Socio-Economic Study on Improved Hydro-Meteorological Services in the Kingdom of Bhutan

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Finnish Meteorological Institute

Department of Hydro-Met Services, Bhutan

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Cover photo: “On the way to eastern Bhutan”; Tayba Buddha Tamang, DHMS.

Contents

List of abbreviations and glossary

AWLS	Automatic Water Level Station
AWS	Automatic Weather Station
BBS	Bhutan Broadcasting Service
BPC	Bhutan Power Corporation Limited
CEA	Cost-Efficiency Analysis
CHP	Chukha Hydropower Plant
DDM	Department of Disaster Management
DGM	Department of Geology and Mines
DGPC	Druk Green Power Corporation
DHMS	Department of Hydro-Met Services
DHPS	Department of Hydropower & Power Systems
DoPH	Department of Public Health
DoR	Department of Roads
DRE	Department of Renewable Energy
DRR	Disaster Risk Reduction
Dzongkhag	District
EWS	Early Warning System
FEMD	Flood Engineering and Management Division
FMI	Finnish Meteorological Institute
GDP	Gross Domestic Product
GEF	Global Environment Facility
Gewog	Block
GLOF	Glacial Lake Outburst Flood
GNH	Gross National Happiness
GNHC	Gross National Happiness Commission
HPP	Hydropower Plant
ICAO	International Civil Aviation Organisation
IWRM	Integrated Water Resource Management
LLS	Lightning Location System
MoAF	Ministry of Agriculture and Forests
MoEA	Ministry of Economic Affairs
NAPA	National Adaptation Programme of Action
NCWC	National Commission for Women and Children
NECS	National Environment Commission Secretariat
NHMS	National Hydro-Meteorological Service
NRDCL	Natural Resource Development Corporation Limited
NSB	National Statistics Bureau of Bhutan
RE	Renewable energy
RICBL	Royal Insurance Corporation of Bhutan Limited
SCBA	Social Cost-Benefit Analysis
SHSB	Strengthening Hydro-Meteorological Services for Bhutan
Thromde	City/Municipal administration
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VA	Vulnerability Assessment
WII	Weather Index-based Insurance
WMO	World Meteorological Organisation
WSCA	Weather Service Chain Analysis
WTP	Willingness-to-Pay

Executive Summary

Bhutan is categorized as a least developed country. Its small population base (738 000 inhabitants in 2011), geographical size, and land-locked position pose significant development challenges. In 2012, the Gross Domestic Product (GDP) was approximately US$1.8 billion, corresponding to US$2400 per capita (World Bank).[1] Agriculture is the dominant source of employment for the majority of the population. Bhutan has significant hydropower resources, and the development of the hydropower sector has boosted the industrial sector, which is developing rapidly. Hydropower exports contribute substantially to the GDP. Tourism activities are also on the rise.

The climate in Bhutan varies substantially due to dramatic variation in its topography and elevation. Approximately 70% of the precipitation is generated by the monsoons, which appear from early June to late September, and approximately 20% of the precipitation falls in the pre- and post-monsoon periods.

Bhutan is susceptible to multiple natural hazards. Earthquakes are the most imminent hazard, as evidenced by past seismic events. Another pertinent hazard, especially with regards to climate change, is the impending risk from Glacial Lake Outburst Floods (GLOFs). Furthermore, Bhutan is vulnerable to recurrent and seasonal hazards such as landslides, flash floods and windstorms, fire on human settlements and forest fires.

The Department of Hydro-Met Services (DHMS) in Bhutan was established in December 2011 under the Ministry of Economic Affairs (MoEA). Currently, the services provided by DHMS consist of the provision of historical weather and hydrological data and a 24-hour weather forecast which is disseminated through the national TV station and newspapers.

This report forms part of a project entitled 'Strengthening Hydro-Meteorological Services for Bhutan', funded by the Ministry for Foreign Affairs of Finland. The aim of the report is threefold:

1) to provide a qualitative overview of the potential benefits to different sectors of Bhutan’s economy by the provision of improved hydro-meteorological services;

2) to provide feedback to DHMS on the needs of its current and potential future stakeholders and services, and;

3) to provide an estimate of the costs and, where possible, monetary benefits of the future services provided by DHMS to the Bhutanese economy and society.

In principle, the value of hydro-meteorological information is derived from the difference in value or utility between a decision involving the use of information and a decision using only prior information or no information at all. The drivers behind the level of realised benefits are the quality of the information, and the timeliness and ability of the involved end users to respond to the information.

The study is based on five sources of information:

1) Preliminary information on the current use and value of improved services was received over a one-day workshop held on the 21st of August, 2013 in Thimphu (List of organisations which were represented is detailed in Appendix A);

[1] http://data.worldbank.org/country/bhutan

2) Interviews with stakeholders were conducted to obtain an in-depth understanding, not only of the value of the services, but also of the preferred communication method of the services. The interviews took place within the 2-week mission to Bhutan between 19-29th of August, 2013 (List of organisations and people interviewed is in Appendix B);

3) Statistics from different sectors has been used where possible.

