-related EWSs can be strengthened.

Key Findings

Despite the frequency of natural disasters and the climatic risks facing Bhutan, the information basis for assessing such risks is at present weak and needs to be strengthened. Between 1994 and 2011, some 87,000 people were affected and over 380 deaths occurred due to natural disasters in Bhutan—mostly arising from the impacts of floods, windstorms, earthquakes, and GLOFs. These have also contributed to extensive damages to infrastructure and to a disruption in agriculture, connectivity, and accessibility within and outside of the country. At present, however, information on specific types of hazards, exposure, and vulnerability is limited.

There is a strong demand for hydrometeorological data, information, and services in a wide range of sectors. Hydrometerological modernization and climate services have cross-cutting effects across all sectors and can, for instance, help the Department of Disaster Management (DDM) improve early warning systems and the level of preparedness and response to disasters. It can help the Department of Civil Aviation use hydromet data for flight operations, allow the Ministry for Agriculture to develop agrometeorological services and help its stakeholders to make decisions at the farm level, and support efforts by the Department of Hydropower and Power Systems to develop hydropower schemes and inform operation and maintenance.

The existing infrastructure and the monitoring and forecasting capacity of the DHMS need to be strengthened. At the time of writing, DHMS did not have access to WIS or regular access to high speed internet. Results from existing monitoring systems are mainly recorded manually. Meteorological measurements are underrepresented at the higher elevations, where access is difficult. Upper air observations also need to be strengthened. Glacier and snow monitoring by public sector agencies is limited and needs to be scaled up to assess the long-term impacts of cryosphere changes on water resources and to mitigate GLOF risks. Limited observation systems and forecasting capacity impairs the DHMS's ability to perform routine weather services, issue weather and hydrological forecasts and warnings for extreme events, and monitor long-term climate trends in the country. There is no forecast verification system in place. At present, Bhutan issues flood warnings but has a poor capacity for flood forecasting. With development partner support, the DHMS is upgrading its observation network, moving to install real-time stations and telemetry and early warning systems for GLOFs in some river basins. Gaps remain, however.

The DMHS is a relatively new department and requires significant capacity strengthening and an adequate budget to support capital investments and operation and maintenance that will ensure the long-term sustainability of services. Targeted training of existing staff in a number of critical areas such as weather and flood forecasting, remote sensing, and database management is needed. The DHMS has a very limited budget for capital investments and for operation and maintenance. Its budget for current expenses and O&M has been approximately USD 550,000 per year since 2011 and is insufficient to support significant expansion of the monitoring network, forecasting, and service delivery.

Recommendations and Road Map

Modernization of the DHMS and strengthening its service delivery mechanism in coordination with user agencies is essential. For the department to build its technical capacity and transform itself into a well-resourced service delivery agency, much remains to be done. While modernization will inevitably be an iterative, gradual, and long-term process, several actions can be undertaken in the short to medium term to facilitate it.

Short-term actions (one to two years)

▶ *Prepare strategic plan based on user needs*

The DHMS's strategic plan should be based on consultation with sector agencies and other stakeholders. To aid this process, a priority action for the DHMS is to institutionalize a systematic process of assessing demand from key stakeholders and delivering services tailored to these needs. This can be done through consultations and user surveys. The plan should have clear goals, targets, and indicators for the plan period, so that key outcomes can be measured. Indicative budget and estimates for O&M should be spelled out. Service provision in response to user needs can also allow the DHMS to explore the potential for generating revenue. The planning process should be iterative and ensure that services cater to user needs and have adequate staff and O&M budget to ensure that they are sustainable over the long run.

▶ *Strengthen DHMS information technology assets and infrastructure*

To enable the DHMS to do more with existing capacity, a key priority is acquisition and installation of the WMO Information System (WIS). This allows communication with the international observing community through the World Meteorological Organization (WMO). Access to a high-speed Internet connection is also critical and must be dedicated to operations at the DHMS. Regional offices will need Internet connections as well. The development of information technology assets has a high priority because data and products will be used by various sectors. This will also require strengthening data management so that data can be retrieved and transformed to build sector-specific products. In addition, numerous improvements in infrastructure are required to help the DHMS develop improved services.

▶ *Focus on high-priority monitoring systems*

The DHMS is currently upgrading its meteorological and hydrological ground monitoring network. In the short term, targeted monitoring systems based on user needs that can provide quick benefits should get priority. For instance, there is a significant need to acquire instrumentation at Bhutan's airports to ensure aviation safety in challenging meteorological conditions. Low-level windshear alert systems and ceilometers could be purchased within a short time frame.

▶ *Improve basic weather and hydrological forecasting*

Another immediate priority area for the DHMS is to improve its forecasting and early warning services, both basic weather forecasting and hydrological and flood forecasting. This can be done through investments in hardware and software, appropriate modeling tools, acquisition of infrastructure (such as workstations), and training for DHMS officials. These important public services should be improved. Follow-up studies need to be done to design appropriate networks for efficient monitoring of groundwater and water quality.

▶ *Pilot end-to-end early warning systems*

Monitoring and forecasting are but one part of strengthening end-to-end early warning systems. The latter includes risk assessments, monitoring and forecasting, communication of warnings to communities, and communities' capacity to respond to warnings. These tasks cut across several agencies and stakeholders including the DHMS, the DDM, the Department of Geology and Mines (DGM), district and local agencies, and communities. It is recommended that in the short term, the DHMS collaborate with DDM to pilot end-to-end EWS in selected hotspot areas. These could be scaled up in the medium term.

▶ *Develop training plan and staff training in key areas*

As DHMS expands and modernizes, staff with relevant expertise will be critical in carrying out its mandates and providing services. A systematic training plan based on needs assessment should be developed to train staff in important topics such as expanded weather and hydrological forecasting; management of data and information; activities related to monitoring snow, glacier, and GLOFs; and the provision of services to user sectors.

▶ *Develop a long-term program for monitoring Bhutan's cryosphere*

Strengthening of snow and glacier monitoring and analysis is needed to plan adaptation to climatic variability and improve the assessment and design of GLOF mitigation related activities. In the short term, the DHMS can prioritize key glaciers to be monitored, establish the techniques to be used for monitoring, and develop an implementation plan for varying time frames. The government should then invest in monitoring in a phased manner through a combination of techniques, ensuring a sufficient budget for sustaining this system. It should also gradually build capacity for assessing glacier change and the impact on major sectors such as hydropower and agriculture. In parallel, staff capacity and skill at DHMS's Snow and Glacier Division should also be strengthened. DGM staff with the needed skills can provide increased support to that division.

▶ *Develop plan for regional collaboration*

Bhutan has a long-standing history of collaboration with its neighbors, particularly India, on weather- and water-related information. This collaboration can be expanded, particularly given the DHMS's capacity constraints. Climate and weather patterns facing Bhutan are transboundary and are best monitored, understood, and predicted by taking a regional and global perspective. Moreover, there is a demand for Bhutan-specific data from regional centers and a demand for regional products and information that the DHMS can use. Collaboration has significant economies of scale for a young organization such as the DHMS. Areas for regional collaboration should be discussed and a plan could be developed through regional consultations. Partnership areas could include collaboration can include partnership on training, forecasting, EWSs for severe events such as cyclones, and so on. These consultations should start in the short term and continue in the medium and long term.

▶ *Strengthen sector-specific hydrometeorological and climate services*

Based on an assessment of sector-specific user needs, in the short term, decision support systems and climate services in one to two targeted priority sectors such as agriculture, hydropower, and infrastructure should be developed. This will involve extensive engagement with selected agencies, improved monitoring of data relevant to those sectors, design and installation of decision support systems, development of sector-specific products, and dissemination to stakeholders and communities.

Medium-term actions (three to five years)

▶ *Prepare a policy and legal framework for DHMS operations*

Development of a national hydromet legal and regulatory framework will help the DHMS clarify its goals and mandate, provide clarity on its roles and responsibilities, give it legal authority for its activities, and facilitate allocation of resources. It will also help the department demonstrate how it will meet its obligations under various international agreements and WMO conventions. Policies for data sharing should also be prepared. The policies and legal framework should be consistent with established guidelines and WMO's proposed recommendations for national hydrological and meteorological service operations.

▶ *Fill approved staff positions that are vacant*

In most DHMS divisions, staff capacity is limited and many of the approved positions are not filled. Out of 195 approved positions, 148 were in place when this report was prepared. The Meteorology Division has 36 staff positions, but only 16 of these were filled. In the medium term, all approved positions that are still vacant should be filled to keep pace with modernization of services and be adjusted on an ongoing basis.

▶ *Enhance the observation network based on assessments of user needs*

A further strengthening of the DHMS's observation network will likely be required based on assessment of user needs and priorities. Requirements for rainfall and water-level data collection may also be identified in the process of hydrological forecast development. These systems can be enhanced in the medium term, after the ongoing development partner–supported upgrading has been completed. There are numerous gaps in the DHMS's observation network, such as lack of upper air observations and access to weather radar data. These can be procured in the medium to long term. In enhancing the observation network, attention should be given not just to user needs but also to costs of operating and maintaining systems.

▶ *Establish DHMS regional offices*

While there are plans to set up regional offices, these have not yet been established. These offices will allow the DHMS office in Thimphu with O&M-related activities in field stations. They will also allow for community outreach in helping interpret weather and flood forecasts, and serve as focal points in collecting data on regional weather-related damage. Most important, the regional centers will manage communication between regional stakeholders and the DHMS. Regional DHMS offices should be fully equipped with adequate infrastructure, computer and communication facilities, electricity, and staff.

▶ *Strengthen national-level organizational aspects*

As a relatively new organization, the DHMS's should focus on strengthening capacity at national and subnational levels. In the short term, the focus should be on strengthening existing capacity and newer divisions such as the Snow and Glacier Division and also on not combining the weather and hydrological forecasting offices, although this was suggested in the approved DHMS organization structure. Over the long run, further analytical work and consultation can be done to assess the best institutional fit for the DHMS.

▶ *Increase the O&M budget to keep pace with modernization*

Over 80 percent of the DHMS's capital budget comes from development partners, including the government of India. The RGoB budget allocated for current costs for the DHMS are about USD550,000 per year. This is not enough if the

DHMS improves its observation systems, glacier monitoring, and service delivery. As the DHMS modernizes, the current budget will need to increase substantially to ensure that investments in information monitoring and forecasting are sustainable.

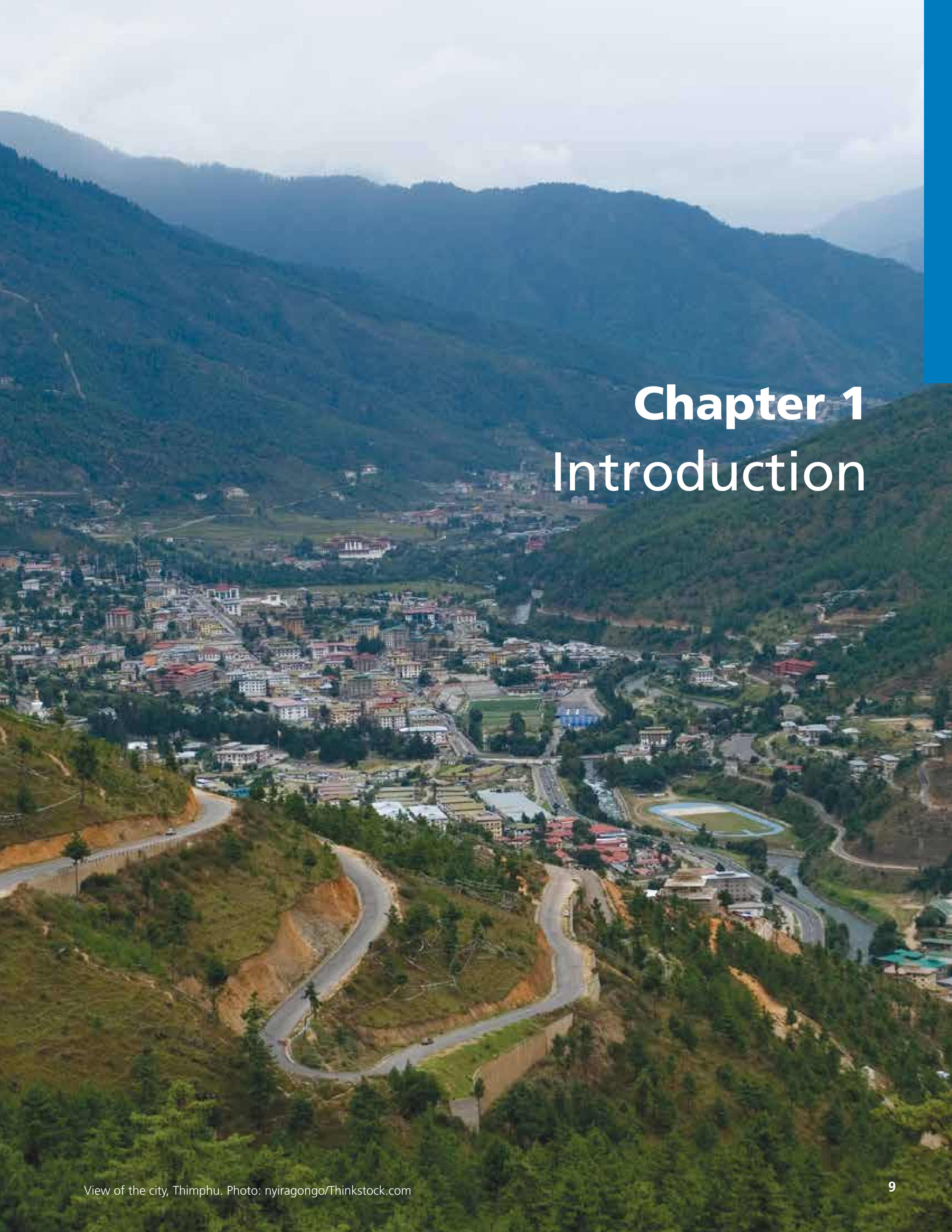
▶ ***Expand hydrometeorological and climate services in additional sectors***

Based on an assessment of sector-specific user needs and lessons from short term, development of climate services can be expanded to an additional one to two targeted priority sectors. As before, this would involve extensive engagement with selected agencies, improved monitoring of data relevant to those sectors, design and installation of decision support systems, development of sector-specific products, and dissemination to stakeholders and communities.

Long-term actions (five years and beyond)

As the DHMS strengthens its capacity and services in a phased manner, it should monitor and evaluate how well it is succeeding on meeting its targets and indicators and should adjust its planning and modernization process accordingly. Adequate staff training, budget, and an iterative planning process based on meeting user needs and learning by doing will be needed to ensure that its services are sustainable over the long term. Long-term modernization will involve learning from short- and medium-term investments and experiences, making adjustments, and ensuring sustainability as the DHMS improves and expands its services. ■

Chapter 1
Introduction



View of the city, Thimphu. Photo: nyiragongo/Thinkstock.com

Bhutan is a mountainous country situated in the southern slopes of the Himalayan range. It has a rugged topography that varies from over 7,500 meters in the north to less than 100 meters in the south. Bhutan's location, climate, and topography make it highly prone to a range of hydrometeorological hazards, including glacial lake outburst floods (GLOFs), flash floods, riverine floods, landslides, landslide dam outburst floods, cloudbursts, windstorms, and river erosion. Flooding is a recurrent phenomenon, especially during the monsoon season. Most of the infrastructure (urban areas, hydropower plants, roads, airports, etc.), fertile agricultural land, and over 70 percent of the settlements are located along the main drainage basins and are therefore at high risk due to flooding.

The country experienced GLOF events in 1957, 1960, 1968, and 1994. The 1994 event was the most devastating, causing enormous damage to property and loss of life in the Punakha-Wangdue valley. In the mid-mountains, landslides triggered by cloudbursts are frequent, and recent occurrences of landslide dam bursts have resulted in major destruction in low-lying areas, including the Thimphu valley. Bhutan is also at risk for tropical cyclones. In 2009, Cyclone Aila caused damages of approximately USD17 million due to destruction of farmland and infrastructure (RGoB 2013c). Flash floods are a recurrent phenomenon, with the eastern and southern regions being the most vulnerable. In 2012, these resulted in extensive damage to infrastructure in Gasa Dzongkhag (district) and downstream in Punakha and Wangdue Dzongkhags.

With climate change, the frequency and intensity of extreme events are expected to increase—with potentially devastating consequences for sectors dependent on water resources. In addition to rising mean temperatures and glacial retreat, there is evidence of the formation of glacial lakes. Of the 2,674 glacial lakes in Bhutan, 24 have been identified as potentially dangerous (Mool et al. 2001). Natural dam formation and dam bursts that could release huge volumes of water pose a major risk to hydropower plants, farmlands, and human settlements. The climate-sensitive agricultural sector provides livelihood and employment opportunities to approximately 56 percent of Bhutan's population (RGoB 2013f). Unpredictability in the timing of monsoons and prolonged drought could adversely affect agricultural production and has long-term implications for food security. Increasing variability in rainfall runoff could also contribute to increased downstream flooding. Poor and rural populations are typically the most vulnerable and disproportionately affected by such events.

Addressing hydrometeorological hazards and strengthening climate resilience are key priorities for the Royal Government of Bhutan (RGoB), and indicators relating to hydromet modernization and improved forecasting are included in Bhutan's 11th Five-Year Plan (RGoB 2013d). As part of its broader agenda to strengthen resilience to disasters and climate change, the RGoB is in the process of modernizing its hydromet observation network, improving weather and flood forecasting capacity, and strengthening community-based early warning systems (EWSs). It is also interested in strengthening provision of climate services to key economic sectors, such as agriculture, infrastructure, and hydropower. To support this process, the Ministry of Finance

Facing page: Punakha, Bhutan's longest suspension bridge over the Pho Chhu river. Photo: nandoart | Thinkstock.com requested technical assistance (TA) from the World Bank. The proposed TA responds to this request.

Objective

The main objective of this TA is to provide recommendations to the government, in particular to the Department of Hydromet Services (DHMS) under the Ministry of Economic Affairs (MoEA), on modernizing its hydrometeorological services, including disaster-related early warning systems. This is done through an assessment of the country's hydromet-related needs and priorities, assessment of its existing observation and forecasting systems, and organizational capacity assessment for service delivery.

Outputs from the TA are expected to help the DHMS strategize a path for modernization, strengthen its design capacity for improving its services, and identify actions needed to put in place institutional arrangements and the capacity to manage weather and climate extremes appropriately. At present, the DHMS does not have a national hydromet services policy but is in the process of preparing a strategic plan to guide its modernization and institutional reform process. The 11th Five-Year Plan's subchapter on strengthening hydromet services outlines the medium-term strategy for modernization and service improvement. The annual plan of implementation in concert with the annual budgeting process serves as the action plan staggered over the five-year period. This TA contributes to this process and proposes a road map of activities that can be taken to move the DHMS from a data-providing organization to a modern service delivery agency.

This TA is being prepared as part of the broader South Asia regional program on "Hydromet Modernization, Disaster Risk Management and Climate Resilience." This program has two pillars:

- National: Strengthening National Disaster and Climate Resilience
- Regional: Regional Cooperation to Strengthen Resilience

The Bhutan TA is one of the activities under the national pillar that aims to strengthen capacity at the national level as a necessary step toward regional dialogue and cooperation. The findings and recommendations will be shared at the subregional level and will contribute to improved learning and understanding of regional disaster preparedness and transboundary climate risks in South Asia.

Approach and methodology

As agreed with the DHMS, the TA is being prepared in two phases. Phase 1, which is the subject of this report, focuses on preparation of a road map for modernization of hydrometeorological services. Phase 2, which has been initiated, focuses on service and demand aspects of the use of weather services for disaster risk management and agricultural management.

Phase 1: Modernizing Weather, Water, and Climate Services: A Road Map for Bhutan

Analysis of key hydrometeorological risks and demand for climate services. As a first step, the study takes stock of the main water-related hazards and climate risks in Bhutan. It identifies key sectoral users of hydromet information and services and assesses their needs and priorities. The analysis is based on secondary literature and extensive consultations with stakeholders.

Assessment of monitoring and forecasting capacity. Next, the study assesses Bhutan's existing meteorological and hydrological monitoring network, its capacity for weather and flood forecasting, and glacier and GLOF monitoring as key elements of end-to-end early warning systems. The report identifies key gaps and areas for strengthening Bhutan's hydromet monitoring and forecasting system.

Analysis of institutional capacity. The study takes an in-depth analysis of the institutional and organizational capacity of the DHMS—the main agency mandated to manage the country's weather services and to work in coordination with other user sectors. Ways to strengthen capacity at the national and subnational levels are proposed.

Recommendations and road map. Based on the above analysis, the study proposes a road map for modernization.

Phase 2: Strengthening Disaster-Related Early Warning Systems and Climate Services

While Phase 1 focuses on understanding user needs and strengthening the supply side of hydromet services, Phase 2 (carried out as follow-up to this report), focuses on demand-side aspects.

Assessment of early warning systems at the river basin level. A detailed analysis of the current status and gaps in end-to-end warning systems for multihazard disaster risks is being undertaken with focus on the Manas river basin. This includes capacity for multihazard risk analysis, assessment of laws/regulations, assessment of basin-level institutions to respond to disasters and climate risks (including community-level response mechanisms and preparedness), and recommendations for strengthening end-to-end EWS for managing disaster risks.

Modernizing agrometeorological services. As part of Phase 2, a detailed assessment of how agromet services can be strengthened in Bhutan is also being initiated. An understanding of farmers' information needs is critical to strengthening agromet services. As such, the TA will help design and develop a survey tool for assessing farmers' climate-related information needs. The analysis will provide the basis for making recommendations on strengthening the capacity of the DHMS and the Ministry of Agriculture and Forest for delivering agromet services to farmers, along with farmers' resilience to weather and climate extremes.

It needs to be emphasized that disaster risk management and climate services are much broader than just improvements in monitoring, forecasting, and early warning systems. They include key activities such as risk identification, risk reduction, risk financing, and post-disaster reconstruction and response—all of which are outside the scope of this paper. The focus here, though limited, sheds light on a small but important aspect of disaster preparedness and climate service delivery. Other aspects will be discussed as a follow-up to this study.

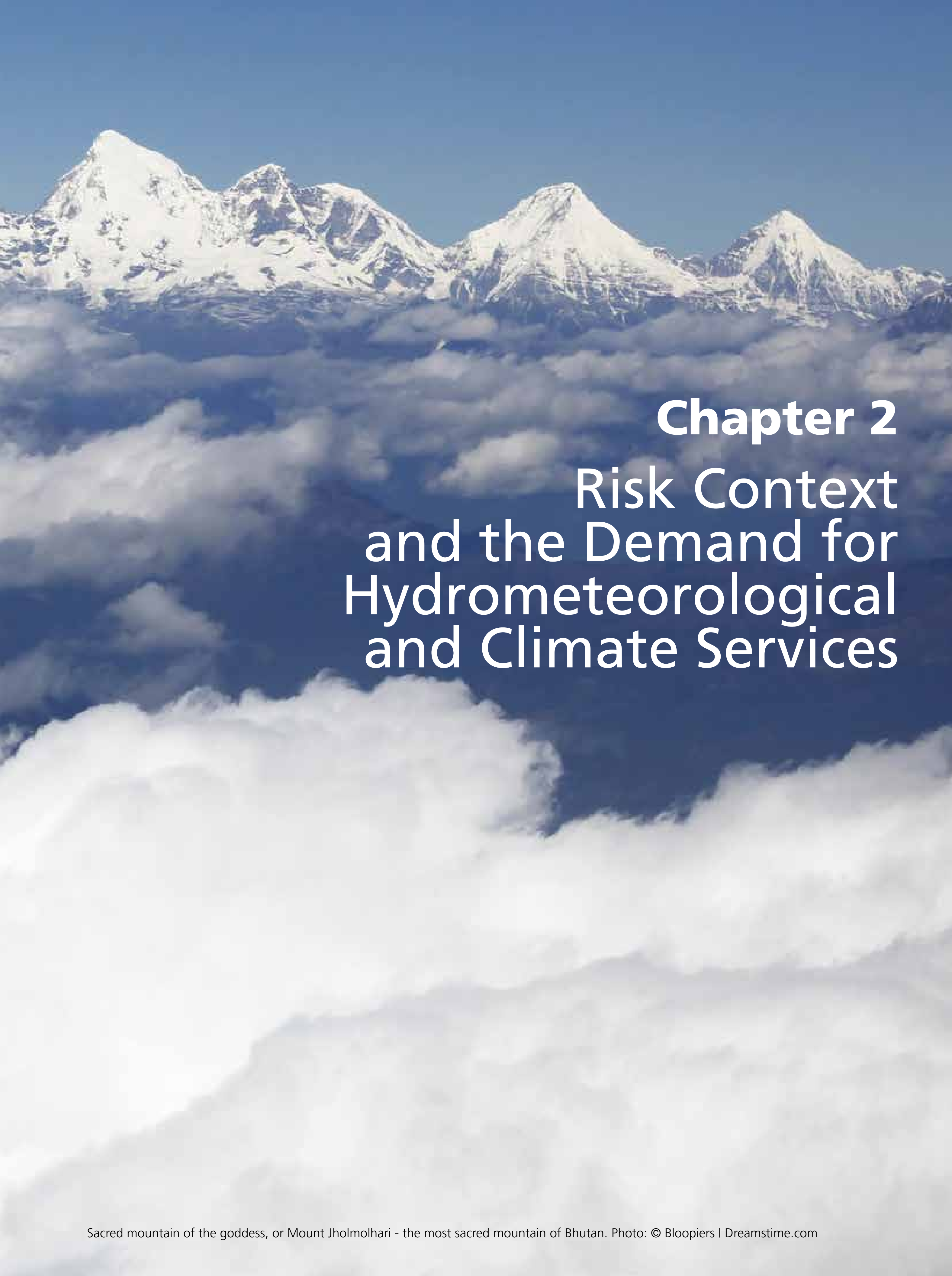
Process of preparation and consultations

The main counterpart agency in Bhutan for this TA is the DHMS. The TA is being prepared in close consultation with the department and with numerous other agencies, including the Department of Geology and Mines (under the MoEA), the Department of Disaster Management (under the MoHCA), the Gross National Happiness Commission, the Ministry of Agriculture and Forests, and the National Environment Commission (see Annex 1 for a list of stakeholders). During preparation of Phase 1, extensive consultations were undertaken with development partners, particularly the Japan International Cooperation Agency (JICA) and the United Nations Development Programme (UNDP), with the aim of donor coordination and partnership (see Annex 2 for an inventory of relevant donor-funded activities at the time of preparation of this report). A draft version of this report was presented at a stakeholder workshop on August 12, 2014, in Thimphu. Feedback and comments received have been incorporated in this study. Upon completion of both phases, a follow-up workshop will be organized to disseminate findings of the full TA.

Organization of the report

Following this Introduction:

- **Chapter 2** assesses the demand for hydromet and climate services from key sectoral users and summarizes their requirements for data, products, and services.
- **Chapter 3** provides an assessment of the existing hydrometeorological observation network and forecasting in Bhutan and areas of strengthening.
- **Chapter 4** focuses on an institutional and organizational analysis related to delivery of hydrometeorological services.
- **Chapter 5** proposes a road map for modernization and capacity building. ■



Chapter 2
Risk Context and the Demand for Hydrometeorological and Climate Services

Sacred mountain of the goddess, or Mount Jholmolhari - the most sacred mountain of Bhutan. Photo: © Bloopiers | Dreamstime.com

Photo: netopaek | Thinkstock.com

Understanding the key natural hazards facing Bhutan and the demand for hydrometeorological and climate services is an important starting point for planning and designing how the country's observation network and forecasting system should be upgraded and what services should be provided. The focus of this chapter is to address this issue. It starts with a brief overview of some of the key natural hazards and climate risks facing Bhutan. It then provides an assessment of the demand for hydromet services based on consultations with various user agencies and stakeholders.

River systems and weather

Situated in the southern slopes of the eastern Himalayas, Bhutan is landlocked, mountainous, and drained by the watershed of the mighty Brahmaputra river basin. Its total area is approximately 38,394 square kilometers, of which about 16,610 square kilometers is 3,000 meters above sea level. From east to the west, the main river systems are the Manas, Punatshang Chhu/Sunkosh, Wang Chhu/Raidak, and the Amo Chhu/Torsa basins (see Map 1). These transboundary river systems run north to south and into the Indian plains. In a small area to the north of Bhutan, rivers run south to north toward China.

The Manas river basin is a tributary of the Brahmaputra River and has a total length of approximately 376 kilometers, of which about two-thirds is in Bhutan. The basin is formed by four principal rivers: the Drangme Chhu, Mangde Chhu, Kuri Chhu, and Chamkhar Chhu. Topographically, the basin is divided into two distinct terrains: the mostly mountainous north and small alluvial plains to the south, bordering India.

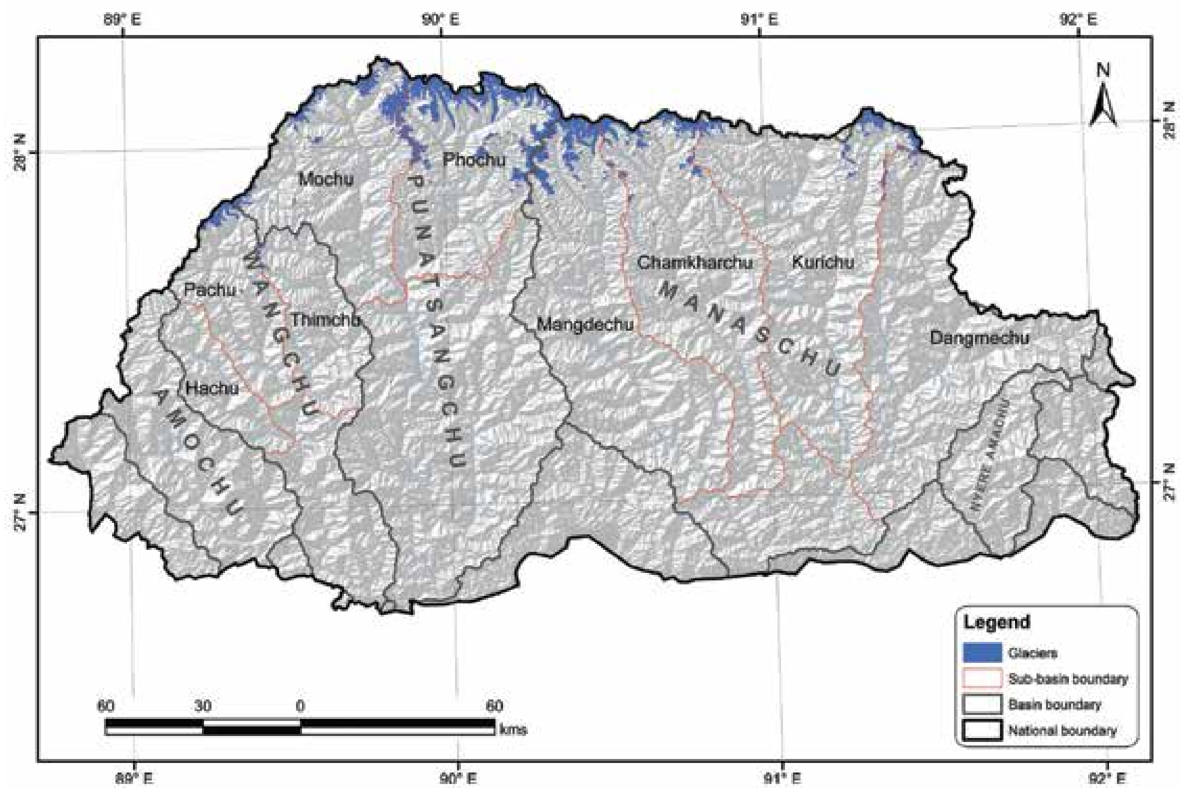
The Punatshang Chhu, in the center of Bhutan, is the second largest river basin and has two main tributaries: the Mo Chhu and Pho Chhu. To the west of the Punatshang Chhu is the Wang Chhu river, also called the Raidak. It is drained by different tributaries coming from the surrounding mountains, with the main tributaries being the Thim Chhu, Paro Chhu, and Haa Chhu. The Amo Chu basin (also known as the Torsa River) originates in Tibet, crosses Bhutan, and flows into the Brahmaputra river about 130 kilometers downstream from the Indo-Bhutan Border. All four of these river systems are fed mainly through permanent and seasonal snows, glacier melt, and monsoon precipitation.

Lakes above 3,000 meters elevation constitute the high-altitude wetlands of Bhutan and are an integral part of the river systems.[1] As discussed in a study done by the World Wildlife Fund (WWF 2011), they contribute to water storage and the hydrological cycle in the mountain ecosystem, regulate microclimates, and provide life support to farmers and pastoralists in downstream areas. They also provide crucial water resources for ongoing and planned hydropower projects commissioned by the government. Based on a recent inventory using remote sensing techniques, there are 3,027 high altitude lakes in Bhutan, mostly in northern and central parts of the country (WWF 2011). These include suprasnow lakes, supraglacial lakes, glacial lakes, lakes in alpine meadows, and marshes. Most suprasnow lakes are found in the Mangde Chhu watershed, and most supraglacial lakes are found in the Punatshang Chhu basin.

Bhutan is characterized by considerable variability of precipitation both spatially and temporally. In general, there is more precipitation in the southern belt of Bhutan, with highest recorded rainfall in Samtse, Gelephu, Phuentsholing, and Samdrupjongkhar, all in southern Bhutan. The altitude range of 100–2,000 meters receives about 2,000 mm of total annual rainfall, the area between 2,000 and 4,000 meters

[1] See also: http://awsassets.panda.org/downloads/haw_report_1.pdf

Map 1 Main river basins of Bhutan

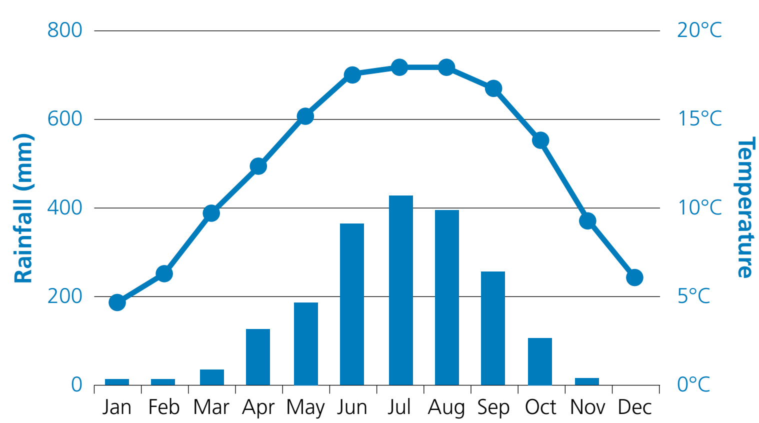


Source: Bajracharya, Maharjan, and Shrestha 2014.

receives about 1,000 mm total annual rainfall, and the northern region above 4,000 meters receives about 400 mm of precipitation annually in the form of snow.

As Figure 1 shows, the temperature and precipitation reach their maximum between June and mid-September, with an average of around 400 mm of precipitation per month and a temperature of 18 degrees Celsius during this period. This monsoon period is usually associated with severe weather events that result in floods, flash floods, and landslides. The months of November to March are typically characterized by little rainfall, which can generate droughts and fires—with devastating impact on agriculture, forests, and rural communities.

Figure 1 Average monthly temperature and rainfall for Bhutan, 1960-90



Source: World Bank, Climate Change Knowledge portal.

Natural disasters and climate-related risks

Bhutan is one of the most disaster-prone countries in the South Asia region. The country is exposed to multiple hazards—most prominently floods, landslides, windstorms, forest fires, and glacial lake outburst floods. The country is also located in the seismic zone V of high earthquake occurrence. It ranks fourth highest in the South Asia region in terms of relative exposure to flood risks, at 1.7 percent of the total population at risk.[2] The socioeconomic repercussions from these events can be high, particularly for poor and marginal communities. Documentation of natural hazard events in Bhutan is undertaken by the Department of Disaster Management (DDM)—but not very systematically or comprehensively due to capacity issues, and it can be strengthened. Based on available information, Table 1 provides a summary of the main hydromet and weather-related hazard events since 2002.

[2] Comprehensive documentation of weather-related hazards in Bhutan is not available. Surveys on those affected by adverse weather-related events such as floods and wind damage have been generally qualitative. Table 1 indicates damages from forest fires, droughts, windstorms, flash floods, and landslides, though there are known instances of riverine flooding that are not documented. Weather-related damages from some events are documented, though unaccounted for in other events. The case of Cyclone Aila in 2009 seems to be an exception, in which damage costs were estimated by the government.

Table 1 **Main hydrometeorological hazard events since 2002**

Year	Climate hazard event	Reported damages	Affected areas
2002	Forest fire	25 houses destroyed by fire leaving 26 families homeless	Haa Dzongkhag
2004	Flash floods	9 lives; damage to 162 houses, 664 acres of farmland, and 39 irrigation channels; loss of 350 million tons of maize, 126 million tons of paddies, and 2,000 citrus trees Transportation remained disrupted for days in the affected Dzongkhags	Six eastern Dzongkhags (Districts)
2005	Forest fire	5 houses destroyed by fire	Trashiyangtse Dzongkhag
2005	Forest Fire	7 shops destroyed by fire	Bumthang Dzongkhag
2005–06	Drought	Damages unknown	Not available
2006	Forest fire	2 deaths; 5 houses and thousands of acres of forests destroyed by fire	Trashigang Dzongkhag
2008	Windstorm	Damages to 249 households, 8 school buildings, religious structures, and 1 government office	Trashigang Dzongkhag
2008	Windstorm	Damages to more than 80 acres of maize crops affecting 96 households	Mongar Dzongkhag
2009	Windstorm	Damages to 114 households	Trashigang Dzongkhag
2009	Cyclone Aila	12 deaths; damages to farmland, infrastructure, etc., amounting to USD17 million	Across the country
2010	Flash floods and landslides	Damages to 2,000 acres of farmland and irrigation channels affecting nearly 4,800 households; 40 acres of pastureland and 1,000 livestock destroyed	20 (all) Dzongkhags
2010	Windstorm	Damages to more than 5,000 acres of farmland affecting 432 households	Across the country
2011	Windstorm	Damages to 2,424 houses, 81 religious structures, 57 schools, 21 health centers, and 13 government buildings	16 Dzongkhags
2011	Flash floods and landslides	Loss of property for 200 households	Industrial estates and residential areas in Phuentsholing and Pasakha
2012	Windstorm	Damages to 143 houses, 1 religious structure, and 1 school	4 Dzongkhags

As shown in Table 2 and Figure 2 (including only the most extreme hazards), floods with more than 222 casualties account for 84 percent of total deaths related to natural disasters in Bhutan, even though they affected only 2 percent of the total population. Storms affect about 75 percent of the population but have historically resulted in about eight times fewer casualties. Floods and cyclones /storms account for about 95 percent of total deaths related to natural disasters; the remaining 5 percent resulting from earthquakes.[3]

Changes in monsoon rain patterns (especially intensified rainfall in short intervals), coupled with the geologically young and unstable Himalayan terrain, have triggered a number of flash floods and landslides in the past decades. Southern and eastern Bhutan, characterized by deeply eroded, steep, and closely spaced gullies, are particularly vulnerable to these disasters. Combinations of flash flood and landslide events in 2003, 2004, 2009, and 2010 claimed a number of human lives, houses, livelihood assets, infrastructure, and scarce farmlands. In particular, the excessive rain brought by Cyclone Aila in May 2009 caused the worst floods across the country in 40 years. During this time, the water flow of the Punatsang Chhu River reached record levels—higher even than levels recorded during the 1994 GLOF event.

In addition to damages to rural livelihood assets, floods and landslides often sever key road networks of the country. There are immense economic impacts on the Bhutanese society when roads are disrupted by floods or landslides because of limited or no alternative detour options in the mountainous terrain. Expanding the national road network and safeguarding it from disruption is considered one of the highest priorities in the 11th Five-Year Plan because the network provides essential market linkages between the rural and urban sectors. Landslide management is important not only to reduce human and material losses but also to sustain the national economy and maintain connectivity between the different districts of Bhutan.

Slopes are highly susceptible to landslides, particularly in the eastern and southern foothills belt. Landslides often create landslide dams. Steep, narrow, and rugged mountains require only a small volume of materials to block a gully, resulting in natural dams. In 2003, a landslide event along the Tsatichhu River created a natural dam 140 meters deep. This dam is located upstream of the Kurichu Hydro Power Plant. If it breaches, the resulting flood will inflict significant damages to the power plant, an

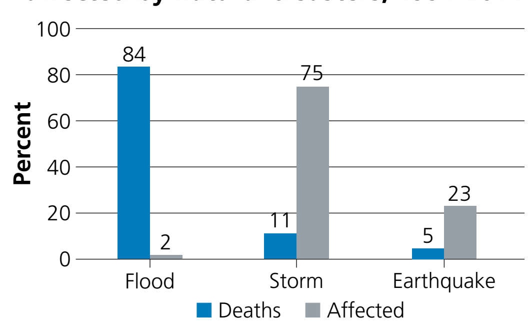
[3] Epidemic outbreaks are not recorded as natural disasters, even though they are closely linked to weather conditions.

Table 2 Number of deaths and individuals affected by natural disasters, 1994-2011

	Deaths	Affected
Flood	222	1,600
Storm	29	65,000
Earthquake	12	20,028
Total	**304**	**87,369**

Source: EM-DAT: The OFDA/CRED International Disaster database.

Figure 2 Number of deaths and people affected by natural disasters, 1994-2011



Source: EM-DAT: The OFDA/CRED International Disaster database.

important revenue earner for the country. If it breaches, the resulting flood will inflict significant damages to the power plant, an important revenue earner for the country.

Erratic monsoonal activities are also increasingly causing extreme windstorms during the spring and multiplying the risk of forest fires during the drier winter seasons. Windstorms in 2008, 2010, 2011, and 2012 caused severe damage to infrastructure and agricultural production. During a medium-sized windstorm in December 2013, reportedly some 40–50 households were affected in Paro and Haa. Between 1999 and 2008, some 526 incidents of forest fire were recorded, affecting over 70,000 hectares of forest areas (approximately 1.8 percent of the country) and causing devastating damage to residential and farm areas. Projected reductions in winter rains in many districts under a changing climate, especially in the next two to three decades, are likely to compound the risk of forest fires. The slow onset of disasters such as droughts and local extreme rainfall are less likely to make news headlines and are therefore less well recorded, but the impacts are often equally detrimental to marginal farmers, who have limited means to mitigate the impacts. For example, the average cereal crop yield peaked in 2004 at 1,256.3 kilograms per acre and has declined by about 20–30 percent in subsequent years. With increasing incidence of extreme events, hard-won development gains can be easily reversed.

The risk of glacial lake outburst floods is a major concern in Bhutan. In October 1994, there was a major GLOF event in the Luggye Tsho glacial lake. At that time, there was little public awareness of the potential dangers from GLOFs. However, since the event, which caused extensive damage along the Punakha-Wangdue valley, there has been increasing awareness of the potential risks from glacier retreat and of GLOFs (National Report on Bhutan for World Conference on Disaster Reduction 2005). Using satellite imagery, the International Centre for Integrated Mountain Development (ICIMOD) has carried out decadal inventories of glaciers and glacier lakes in the Himalayas, including in the Bhutan Himalayas. The 2001 inventory identified 677 glaciers (with a total area of approximately 1,317 sq. km.) and 2,674 glacial lakes, of which 24 were classified as potentially dangerous (see Table 3 and Map 2) (Mool et al. 2001). A repeat inventory in 2010 identified 885 glaciers with a total area of 642 (+/- 16.1) sq. km. (Ives, Shreshtha, and Mool 2010; Bajracharya, Maharjan, and Shrestha 2014). The 2010 inventory shows that since the 1980s there has been a general trend of increase in the number of glaciers and decrease in glacier area. Accelerated melting of glaciers, which act as natural water retention and dispensing mechanisms, can disrupt the hydrological regime of perennial river systems and have a profound effect on water availability and productivity of water-dependent sectors such as agriculture and hydropower. Changes in the cryosphere, thawing of snow from higher temperatures, and variability of precipitation can further trigger glacier outburst floods (Rupper et al. 2012).

Table 3 Glaciers, glacial lakes, and lakes identified as potentially dangerous, 2001

	Glaciers			Glacial lakes		
	Number	Area (sq. km)	Ice reserves	Number	Area (sq. km)	Potentially dangerous
Amo Chu	0	0	0.00	71	1.83	0
Wang Chu	36	49	3.55	221	6.47	0
Puna Tsang Chu	272	503	43.27	980	35.08	13
Manas Chu	310	377	28.77	1383	55.51	11
Nyere Ama Chu	0	0	0.00	9	.07	0
Northern Basins	59	388	51.72	10	7.81	0
Total	**677**	**1317**	**127.31**	**2674**	**106.77**	**24**

Source: Mool et al. 2001.

As the Intergovernmental Panel on Climate Change Fifth Assessment Report highlights, increases in temperature and precipitation are likely to exacerbate the frequency and intensity of extreme events in South Asia (IPCC 2014). In Bhutan, this could lead to an increase in the incidence of flooding, landslides, and GLOFs, potentially causing severe economic damage and adversely affecting lives and livelihoods. Changes in the timing and duration of monsoons could amplify the socioeconomic challenges for Bhutanese society, especially in rural areas where farmers mainly rely on rain-fed agriculture. The rural poor are the most vulnerable as they are least equipped to adapt to slow-onset changes related to climate variability.

Many of the key economic sectors in Bhutan are highly dependent on weather and climate hazards. Three sectors account for 45.33 percent of Bhutan's gross domestic product (GDP): agriculture, livestock, and forestry (16.99 percent);

Map 2 Glacier lakes of Bhutan considered potentially dangerous

Source: ICIMOD (2001)

electricity and water supply (12.37 percent); and construction (15.97 percent) (RGoB 2013b). For instance, hydropower is a key sector in terms of both its contribution to the GDP and as a major source of foreign exchange generator, with most of the electricity exported to India. Of the total electricity consumed in Bhutan, 98.9 percent comes from hydropower. The hydroelectric sector is highly exposed to floods and climatic risks, which could potentially have huge negative repercussions on this sector and the GDP.

Another major contributor to the GDP is the agriculture sector. According to the most recent National Labor Force Survey, agriculture provides employment to about 56 percent of the labor force (RGoB 2013f). It is primarily subsistence farming, and the sector constitutes the majority of income, employment, and food security for most Bhutanese, particularly the poorest. Agriculture is also highly weather and climate vulnerable through changes in temperature, climate variability, and changes related to the timing and intensity of monsoons. Development of agrometeorological services for different agroecological zones for farmers to help plan and adjust their farming practices to changing weather patterns can significantly facilitate adaptation efforts in the agricultural sector. Detailed quantitative estimates of the economic costs of natural disasters and climate risks for Bhutan's GDP and the potential benefits from modernization of hydromet and climate services are so far not available and should be prepared.[4]

[4] For a qualitative assessment, see "Strengthening Hydro-Meteorological Services for Bhutan," undertaken with support from the Finnish Meteorological Institute. One of the study's main objectives is to provide a qualitative overview of improved hydrometeorological services and feedback on end-user needs and to provide a financial estimate of benefits obtained for the Bhutanese economy as a result of strengthening hydromet services. The study does not provide quantitative estimates of the impact of natural disasters to Bhutan's gross domestic product.

Demand for hydromet information and services

The Department of Hydromet Services can provide a range of information to sector agencies and users, including data, products delivered by the international community (such as monsoon forecasts, climate predictions), derived products (such as road weather forecasts, fire weather outlooks, or any special weather statements issued and entirely developed by the DHMS), and services such as feasibility studies and technical assistance. To better understand the demand and needs of user agencies for hydromet data and services, extensive consultations were undertaken during the preparation of this study. The rest of this chapter summarizes the main information needs and priorities of key sectors and underscores the urgency for modernizing hydromet services in Bhutan.

Department of Civil Aviation (DCA)

The DCA is part of the Ministry of Information and Communications. Formed in 1986, it is responsible for regulating aviation safety, airport regulation, and providing air navigation services. Its main office is at the Paro International Airport—the only international airport in the country. DCA also supports flight activities at regional airports in Bumthang (under operation), Yonphula (under up- gradation), and Gelephu (construction completed but yet to commence operation). Within the DCA is the Aviation Meteorology Section (AMS), which is part of the Air Navigation Section. Pilots rely on AMS observations for safe landings and departures. AMS is responsible for collecting meteorological information at the airport, such as wind speed and direction. It also passes on surface observations to the pilots of arriving and departing aircraft. AMS has established two automatic weather observing systems (AWOS), which are generally equipped with the following sensors: barometric pressure, temperature and relative humidity, visibility, cloud height, and precipitation accumulation. However, the

AWOS stations in service at Paro International Airport lack cloud height and visibility sensors. Air navigation is largely left to the pilots, who operate under visual flight rules.[5] Despite the meteorological observations collected at Paro International Airport, pilots do not have critical information regarding turbulence, which can make landings and takeoffs difficult, if not highly dangerous.

Discussions with DCA officials highlighted significant demand for improved hydromet data and products. Several technologies can help detect air turbulence and ensure safe flight conditions. These include a ceilometer, which can detect cloud base above the airport and provide pilots with information to determine visibility during aircraft approach and departure. Another is a windshear turbulence warning system, which provides alerts for terrain and convective-induced wind shear. This system can provide real-time wind shear and turbulence alerts to pilots and air traffic controller staff and up to 12-hour forecasts of terminal area turbulence to aviation meteorologists. There is also significant demand for weather forecasts that affect flight operations (see Table 4).

Department of Agriculture (DoA)

Weather, water, and climate play a prominent role in agricultural production. From planting through irrigating to crop harvesting, farmers and pastoralists need weather information to optimize crop production. Moreover, pest infestations and crop diseases are often associated with changes in weather. Flash floods, hailstorms, and extreme weather events cause considerable damage to crops, and during harvest season this can result in the loss of an entire crop. The forecasting and detection of these events, development of weather bulletins, and targeted agro advisory services can help DoA inform extension workers and farmers and support decision making at the farm level. Changing weather patterns and climate variability are expected to cause changes in the growing season. This will need to be recorded and tracked so that DoA can develop information packages and inform farmers about changes in crop planting, fertilizing, and harvesting times and can promote increased resilience.

Table 4 Department of Civil Aviation requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Temperature
	Relative humidity
	Wind speed
	Wind direction
	Wind shear
	Ceilometer
	Products
Processed data or information collected from different sources	Wind shear advisory
	Satellite pictures
	Short-range forecast
	Medium-range forecast
	Severe weather warning
	Wind and wind shear forecast

Officials at DoA expressed high demand for agromet data and climate services that can help farmers from different agro climatic zones make decisions related to planting, watering, pest and disease treatment, and harvesting (see Table 5). The current network is sparse and unable to capture the numerous agro climate zones. DoA requires a denser meteorological monitoring network to monitor the country's microclimates and has therefore directly funded the rehabilitation of numerous climate stations. There is also strong demand for medium and longer-term forecasts that would allow the agriculture community to plan crop treatments to prevent losses from pests and

[5] This refers to a set of regulations under which the pilot operates an aircraft in weather conditions generally clear enough to allow the pilot to see where the aircraft is going. The pilot must be able to operate the aircraft with visual reference to the ground and by visually avoiding obstructions and other aircraft.

disease. Development of agromet services would involve collaboration between and capacity strengthening of both the Agromet Section under the Meteorology Division at the DHMS and relevant departments within the Ministry of Agriculture.

Table 5 Department of Agriculture requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Climate data
	Synoptic data
	Products
Processed data and advisory	Weather forecast
	Flood and drought forecasts
	Flash flood forecast
	Climate forecast
	Frost advisory
	Agro-advisory bulletins with information specific to different crops in different agro-ecological zones

Department of Hydropower and Power Systems (DHPS)

As mentioned, hydropower is a key economic sector in Bhutan. Currently, the existing hydropower schemes are mainly run-of-the-river and do not have the capacity to store or manage water much beyond generation scheduling. However, future hydropower projects in Bhutan are expected to have the ability to store and manage water. This will be useful in managing flood flows, but it will also create a need for real-time hydromet data so that reservoir operations can be performed in a thoughtful manner. This will result in an increased dependence on real-time hydromet data.

The DHPS relies heavily on the stations operated by the DHMS because it does not operate any of its own hydromet stations. However, data are often found to be incomplete. For instance, daily observations of rainfall and climate were not recorded on some weekends or when the observer is not available. Also, data quality is often not reliable, which directly affects the quality of the design studies and the operation of hydropower generation schemes.

Consultations highlighted the need for accurate hydrometeorological data, particularly rainfall, river discharge, and climate data, to help develop the design of hydropower schemes. They expressed need for data from hydromet stations spread more consistently through the country, particularly at higher elevations.[6] A higher density of stations would be desirable and would lead to a better estimate of basin runoff, which is ultimately used in the design and efficacy of a given hydropower generation scheme. DHPS expressed interest in numerous hydromet products and special analysis of data on an as-needed basis (see Table 6). It also expressed willingness to pay the DHMS for the timely delivery of these products and special analysis. Examples of required analysis include probable maximum precipitation, probable maximum flood, depth duration frequency, and depth duration curve. DHPS is interested in the DHMS developing more thorough quality assurance/ quality control, which will yield more highly valued data.

Ministry of Works and Human Settlement (MoWHS)

The MoWHS is another major user of DHMS data, and several departments within the ministry expressed the need for DHMS services. The Department of Engineering Services (DES) has an interest in water supply and sanitation and flood management. The DHMS hydrological records would be of great value to DES. DES

[6] As discussed in Chapter 3, hydromet stations, especially rainfall stations, are often placed in the lower-lying valley, with few stations located in the higher rainfall accumulation zones in the higher mountains.