4) A second workshop on the results of the socio-economic assessment was held on the 29th of January, 2014 in Thimphu. The preliminary results of the study were presented at the workshop and the stakeholders were given opportunity to provide feedback.

5) Stakeholders who participated in the workshops (August, 2013 and January, 2014) and acted as interviewees were given the opportunity to provide feedback on a draft of the report.

The sectors covered in this report include the energy, agriculture, tourism, aviation, disaster risk reduction and management, roads, public health, construction, insurance, natural resource management and climate change monitoring.

The future prospects of DHMS are given in the 11th Five Year Plan for 2013-2018. Within the context of this report, four potential services were identified. The benefits of these services to different economic sectors and society as a whole are assessed below.

Historical hydro-meteorological information

The socio-economic benefits of historical data stem from two different sources and for two time scales: the benefits of the current measurement station network with quality-controlled data are assessed for 2015-2030; and the benefits of an extended network, as a result of NAPA II project, for 2015-2030 and 2020/2025-2030. The extended network provides immediate benefits if the measurements are combined with the existing measurement data, and after 10 years when the data from new locations become climatologically representative. The benefits are assessed, where possible, for each sector directly. In most cases there was no possibility to derive monetary estimates. Furthermore, the overall benefits to society stemming from the use of historical data in the sectors are assessed on a scale of +…+++++. The higher the number of + -signs, the higher is the benefit to society. If the +-signs are in brackets, the benefits are conditional on factors which are not under the control of DHMS.

Sector	***Current network; quality-controlled data; benefits for 2015–2030***	***Extended network, 2015–2030***	***Extended network; 2020/2025-2030***
Small-scale energy production	Improved design of small-scale hydropower plants +	Improved design of small-scale hydropower plants +	Improved design of wind, solar and hydropower plants (++++)
Large-scale hydropower	Improved design of hydropower plants ++	Improved design of hydropower plants ++	Estimated yearly value Nu 67 Million (about 790 000 Euro) per HPP +++++
Agriculture	Long-term planning of	Long-term planning of	Long-term planning of

	most suitable crops, weather index -based insurance scheme ++	most suitable crops, weather index -based insurance scheme +++	most suitable crops, weather index -based insurance scheme +++++
Tourism	marketing to increase the number of tourists, especially during lean seasons ++	marketing to increase the number of tourists, especially during lean seasons ++	Estimated yearly value approximately USD 1.4 million (starting 2020) ++++
DRR	Hazard-mapping, land-use and spatial planning +++	Hazard-mapping, land-use and spatial planning ++++	Hazard-mapping, land-use and spatial planning +++++
Public Health	Forecasting and assessment of outbreaks ++	Forecasting and assessment of outbreaks ++	Forecasting and assessment of outbreaks +++
Insurance	Risk assessment, pricing, weather index -based insurance scheme +	Risk assessment, pricing, weather index -based insurance scheme ++	Risk assessment, pricing, weather index -based insurance scheme +++
Water resource management	National Water Resource Inventory +++	Management of water resources +++	Management of water resources ++++
Climate Change	Climate change monitoring +++	Climate change monitoring +++	Climate change monitoring ++++

The benefit summary shows that the provision of historical high-quality hydro-meteorological information is vital for practically every sector assessed in the report. The standard period for determining the climatological normal of different weather parameters is 30 years, which is not feasible in Bhutan with the current length of the historical time series. However, the current quality-controlled observational data possessed by DHMS can be used to determine 10-year average parameter values (World Meteorological Organisation, 2011), and can be updated with the data from the new stations installed through the NAPA II Project. The new weather and hydrological stations will be of value ten years after the installation at the earliest.

To reap the full benefits of the historical observations, data management, regular maintenance and calibration of the AWSs and AWLSs are crucial. It is a costly endeavour but guarantees that economic sectors which are highly important for the Bhutanese economy, most notably hydropower production, agriculture and tourism, can plan their operations better and improve their performance in the long run. Furthermore, high benefits occur from efficient risk management in every sector and in society. Insurance sector plays also a key role in risk reduction and recovery.

Current observations

The only sector greatly benefiting from current observations is the aviation sector, which would not operate without the service. This is highly important for the Bhutanese economy, as the majority of the tourists arrive by air. Furthermore, current observations have clear indirect benefit stemming from the use in weather forecasting and particularly when weather forecast information is turned into early warning, increasing the value of the observations during extreme weather situations when the progress of the phenomenon can be monitored.

Forecasts

The socio-economic benefits of weather and hydrological forecasts and the seasonal outlook are assessed for 2015–2030. As with the historical data, the overall benefits to society, stemming from the use of hydro-meteorological forecasts are assessed on a scale of +…+++++. The higher the number of + -signs, the higher is the benefit to society. If the +-signs are in brackets, the benefits are conditional on factors which are not under the control of DHMS.