Table 6 Department of Hydropower and Power Systems requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Rainfall
	Temperature
	Suspended sediment
	Wind speed
	Wind direction
	Data
	Products
Processed data and advisory	Quantitative precipitation forecast
	Runoff forecast
	Temperature forecast
	Flood forecast
	Wind forecast
	Services
Site-specific services requiring further calculation and analysis by DHMS	Probable maximum precipitation (PMP)
	Probable maximum flood (PMF)
	Other information for feasibility studies

must consider the effects of hydrology and meteorology within the Flood Management Division and the Water Supply and Sanitation Division. Systematic rainfall and surface water data can contribute to improved design and management of Bhutan's developing road system.

The Department of Roads (DoR), also under the MoWHS, is involved in construction of roads and bridges, the management of which will benefit from better quality hydromet data. DoR has developed a Road Information Center, where road closures are reported to the public. Real-time hydromet information would be used to enhance the DoR road information portal by considering weather conditions that would affect road conditions.

DoR expressed the need for high-quality historical rainfall and runoff data to design road features such as culvert capacity and bridge heights (see Table 7). Water level data are important for bridge construction, so bridge designs can accommodate historically high water levels. DoR also expressed demand for accurate medium-range forecasts for the maintenance and the construction of bridges. These forecasts should include rainfall, quantity of rainfall, runoff, and the temperature and relative humidity. The rainfall forecasts and intensity forecasts could also greatly aid DoR in developing a broader understanding of the risk of landslides. These forecasts should be narrow enough in scope to provide rain quantity and rain rates by region.

The Department of Human Settlement, also under the same ministry, is mandated to identify potential growth centers and carry out detailed topographic surveys of specific areas and regions for the preparation of settlement development plans, so it would also greatly benefit from data on rainfall, GLOF and other high-risk areas, and flash floods. This would help the department carry out flood analysis and feasibility studies related to settlement planning. Other parameters such as temperature, wind speed, and direction would also help the department to plan sustainable energy-efficient settlements, contributing to the green growth of the country.

Department of Geology and Mines (DGM)

The DGM under the Ministry of Economic Affairs was established in April 1981. Prior to this, most of the geologic mapping was undertaken by the Geological Survey of India, which, by mutual agreement, ceased involvement in Bhutan in 2002. The DGM has four divisions: Geological Survey of Bhutan (GSB), Glaciology, Seismology, and Mining. The GSB and the Glaciology Division are significant users of hydromet data. The GSB is responsible for monitoring geohazards induced by climate change, such as landslides. The Glaciology Division is tasked with monitoring glacial lakes and remedial measures for GLOF risk reduction, mainly from the geological and geomorphology perspective.

Table 7 Ministry of Works and Human Settlement requirements for hydromet information

Data	Parameters
Data collected directly by DHMS	Rainfall
	Water level
	Discharge
	Temperature
	Wind speed
	Wind direction
	Products
Processed data and advisory	Quantitative precipitation forecast
	Winter storm forecast
	Travel advisory
	Travel warning
	Temperature forecast
	Wind forecast
	Services
Site-specific services requiring further calculation and analysis by DHMS	Depth Duration Frequency
	Probable maximum flood
	Probable maximum precipitation
	Other hydrological and hydraulic Data required for design of bridges and highways

Much of DGM's work is structural, which requires knowledge of climate change and the rate of change so that structural mitigation measures can be effectively and efficiently designed.[7]

Discussions with DGM indicate a high demand for accurate rainfall data, such as rainfall totals, intensity, and duration (see Table 8). To acquire this type of data, rainfall measurements will need to become automated and set to collect data at very short intervals (every five minutes, or based on the event). DGM expressed interest in a subnetwork of stations adjacent to landslide areas because rainfall and intensity of rainfall can vary greatly over very short distances. This would be very useful in designing structural mitigation measures.

DGM would benefit from a real-time automatic network operated by the DHMS as platforms to mount seismic sensors. In this way, the network infrastructure can be shared, reducing the overall implementation costs if each network were implemented separately. There are also opportunities for services related to climate reports and special analysis of rainfall data to better determine the rainfall characteristics at various landslide areas.

Table 8 Department of Geology and Mines requirements for hydromet information

Data	Parameters
Data directly collected and analyzed by DHMS	Rainfall, intensity, and duration
	Services
Site-specific services requiring further calculation and analysis	Depth duration frequency, depth duration curves
	Other studies of rainfall over a smaller area

Department of Disaster Management

As discussed earlier, Bhutan is highly vulnerable to various hydrometeorological hazards. The DDM's main mandate is disaster preparedness and post-disaster response. Consultations with DDM showed that it will benefit immensely from a broad range of meteorological data, information, and products (see Table 9). Of prime importance are accurate forecasts of disasters, including heavy rain, flash floods, landslides, and cyclones, with sufficient lead time. These forecasts are key elements of end-to-end early warning systems, which at present are very weak in Bhutan. With donor support, early warning systems for GLOF have been set up in some river basins. DDM is a key user of the GLOF early warning system operated by the DHMS. Once a GLOF event is detected,

[7] The Department of Geology and Mines also receives funds through the National Adaptation Programme of Action 2 project. These funds are designated for the formulation of a historical landslide database and structural mitigation in landslide zones to prevent future landslides.

DDM is notified to help prepare and respond to the disaster. Accurate extended-range weather forecasts that provide improved lead time would also be highly valuable and help communities prepare for hazards and climate risks.

Table 9 Department of Disaster Management requirements for hydromet information

Data	Products & Services
Processed data and advisory requiring analysis by DHMS	Wind advisory
	Flood advisory
	Flood forecast
	Flash flood forecast
	Fire weather outlook
	Red flag forecast
	GLOF Early Warning
	Cyclone forecasts
	Forecasts for thunderstorms and severe weather

Road Safety and Transport Authority (RSTA)

RSTA provides all motor vehicle related regulatory and documentation services, such as vehicle registration, driver licensing, road worthiness testing, vehicle emissions, passenger transport service regulation, traffic regulations, and road safety. It uses general weather forecasts to help manage transport. Severe weather, rainfall, and snowfall affect road conditions. Currently, RSTA receives its information from radio broadcasts and would benefit from improved data and services from the DHMS (see Table 10).

Table 10 Road Safety and Transport Authority requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Temperature
	Rainfall
	Road weather
	Products
Products and advisory requiring analysis by DHMS	Snow advisory
	Storm warning
	Weather forecasts

Department of Forests and Park Services (DFPS)

The Watershed Management Division (WMD) within DFPS has the primary responsibility for managing Bhutan's watersheds. WMD is a consumer of stream discharge, stream sediment, and climate data. Wind direction and other climate variables are used in categorizing watersheds. WMD is in need of high temporal resolution rainfall data of 15 minutes and shorter (see Table 11). These data would be helpful in understanding the impact of high-intensity rainfall on Bhutan's watersheds. There are currently no records of short-term high-intensity rainfall to the extent required by WMD. Thus, the link between rainfall events and the damage done to the watershed is largely unquantified and unknown. This is expected to become more of a problem with climate change.

Table 11 Department of Forests and Parks requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Rainfall
	Climate
	Products
Products and advisory requiring analysis by DHMS	Climate forecasts
	Services
Site-specific information requiring processing and analysis of data by DHMS	Depth Duration Frequency analysis and curves

National Environment Commission (NEC)

The NEC is a policy and advisory agency that regulates activities associated with the environment. It is a multisectoral body providing policy decision support to the government, and it coordinates policy implementation relating to the protection, conservation, and improvement of the environment. It is also the national coordinating body for monitoring implementation of the National Adaptation Programme of Action (NAPA). Given its role on environment and climate change, NEC relies heavily on DHMS data and analysis for making policies relating to climate change adaption and mitigation relevant for Bhutan. Like other stakeholders, the NEC expressed a strong need for "value added" products in addition to data (see Table 12).

Table 12 National Environment Commission requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Temperature
	Relative humidity
	Wind speed
	Wind direction
	Rainfall
	Solar radiation
	Air quality
	Water quality
	Water discharge
	Products
Products and advisory requiring processing and analysis by DHMS	Climate summary by station
	Climate summary by region
	Services
Sector-specific services requiring analysis by DHMS	Climate analysis by sector

Ministry of Health (MoH)

One of main priorities for the MoH, which is tasked with delivery of health services, is water quality data, particularly in smaller streams for drinking water supply. The Public Health Engineering Division expressed the need for climate data and seasonal forecasting to help properly analyze the needs and requirements for safe and cost-effective drinking water systems (see Table 13). Weather-related data analysis of climate trends is also needed to monitor and track the incidence of various vector-borne diseases.

Table 13 Ministry of Health requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Temperature
	Relative humidity
	Wind speed
	Wind direction
	Rainfall
	Solar radiation
	Air quality
	Water quality
	Water discharge
	Products
Products and advisory requiring processing and analysis by DHMS	Climate summaries
	Seasonal weather forecasts

Department of Renewable Energy (DRE)

The DRE was established in 2011 with the mandate to serve as the central coordination agency and focal point related to renewable energy development. The vision of DRE is to provide diverse forms of green and renewable energy solutions and energy-efficient options aimed at enhancing energy security and sustainable development. The Solar Energy Section, Wind Energy Section, and Small Hydro Development Section require high-quality hydromet data to carry out designs on developing sustainable power generation. The DHMS could have a great deal of work through DRE in the planning of alternative energy production systems. Required data include high-quality climate data and products and services related to the processing of climate data (see Table 14).

Table 14 Department of Renewable Energy requirements for hydromet information

Data	Parameters
Data directly collected by DHMS	Temperature
	Relative humidity
	Wind speed
	Wind direction
	Solar radiation
	Products
Products and advisory requiring processing and analysis by DHMS	Climate summaries
	Wind rose

Tourism Council of Bhutan

The Tourism Council of Bhutan is mandated with tourism planning and policy, including formulating and implementing a national tourism policy and strategy in consultation with relevant stakeholders. It is responsible for regulation and monitoring—including developing and implementing relevant guidelines, developing regulatory measures on the sustainable use of natural and cultural resources, and ensuring compliance—and for coordination to establish a safe environment for visitors, facilitate mobilization of resources and private sector investment, and promote tourism as an important national priority.

Currently, the tourism industry provides weather information based on historical data that are very general, and it only gives an idea of the range of temperature and whether it is rainy or not during the respective season. Without proper data on weather forecast, tour operators face challenges in planning activities, especially trekking and camping. If weather forecast including rain forecast is made available, this would greatly benefit the tourism industry in day-to-day operations. It would help plan touristic activities that would directly have a huge impact on the experience of the visitors. Having good data on hydromet would also benefit the aviation sector, and this indirectly has a major impact on tourism since one of the main factors facilitating tourism is accessibility. The information needed by the Tourism Council mainly includes weather-related information such as temperature, relative humidity, snowfall, and rainfall, along with forecasts and warnings about different hazardous and extreme events such as floods and landslides.

Summary

This chapter confirms that there are a wide range of users of hydromet information and services in Bhutan and that there is a strong demand for hydromet data and services (see Table 15). Understanding the needs and priorities of key user sectors and designing services in response to them will be critical to any modernization of DHMS services. ■

Table 15 Summary of demand for hydrometeorological services

	Product or Service of Interest to Particular Sector									
DHMS Product/Service	Hydropower	Agriculture	Disaster management	Transport	Health	Environment	Watershed management	Tourism	Flood mitigation	Construction industry
Improvement of weather forecasting capacity	✓	✓	✓	✓	✓			✓		✓
Improvement of flood forecasting, including flash flood early warning systems	✓	✓	✓				✓		✓	
Development of Early Warning Systems for prevention of landslides	✓	✓	✓	✓			✓		✓	
Monitoring and forecasting of forest fires	✓	✓	✓			✓	✓			
Quality hydromet data and basic products available to stakeholders	✓	✓			✓	✓	✓		✓	
Seasonal and monthly climate predictions	✓	✓	✓		✓	✓		✓	✓	
Remote sensing products for monitoring and forecasting hazards	✓	✓	✓			✓	✓			
More hydromet data in areas of high altitude and small rivers	✓	✓	✓				✓		✓	
Mapping of flood and landslide prone areas	✓	✓	✓	✓		✓	✓	✓	✓	✓
Weather and climate products tailored for specific stakeholders	✓	✓	✓	✓	✓				✓	✓
Water quality monitoring and standards		✓			✓	✓	✓			

Chapter 3
Monitoring Network and Forecasting

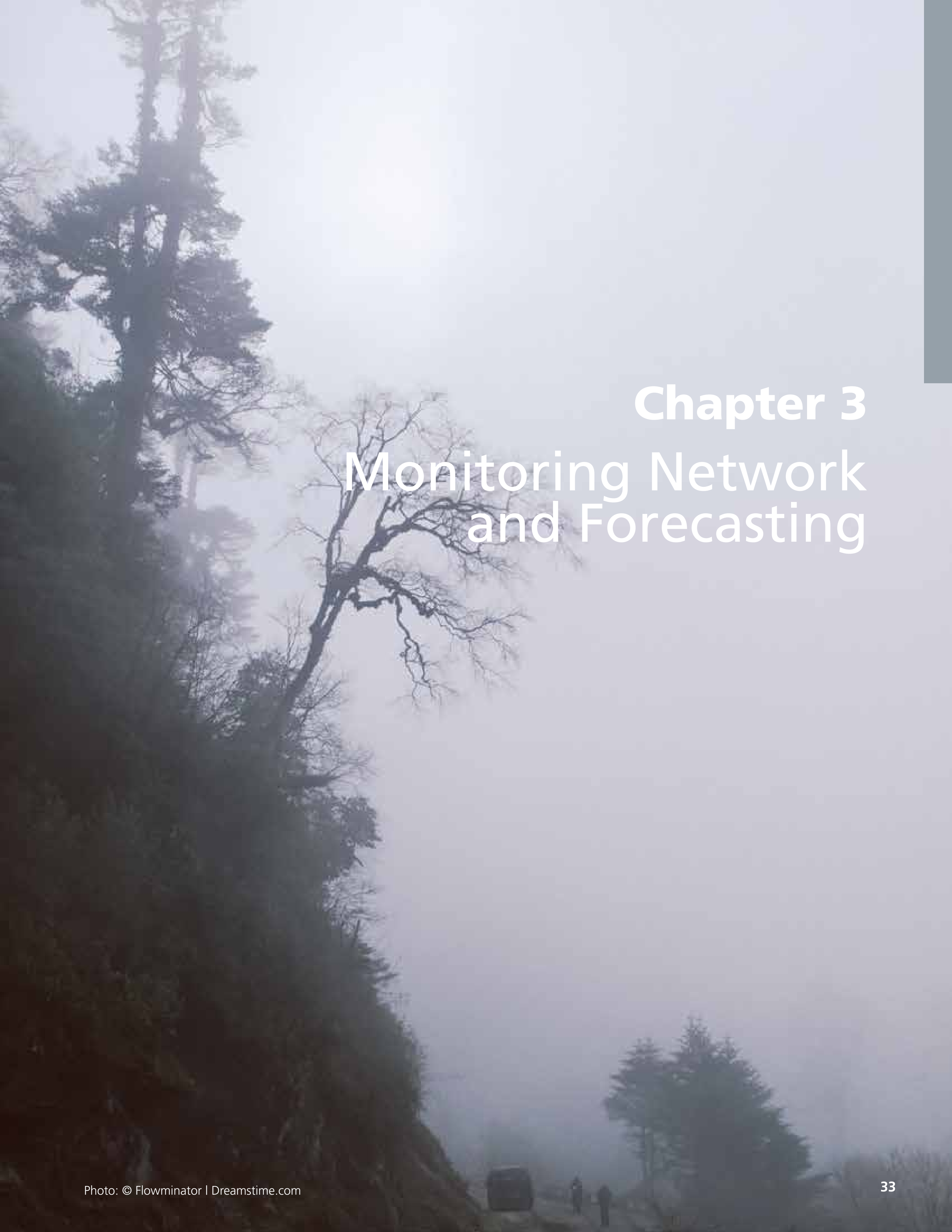
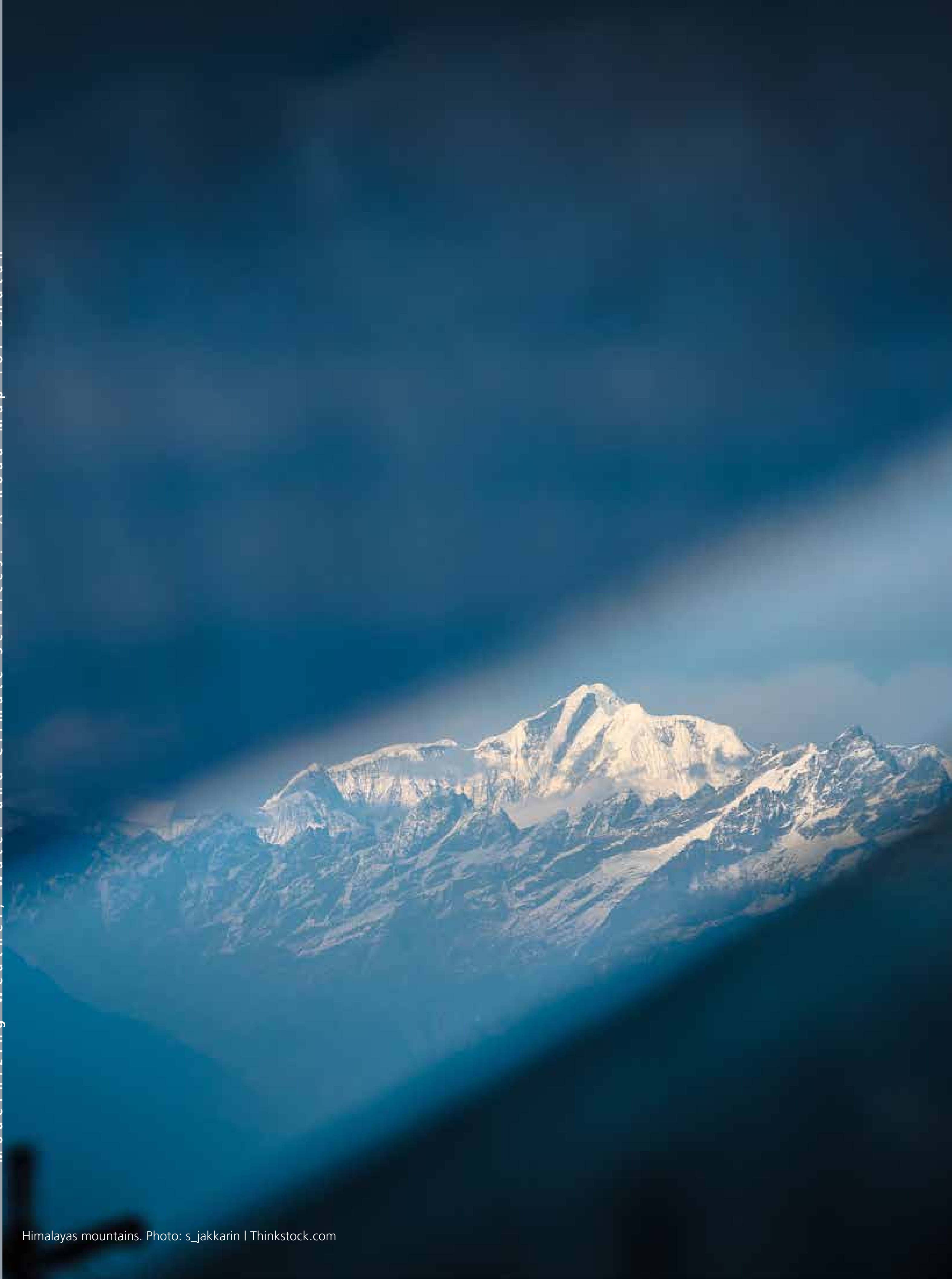


Photo: © Flowminator | Dreamstime.com



Himalayas mountains. Photo: s_jakkarin | Thinkstock.com

Modernization of Bhutan's hydrometeorological observation network, forecasting, and early warning systems is currently in its initial stages. As a relatively new department, the Department of Hydro-Meteorological Services is beginning to acquire the infrastructure that is required of demand-responsive national hydromet agencies. This chapter assesses Bhutan's existing hydromet network and forecasting capacity. The objective is to understand the baseline network, identify gaps, and help chart the course and sequence for the DHMS's network modernization.

Meteorological observation network

Surface meteorological stations are an extremely important part of any national hydrological and meteorological service. Data from these stations are assimilated in numerical models and used to validate forecasts. At present, the DHMS operates 92 weather stations consisting of 20 Class A stations, 11 automatic weather stations (AWSs), and 61 Class C weather stations (see Map 3).[8] The weather stations generally measure temperature, precipitation, relative humidity, wind speed, wind direction (or wind run), solar radiation, and atmospheric pressure. Class A stations are manually operated, in which the observer makes two readings per day and reports these readings to the headquarters daily (by telephone) and monthly (with reports). These stations are also called "synoptic stations" and are used to build meteorological products such as weather charts. This form of data is usually shared through the World Meteorological Organization (WMO) Information System (WIS). It is used by meteorologists around the world to prepare forecasts and is assimilated into numerical models to produce weather prediction products. However, because the DHMS is not connected to the WIS, it is not transmitting nationally collected data out of the country. The AWSs collect and relay data automatically, without an observer.

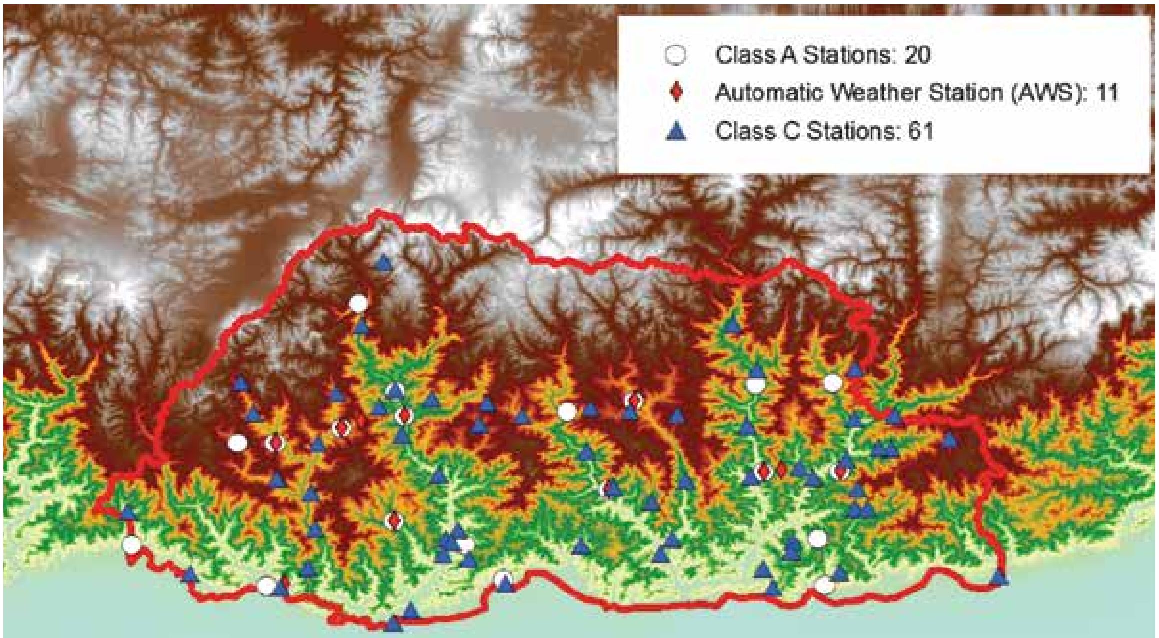
Like Class A stations, Class C stations are manned stations with observations recorded either on a chart or read nominally once every day at the same time (usually in the morning). These stations are considered climate stations, and observations are generally relayed back to the headquarters by post. These data are not used for near real-time synoptic analysis, nor are they sent to the international meteorological community for model assimilation. Rather, they are simply collected to document the climate and are available for assessing climate trends. Data collected include minimum and maximum temperatures over the past 24 hours and daily rainfall. These data are used by various stakeholders for planning purposes. At present, however, the DHMS does not have the capacity to undertake detailed climate analysis.

The Department of Civil Aviation operates two automatic weather observing system stations at two locations near the runway at Paro International Airport. These data are shared with the international aviation and meteorological community through an aviation meteorology communication system. These stations measure weather conditions at the airport and are used by commercial pilots to help with decision making related to flight navigation. AWOS data are used similarly to Class A stations and are usually included in synoptic analysis and provided to the international community through WIS.

There are no "purely" agromet measurement stations, though the synoptic (Class A) and climate (Class C) stations can be used to support the agricultural community. There are no fire weather stations. Bhutan also lacks upper air (radiosonde) measurements and weather radars.

[8] The 11 automatic stations are located with the Class A manned stations.

Map 3 Bhutan DHMS surface meteorological network indicating the locations of AWS, class A, and class C stations

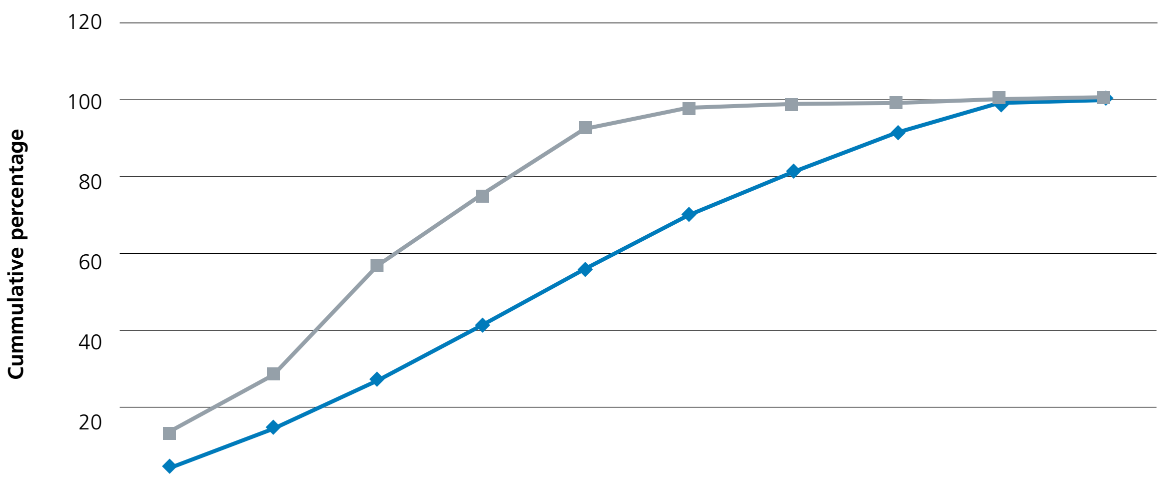


Source: DHMS 2014.

The representativeness of the surface meteorological observation network in monitoring the numerous climates in Bhutan is an important and challenging issue. Each climate zone should be monitored so that any changes or variation in climate can be recorded.

An assessment of the representativeness of the meteorological stations with respect to elevation zones has been analyzed to determine which elevation zones may be over- or underrepresented (see Figure 3).

Figure 3 Cumulative frequency distribution of station elevations compared to Bhutan country elevation distribution



	0-599	600-1199	1200-1799	1800-2399	2400-2999	3000-3599	3600-4099	4200-4799	4800-5399	5400-5499
CE	4%	14%	27%	41%	55%	70%	81%	91%	99%	100%
SE	13%	128%	57%	75%	92%	98%	99%	99%	100%	100%

Source: World Bank team
Note: CE = country elevation; SE = station elevation

The two curves in Figure 3 represent cumulative frequencies of both meteorological (Class A, AWS, and Class C) elevations and the distribution. The blue curve is the cumulative frequency of the elevation area of Bhutan. For instance, the graph shows that 55 percent of the land mass is at or below 2,999 meters. However, 92 percent of the stations are located at or below 2,999 meters, and only 8 percent of the stations are at elevations equal to or higher than 3,000 meters. Thus the higher elevations are underrepresented compared with the lower elevations.

In addition, the gaps in Bhutan's precipitation network are generally located in the northern part of the country, which is remote, difficult to access, and at very high elevations. This is of little surprise because of the difficulty in locating, installing, and maintaining stations at Bhutan's high elevations, although they represent a significant area of the country. To address this, stations can be added to the zones above 3,000 meters. This will result in a station elevation distribution that more closely represents the country elevation zones.

The WMO (2008a) has established a set of guidelines with regard to the density of hydrological monitoring stations (see Table 16). A mostly mountainous country, with an area of 38,394 square kilometers, Bhutan should have precipitation gauges every 250 square kilometers. This translates to 154 precipitation stations (AWS are not included in the total because they are found at some Class A sites). Map 3 indicates gaps in the meteorological monitoring network in the northern part of the country and along the southern edge of the network. While density of surface meteorological stations needs to be strengthened, a more detailed follow up study is needed to determine network density more accurately.

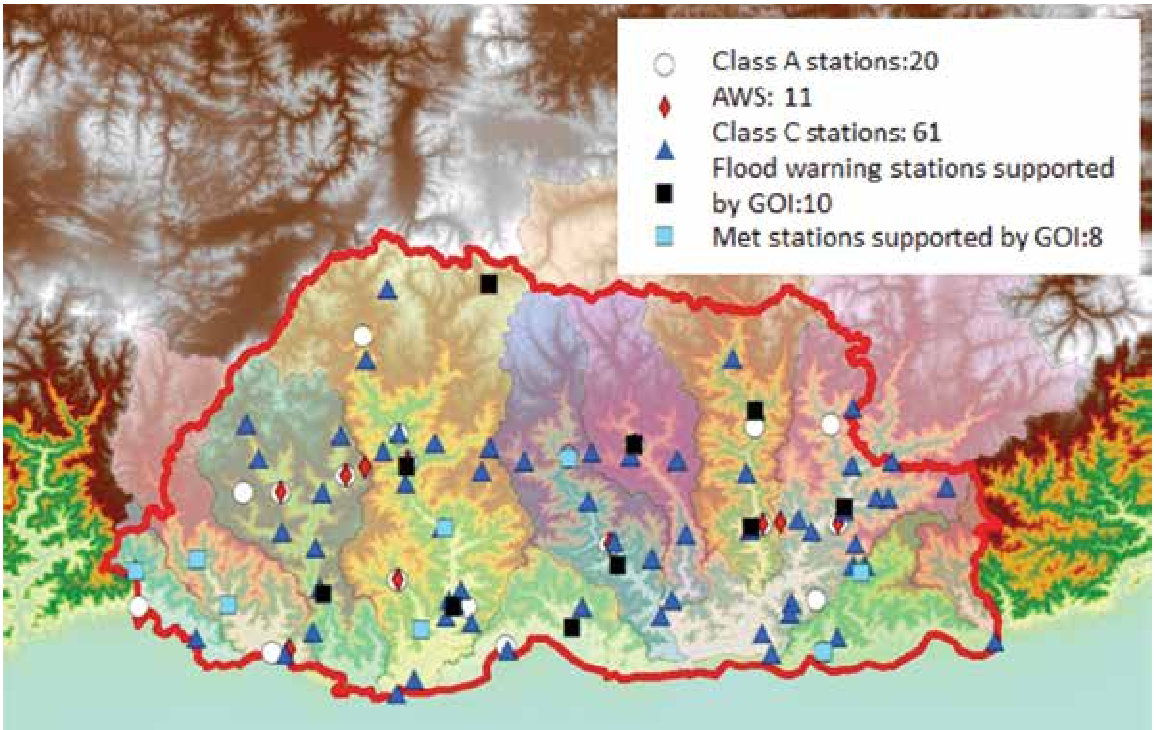
The government of India (GoI) and the Royal Government of Bhutan are cooperating in the operation of some hydromet stations and sharing of data. GoI provides funds to RGoB for the operation of hydromet stations of interest that lie within Bhutan. All hydromet stations within Bhutan are owned and operated by the DHMS, as the agreement only relates to the sharing of the operation and maintenance expenses of the stations and the delivery of data to the Central Water Commission (CWC) in India. CWC uses the data to determine the quantity and timing of transboundary river discharge, which in turn is used in developing river forecasts in the part of India that is downstream of Bhutan. Map 4 shows DHMS meteorological stations (also shown in Map 3) that are covered under the agreement between GoI (through CWC) and RGoB (through DHMS). The DHMS hydromet stations used to support CWC have different sensor packages, but they mainly focus on the collection of water level, precipitation, and temperature.

Table 16 Recommended minimum densities of stations

Physiographic unit	Precipitation: Non-recording	Precipitation: Recording	Evaporation	Streamflow	Sediments	Water quality
Coastal	900	9,000	50,000	2,750	18,300	55,000
Mountains	250	2,500	50,000	1,000	6,700	20,000
Interior plains	575	5,750	5,000	1,875	12,500	37,500
Hilly/ undulating	575	5,750	50,000	1,875	12,5000	47,500
Small islands	25	250	50,000	300	2,000	6,000
Urban areas	–	10-20	–	–	–	–
Polar/arid	10,000	100,000	100,000	20,000	200,000	200,000

Source: WMO 2008.

Map 4 DHMS surface meteorological network with the stations supported by the government of India



Source: DHMS 2014.

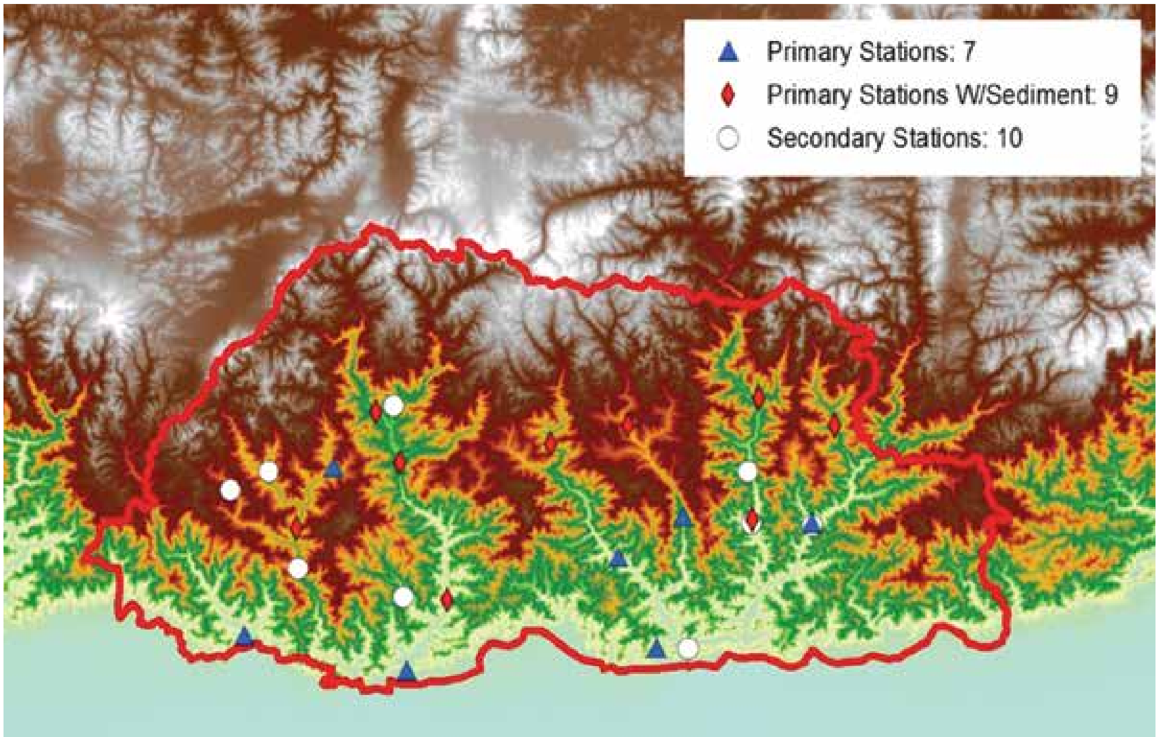
The DHMS is in the process of receiving support under the UNDP-funded NAPA II project to further strengthen its surface meteorological observation network. Given this, the density of meteorological monitoring stations will likely be adequate.

Station operation and maintenance

While critical, station density is not the sole measure of the effectiveness of the networks. The few stations that have been automated, along with the stations that were installed as part of the GLOF network, do not have proper arrangements for maintenance and repair. So although there are likely to be sufficient numbers of stations, several existing stations are not in working order. This is mainly attributed to budget constraints that limit the mobility of DHMS staff. The budget for operation and maintenance (O&M) are from the government—namely, the DHMS budget. The main constraints to the maintenance and repair of existing automated stations are the limited budget and insufficient government pool vehicles and budget to hire vehicles, hindering the mobility of staff for maintenance. The DHMS does not have enough government pool vehicles to cater to every station to carry out regular maintenance. Establishing regional offices would be very helpful to facilitate this task.

At present, the surface meteorological observation network is largely manual. Field staff make measurements and transfer the information to headquarters through telephone or by post. Data are collected twice a day for Class A stations and once a day for Class C stations. It is necessary to automate data collection and transfer to headquarters to the extent possible if the DHMS is going to provide necessary and accurate forecasts. The automation of data collection and transmission will allow

Map 5 DHMS surface hydrological stations consisting of primary and secondary stations and primary stations with suspended sediment sampling



Source: DHMS
Note: W/Sediment refers to stations that have sediment sampling

data to be used in real time while also allowing the notification of exceptional meteorological events (such as heavy precipitation caused by cloud burst, or damaging wind events) automatically. This is especially important for early warning related to rainfall events that lead to high water or crop damage. Automation of data will also help improve the frequency and quality of data collected and in turn contribute to more accurate forecasts.

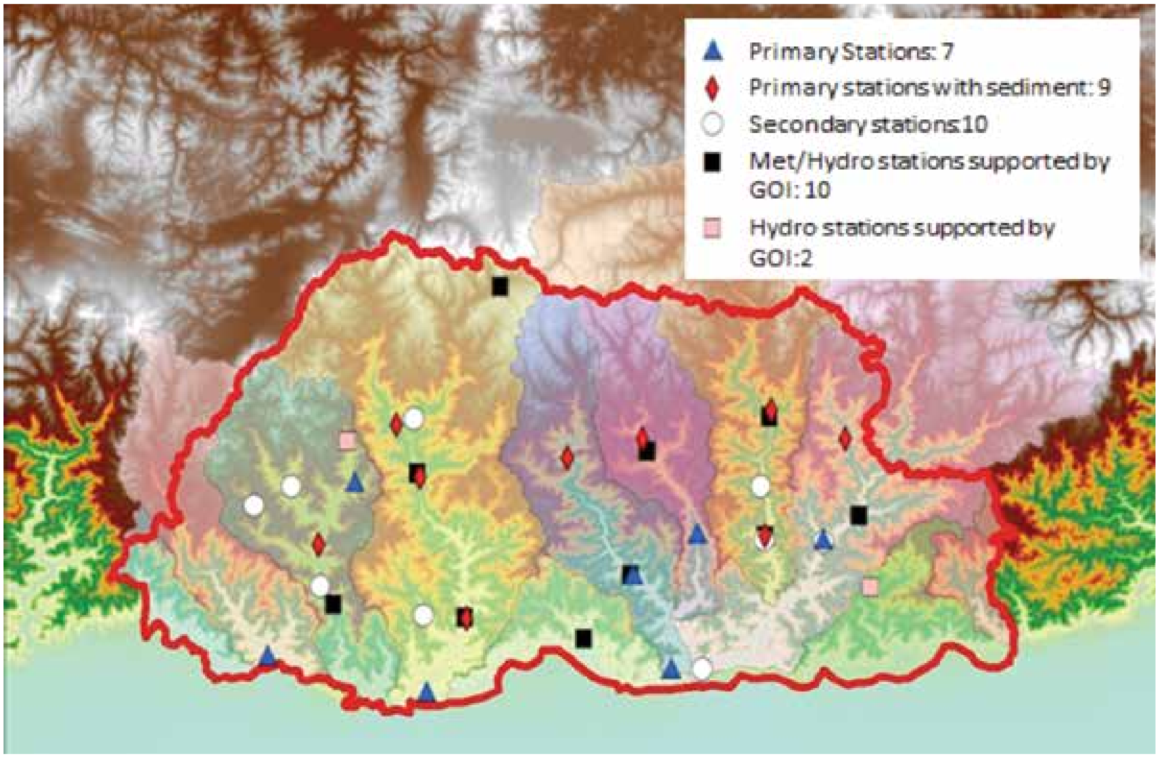
Surface hydrological network

The DHMS operates 26 surface water stations (see Map 5). Sixteen of these stations are water level and discharge (primary) stations, and the remaining 10 are secondary stations where water level measurements are observed from staff gauges. Sediment samples are collected from 9 of the 16 primary water level and discharge stations. There are no groundwater monitoring stations or water quality stations currently operated by the DHMS. For the secondary hydrological stations, site staff also carry out daily discharge measurements using the traditional float method besides water level.

The Indian government, through the CWC, also provides funding to the DHMS for the collection of hydrological data. The location of these stations and DHMS stations is indicated in Map 6.

The DHMS monitors river basins throughout Bhutan. Based on a qualitative analysis, it is apparent that flood warning stations are located mainly along big rivers, and the network is sparse in smaller rivers. Several tributaries have no monitoring, especially at the international border with Tibet in northeastern Bhutan. Additionally, the reservoirs should have water level and discharge measurements on the major tributaries. Suspended sediment sampling should be added to these sites. Another shortcoming of the existing hydrological networks is

Map 6 Hydrological stations operated in Bhutan including those supported by the government of India



Source: DHMS 2014.

that only a fraction of the stations include discharge measurements (staff gauge only). The development of a river forecast model system will require the hydrological stations to provide discharge, as discharge is a primary input to river forecast models.

The actual design of a river gauging network depends more on purpose-driven aspects than spatial aspects alone. Knowledge of major reservoirs, for example, is used in establishing stream gauging stations. The presence of downstream communities and the lead time required to warn these communities of floods, the location of critical infrastructure (such as roads, hydropower), land use information (presence of agriculture, human settlements), and so on are all significant factors in the design of a flood forecasting network. A thorough analysis of stream gauge records will need to be undertaken to properly design the stream gauging network for flood forecasting and water supply. This would include a more detailed analysis of available stream gauge records and hydrographs. At the time of writing this report, there are several concurrent donor-funded projects with the DHMS that are expected to add to the number of stream gauges, though many of these will still be without discharge measurement. The data have not been evaluated, but they should be in a follow-up consultancy.[9]

[9] The spatial representativeness of the hydrological monitoring network cannot be properly evaluated without engaging in a more thorough analysis of the hydrological data and the socioeconomic losses caused from flooding. It is recommended that the network density of the hydrological monitoring network be part of a follow-up consultancy that will also develop and calibrate hydrological modeling for DHMS. As part of such a consultancy, an analysis of the benefit of flood forecasting would need to be performed for a network design based on needs rather than typical network density and locations. During the course of model development, even more station locations can be identified such that the performance of the flood forecast model is fully optimized.

Glacier and GLOF monitoring and early warning systems

The Department of Geology and Mines has been monitoring glaciers and glacial lakes in northern Bhutan. In 1996, it prepared an inventory of glaciers and glacial lakes in major river basins using maps produced by the Survey of India based on air photographs of 1956 and 1958 and satellite images (Ives, Shreshtha, and Mool 2010). At the regional level, the International Centre for Integrated Mountain Development has been monitoring decadal shifts in glaciers in the Bhutan Himalayas based on satellite data.

At the DHMS, the Snow and Glacier Division (SGD) is the newest and smallest division; it was formed at the beginning of 2013. The division is responsible for studying snow and glaciers of the country through field measurement systems and remote sensing techniques. It is expected that its data, services, and analysis will help others understand the complete hydrological system of Bhutan and ascertain climate change impacts related to the Bhutan Himalayas. Some of the proposed activities by SGD include a Glacier Mass Balance System of measuring the glaciers and their retreat rates, snow surveys and snow pack measurements to find out snow variations across regions and their time period, and the installation for permanent monitoring of snow and glacier stations.

Within the DHMS, the capacity for glacier monitoring is just being established. One glacier in the Chamkhar Chhu basin is being monitored by the DHMS through glacier mass balance. Another technique used is ice-penetrating radar, which finds the volume of ice after knowing the area and depth. It allows annual monitoring of the volume of ice retreat or gain and helps identify debris-covered glaciers. A pilot project has been conducted at Thana glacier upstream of Chamkhar Chhu. A third technique used is snow pit measurement, which measures snow density, depth, and snow-water equivalent and identifies the snow grain sizes. It gives a rough idea of snowmelt contribution to downstream or to the accumulation. An AWS near Thana has measured relative humidity and air temperature on an hourly basis since 2013.

The SGD is also engaging in several research and collaborative activities. At the time of writing this report, these included the following.

- The division started manual snow observations in 2013 winter at Semtokha (Thimphu), Namgayling (Haa), DSC (Paro), Gasa, and Chamkhar (Bumthang), along with the existing Class A meteorological stations by meteorological observers. Manual snow depth measurements using rulers are made every time there is a snowfall or at 7AM after a snowfall event. Snow water equivalent are also determined using the melting method. The same measurements are also done at the high-altitude passes on the national highways at Hongtsho (Thimphu), Pelela (Wangduephodrang), Yotongla (Trongsa), and Thrumshingla (Bumthang) through part-time observers.
- With the Norwegian Water Resources & Energy Directorate, the ongoing Phase-IV of the Norwegian Agency for Development Cooperation (NORAD) Project, a site has been chosen at Thanagang glacier upstream of Chamkhar Chhu to support the DHMS for sustainable data provision to accelerated hydropower development and other uses. The in-situ measurements of the glacier using ablation stakes are done annually starting from 2012 and will be continued in the future for glacier mass balance. Air temperature and relative humidity measurements are also done here through an automatic station. Snow measurements such as snow pits and transects are also planned to be set up in the area. Further, the Bavarian Academy of Science and Humanities and SGD conducted a glacier thickness measurement using Ice Penetrating Radar (IPR) in the beginning of April 2104. The Academy and the DHMS aim

to test the IPR and understand the glacier morphology of Bhutan in order to propose a countrywide ice thickness study in the near future.

- Another ongoing research project, by Brigham Young University and Columbia University, intends to quantify the glacier contribution to water resources (present and future), assess impact of glacier melt and retreat on GLOF potential, and assess paleo-climate. The project is working on Tachenggay glacier near Metatshota Lake, close to Rinchen Zoe la in the upstream of Mangde Chu, and includes mass balance research. The assessment is planned to be done annually and also expanded into the Lunana glacier complex.
- The SGD is planning to set up several automatic snow stations that will provide them with snowfall data such as snow depth and other weather parameters. An Automatic Snow Station at Chelela Pass, 4000m above sea level, was being installed in June 2014. SGD plans to install at least three such stations in 2014–15 in the high altitudes of Wangchu and Manas basins.
- A cryosphere monitoring program in Bhutan is being planned by the DHMS and ICIMOD from July 2014 for five years under Norwegian government funding. The goal of the project is to understand the cryosphere of Bhutan for better decision making. The project has four components: remote sensing analysis to determine 15 hotspot glaciers, a field study of a glacier, capacity building, and setting up a cryosphere knowledge center for Bhutan.

The DHMS operates a GLOF early warning system in the Punakha-Wangdue Valley. It was funded by the Least Developed Countries Fund, RGoB, UNDP, the Austrian Development Agency, and the World Wildlife Fund of Bhutan under the National Adaptation Programme of Action project. The EWS consists of six stations that report water level, and a system of 17 siren stations used to warn communities based on rapidly rising water levels from the six stations. The GLOF early warning system does not require meteorological or hydrological forecasts because it is a self-contained observation system intended to operate without staff intervention. With support from Japan International Cooperation Agency, GLOF early warning systems are also being planned in the Mangde Chhu and the Chamkhar Chhu river basins (JICA 2013).

As evident from this description, while there are numerous activities to monitor snow and glaciers in Bhutan and there is strong collaboration with regional institutions such as ICIMOD, comprehensive monitoring of snow and glaciers is not currently being done by the government, and there is very limited capacity within government for cryosphere monitoring. Going forward, it will be crucial to systematically identify the priority glaciers in the Bhutan that should be monitored and to prepare a design and long-term plan for improving monitoring and capacity building of government agencies. Given that there are similar capacity gaps in neighboring countries as well, this could be done in a collaborative way as part of a subregional or regional program.

Product reception through connection to the WMO Information System

The WIS is a communication network that relays national meteorological data into the meteorological center of the WMO and back out to all national meteorological institutions. WIS products that directly measure the environment in and around Bhutan are numerous and consist of several satellite systems. Bhutan is not yet connected to the WIS, though it is understood that connection to WIS is being facilitated with support from JICA. The reception of these valuable data and products can greatly enhance the ability of the DHMS to monitor meteorological and hydrological conditions in Bhutan at very little cost, without the cost

Table 17 DHMS observation systems

Observation system	DHMS	DCA
Surface meteorology stations (Class A)	20	0
Surface meteorology stations (Class C)	61	0
Automatic weather stations	11	0
Automatic weather observing systems	0	2
Principal hydrological stations	16	0
Secondary hydrological stations	10	0
Flood warning stations	28	0
Sediment sampling stations	11	0
Automatic GLOF water level stations	10	0
Automatic GLOF weather stations	3 (+ 1 is being added)	0
Agromet stations	0	0
Fire weather stations	0	0
Groundwater stations	0	0
Water quality stations (suspended sediment only)	11	0
Glacial monitoring stations	2	0
Snowpack monitoring stations	1(+3 to be added)	0
Upper air (radiosonde)	1 (in planning stage)	0
Doppler weather radar	0	0
WIS product reception	In Planning Stage	0
Remote sensing products	0	0

of operating and maintaining the observation systems such as environmental satellites.

Remote sensing products

The remote sensing products used by the DHMS are limited to what is available from other national hydrological and meteorological services or from National Meteorological Service websites and those that are in the global public domain. For instance, the Indian Meteorology Department (IMD) provides satellite imagery of Bhutan from the *Kalpana* satellite. Table 17 summarizes the observation assets in operation by the DHMS, including the DCA, in Bhutan.

Data management, storage, and quality

Data are available for the last 17 years, and all collected data have been digitized. Some of the climatic observations go as far back as 1985. Also, somewhat discontinuous rainfall data from a few locations are available dating back to 1950s. There was no quality check for data collected before 2010. A few basic tools for quality check are used for data since 2010.

The DHMS stores a modest amount of information compared with typical national hydrological and meteorological service centers, because it collects very few data. The raw data manually collected from meteorological stations are first entered into a database called HYDATA[10] in the head office at Thimphu, and then the same data are updated in Excel spreadsheets to ensure quality check. The data are later archived in Excel format and also saved in hard copy. The

[10] HYDATA is proprietary software where an annual fee is required to keep the system operating. It is the name of a software product and is the name in full form.

DHMS collects and archives observations from surface stations, consisting of the surface weather stations (automatic weather station, Class A, and Class C), hydrological stations, and snow and glacier stations. Since there is no connection to WIS, data and products from international meteorological centers are not available and thus are not stored.

Products available over the WIS that would be of great value to the DHMS and could be stored on local servers for later analysis and distribution include satellite products, numerical weather forecasts (both model output statistics and graphical output), and surface data from regional stations.

The DHMS uses quality control on its data and uses HYDATA for the quality control of at least hydrologic data. The process of meteorological data quality control is unknown at this time.

DHMS outreach is limited by its website because it appears to be offline much of the time.[11] This, of course, interrupts the lines of communication and reduces visibility between the DHMS and the public. Instead, the DHMS relies on a partnership with public broadcasters to distribute information, such as the 24-hour weather forecasts made by the DHMS. The department is limited to providing data on a request basis only, as the website does not provide a method to download either real-time or archived data. Data provided on a request basis means that the sparse DHMS staff must manually gather the data required and send this off to the users. Automation of this process will allow DHMS staff to tend to more important tasks, such as developing and refining forecast techniques.

Data processing and analysis are found to be commensurate with the modes of data recording and transfer from the field. Data processing can handle the existing stream of data, but with the anticipated volumes of data and information to be collected, there will be an increase in data volume by several orders of magnitude. This will require strengthening of the database management system.

Data transmission and maintenance

Field staff transfer data to headquarters at 3 pm daily by telephone (maximum and minimum temperature, rainfall, cloud coverage, and relative humidity). In addition, data on rainfall, storm, and lightning are conveyed by telephone when a severe weather event occurs. At the main DHMS office in Thimphu, data are first entered in a register and then entered in the model for forecasting weather for the next day. For Class A stations, data recording is done by DHMS staff in all 20 districts. On-site operators record more details, such as wind speed and sunshine hour, but they only communicate to headquarters what is required for the weather forecast. The entire observation sheet is sent to headquarters at the end of every one or two months, and a field book is maintained at the site. For Class C stations, the DHMS has hired part-time observers who maintain a field book and send the observation sheet to Thimphu every three months. These data are for the record and can be used for climate data such as for monsoon outlooks, cold waves, heat waves, and cyclones and are eventually stored in a database in Thimphu. For these manual stations, data loggers and other spare parts are stored in the head office. The only quality checks for collected data is done at the head office. No data processing or analysis is done.

Observers stationed at the sites conduct minor maintenance. A team of technicians from the field offices and officials from the head office conduct the annual maintenance. When there are major technical issues, the same teams attend as needed.

[11] See the DHMS website: http://www.moea.gov.bt/departments/department.php?id=4.

Photo 1 Meteorological Division work area for preparing national forecasts

Source: World Bank team.

For flood warning stations, the hourly water level information is passed on to the nodal control centers and the head office through high frequency radio. This information is then passed on to partners in India in West Bengal and Assam. For automatic stations, data come directly to the server in the head office through General Packet Radio Service (Internet over mobile network) and through the Global System for Mobile Communications Standard used by mobile communications providers' short message service.

Analysis and forecast systems

The DHMS provides skeletal hydromet data, products, and services at this time. It currently prepares forecasts using a single computer. Photo 1 shows the existing computer systems used to prepare the daily weather forecasts. The DHMS does not have either a meteorological or hydrological forecast system in place that allows for the development of forecasts through a meteorological workstation. These are extremely valuable because they automatically assimilate meteorological data and products, and numerous products can be viewed on a single screen. This simplifies the task of preparing forecasts, allowing the forecaster to analyze the many streams of data rather than manually collecting and switching between screen views to evaluate data.

Use of IMD and other agency forecasts and products

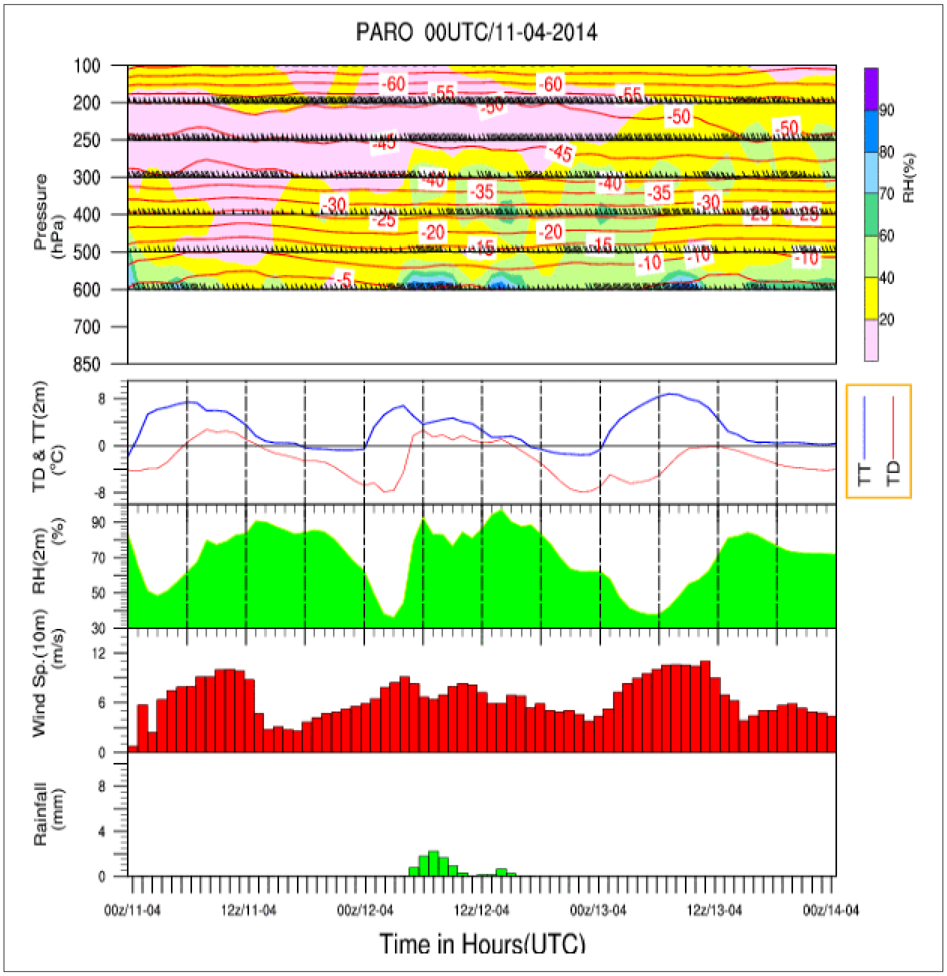
The Meteorology Division at the DHMS issues 24-hour weather forecasts once a day for one selected location for one district, relying heavily upon other international centers for information. The DHMS's weather forecasts are deterministic, and currently they do not have the capability to produce probabilistic forecasts. Based on specific users' requests, the Division provides three-day forecasts but with a lot of uncertainty.

More generally, forecasts are prepared using meteograms issued by the Indian Meteorological Department for cities in India close to the Bhutan border and experimentally for Paro and Thimphu. Building upon IMD forecasts, meteorologists at the DHMS make adjustments with a spreadsheet. The IMD provides the DHMS special access to meteograms for stations near the border between India and Bhutan. An example of a meteogram developed by the IMD for Paro is shown in Figure 4.

The DHMS takes this type of product from IMD and projects the results for different cities within Bhutan for 24-hour forecasts. The use of meteograms is a good idea, and it would become more powerful if the meteograms used were generated from a broad set of numerical models and plotted with the verification of past data. Figure 5, produced from the Iowa State University website, shows an example of a meteogram for accumulated snowfall using 12 different model inputs. It would be beneficial for the DHMS to acquire the capability to generate meteograms such as this automatically for use by weather forecasters.

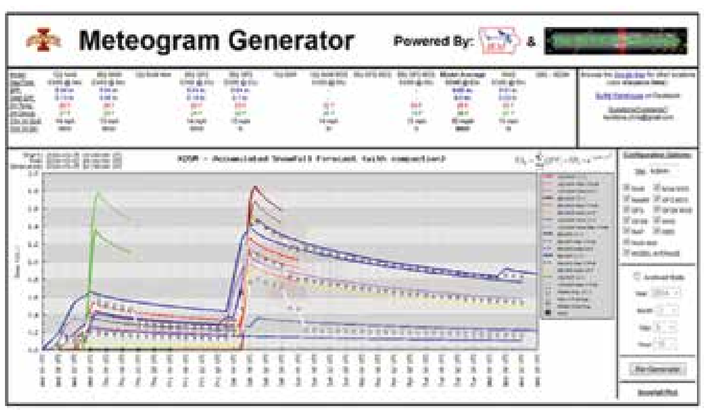
The DHMS also subscribes to MetGIS, which is a cloud-based forecast system (used over the Internet with data and products residing

Figure 4 **Meteogram developed by IMD for Paro, Bhutan, April 11, 2014**



Source: http://www.meteor.iastate.edu/~ckarsten/bufkit/image_loader.phtml

Figure 5 **Example of a Meteogram**



Source: http://www.meteor.iastate.edu/~ckarsten/bufkit/image_loader.phtml elsewhere). This service is reasonably priced at about €2,500 per year and provides forecasts based on numerical models run by the European community that are also freely available on WIS. Unfortunately, the MetGIS product does not include a complete suite of models developed in other international meteorological communities. Having all models would allow the forecasters to compare the forecasts between different models and select the best performing model for a given situation. Other obstacles to getting data from MetGIS, or any other source on the Internet, are the general problems with Internet availability and significant interruptions to Internet connectivity at the DHMS forecast office. Challenges with using MetGIS also relate to the frequency of updates. Since it is only updated twice a day, in the absence of other tools, forecasters are forced to use older updates for forecasting.

The DHMS is also exploring the development of a non-hydrostatic mesoscale model using the Weather Research and Forecasting (WRF) model developed in the United States. The DHMS uses the Global Forecast System (GFS) global data to initiate the model, with no other data assimilation. There can be at least three model runs in 24 hours as it takes approximately 6 hours to run the model. Currently the WRF is being calibrated and, once operational, it is expected to improve the accuracy of forecasts produced by the department. The model run is often hindered by insufficient Internet bandwidth in populating the WRF model with the GFS global data. Lack of Internet bandwidth combined with insufficient computer processing power has marginalized this effort.

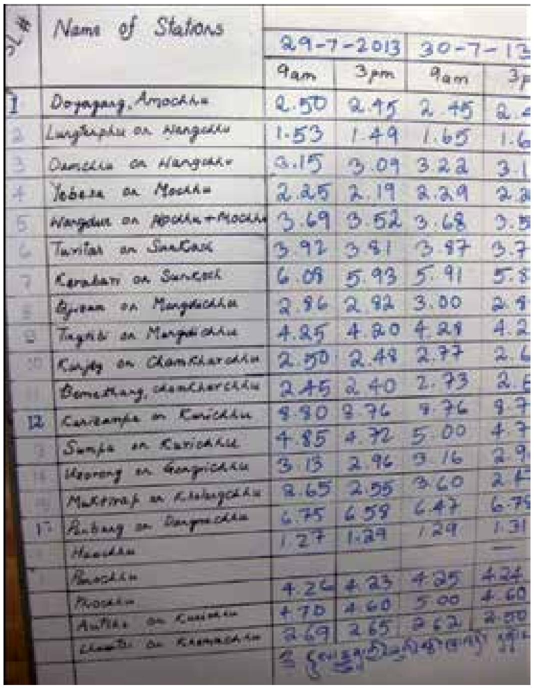
Currently, the DHMS does not have the ability or the observation system to monitor or forecast significant hydrometeorological and severe weather events in Bhutan, such as wind storms, hail, and cloud burst. The DHMS does issue some severe weather forecasts on cyclone warnings, heavy rainfall, and snow forecasts. Severe weather forecasts need to be further developed through the introduction of better forecast tools and instruments, such as radars, and developing the capacity of the forecasters. Forecast on threats to air navigation, such as wind shear, lies with the DCA and is not within the mandate of the DHMS. The DHMS issues an annual monsoon outlook, which gives information, among other factors, on the quantity and onset of the monsoon mainly as information for farmers. It is done by using the Climate Predictability Tool and statistical analysis, with results verified from the regional outlooks.

The mandate of the Meteorology Division also includes climate change assessment. However, it does not have the right tools and access to global data. The availability of meteorological data for the last 17 years is not sufficient to assess long-term climate trends within Bhutan. The Meteorology Division needs to develop this capacity. Going forward, the Meteorology Division should first improve the accuracy of short-term forecasts and then build the capacity for longer-range forecasts and climate analysis.

Hydrological forecasts and warnings

The Flood Warning Section (FWS) under the Hydrology Division does not produce any flood forecasts but issues flood warnings when high levels in rivers are observed. Water levels, which are observed at varying frequencies across seasons, are relayed to headquarters. The information is placed on a whiteboard and shared throughout the Hydrology Division. The Division issues flood warnings based on a routing scheme using water level and discharge data from higher elevation hydrological stations to warn downstream communities of high water. Photo 2 shows a whiteboard at the DHMS office in Thimphu, displaying water level at 21 of the 26 primary and secondary stations. Water level and discharge data are the key input used in issuing

Photo 2 Whiteboard with recorded water levels from surface water stations at DHMS office in Thimphu



Source: World Bank team, February 2014.

flood warnings in Bhutan, as the Hydrology Division does not use hydrologic models

With 40 staff members, FWS is fully funded by the government of India through CWC. FWS collects and shares data with India for use in monitoring downstream floods. Although information from these stations is shared with the central office in Thimphu, it is not used to provide flood warning within Bhutan in any systematic way. If the data indicate possible floods within the country, information is shared informally (likely through a telephone call) in an ad-hoc manner with DDM, as there is no standard operating procedure in place or institutionalized mechanism to share information.

There is a standard operating procedure for GLOF in the Punakha-Wangdue valley, for which an early warning system is also in place, and the Hydrology Division (HD) informs the agencies accordingly. The Hydrology Division also monitors, through FWS, a few glacial lakes (Luggye, Thorthormi, Rapstreng, and Baytsho), where the water level is measured with an automatic system as a part of GLOF EWS in the Punakha–Wangdue Valley.

FWS used to be a separate unit; the main reason behind merging it with HD was to institutionalize the use of data collected for both India and Bhutan. The mechanism for dissemination and information sharing between agencies and to the public needs to be further worked out. As the HD program is transformed from a warning program to a forecasting and warning program, provisions to handle real-time data and an operational flood forecast model will require considerable improvement in human skills and computer resources.

Forecast skill and verification

As discussed, the DHMS's forecast process is relatively simple, and the accuracy of forecasts is unclear. This is attributed to the lack of a forecast verification system and feedback of the verification results into the forecast development process. Continuous improvement in forecasting is driven by a strong verification process that includes the evaluation of the performance of numerical weather products and the performance of the forecast meteorologist in building the forecast. A forecast verification process that produces feedback will lead to rapid and substantial improvements in the weather forecasts. In addition to upgrading the observation network, improvement in the DHMS's capacity to provide accurate and timely warnings and forecasts and strengthened service delivery will require improvements in a number of areas (see Table 18).

Summary

The DHMS's limited observation system and forecasting capacity impairs its ability to perform routine weather services, issue weather and

Table 18 Assessment of the DHMS's ability to provide key hydromet information

Task	Acceptable	Needs strengthening	Needs to be established
Agromet information delivery			✓
Climate forecasting			✓
Data center		✓	
Fire weather forecasting			✓
Flash flood forecasting			✓
Flood forecasting			✓
Monsoon forecasting			✓
Monsoon Outlook		✓	
Numerical weather prediction		✓	
Operation and maintenance		✓	
Public information delivery		✓	
Quality assurance/quality control			✓
QPF			✓
Weather forecasting		✓	
Web presence		✓	

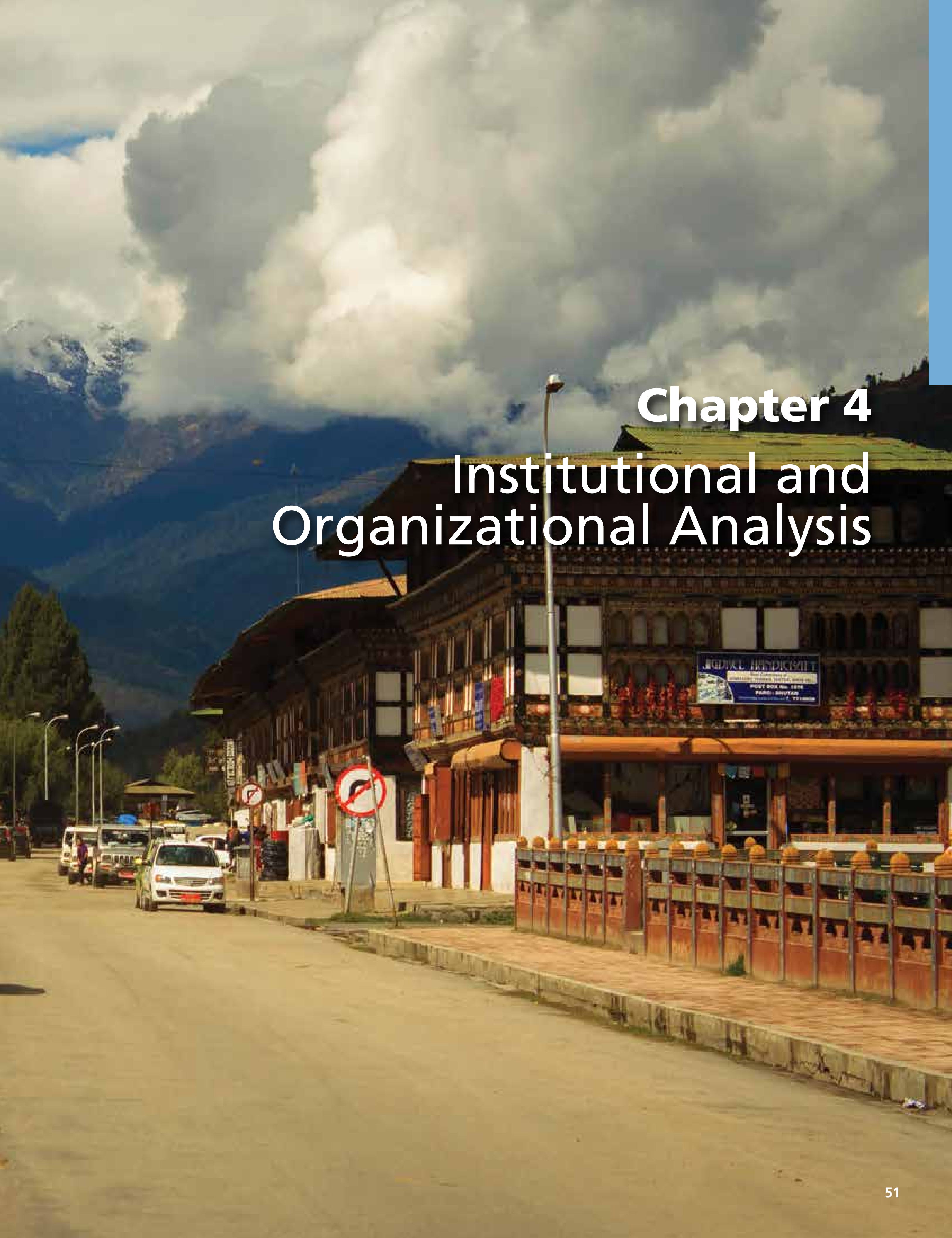
Source: World Bank team

hydrological forecasts and warnings for extreme events, issue medium- or extended-range forecasts, and monitor long-term climate trends in the country. It also presents a gap in global data that would be useful to assimilate into global and regional numerical weather prediction models being run at global and regional centers. At the moment, the DHMS lacks the basic infrastructure, such as reliable Internet connectivity, a link to the WIS, or adequate computing resources, to carry out its tasks. Its ground monitoring system is mainly manual, and there is a need to invest in real-time stations and telemetry in a sustainable way. Meteorological measurements are underrepresented at the higher elevations, where access is difficult and the climate is forbidding. Only one station represents 19 percent of the land area above 3,600 meters. While regional institutions are partnering with the DHMS to monitor decadal shifts in glaciers in the Bhutan Himalayas, the DHMS needs to strengthen its own capacity in cryosphere monitoring and early warning systems, given its mandate. Existing research has highlighted 24 glacial lakes that are potentially dangerous. Even considering ongoing development partner support to strengthen GLOF early warning systems in the Mangde Chu and Chamkhar Chu river basins, there is a significant need to strengthen GLOF early warning systems in the remaining high-risk glacial lakes in Bhutan.

While network density needs to be improved, the DHMS also needs to strengthen its capacity in areas yet uncharted, such as developing the capacity for upper air observation, having access to radar, and developing capacity for weather and hydrological forecasting. The development of these forecast systems will require enhanced computing power, training, and a highly reliable, high bandwidth Internet connection along with connection to WIS. Most important, in coordination with user agencies, the DHMS needs to upgrade its infrastructure and capacity to deliver demand-driven sector-specific climate services, such as agromet services, that can meet the weather and climate information needs of user communities in Bhutan. ■

Photo: mantosh | Thinktock.com

Chapter 4
Institutional and Organizational Analysis



This chapter reviews the institutional and organizational structure of the DHMS at the national and subnational levels and identifies areas needing capacity strengthening. The information is based on detailed discussions carried out with DHMS officials and other stakeholders.

Institutional history of the DHMS

The genesis of hydromet services in Bhutan dates back to 1965, when a few rain gauges were established by RGoB. Collection of temperature data started in 1977 (at Paro Airport and Bhur).[12] The importance of hydromet data in Bhutan was recognized in the early 1980s for hydropower development by the Department of Power (DoP) under the Ministry of Trade and Industry (renamed the Ministry of Economic Affairs in 2007) and for agricultural development by the Department of Agriculture (DoA) under the Ministry of Agriculture. The earliest stations (Class C: climatology stations) installed by the DoP commenced in 1981, while all DoA stations commenced in 1985.

Prior to 1990, in the absence of a central agency responsible for hydrometeorological data collection, data were collected by the respective line agencies to fulfill their requirements as needed for project implementation. Then during implementation of the Bhutan Power System Master Plan project by the DoP in 1990–93, a national hydrometeorological network covering the whole country was designed and implemented. In July 1991, the hydromet unit under the DoA was transferred to the DoP, and the Hydrology and Meteorology units were created under the DoP in 1991. Sections on data collection and sediment lab were also established. When the Department of Telecom became a corporation in 2001, its hydromet section was transferred to the DoP and named the Flood Warning Section.

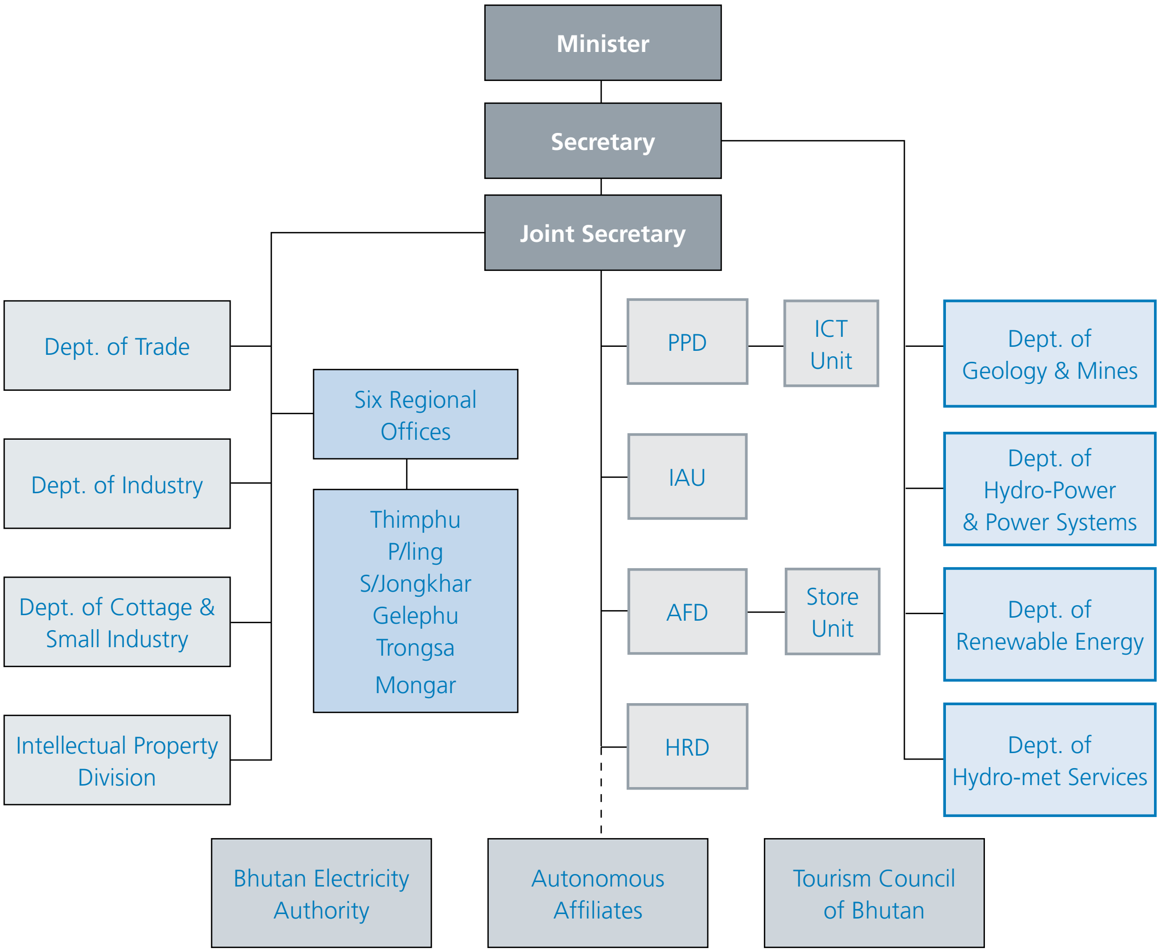
[12] The Bhur Met station was established by the Ministry of Agriculture, and the Met station at Paro Airport was established by the Department of Civil Aviation).

In July 2002, when the DoP was restructured into the Department of Energy (DoE), the Bhutan Power Corporation, and the Bhutan Electricity Authority, the Hydromet Services Division (HMSD) was created under DoE. The HMSD consisted of Hydrology, Meteorology, and Flood Warning Sections. It had the responsibility for planning and designing the hydrometeorological network for hydropower planning, weather and flood forecasting, energy generation scheduling, dissemination of data to end users (hydropower plants, other design/development agencies, etc.), publishing data books, and international cooperation in flood warning and flood prevention measures. The HMSD was established as an equivalent to national hydromet services of other countries mandated with the national responsibility for hydrology and meteorology. In December 2011, the HMSD was upgraded to a full-fledged department and named the Department of Hydromet Services as a national center for weather, climate, and water resources to establish and operate a national hydrometeorological network for data collection. The decision to establish the DHMS was approved by the Cabinet (Council of Ministers) and subsequently created by the Royal Civil Service Commission as per the endorsement by the Cabinet. It is designated as the main technical agency responsible for providing early warnings related to hydrometeorological hazards, including glacier lake outburst floods.

Department of Hydromet Services: 2011–present

The DHMS is one of eight departments under the MoEA (see Figure 6). The MoEA's overall mandate is to promote a green and self-reliant economy sustained by an information technology (IT)-enabled knowledge society. Its activities are guided by the philosophy of gross national happiness, with the mission of creating an enabling environment, including institutions and infrastructure, for the sustainable growth of the economy through the public and private sectors.

Figure 6 **Ministry of Economic Affairs Organizational Structure**



Source: RGoB 2014.

The DHMS is Bhutan's national center for weather, climate, and water resources. Its mandate is to provide reliable and timely hydrometeorological information and services needed by various agencies, users, and the public. Its main functions are highlighted in Box 1.

Consultations with stakeholders during the preparation of this report indicates that there is an ongoing discussion on the organizational location of the DHMS within the MoEA, and its alignment with the overall mandate of MoEA, particularly given the DHMS's unique mandate to provide weather, water, and climate services to diverse sectors beyond the mandate of the MoEA. Even though it is a small and relatively new department, the DHMS enjoys strong support from senior officials at the MoEA at the time of writing this report. Also, as discussed earlier, it is a new organization and has historically had several different organizational homes. Given this, at present it is recommended that the focus should be on strengthening the country's monitoring, forecasting, and human resource capacity and on developing the capacity of basic weather and hydrological service delivery. The issue of the institutional location of the DHMS, while important, requires more detailed political economy analysis and consultations, which is outside the scope of this report and can be addressed as a follow-up to this activity.

Box 1 The Department of Hydromet Services

- Develop policies, legislation, and regulations related to hydromet services
- Establish and operate national hydrometeorological network to monitor and collect weather, climate, water, and environmental data
- Set up and operate telecommunication for data acquisition, information dissemination, and delivery of hydromet-related services
- Advance science and technology in weather, climate, and water through research and development
- Participate in the development and operation of national multihazard early warning system
- Fulfill relevant international and regional commitments and further national interest through participation in programs and activities under such agreements and conventions
- Set up and operate data archival, processing, and forecasting system to develop hydromet services for protection of life and property
- Develop capacity in the field of hydrology and meteorology

Source: DHMS 2014a.

Importance of appropriate policies and regulations

There is a need to provide a better policy, legal and regulatory perspective of the DHMS in the context of legal instruments like the National Environmental Protection Act, Disaster Management Act, Water Act, and others that are contingent on provision of effective hydromet services. As suggested by the World Meteorological Organization, most national meteorological and hydrological services (NMHSs) should have a policy and legal framework to guide their activities (see Box 2). At present, however, the DHMS does not have a national hydromet services policy or associated regulations that can support delivery of hydromet services. Absence of a legal framework affects The DHMS's credibility with end users. The process of preparing a policy was recently initiated. Preparation of a legal framework is also needed to validate and legitimize the DHMS's mandate and service delivery goals and to clarify the types of services that users can expect.

The DHMS also does not have a data sharing policy with either internal or external users. It shares data for free on request from various agencies. Interested parties submit a requisition officially through a data requisition form, and the DHMS provides raw data. A data sharing policy could be important for the DHMS because with a cutting-edge open data policy, the department can also lead the way and show how data sharing can improve weather forecasting and climate prediction both for its national purposes and for regional and global weather and climate prediction. The policy can outline types of data, hydromet services, and products that it produces and can be shared; who can have access; the timeliness and relevance of data and information sharing for routine and extreme events; and the contribution to global public goods. Implementing a data sharing policy can also provide guidance on data management and help the DHMS share information in an efficient way internally and with national, regional, and international stakeholders.

Developing a national framework for climate services

As per the WMO-led Global Framework for Climate Services (GFCS) initiative (see Box 3),[13] climate services refer to the provision of climate information that can support decision

[13] For more information, see WMO 2009e and Hewitt, Mason, and Walland 2012.

Box 2 WMO recommendations for national meteorological and hydrological services

Legal, institutional, and multilateral issues

- A legal foundation and the integration of hydromet services into national development policies are essential to successfully implement NMHS.
- Consider all advantages of regional cooperation and work in close collaboration with other NMHSs in the area of data sharing, transfer of capacity, knowledge sharing, training, etc.
- Consider all international agreements on climate services.

Observing, monitoring, and data sharing

- Use standardized system according to WMO's Global Climate Observing System.
- Establish the connection and implement the WMO Information System. A good Internet connection is necessary to efficiently process hydromet data and ensure good communication with other national stakeholders and international partners.
- Feedback from end users is crucial to ensure that hydromet delivery services meet users' needs. It is essential to guarantee a continuous improvement of hydromet services provided by the NMHS.
- Build strong relations with media to enhance service delivery to end users.

Data processing and forecasting

- Ensure good computer resources and equipment and trained human resources to ensure the quality of services.
- Rely on regional specialized meteorological centers, global producing centers, and regional climate centers, which provide useful data and information for implementing activities in the area, such as agriculture, water resources, energy, and health.

R&D and new technologies

- Always consider R&D and the research of the best-suited technologies (hydrological and meteorological equipment, computer resources, etc.) to enhance hydromet delivery services.

Training

- Training is critical for both technical and nontechnical staff and for employees on the field and at headquarters. Training must cover building capacity of technical staff working on hydrometeorological modification and forecasting as well in other sectors such as administrative support and communications.

Source: World Meteorological Organization, "Statement on the Role and Operation of National Meteorological and Hydrological Services for Directors," Cg-XVI, annex to paragraph 11.7.1 of the general summary.

making and allow users to reduce the impacts of climate-related hazards and increase benefits from benign climate conditions. Development of climate services needs to be based on credible information, be responsive to user needs, and have adequate engagement between users and providers (Hewitt, Mason, and Walland 2012).

At present, Bhutan does not have a national framework for climate services. As discussed in Chapter 2, there is significant demand from a range of sector agencies for hydrometeorological and climate services. And as described in Chapter 3, some elements of the framework (e.g., observations and monitoring pillar) are already being developed. However, much needs to be done over the years in developing research capacity for climate services, a historical climate database and real time observation network, climate services information systems, and a user interface platform through collaboration with other sector agencies. Given their impact on the economy and the importance to economic growth and livelihoods, three sectors—disaster preparedness, hydropower, and agriculture—could be considered priority areas for the development of climate services.

Box 3 Global Framework for Climate Services

The Global Framework for Climate Services is a WMO-led initiative that started in 2009. Its objective is to "enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale" (WMO 2009e).

GFCS work at present focuses on four sectors: agriculture and food security, water, health, and disaster risk reduction. GFCS has four main pillars:

- *User interface platform.* This is a provider-user interface that engages users to determine their needs and priorities and the products that will be useful and that identifies capacity development requirements with the aim of using the feedback to adjust research and observational efforts.
- *Climate services information systems.* This refers to a mechanism through which information about past, present, and future climate is routinely collected, stored, and processed to generate products and services across climate-sensitive activities.
- *Observations and monitoring research.* This refers to collection, management, and dissemination of climate observations, data, and metadata.
- *Modeling and prediction.* This pillar focuses on improving the scientific quality of climate information by providing an evidence base for the impacts of climate change and variability and the cost-effectiveness of using climate information.

Capacity development cuts across and is needed for all four areas.

Source: Hewitt, Mason, and Walland 2012.

Organizational structure of the DHMS

Since December 2011 the DHMS has developed an organizational structure that accounts for most of the important divisions and sections common to national hydrological and meteorological service institutions internationally. Quite significantly, it combines meteorological and hydrological sections within the same department, making coordination between forecasting and service delivery easier. This is often not the case (e.g., in Sri Lanka, India, and Bangladesh), which makes coordination between meteorology and hydrology challenging. Figure 7 provides the approved organizational map of the DHMS, although some of these units are not yet in place.

The DHMS Director leads management of the department's four divisions. These include Planning Coordination and Research Division (PCRD), the Meteorology Division (MD), the Hydrology Division, and the Snow and Glacier Division. The Aviation Meteorology Division is still with the Department of Civil Aviation. A Chief heads each of the four divisions. Each division has several sections.

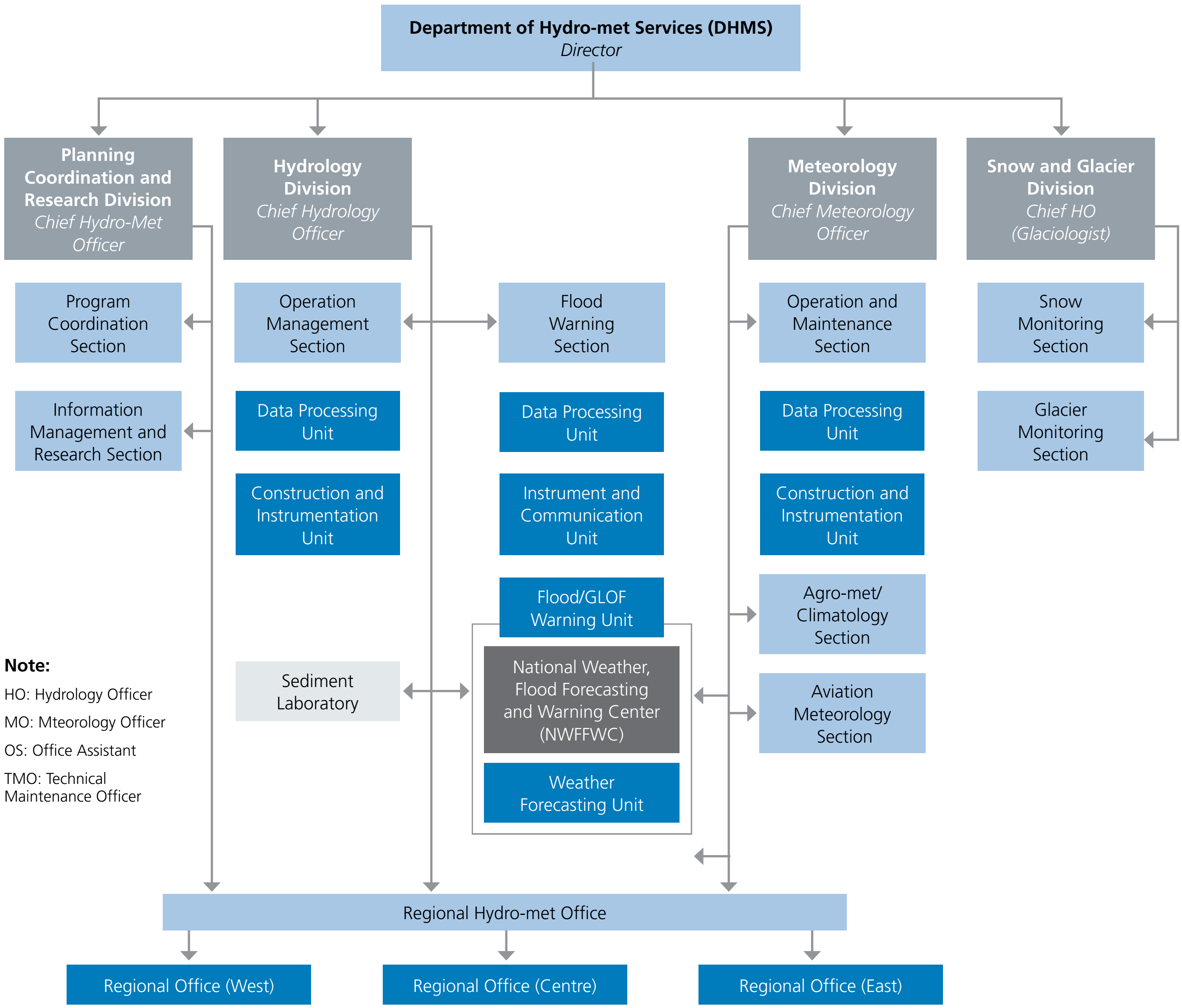
Some adjustments to this organizational structure may be advisable. First, both the Hydrology Division and the Meteorology Division have their own operation and maintenance sections, which is a duplication of effort. A separate division could be established to handle operation and maintenance for all of the DHMS. It could also house the calibration facility. An O&M Division could account for all equipment and support regional centers in their efforts to maintain field equipment. In the future, it could also maintain such systems as upper air and radar.

Second, the approved organogram combines the functions of weather and flood forecasting and warning in the National Weather and Flood Forecasting and Warning Center. There is a substantial difference in these three activities, so combining them does not add value. The Weather Forecast Center would be better off

Figure 7 **Department of Hydromet Services**

Organogram of Department of Hydrology and Meteorology Services (DHMS)
Ministry of Economic Affairs

(Approved by RCSC Order No. RCSC/HRMD/7/2011/316 dated 21 July 2011)



remaining a section under the Meteorology Division, with the River Forecast Center a section under the Hydrology Division. The Warning Center can actually be a section under PCRD, which already handles communication between the DHMS and stakeholders.

Planning, Coordination, and Research Division

As its name suggests, the PCRD is responsible for the important tasks of planning, budgeting coordination, and research at the DHMS. It is also responsible for human resources, staffing, and training. In addition, it is responsible

Table 19 Functions of the PCRD and identified gaps

Functions	Identified gaps
▶ Planning and designing of hydromet monitoring network required for hydropower, flood, and weather forecasting ▶ Prepare fiscal budget (capital works) and five-year plans for the department ▶ Provide technical sanction to implement works by the department ▶ Monitoring and evaluation of department plans, programs, and activities ▶ Database management and quality control ▶ Publication of reports, bulletins, and data yearbook and dissemination ▶ Maintain web page and servers ▶ Act as focal point for releasing hydrometeorological information to national and international agencies and donors through head of agency ▶ Improve methods, procedures, and techniques in hydrometapplication including station network design, specification, and standardization of instruments and database management system ▶ Research related activities on hydrometeorology and water resources, climate change impacts, etc. ▶ Coordinate with other agencies, ministries, and external stakeholders ▶ Evaluate staffing patterns, human resources, and recruitment of technical and support staff in coordination with Human Resources Department, skills training	▶ Inadequate staff for planning and describing stakeholders' needs ▶ Lack of technology and tools for data quality checking and a comprehensive database management system ▶ Lack of staff and software for data integration ▶ Lack of trained staff to fully carry out the functions ▶ Lack of trained staff to fully carry out the functions ▶ Lack of research orientation, staff, technology and tools (models) ▶ Lack of trainers within the DHMS

for data and information management, and communication with stakeholders. This includes processing and archiving hydrometeorological data; maintaining the quality and security of archived data; publishing reports, bulletins, and data yearbooks; maintaining and updating the department's common database, web page, and servers; and being the focal point for releasing hydrometeorological information to national and international agencies.

Several factors constrain PCRD's capacity to deliver on this wide and complex function (see Table 19). First, for PCRD to undertake planning and design activities, it must have a strategic plan. Such a plan is currently under preparation but is not yet in place. Another critical challenge is limited staffing. At present, the PRCD has only eight staff members, and two approved positions are unfilled. With such limited staff, the PCRD is not in a position to fully carry out all of its activities. Further, infrastructure constraints, such as the absence of a comprehensive database management system, limited Internet connectivity, and limited access to software for data integration, constrain PCRD's activities. The division also does not have the capacity and tools (models) to undertake extensive research or the technical skills to do staff training. Strengthening PCRD will be an important part of institutional reform in the DHMS's modernization process.

Meteorology Division

Until a few years ago, the MD catered mainly to the needs of the hydropower sector. Now it is a division under the DHMS and currently operates and manages the surface weather stations and provides a 24-hour weather forecast. Within the MD are the Agromet and Climatology Section and the Aviation Meteorology Section. The MD has 36 approved staff positions at the

Table 20 Functions of the MD and identified gaps

Functions	Identified gaps
▶ Administer and review the implementation of department's meteorological plans, programs, and policies ▶ Provide daily weather forecast information to the public based on observation and study of models ▶ Research and study long-range forecasts; prepare seasonal forecasts (monsoon outlook) annually for information to public ▶ Study/observe extreme weather events such as cyclones and heavy rainfall for press release and timely information to public ▶ Analysis and research works on climatic data for specific purposes ▶ Planning of meteorological network and establishment of new stations; operation and maintenance of existing meteorological network (11 real time AWS, 20 Class A, 61 Class C stations) across the country ▶ Meteorological data collection, quality control, archiving and database management; provide climate data and services to government for planning of developmental activities for specific studies and projects, including in private sector ▶ Data processing in coordination with PCRD for archive in a central database for statistical analysis, dissemination, and publication ▶ Maintain agrometeorology and related information database required for Renewable Natural Resources (RNR) sector in future ▶ Collect and provide aviation forecast services in future	▶ Lack of models and computer resources ▶ WIS link with WMO not yet established ▶ Lack of specifically trained staff ▶ Lack of adequate funds, mobile lab for recalibration, and maintenance and field technical staff ▶ Lack of technology and tools for data quality checking and a comprehensive database management ▶ Agromet section not fully established; aviation meteorology not yet merged with the DHMS

headquarters in Thimphu, of which 16 are filled and 20 are not filled. Currently, the MD has 16 staff at headquarters and 20 field staff (mapped with regional offices) involved in data collection and maintenance of equipment related to the synoptic and climate stations.

Some of the main constraints faced by the MD are listed in Table 20. As with other divisions, these are related to technical, institutional, and financial factors. As discussed in Chapter 3, one main constraint is the lack of sufficient and adequately trained staff. Local universities do not have departments that provide training in meteorology. Even though some sections are organizationally approved, they have limited staff. For example, the Agromet and Climatology section has one staff member and the Aviation Meteorology has no staff assigned. With such limited staffing, it is not possible for these sections to carry out routine weather forecasting or sector-specific climate service delivery.

Moreover, the division's activities are constrained by limited Internet connectivity and a lack of access to an automated observation network, models, infrastructure, and computer resources. Without connection to the WIS link, the MD cannot access global or regional data. Nor can it relay data back to the WIS. All of these factors constrain its services relating to weather forecasting and climate monitoring and prediction.

Hydrology Division

The Hydrology Division is in charge of monitoring and maintaining the hydrology network, sediment sampling, and related operational hydrology activities (see Table 21). It is also responsible for issuing flood warnings and forecasts to mitigate flood-related disasters

Table 21 Functions of the HD and identified gaps

Functions	Identified gaps
▶ Administer operational hydrology plans and programs ▶ Establish hydrological, flood/GLOF monitoring and warning, and sediment sampling stations ▶ Monitor and maintain overall operation of communication facilities ▶ Transmit real-time data from the monitoring stations to Data Processing Unit and also to NWFFWC ▶ Collect low-flow data from east-west tributaries, ad hoc measurements of rivers and streams based on agency requests ▶ Maintain a hydrological and sediment database and undertake primary data processing in coordination with PCRD ▶ Provide timely flood forecasting and warning services to mitigate flood-related disasters ▶ Transmit flood information to the National Emergency Operation Center (Department of Disaster Management), hydropower generation companies, and related agencies ▶ Share and exchange real-time hydrometeorological data with other countries and other regional and international organizations	▶ Lack of funds and technical staff for maintenance; lack of mobile workshop for recalibration, maintenance of equipment ▶ Most appropriate mode of transmission not yet found; lack of funds; recurrent costs ▶ Lack of measurement network ▶ Lack of comprehensive database system ▶ Lack of modeling technology and trained staff ▶ Lack of policy guidelines, coordination mechanism, and standard operating procedure

and early warnings of glacier lake outburst floods; transmitting flood information to the National Emergency Operation Center (at the Department of Disaster Management), hydropower generation companies, and related agencies; and exchanging real-time hydrometeorological data with other countries and regional and international organizations. At present, there are only three HD sections: Operation and Maintenance, Sediment Laboratory, and Flood Warning. Flood/GLOF Warning is one of the Units under the Flood Warning Section. In the approved organizational structure, the National Weather and Flood Forecasting and Warning Centre (NWFFWC) is proposed but it is not yet operational. It was proposed that the NWFFWC will have staff from both MD and HD to work together. Staff from NWFFWC will mainly be from the Flood/GLOF Warning Unit of FWS in HD and from the Weather Forecasting Section of MD.

Operationally, the HD meets its designated functions only partially. As discussed in Chapter 3, at present the FWS under the HD does not produce forecasts but only flood warnings, when river water levels are high.

The HD faces a combination of institutional, organizational, technical, and resource challenges. It has 27 approved staff positions, of which 17 are in place and 10 are not filled. Of the 17 existing staff, 8 are based in Thimphu. Their activities include issuing flood warnings and performing suspended sediment analysis. There are also 75 nontechnical field positions mapped to the HD. The HD relies on them for water level measurements across the country and operation and maintenance of hydrological stations. However, there is a dire need for staff training in a number of areas, including hydrological analysis and modeling (hydrology, flood routing), flash flood analysis, sediment monitoring and data analysis, and dissemination of flood warnings (web-based interfaces). Moreover, the absence of policies, regulations, and standard operating procedures for flood early warning systems limits the division's ability to perform its work.

Further, the HD does not have any modeling capacity and does not perform flood forecasts that extend beyond monitoring water levels and warning downstream users. It suffers

Table 22 Functions of the SGD and identified gaps

Functions	Identified gaps
▶ Formulate polices, plans, and programs related to snow and glacier monitoring in Bhutan ▶ Manage and coordinate the general operations of the snow and glacier monitoring networks in consultation with other divisions of the department ▶ Establish new snow gauging and glacier mass balance stations in the country ▶ Initiate and conduct snow surveys and measurements across country; coordinate with national line agencies pertaining to snow and glacier monitoring works, data collection, etc. ▶ Initiate and conduct studies and research on snow and glaciers ▶ Maintain regional, national, and international cooperation related to cryopshere science, data collection, data sharing, etc. ▶ Provide technical input and support to the RGoB on various issues, strategies, and prospects related to the country's water resources and climate change, especially related to snow and glaciers	▶ Policy to be developed by RGoB ▶ Program not yet started; lack of funds and staff ▶ Lack of funds and staff ▶ Need RGoB policy clarifying roles of different agencies ▶ Lack of technology and tools ▶ WIS link with WMO not established

from a lack of funds and technical staff for maintenance and a lack of mobile workshops for recalibration and maintenance of equipment. The measurement network and appropriate mode of data transmission, as discussed in Chapter 3, also need to be developed. Data storage, management, and processing must also be upgraded through a comprehensive database system and the use of improved modeling technology. Moreover, database software capable of performing time series analysis (including statistical) and modeling software (hydrological, river hydrodynamic, forecasting) needs to be acquired. The division faces an ongoing lack of funds for capital and recurrent costs. The lack of fully functioning regional offices also constrain it.

The DHMS, particularly its Hydrology Division, has strong ties with the government of India under bilateral cooperation agreements. Cooperation between the GoI through the Central Water Commission and Bhutan on data sharing goes back to the 1950s. The Flood Warning Section under the Hydrology Division was set up by the GoI. This section transmits rainfall and river level data for flood forecasting and warning purposes to the Indian states of Assam and West Bengal. The CWC has 15 water level and rainfall stations in Bhutan. They are mainly manual, but GoI is in the process of replacing them with automated stations. The FWS within the Hydrology Division is fully funded by the GoI, which also supports the salaries of about 40 DHMS staff.

Snow and Glacier Division

The SGD is tasked with monitoring the country's snowpack and glaciers. Its programs are aimed at tracking the accumulation and melting of the snow and glacial fields. The SGD is tasked with preparing policies and plans related to snow and glaciers, managing and maintaining the monitoring network, and undertaking surveys across the country (see Table 22). However, being established in 2013, it is the newest division at the DHMS and is not able to fully meet its mandate and faces constraints similar to those of other divisions.

The SGD has 13 approved positions. Of these, 5 are filled and 8 are unfilled. The existing staff undertakes snow and glacier monitoring and analysis, as discussed in Chapter 3. Lack of sufficient staff, resources, monitoring network, and infrastructure make it difficult for officials to systematically monitor glacier change or undertake any related research. The division carries out its functions in a limited way, preparing reports on the status of the snow and glacier fields and making this information available to stakeholders.

Given the importance of snow and glacier monitoring, the need to strengthen this division cannot be underestimated. In addition to strengthening the monitoring network, the division needs additional funds and staff to properly manage and coordinate all operations, such as establishing new snow gauging and glacier mass balance stations; initiating and conducting snow surveys; conducting measurements and data collection; and maintaining national, regional, and international cooperation related to cryopshere science and research. SGD staff also need training to provide technical input and support to the RGoB on various strategies related to the country's water resources and analysis of climate change and variability.

SGD's mandate also links with the Department of Geology and Mines, which has traditionally carried out monitoring and mitigation-related activities with respect to snow, glaciers, and GLOFs and which has expertise in this area. As SGD's capacity on monitoring is gradually strengthened, it can continue to collaborate and coordinate with DGM, which eventually can mainly focus on mitigation-related activities.

Regional and national capacities of the DHMS

At present, the DHMS has approximately 148 staff members, with 53 positions in headquarters and 95 located in the *Dzongkhags* (administrative districts) (see Table 23). All technical positions are at headquarters and are joined by a similar number of nontechnical staff. The field positions are all nontechnical positions.

Most of the technical positions are filled by engineers. There are few university-trained meteorologists, atmospheric scientists, or hydrologists (see Table 24). This is a significant gap because the national hydrological and meteorological service staff has to be trained to cover all basic functions related to weather services, meteorology, atmospheric science, and hydrology.

The total number of DHMS staff as approved in the 10th Five Year Plan is 155. Out of the 7 vacant positions, 4 are engineers and 3 technicians. As information technology support to all departments under MoEA has now been centralized by the Ministry, the approved IT staff person has now been transferred to the Ministry (though is currently on a long study leave abroad). Therefore, at the time of drafting this report, the DHMS was facing problems in maintaining its servers and PCs and upgrading its computing facilities.

Across all divisions at the DHMS, there is a need for training and technical capacity strengthening. As previously discussed, DHMS staff members have little or no access to multiple numerical models that would help forecasters understand the forecasts' uncertainty. Understandably, knowledge of these models is not well known to the MD staff. When products and data start streaming in from international meteorological centers, a gap in understanding how to use and interpret these products will exist.

As the DHMS begins modernizing, and as more data populate DHMS forecast systems, DHMS staff will need training on how to use the information and tools that are part of the forecast systems. A flexible, affordable, and sustainable training program will be required. The capacity building and training effort must be multifaceted and should include a combination of travel

Table 23 DHMS existing staff capacity

		Regional offices			
	Headquarters	Mongar, east	Thimphu, west	Bumthang, central	Total
Director's Office	3	0	0	0	**3**
PCRD	8	0	0	0	**8**
HD	17	24	36	15	**92**
MD	16	7	8	5	**36**
SGD	5	0	0	0	**5**
Pool staff	4	0	0	0	**4**
Total	**53**	**31**	**44**	**20**	**148**

Source: DHMS 2014.

Table 24 DHMS existing staff capacity by professional category

Dept./Division	Engineers / Hydrologists / Meteorologist	Technicians / Non-technical	Admin Support
DHMS	2		5
PCRD	7	1	
Meteorology Division	4	12	
Hydrology Division	9	8	
Snow & Glacier Division	4	1	
Regional offices		95	
Total	**26**	**117**	**5**

abroad, a university degree, in-country focused training, and an eLearning certificate or focused training.

At present, the activities of the DHMS are highly centralized, and there is limited capacity at the regional or basin level. At the time of preparation of this assessment, none of the regional offices had been fully established or equipped. Existing staff members stationed out of the headquarters are mapped to the three regions and to divisions for ease of understanding by the office, which is why they are listed under regions in Table 23. Going forward, the regional offices will need to be established and equipped to facilitate DHMS activities.

The DHMS is planning to establish two regional offices during the 11th Five-Year Plan. These include offices in Bumthang and Mongar that will serve the central and eastern regions, respectively. The office at Thimphu also serves as the western regional office. Regional offices are being constructed with help from the RGoB. The main task of the regional offices is expected to be O&M of the ground monitoring network and sharing data upon request to users regionally. In regional offices, the physical infrastructure (building) with computers and Internet facilities is needed. Further, as the offices are set up, technical staff to supervise gauge readers and data checking and the digitizing of manual data will also be needed. It is expected that these regional offices will be involved in providing outreach to regional stakeholders and be a center of operations for fieldwork in the respective regions.

Table 25 DHMS budget for fiscal years 2012–13, 2013–14, and 2014–15
(in million USD and million Ngultrums)

	2012–13	2013–14	2014–15
RGOB			
Current	USD 0.516 (Nu. 30.947)	USD 0.576 (Nu. 34.575)	USD 0.550 (Nu. 33)
Capital		USD 0.174 (Nu. 10.448)	USD 0.378 (Nu. 22.676)
Development Partners			
Current			
Capital	USD 0.237 (Nu. 14.215)	USD 0.571 (Nu. 34.242)	USD 1.426 (Nu. 85.586)
GOI (flood warning activity)			
Current	USD 0.230 (Nu. 13.794)	USD 0.233 (Nu. 14.009)	USD 0.222 (Nu. 13.31)
Capital	USD 0.112 (Nu. 6.695)	USD 0.149) (Nu. 8.94)	USD 0.227 (Nu. 13.61)

Note: Conversion rate of 1USD = Nu. 60

DHMS resources and budget

The overall planning is based on guidelines and policy framed by the Gross National Happiness Commission, which is the central planning agency of the RGoB. The planning takes place for a duration of five years and the priority is based on the national goals and interest of the nation, the DHMS's mandates, and the availability of resources and capacity. In line with the 11th Five-Year Plan, the department is also directed to prepare a five-year Human Resources Development master plan to make available long- and short-term trainings that are relevant to the department and to individual officials.

The DHMS was established in 2011. Its budget for the financial years 2012–13, 2013–14, and 2014–15 is provided in Table 25. The budget is divided into current and capital. The budget comes from three sources: RGoB, development partners, and the government of India for the flood warning activities.

The budget under the heading "current" includes staff salary and allowances and under the heading "capital" includes O&M of existing works / equipment and new works. In the FY 2012–13, no RGoB budget allocation was made against capital expenditure due to the fact that

Figure 8 DHMS budget
(in million USD)

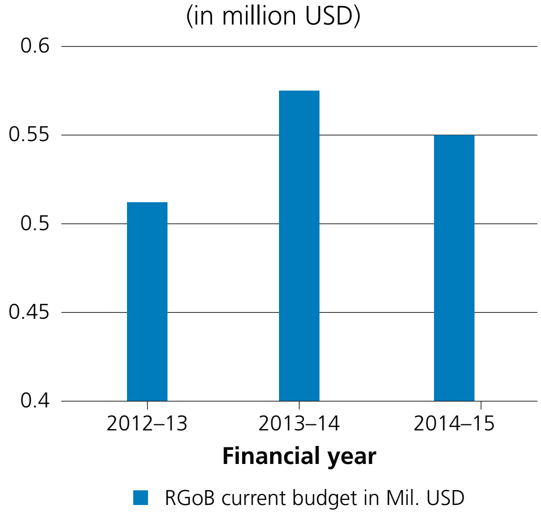


Figure 9 Funding allocations on capital expenditures
(in million USD)

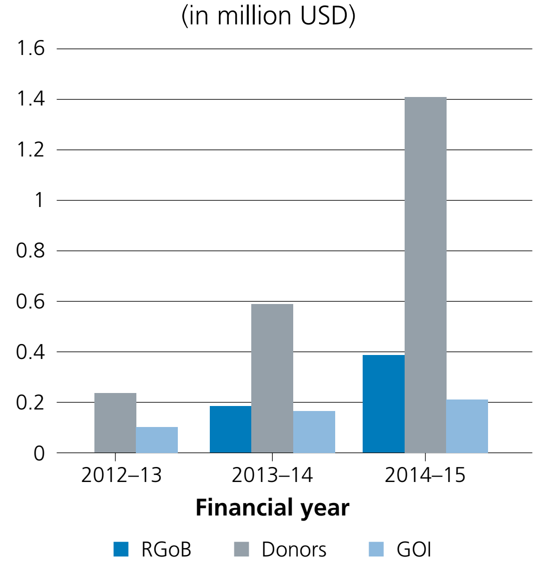
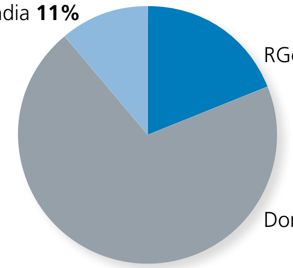


Figure 10 Capital Budget of the DHMS for FY 2014–15



the government had been dissolved and the new government did not consider this provision. In 2013–14, the capital budget for the new Glacier and Snow Division was introduced. The 2014–15 donor budget includes USD1 million (Nu. 60 million) from the UNDP / NAPA project and USD0.361 million (Nu. 21.63 million) from the Mangdechhu Hydroelectric Project. Budget figures from other donor programs that are directly implemented by donors (JICA, Finnish Meteorological Institute) are not available from the DHMS. Similarly, expenditures of other cooperative programs (ICIMOD, NORAD, the U.S. Agency for International Development) are not accounted for in the DHMS budget.

Figure 8 shows the trend of RGoB budget allocation on current expenditures in three fiscal years. Figure 8 shows that the operation and maintenance budget for the DHMS is very limited, and in 2014–15 it was approximately USD0.550 million (Nu. 33 million). As the DHMS modernizes, increasing the operation and maintenance budget and the budget for current expenditures will be critical to long-term sustainability of hydromet systems and delivery of services. Without this, modernization efforts could be jeopardized despite RGoB and development partner investments in capital expenditures.

As Figure 10 shows, for the Fiscal Year 2014–15, out of the total capital budget of USD 2.12 million (127.21 million NU), donor contributions cover 70 percent, the RGoB contribution is 19 percent, and the remaining 11 percent is from the government of India. Thus over 80 percent of the capital budget came from external sources—showing the high reliance of the DHMS on external support for capital expenditures.

Many of the water- and weather-related hazards and climate risks that Bhutan faces have regional dimensions. Examples include tropical cyclones that severely affect Bhutan and also Bangladesh and the eastern coast of India; severe thunderstorms that commonly affect Nepal, Bhutan, India, and Bangladesh; and flooding between Bhutan and northeast Indian states. Further, the monsoon system that brings over 70–80 percent of water to South Asia over the summer months has a major influence on key productive sectors such as agriculture and hydropower in Bhutan and in other countries in the region. Small variations in the timing and quantity of monsoon can have a major impact on agricultural productivity in several South Asian countries. For transboundary weather-related risks, it makes sense for Bhutan to collaborate with neighboring countries and to build on tools and forecasts already available regionally and in the public domain instead of building that capacity from the start.

At the regional level, the DHMS is already collaborating and partnering with neighbors. As discussed, the DHMS has long-standing bilateral collaboration with the GoI on sharing flood-related data and warnings. The DHMS also collaborates and uses products issued by the Indian Meteorology Department for weather forecasting. Given the impact of Cyclone Aila on Bhutan's economy in 2009, it will be important for RGoB to collaborate with IMD, build on regional tropical cyclone forecasts already issued by IMD, and tailor them to Bhutan's context and conditions.

Bhutan is also part of several ongoing pilot regional initiatives. This includes participation in the WMO-led and IMD-coordinated South Asian Climate Outlook Forum (SASCOF)

Table 26 **Activities by regional resource centers that can benefit the DHMS**

Regional Resource Center / Partner	Activities done by regional resource center / partner	Activities the DHMS can strengthen in cooperation with regional partners
BMD, IMD	Tracking of tropical cyclone, landfall, real-time satellite image analysis, modeling	Analysis of impact of landfall in Bhutan, warning of heavy rainfall and extreme wind conditions
IMD, NCMRWF (India), RIMES (Bangkok)	Weather forecasting, climate modeling; numerical weather prediction, short-, mid-, and long-term forecasting (QPF, temperature)	Down-scaling, producing resolution outputs, QPF for catchment-wise flood forecasting in Bhutan, temperature for snow melt modeling; capacity building
ICIMOD	Mapping and monitoring of glaciers using remote sensing, GLOF analysis, and modeling; capacity building HKS HYCOS, regional flood outlook	Land-based monitoring (glacier, snow), GLOF monitoring and warning, capacity building in cooperation with ICIMOD in glacier monitoring with remote sensing tools; coordination with DGM Flood forecasting, capacity building
WMO	Regional synoptic data sharing via WIS, global satellite-based meteorological data, products, forecasts; flash flood guidance system	Meteorological forecast in Bhutan, data sharing via WIS, implementation of flash flood guidance system in Bhutan (localization)
BIMSTEC, SDMC, SMRC	General regional cooperation in hydrometeorology and climate-related information	Enhanced regional cooperation, data sharing and using data in the public domain, capacity building
CWC (India)	Flood monitoring and warning in Bhutan and India	Improved flood forecasting and warnings in Bhutan
AIT (Bangkok)	Provision of technologies (JAXA), capacity building	Obtain real-time Modis data, capacity building

process. Regional Climate Outlook Forums were established over 10 years ago by WMO and bring together national, international, and regional experts and officials from national hydromet agencies to produce regional climate outlooks. The recently concluded session of SASCOF, for instance, discussed the various climatic features that may influence the South Asian summer monsoons.

Another regional activity that the DHMS participates in is the pilot Severe Thunderstorm Observation and Regional Modelling program being carried out under the South Asian Association for Regional Cooperation and led by the IMD. The program focuses on better understanding of the Nor'westers that result in severe damages and commonly affect India, Nepal, Bangladesh, and Bhutan. While the DHMS is already working with this program, this collaboration can be further strengthened.

By developing its own monitoring, forecasting, and human resource capacity, the DHMS will be able to make better use of information that is already readily available in the public domain.

Some of the key regional resources available to the DHMS are listed in Table 26. Also presented are activities carried out by the regional resource centers / partners and possible activities that can be done by the DHMS to improve hydromet information and products for Bhutan.

International and regional meteorological centers can be of great help to the DHMS. A number of very costly tasks are better handled at the international level or at the South Asia regional level. However, it needs to be clarified that not all solutions can be found at the regional and international centers. A national hydromet agency such as the DHMS is required and has a pivotal national mandate, including engaging in the feedback process with in-country local stakeholders; improving local forecasts based on local experience, which also involves the development of a forecast verification scheme to more completely understand trends and bias; and supporting early warning systems, which requires a local presence and extreme focus on conditions over local areas.

Some of the activities that a regional meteorological center can provide for Bhutan and other South Asia countries include the following:

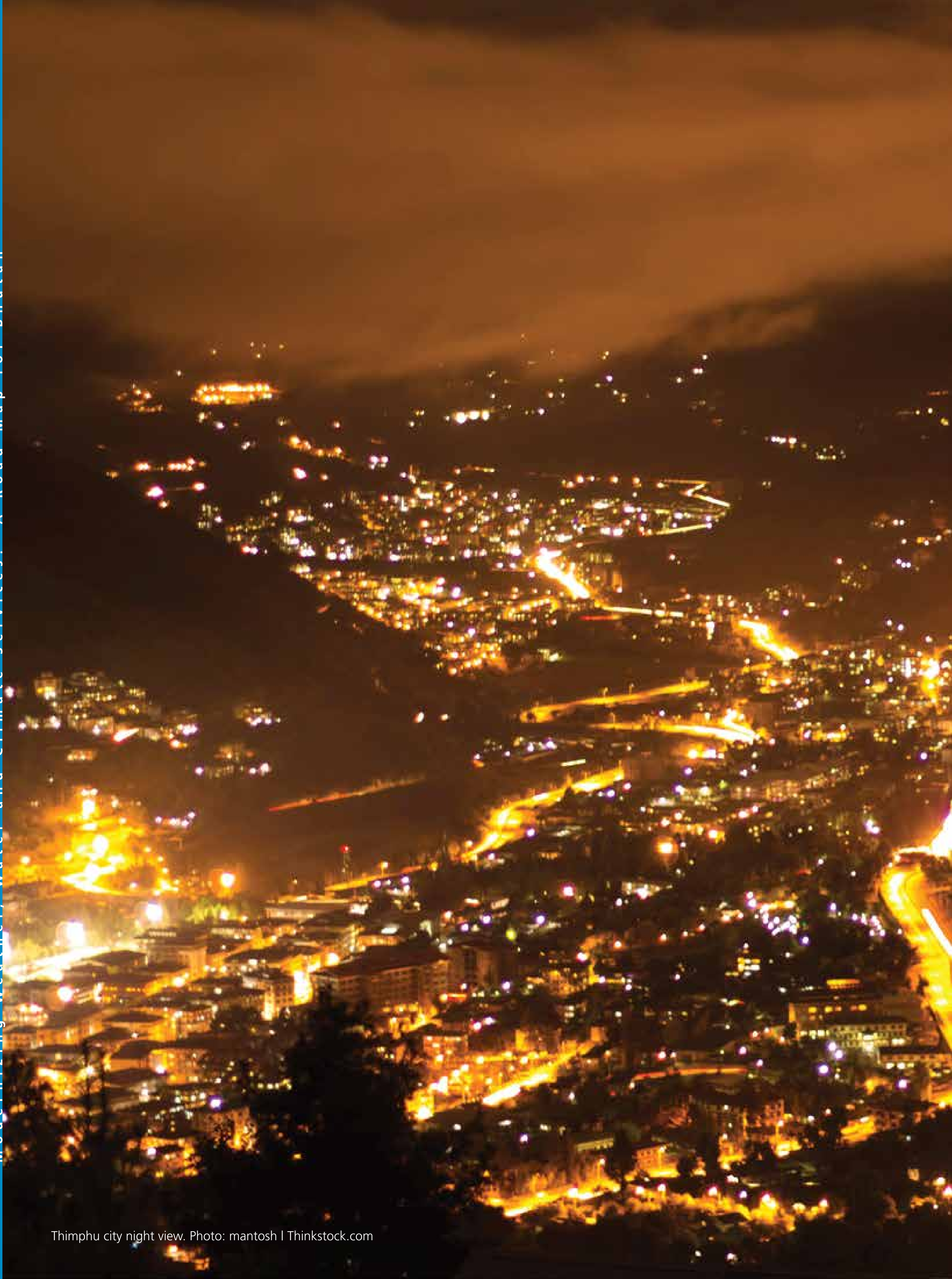
- Running numerical weather prediction models at the mesoscale level for all countries in the region, including producing mesoscale model quantitative precipitation forecast up to 15 days in a gridded form for all countries in the region; producing all mesoscale model output statistics to the national meteorological centers
- Collecting and sharing remote sensing data, such as satellite pictures with country-level zooming for each country in the region. Other satellite products, such as products from Tropical Rainfall Measuring Mission and other satellites; radar products collected throughout the region; lightning products collected throughout the region
- Current weather-related events such as extreme weather advisories; reports of ongoing hazardous meteorological and hydrological events among regional countries (e.g., tropical cyclones, thunderstorms); monsoon onset and retreat; regional climate outlooks

Regional meteorological center activities are often the most difficult ones to perform for a small national hydrological and meteorological service with a conservative budget, which is why collaboration and partnership with a regional center can be successful. Rather than numerous countries engaging in what would be costly and technologically prohibitive activities alone, a regional center can address this. The regional center can take on highly technical and costly exercises, such as numerical weather prediction (which, for instance, would be of great value to the DHMS).

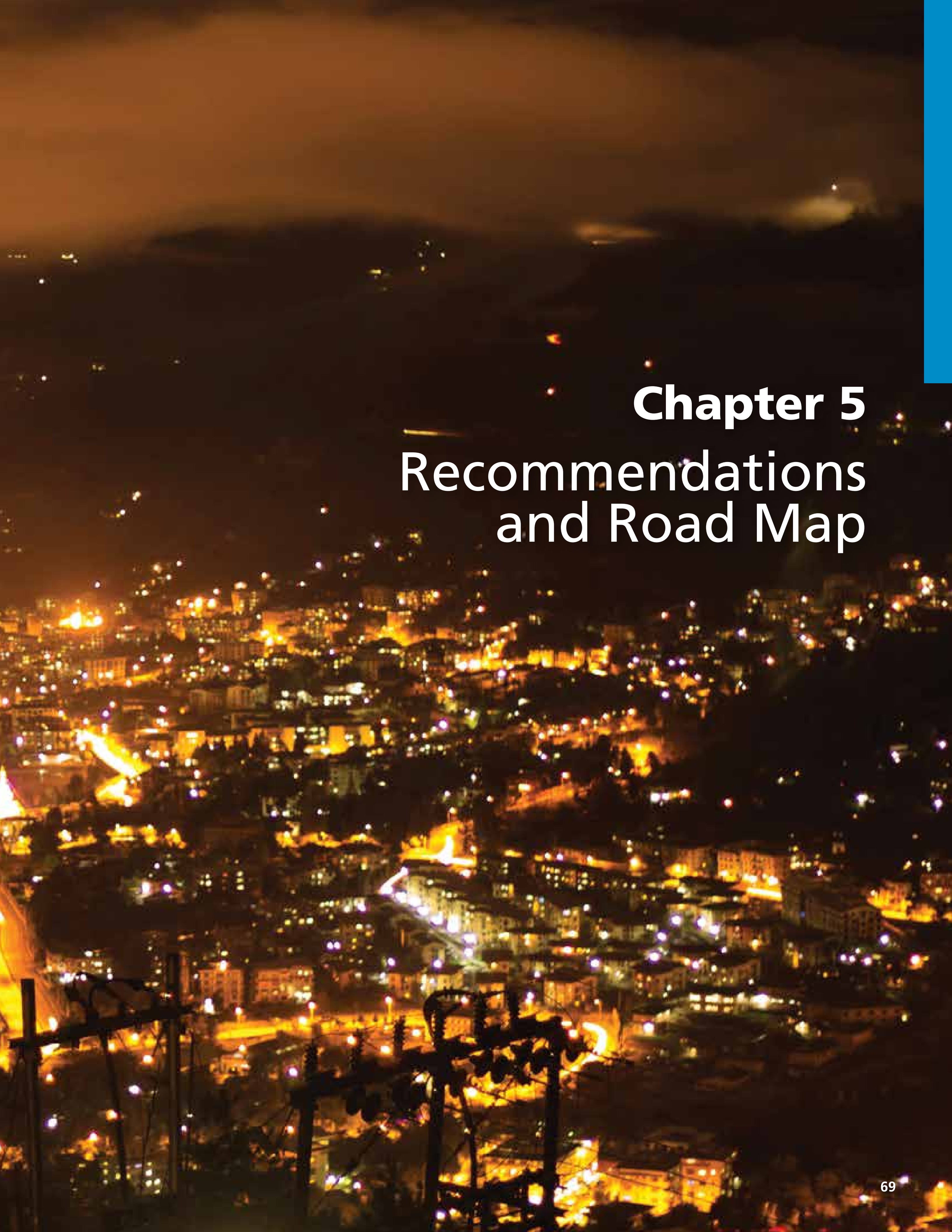
This does not mean the regional center would be making forecasts for Bhutan but it would move the numerical weather products and model output statistics to the countries in the region. The DHMS could then analyze this information and add local forecasting techniques to provide a high-quality national forecast. The regional countries can adapt the data to their own situations and apply model tendencies and biases in providing the best forecast. Regional meteorological centers can also be useful in providing training, including distance learning and web-based training. Numerous regional meteorological centers serve regional interests, such as climate centers, tropical cyclone warning centers, and specialized meteorological centers. The development of strong mechanisms of cooperation with these can be another key to the success of the DHMS.

Summary

In line with the 11th National Five Year Plan (2013–18), the overall objective of capacity strengthening is to transform the DHMS from a "data collecting agency" into a "reliable and credible hydromet service provider." As this chapter highlights, for the DHMS to move from the former to the latter, several issues need to be addressed. The DHMS needs to develop a systematic process of assessing user needs, prepare a strategic plan based on user needs and demands to guide its planning processes, put in place an adequate policy and regulatory framework, improve its technical and human resource capacity by filling approved positions and investing in training its existing staff, invest in infrastructure with a focus on service delivery, and improve its operational budget to ensure that investments in monitoring, forecasting, and service delivery are sustained over the long run. ■



Thimphu city night view. Photo: mantosh | Thinkstock.com



Chapter 5
Recommendations and Road Map

As discussed in previous chapters, DHMS is a relatively new agency. The services it is mandated to provide are critical to the long-term sustainability of key economic sectors in Bhutan. Hence, modernization of the DHMS and strengthening its service delivery mechanism in coordination with user agencies is essential. With development partner support, the DHMS is already in the process of upgrading its observation network and infrastructure. It also has many of the key organizational elements of a national hydrological and meteorological agency. However, for the DHMS to build its technical capacity and transform itself into a well-resourced service delivery agency, much remains to be done. Based on the analysis in this report, this chapter concludes with some recommendations and a "road map" for modernization—and how these activities can be sequenced.

While the process of modernization will inevitably be an iterative, gradual, and long-term process, several actions can be undertaken in the short to medium term to facilitate this by building on ongoing development partner–supported activities.

Short-term actions (one to two years)

1. Prepare strategic plan based on user needs

For the DHMS to transition from primarily data collection to a modern service delivery agency, the department should institutionalize a systematic planning process based on consultation with stakeholders. To aid this process, a priority action for DHMS is to institutionalize a systematic process of assessing demand from key stakeholders and delivering services tailored to these needs. This can be done through discussions with them and user surveys. The plan should have clear goals, targets, and indicators for the plan period, so that key outcomes can be measured. Indicative budget and estimates for O&M should be spelled out. There are many important users of DHMS products and services, including hydropower, agriculture, tourism, infrastructure, disaster risk management, and aviation. The DHMS will need to work in collaboration with these sector agencies to strengthen its capacity for service provision and to build information and decision support systems to cater to those needs. Service provision in response to user needs can also allow the DHMS to explore the potential for generating revenue. The planning process should be iterative and ensure that services cater to user needs and have adequate staff and O&M budget to ensure that they are sustainable over the long run.

2. Strengthen DHMS IT assets and infrastructure

To enable the DHMS to do more right away with existing capacity, a key priority is acquisition and installation of WIS and reliable high-speed Internet. The WIS provides communications to the international observing community through the WMO. This will be the source of data and numerical weather prediction products that the DHMS can use to develop forecasts and deliver high-quality information to stakeholders. Access to a high-speed Internet connection is also critical and must be dedicated to operations at the DHMS. These communication facilities will enable the DHMS to further explore the integration of satellite/earth observation data products that are becoming increasingly powerful and important—perhaps by linking with, for example, NASA/NOAA/USGS/ESA. DHMS headquarters should have a minimum of two Internet connections, preferably operated by different providers. A possible path for the second Internet connection could be space communications. Internet connections are also required for the regional offices, of which two are planned (in addition to the one at Thimphu). The combination of adding WIS (and software that uses the WIS data stream) and high-speed Internet will improve substantially the operations and services the DHMS can provide. The development of IT assets has a high priority because data and products will be used by various sectors. This will also require a strengthening data management so that data can be retrieved and transformed to build sector-specific products.

In addition to access to information technology hardware and software and access to the Internet, numerous improvements in infrastructure will be required to move the DHMS forward in developing improved services. This includes items such as database server, webserver, data processing server, meteorological forecast system server, hydrological forecast system server, personal computers, routers, switches, etc. It also includes facilities such as buildings, office equipment, vehicles, and miscellaneous items used in performing activities expected of a NMHS.

3. Focus on high-priority monitoring systems

The DHMS is currently in the process of upgrading its meteorological and hydrological ground monitoring network with development partner support. This is an important process and should be completed. In the short term, targeted monitoring systems based on user needs, that can provide quick important benefits should be prioritized. For instance, there is a significant need to acquire instrumentation at Bhutan's airports to ensure aviation safety in the challenging meteorological conditions. In particular, windshear alert systems and ceilometers are required. This instrumentation is necessary to assure aviation safety and is warranted for immediate purchase.

4. Improve basic weather and hydrological forecasting

Another immediate priority area for the DHMS is to improve its forecasting services, both basic weather forecasting and also hydrological and flood forecasting. This can be done through investments in hardware and software, appropriate modeling tools, acquisition of infrastructure (especially workstations), and associated training for DHMS officials. Currently the Meteorology Division performs a single 24-hour weather forecast for various cities throughout Bhutan using a relatively primitive template to provide forecasts. There is no forecast verification system in place. This important public service should be improved. The Hydrology Division issues only flood warnings and does not issue any flood forecasts. Another important priority for the DHMS would be strengthening hydrological and flood forecasting services.

Improvements to the Meteorology Division will include the design and acquisition of a forecast system. A typical forecast system would include several workstations that will be able to stream forecast models and data from regional and international meteorological centers over WIS and the Internet. The workstations and associated processes will give the Meteorology Division the capability to develop longer-range weather forecasts and climate predictions.

Hydrological forecasts are highly dependent on meteorological forecasts to achieve useful hydrological forecast lead time, which is driven primarily by quantitative precipitation forecasts (QPFs). Hydrological forecasting requires improved rainfall forecasts in the near and extended range. The Hydrology Division is a stakeholder of the Meteorology Division. Thus, strengthening the Meteorology Division will have important benefits for strengthening the Hydrology Division, without which the latter would not have the necessary information to make high-value-river forecasts. After a robust weather forecast service is developed, a series of products can also be developed to service a wide array of stakeholders and users. The Hydrology Division is also responsible for improving groundwater and surface water quality measurements. Follow-up studies need to be done to design appropriate networks to efficiently monitor groundwater and water quality.

5. Pilot end-to-end early warning systems

Monitoring and forecasting are but one part of strengthening end-to-end early warning systems. The latter includes risk assessments, monitoring and forecasting, communication of warnings to communities, and the capacity of local communities to respond to those warnings. EWSs are critical for disaster preparedness. These tasks cut across several agencies including the DHMS, DDM, DGM, district and local agencies, and communities. While strengthening multihazard end-to-end EWS in Bhutan is likely to be a medium- to long-term process, it is recommended that in the short term, the DHMS collaborate with the DDM to pilot end-to-end EWS in selected hotspot districts or areas. Selection of hotspot areas should be carried out in coordination with other agencies.

6. Develop training plan and staff training in key areas

As the DHMS expands and modernizes its services, adequate staff with relevant expertise will be critical in carrying out its mandates and services. To address this, in the short term, a training plan based on needs assessment should be developed for training staff in important areas such as expanded weather and hydrological forecasting; the management of data and information; activities related to monitoring snow, glaciers, and GLOF; and the provision of services to users. The training program should be flexible, affordable, and sustainable. It can include a combination of travel abroad, university degree, in-country focused training, eLearning certificate or focused training, and so forth. Staff development in terms of acquiring degrees will be a lengthy process, thus in-country to the extent possible should be utilized. Table 27 presents a list of topics where training is suggested.

Table 27 Recommended areas for training

Subjects for Training
Aviation meteorology
Climate modeling, analysis
Convective weather
Emergency management
Fire weather
Glacial science related to GLOF and glacier monitoring
Hydrology and flooding
Mesoscale meteorology
Monsoon meteorology
Mountain meteorology
Preparing hydrological forecasts
Preparing national meteorological forecasts
Quality management
Quantitative precipitation forecast/ Quantitative precipitation estimates
Radar meteorology
Satellite meteorology
Tropical meteorology: cyclones
Use and calibration of hydrological models
Winter weather

Numerous distance learning programs can also augment and reinforce other forms of training. The advantage of distance learning is that these programs come at no cost aside from the staff time. Examples of distance learning programs are listed in Table 28.

Experience from other countries suggests that the DHMS may need to send some staff for post-graduate degrees (as was done in Mozambique) and give considerably more time to institutional adjustments. While it waits for trained staff to return, it may also need to rely more on twinning arrangements with other Meteorology services. Regardless, the adjustments in the DHMS's work force are likely to be major. Neglect of this important issue often delays modernization of hydromet services despite intensive donor efforts and investments.

Table 28 Distance learning programs

Environmental Satellite Resource Center	http://www.meted.ucar.edu/esrc/
EUMETSAT Training Library	http://www.eumetsat.int/website/home/Data/Training/TrainingLibrary/index.html
EUMETRAIN Training Resources	http://eumetrain.org/resources.html
MetEd (Education and training resources produced by the COMET Program)	https://www.meted.ucar.edu/index.php
VLab Virtual Resource Library	http://www.wmo-sat.info/vlab/virtual-resource-library/
WMO Commission for Aeronautical Meteorology Resources	http://www.caem.wmo.int/moodle/
WMO Education and Training Programme	http://etrp.wmo.int/moodle/

7. Develop a long-term program for monitoring Bhutan's cryosphere

Glaciers are one of Bhutan's greatest natural and water resource assets while also serving as an indicator of climate change and variability. Strengthening of snow and glacier monitoring and analysis is necessary for planning adaptation to climatic variability and improved assessment of GLOF-related disasters. While regional agencies such as ICIMOD have undertaken highly valuable monitoring work, government capacity remains weak and should also be strengthened. A comprehensive program for monitoring Bhutan's cryosphere should be developed. In the short term, the DHMS can start with prioritizing key glaciers to be monitored, the combination of techniques to be used for such monitoring, and the development of short-, medium-, and long-term implementation plans. The government should then invest in monitoring in a phased manner through a combination of techniques (ground monitoring, remote sensing, etc.), ensuring sufficient budget for sustaining this system. It should also gradually build capacity for assessing glacier change and impact on major sectors such as hydropower and agriculture.

In parallel, staff capacity and skill at the DHMS's Snow and Glacier Division should also be strengthened to allow monitoring and assessment of priority glaciers. In doing so, the SGD should coordinate with the DGM, which historically has had significant expertise in glacier monitoring. DGM staff with these skills can also provide increased support to SGD as organizationally possible.

8. Develop plan for regional collaboration

Bhutan has a long-standing history of collaboration with its neighbors, particularly India, on weather- and water-related information. This collaboration can be expanded, particularly given the DHMS's capacity constraints. Climate and weather patterns facing Bhutan are transboundary and are best monitored, understood, and predicted by taking a regional and global perspective. Moreover, there is a demand for Bhutan-specific data from regional centers and a demand for regional products and information that the DHMS can use. Collaboration has significant economies of scale for a young organization such as the DHMS. Areas for regional collaboration should be discussed through regional consultations and can include partnership on training, forecasting, EWSs for low-frequency, high-impact events, such as cyclones, and so on. Consultations to further strengthen regional collaboration can take place in the short term and continue in the medium and long term.

9. Strengthen sector-specific hydrometeorological and climate services

Based on an assessment of sector-specific user needs, in the short term, decision support systems and climate services in one to two targeted priority sectors such as agriculture, hydropower, and infrastructure should be developed. This will involve extensive engagement with selected agencies, improved monitoring of data relevant to those sectors, design and installation of decision support systems, development of sector-specific products, and dissemination to stakeholders and communities.

Medium-term actions (three to five years)

10. Prepare a policy and legal framework for DHMS operations

The DHMS at present does not have a policy and regulatory framework to guide its activities. Development of a national hydromet legal and regulatory framework will help the department clarify its goals and mandates, provide clarity on its roles and responsibilities, accord it legal authority for its activities, and facilitate allocation of resources. A hydromet legal framework will also help the DHMS demonstrate how it will meet its obligations under various international agreements and WMO conventions. Concurrently, more-specific policies such as for data sharing should also be prepared. Since hydrometeorology is a transboundary issue, it is also important that the RGoB take into account cooperation with neighboring countries and WMO when building the legal framework. The policies and legal framework should be consistent with established guidelines and recommendations for national hydrological and meteorological service operations proposed by the WMO.

11. Fill approved staff positions that are vacant

In most DHMS divisions, staff capacity is limited, and many of the approved positions are not filled. Out of a total of 195 approved positions, 148 were in place at the time of preparation of this report. This makes it very difficult for the divisions to fulfill their mandate. In the medium term, all approved positions that are still vacant should be filled to keep pace with modernization of services and be adjusted on an ongoing basis. Table 29 shows divisions and technical skills where staff capacity needs to be strengthened.

As Table 29 shows, the Meteorology Division at present has 36 staff positions but only 16 of these are currently filled. It is important that these positions be filled as the DHMS moves forward in improving its weather forecasting services. The increase of staff with relevant technical expertise will allow the Meteorology Division to develop skills in the interpretation of numerical weather forecasts and aid the development of forecasts up to and beyond 15 days. Also, this will allow the weather forecaster to develop forecasts for severe weather, which are not performed at this time. DHMS staff has little or no access to multiple numerical weather models that would help weather forecasters do their job. Many of these products are or will be available from meteorological centers from around the world. As products and data start streaming in from international meteorological centers, the DHMS will need capacity to use and interpret these products. Strengthening of the Meteorology Division, specifically forecast services, will also be vital to the improvement of all other science divisions and will help support the development of flood and flash flood forecasts in the Hydrology Division.

Similarly, capacity strengthening of the Hydrology Division is also needed so it can address river forecasting for flood management and reservoir operations. The newly trained or new staff will need to be focused on hydrological forecasts using models such as those from the Hydrologic Engineering Center (U.S. Army Corps of Engineers). These staff will calibrate models and run them. Hydrologic forecasters and analysis plus support personnel will be needed. They will refine rainfall predictions so that forecasts can extend beyond the current 24 hours. Additionally, as the Hydrology Division moves to expand and modernize

Table 29 Human resource and skills gaps

Office/division	Total approved positions	Existing positions	Gap (+/- from existing)	Comments/Skills Needed
National Office at Thimphu				
Office director	3	3	0	n.a.
PCRD	10	8	2	Additional staff with skills in Information technology, human resources, training officer, technicians would be advantageous
HD	29	17	12	Skills needed include Hydrologic forecasters, hydrologic analysis and support, meteorologists/hydrologists, technicians. This could be addressed by training existing staff and filling approved positions.
MD	36	16	20	Skills needed include meteorologists, weather forecasters, synoptic meteorologists. This could be addressed by training existing staff and filling approved but vacant positions.
SGD	13	5	8	Division can be strengthened by adding Glacier scientists, snow hydrologists, and technicians by filling approved but vacant positions..
Central Technical and Logistics Division (formerly Centre Store and Repair Unit)	1	1	0	Meteorology/hydrology officer, meteorological/hydrological technicians .(instrumentation). Here the number of approved positions should be increased to address skill gaps.
Subtotal	**91**	**49**	**42**	
Regional offices				
Regional office, east	32	31	1	
Regional office, west	43	44	-1	
Regional office, central	26	20	6	
Subtotal	101	95	6	
Pool staff	3	4	-1	
TOTAL DHMS	**195**	**148**	**47**	

the hydrological network, hydrographers (hydrological technicians) will be required to manage the automated network and make river discharge measurements required for the river forecasting process. It is recommended that the hydrographers establish office space at the regional offices.

12. Enhance the observation network based on assessments of user needs

Table 30 is a summary of the DHMS's existing and planned observation network infrastructure. Once the DHMS has assessed user needs in priority sectors/ or hotspot areas within the country, there will likely be a need to enhance the monitoring and observation system in those areas to address user needs. Further, in the process of hydrological forecast development, requirements for additional rainfall and water level data may be identified. These systems can be enhanced after the ongoing development partner–supported upgrading has been completed. Based on analysis carried out in this report, it was determined that there are numerous gaps in the DHMS observation network. For instance, it does not undertake

Table 30 DHMS observation network enhancement

Infrastructure	Existing	Donor planned	Additional to be based on analysis of user needs
Hydromet observing and warning systems			
Automatic weather stations	11	60[1] 1[2] ?[3]	TBD
Automatic water level stations	16	39[1] ?[3]	TBD
Automatic full climate stations	0	0	TBD
Climate stations (manual)	61	0	0
Automatic agromet stations	0	0	TBD
Automatic fire weather stations	0	0	TBD
Automatic groundwater stations	0	0	TBD
Automatic water quality stations	0	0	TBD
GLOF stations	6	0	TBD
GLOF siren stations	17	4[2]	TBD
GLOF warning systems	1	2[2]	TBD
Other early warning systems	0	0	TBD
Radiosonde	0	0	1 (estimate)
Weather radar	0	0	1(estimate)

[1] NAPA 2 Project.

[2] JICA: pilot GLOF warning system along Mangde Chhu River upstream of Trongsa and Chamkhar Chhu River upstream of Bumthang will receive two AWLS.

[3] HYCOS: not expected to be more than five stations.

Note: A "?" in any field implies that this number is unknown at this time and will need to be determined through further analysis as a follow-up to this report.

upper air observations. Also, there is no weather radar in Bhutan at present. The choice of equipment, technology, and placement of assets will need to be based on follow-up studies that rely upon a detailed assessment of weather-related threats in damaging weather and flood-prone areas, analysis of user needs for data and information, and close examination of data and station networks. In enhancing the observation network, however, attention should be given not just to user needs but also to costs of operating and maintaining systems such as radiosondes, such that capital investments are sustainable over the long run.

13. Establish DHMS regional offices

In all NMHS organizations, including the DHMS, subnational offices are necessary to support the activities being carried out in the central offices. In Bhutan, these have not yet been established, although there are plans to do so. Establishing these offices is crucial because they will allow the DHMS office in Thimphu to perform operational and maintenance activities on weather and water-level stations. They will also allow for community outreach in helping interpret weather and flood forecasts and will serve as focal points in collecting data on regional weather-related damage. Most important, the regional centers will manage communication between regional stakeholders and the DHMS. This would include distributing forecasts, explaining forecasts, collecting information on regional weather and water events, and forwarding this information to the DHMS. The regional centers will also provide a base for regional operations for other divisions within the DHMS. For instance, hydrographers can be stationed at and operate from the regional centers and can support staff in other DHMS divisions. Regional DHMS offices should be fully operational—with adequate infrastructure, computer and communication facilities, electricity, and staff resources.

14. Strengthen national-level organizational aspects

As discussed, the DHMS is a relatively new organization. As such, its focus should be on strengthening capacity at the national and subnational levels. In the short term, the focus should be on strengthening existing capacity and newer divisions such as the Snow and Glacier Division and also not combining the weather and hydrological forecasting offices, as suggested in the approved DHMS organization structure. Over the long run, further analytic work and consultation can be carried out to assess the best institutional fit for the DHMS.

15. Increase the O&M budget to keep pace with modernization

An analysis of capital and current budget shows that over 80 percent of the DHMS capital budget comes from development partners, including GoI. Moreover, RGoB budget allocated for current costs for the DHMS are about USD550,000 per year. This is not enough if the DHMS improves its observation systems (such as upper air observations) and its glacier monitoring and service delivery. As department modernizes, the current budget will need to increase substantially to ensure that investments in information monitoring and forecasting are sustainable.

16. Expand hydrometeorological and climate services in additional sectors

As part of the assessment of sector-specific user needs in the short term, the demand for specific data, information, and services will be identified. Based on this, decision support systems and climate services in one to two targeted priority sectors such as agriculture, hydropower, and infrastructure should be developed in the short term. This will involve extensive engagement with selected specific sector agencies, improved monitoring of data relevant to those sectors (such as data relevant for agromet services), design and installation of decision support systems, development of sector-specific products, and dissemination to stakeholders and communities. Development of climate services in a few sectors will provide important lessons for expanding and scaling up such services to other sectors, which can be done over the medium and long term. In developing its sector-specific climate services, the DHMS could also consider putting in place a National Framework for Climate Services aligned with WMO's Global Framework for Climate Services.

The key to providing a broad spectrum of products to stakeholders in Bhutan is to automate the product generation to the extent possible. Examples of sector-driven products may include zero to seven-day quantitative precipitation forecasts and a minimum/maximum temperature forecast for agriculture. The concept of automatic data processing and product development can be referred to as the "data factory." This type of product generation is the basis for service delivery to stakeholders in a typical national hydrological and meteorological service.[14] It is recommended that the data factory be developed as a joint activity between the DHMS, stakeholders, and a consultancy service that will guide the architecture of the data factory and build the process resulting in the generation of necessary products.

Figure 11 illustrates the flow of information of DHMS products from origination to the eventual landing place (stakeholders). Development of the data factory will require assessing stakeholder requirements, cataloging these requirements, and building a suite of appropriate products and decision support systems. Information gathered from the stakeholders would define not

[14] The concept of a data factory and the capacity development required to provide these outputs are discussed in greater detail in Benichou n.d. Although the concept is not new, the document describes the general architecture and path to capacity development.

only the product but also the frequency of the product generation and the desired method of transferring the products to stakeholders.

The flow of information illustrated in Figure 11 begins with data streaming in from the DHMS hydromet network and from regional and international meteorological centers. All of this information would be placed in the DHMS data store. From there the information can flow in two general directions. Data used for meteorological and hydrological forecasts can flow to the forecast sections to be used in the preparation of forecasts. The second direction is indicated by the dashed line leading from the DHMS data store directly to the data factory. Examples of data that flow directly to the data factory from the data store include satellite pictures, meteograms, and other products generated by regional and international centers.

The data stream handed off to forecast divisions within the DHMS would be used to produce forecasts and products, just as rainfall forecasts from the Meteorology Division are used to produce flood and flash flood forecasts by the Hydrology Division. Products would be reviewed by DHMS staff before being distributed to stakeholders of that sector. For instance, Agriculture Meteorology staff, under the Meteorology Division, would review all products related to the agriculture sector. The

Figure 11 Transforming data into products and services

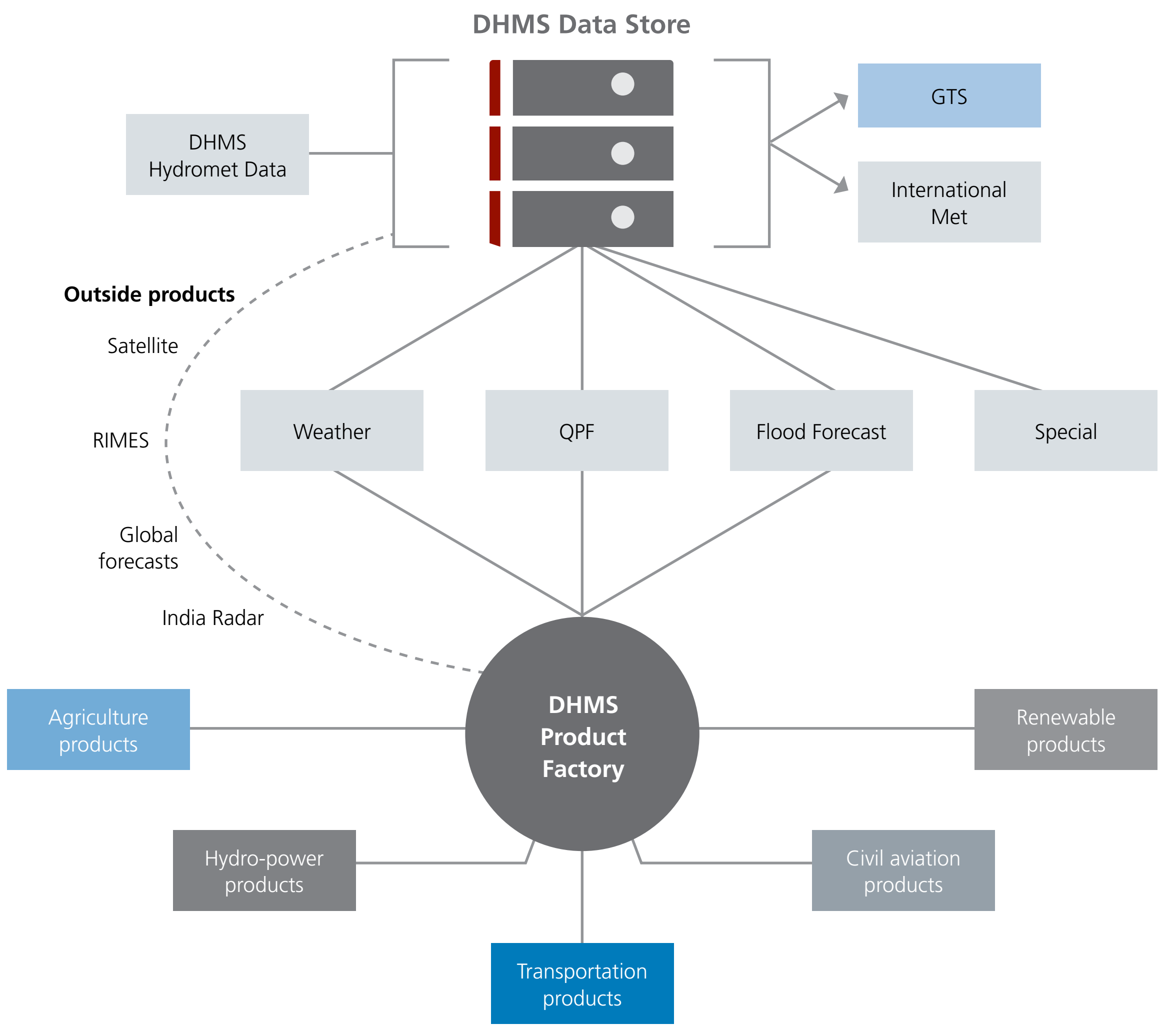


Table 31 **Road map and sequencing activities**

Sequencing of Activities in Number of Months	6	12	18	24	30	36	42	48	54	60
Short- to medium-term actions (1–2 years)										
Prepare strategic plans based on user needs	■									
Strengthen DHMS IT assets and infrastructure	■	■	■							
Focus on high-priority monitoring systems	■	■	■							
Improve weather and hydrological forecasting			■	■						
Pilot end-to-end early warning systems		■	■	■						
Develop training plan and staff training in key areas	■	■	■	■						
Develop a long-term program for monitoring Bhutan's cryosphere	■	■	■	■						
Develop plan for regional collaboration	■	■	■	■						
Strengthen sector-specific hydrometeorological and climate services	■	■	■	■						
Medium-term actions (3–5 years)										
Prepare a policy and legal framework for DHMS operations	■	■	■	■	■	■				
Fill approved staff positions that are vacant	■	■	■	■	■	■	■	■	■	■
Enhance the observation network based on assessments of user needs			■	■	■	■	■	■		
Establish DHMS regional offices			■	■	■	■	■	■		
Strengthen national-level organizational aspects					■	■	■	■		
Increase the O&M budget to keep pace with modernization					■	■	■	■	■	■
Expand hydrometeorological and climate services in additional sectors					■	■	■	■	■	■

skill set needed by the staff operating the data factory would be information technology, with a preferable background in meteorology and hydrology information.

Long-term actions (five years and beyond)

As the DHMS modernizes its institutions, capacity, and services in a phased manner, it should monitor and evaluate how well it is succeeding on meeting targets and indicators. The long-term process of modernization will involve learning from the short- and medium-term investments and experiences, improving on existing services as the DHMS scales up its services.

However, two factors are critical to enable and sustain these activities over the long run: the availability of staff with relevant skills and training to effectively operate and deliver services plus adequate budgetary resources not just for capital investments but also for long-term operation and maintenance. Currently, the DHMS is very much focused on developing technical capacity and infrastructure to cater to modernization of hydromet services in order to fulfill its mandate. At the same time, however, the DHMS is struggling with the budget allocation from the government for maintenance of existing stations. Therefore, the whole process of modernization of hydromet services in order to build the capacity of the DHMS for service delivery should be in a gradual and phased manner.

While the DHMS proposes to strengthen its capacity to improve weather, disaster-related early warning systems, and climate services, it would be crucial for it to present the budget required for maintenance of equipment on a yearly basis and to garner support from the Ministry of Finance to support its needs. Assessing the current expenditures on operation and maintenance of the hydromet system and ensuring operability of future networks is vital to modernization efforts. This effort needs to be accepted with an expected increase in the O&M costs of the observing networks and forecasting systems, with clear benefits of disaster reduction and economic development.

Recognizing the need to have budgetary support for operation and maintenance of newly developed equipment and systems, it would be important for the DHMS to make national as well as local agencies aware of the direct as well as spill-over benefits of modernization of hydromet services to the priority sectors in Bhutan: hydropower, agriculture, disaster risk management, tourism, aviation, construction industry, and transport. The DHMS should also acquire the needed political support and will to put in place the required policies and the legal and regulatory framework that would create the enabling environment for strengthening the department and service delivery. ■

Annex 1: Stakeholders Consulted

Name	Title	Organization
Mr. Choiten Wangchuk	Director General	Department of Public Accounts, Ministry of Finance
Ms. Chuni Dorji	Program Officer	Department of Public Accounts, Ministry of Finance
Mr. Karma Tsering	Director	Department of Hydro-Met Services, Ministry of Economic Affairs (MoEA)
Mr.Karma Dupchu	Chief, Hydrology Division	Department of Hydro-Met Services, MoEA
Mr. Phuntsho Namgyal	Chief, Planning, Coordination & Research Division	Department of Hydro-Met Services, MoEA
Mr. Singye Dorji	Chief, Meteorology Division	Department of Hydro-Met Services, MoEA
Mr. Sonam Dorji	Data Manager, Meteorology Division	Department of Hydro-met Services
Mr. Tayba Buddha Tamang	Meteorologist	Meteorology Division
Mr. Sangay Dawa	Program Officer	Department of Disaster Management, Ministry of Home & Cultural Affairs (MoHCA)
Mr. Jigme Chogyal	Program Officer	Department of Disaster Management, MoHCA
Mr. Lungten Norbu	Specialist	Council for Renewable Natural Resources of Bhutan
Ms. Medon Yaganagi	Dy. Chief Research Officer	Council for Renewable Natural Resources of Bhutan
Mr. Chencho Dukpa	Chief	Council for Renewable Natural Resources of Bhutan
Ms. Kinley Tshering	Chief Horticulture Officer	Department of Agriculture
Mr. G.B. Chettri	Specialist	Department of Agriculture
Mr. Namgay Dorji	Information Management Section Head	Department of Livestock
Mr. Jigme Wangchuk	Chief	Department of Livestock
Ms. Kinley Dem	Forest Ranger	Watershed Management Division, Department of Forests and Park Services
Ms. Kuenzang Om	Agriculture Officer	Watershed Management Division, Department of Forests and Park Services
Mr. Dorji Rinchen	Specialist	Department of Agriculture and Marketing Cooperative
Mr. Thinley Namgay	Chief, Climate Change Officer	National Environment Commission
Mr. Wangchu Namgay	Dy. Chief Program Coordinator, Development Cooperation Division	Gross National Happiness Commission
Mr. Rinchen Wangdi	Chief Program Coordinator	Gross National Happiness Commission
Ms. Miharu Furukawa	Project Formulation Adviser,	Japan International Cooperation Agency
Mr. Yasuhiko Kato	Chief Adviser	Japan International Cooperation Agency
Mr. Sonam Yangley	Director General	Department of Geology and Mines
Mr. Dawchu Dukpa	Chief Seismologist	Department of Geology and Mines
Ms. Pelden Zangmo	Chief, Preparedness and Mitigation Division	Department of Disaster Management

Name	Title	Organization
Mr. Tshering Wangchuk	Program Officer	Department of Disaster Management
Mr. Chencho Tshering	Program Officer	Department of Disaster Management
Mr. Tshering Gyeltshen	Office Chief	Department of Forests and Park Services
Ms. Pratigya Pradhan	Head of Project Department	Druk Green Power Corporation
Mr. Karma Rapten	Assistant Resident Representative	United Nations Development Programme

Annex 2: Donor-Funded Activities[15]

Title	Time Frame	Description		Budget
UNDP-GEF – NAPA 2		**Background**	**Details**	
Addressing the risk of climate-induced disasters through enhanced national and local capacity for effective actions	Three years starting in March 2014	This project has three components: ▶ Risk reduction from climate-induced floods and landslides—This component focuses on protecting economically significant cities from intense floods through on-ground concrete interventions. ▶ Enhanced adaptive capacity at community level—This component will be implemented in four selected districts to fund design and construction of climate-resilient water harvesting, storage, and distribution systems. ▶ Enhanced national capacity for managing climate risks—This component will be implemented by the Department of Hydromet Services (DHMS) with a budget of USD4,410,000 to support improvements in meteorological network coverage as well as water monitoring stations.	This activity will support about a tenth of the monitoring stations needed in the country. The details of activities under the third component implemented by the DHMS are: ▶ Installation of 60 automatic weather stations (AWSs) for which the locations are identified—34 current Class C stations will be upgraded and 26 totally new ones ▶ Installation of 39 automatic water level stations (AWLSs)—11 upgrades and 28 new ▶ Installation of six cable way stations for measuring the river discharge ▶ Mass balancing station—1 ▶ Capacity development of the DHMS—broadly defined in water resources, how to maintain the stations and operation; about 5 percent of total allocation of funds ▶ Detailed study in Wangchhu (Paro, Thimphu, and Haa Chhu) focused on Thimphu Chhu, starting from Lingzhi and ending at Bunakha or Chunzom—such as for flood forecasting, high flood and water availability in the river, trend of flow and volume change over seasons and years; analysis from data of 20 years till date will be used to make projections; early warning stations will also be installed for multihazards such as flash floods and glacial lake outburst flood (GLOF) ▶ Off-site data backup security system in some offices	USD4,410,000

[15] This table is based on best available information at the time of writing this report. Contents of this table will need to be updated as development partner activities evolve.

Title	Time Frame	Description		Budget
UNDP-GEF – NAPA 2		**Background**	**Details**	
JICA				
Capacity development of GLOF and rainstorm flood forecasting and early warning	Three years starting in October 2013	The main purpose of the project is to: ▶ Enhance capacity of the DHMS and related agencies on GLOF/ rainstorm flood risk assessment, development planning, disaster prevention, flood forecasting and warning as well as emergency information sharing among relevant agencies. ▶ Develop early warning system for GLOF/ rainstorm in the pilot basins of Mangdechhu and Chamkharchhu. ▶ Enhance emergency response capacity against GLOF/ rainstorm floods at central and local level in the pilot basins.	For both Mangde-chhu and Chamkhar-chhu, AWLS, AWS (approximate cost: Nu. 1,800,000 for each (USD30,000)), siren towers, control rooms with antenna to receive satellite data and loudspeakers will be installed; WIS (global telecommunication service message switching system) will be installed in the head office so that the DHMS will have free access to all World Meteorological Organization members' climate data Mangde Chhu—2 AWLS, 1 AWS, and 3 sirens Chamkhar—3 AWLS, 2 AWS, and 6 sirens AWLS indicated include precipitation, temperature, and other weather sensors The flood zonation of Chamkhar will be updated and Community Based Disaster Risk Management (CBDRM) will also be carried out in the two pilot basins with the Department of Disaster Management (DDM) The JICA project team has eight experts who will also help in the development of a data collection platform in the National Weather and Flood Forecasting and Warning Center (NWFFWC) and provide hands-on training on how to receive, analyze, and archive data; the JICA team will also set up instruments for communication within the basins and with the NWFFWC at the headquarters in Thimphu The project is also providing hands-on training as a part of capacity building to the DHMS as well as line agencies in both Bhutan and Japan.	

Title	Time Frame	Description		Budget
UNDP-GEF – NAPA 2		**Background**	**Details**	
The Finnish Meteorological Institute				
Strengthening hydromet Services in Bhutan	32 months starting in September 2013		▶ Socioeconomic impact analysis of services provided by the DHMS ready by January 2014 ▶ Support to develop National Hydro-met Services Policy on how the DHMS should provide services—for example, whether to sell or give for free, how to charge fees is applicable; mandates of the DHMS; policy draft has not yet started; DHMS staff will have to work on this and it will be supported by the Finnish Meteorological Institute in terms of study tours and technical review of draft ▶ Data management in quality control system; develop standard operating procedures for quality control of data management and data processing and analysis for climate change studies; done by them ▶ Help develop communication strategy with public, DDM, media, etc., or it could be within the hydromet network in Bhutan, for everyday situation and also during emergencies ▶ Study tour and training in seasonal forecasting and instrumentation in Finland	480,000 euros

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