Sector	***72-hour forecast – 3-hour time resolution; 2015/2020–2030***	***Seasonal forecasts; 2015–2030***
Small-scale energy production	Consumption and production estimations, secure electricity supply (starting 2020), aid in operation ++	Production estimations +
Large-scale hydropower	Production estimation, improved operation and maintenance, yearly value Nu 65.8 million (approx. 771 445 Euro ++	Production estimations +
Electricity distribution	Prepare for damage, inform customers (++)	
Agriculture	Improved farming practice ++++	Adaptation to yearly variation in rainfall patterns +++++
Tourism	Expand tourism to areas currently without forecast; Nice-to-know information +	Increase the number of tourists, improved planning and preparedness +
Aviation	Benefits from nowcasts +++	
Public Health	Benefits from warnings on extreme temperatures, heat and cold waves ++	Prepare for outbreaks, inform the public ++
Road Transportation	Prepare for road blocks and mobilise the workforce earlier, inform the public ++	Improved planning and preparedness +
Natural Resource Use	Optimise the operations in the stone quarries and forests ++	Optimise the operations in the stone quarries and forests ++

Forecasts were not the most important service requested from DHMS, as the majority of the sectors considered historical information more important. However, the benefit summary shows that there are major benefits from the 3-day and seasonal forecasts. The value creation requires improvements not only in the accuracy of the forecast, but also in dissemination and use of the information. For instance education and training of farmers and the general public is necessary before the benefits start to accrue.

Early Warning System

Bhutan is highly susceptible to natural hazards. Therefore, the potential value of a reliable, well-functioning early warning system (EWS) is high. The direct benefit of a EWS is the prevention of loss of life, decreased number of injured people and affected livestock. This has far-reaching indirect impacts on families and communities, and is beyond economic analysis. Avoided losses not only decrease the suffering of the individuals, but also decrease the need of food aid and support from the government when a disaster strikes.

In current circumstances, the benefit creation of a multi-hazard EWS in Bhutan is not only a matter of improved forecast skill, but requires improvements in the dissemination and use of the warning. The potential economic value of a EWS was not assessed in this report. However, Hallegatte (2012) reaches a conclusion that depending on the circumstances, the cost-benefit ratio of investments on EWS ranges from 1:4 to 1:35.

A 3-day weather forecast is already in the current capability of DHMS, as the MetGIS used by DHMS is producing a forecast three days ahead. The accuracy of the current 24-hour and the potential 3-day forecast is unknown. For professional use, such as for the Department of Disaster Management, a longer forecast could be produced with the help of forecasts freely available on the internet. This would not necessarily be disseminated to the general public, but if the authorities could be informed well in advance of potentially hazardous events, the efficiency of the preparedness and response measures would increase and much of the damage could be avoided or the recovery time reduced. This would however need some capacity building of DHMS on producing the medium-range forecast of acceptable accuracy. As floods are a major threat in Bhutan, a hydrological forecast and warning capacity should be developed.

Socio-economic development will both increase and decrease the value of warnings. In general, when people become wealthier and urbanisation increases, people become less vulnerable to natural disasters as they have access to better housing and they are less dependent on agricultural income. However, developed societies are often more vulnerable to natural disasters due to increased capital stock and the dependence on information technology.

EWS would greatly benefit the hydropower sector in terms of avoiding the damages to the infrastructure by improved operation of the gates. EWS can also prevent physical harm to tourists. As all international tourists travelling in Bhutan have an itinerary, the location of the tourists is fairly well known and early warning services could mitigate the impacts of hazardous weather on tourism effectively. This would improve the safety and satisfaction of the tourists, and the overall perception of Bhutan as a safe place to travel. This may raise tourist numbers depending on the extent the potential tourists are deterred by perceived lack of safety.

Costs and funding

The hydro-meteorological network and forecasting capacity is currently going through substantial expansion due to several projects funded by international donors. Therefore, not much additional funding at this point is required from the public funds. However, the operational cost of the DHMS staff, data management cost and maintenance of the measurement stations must be provided through public funds. As the public budget of

Bhutan is small and there are many competing development goals, the funding for the DHMS services must be well justified. This report shows that the socio-economic benefits of the future services provided by DHMS are very high, particularly when the costs of the international projects are excluded.

The general weather forecast should be publicly funded and be free-of-charge. However, the historical hydro-meteorological data is of economic value to several sectors and could in the future provide revenue to DHMS to cover part of the operational costs. During this study, large-scale hydro-power, tourism, construction and insurance sectors indicated their willingness-to-pay (WTP) for good-quality historical data. However, public funds are needed to achieve the level of quality required. Before the sectors would pay for data, it must meet quality standards and efficient dissemination. This requires proper data management facilities and guaranteed maintenance and calibration of the upgraded and new automatic measurement stations.

Tailored weather and hydrological forecasts and warnings are economically valuable to some sectors (e.g. large-scale hydro-power, tourism) and some of these sectors may also have WTP for timely, reliable, accurate forecasts and warnings.

Cost-benefit analysis

The overall present value cost-benefit ratio is 3.1, taking into account the high initial costs of modernising DHMS. However, these costs are covered by international co-operation. Excluding the project costs in the beginning of the assessment period increases the net present cost-benefit ratio to 5.5. The yearly benefit ratio increases substantially in 2025, up to 8-9, when the benefits of the historical data start to accrue. However, this requires that the NAPA II project is successfully implemented and the station network maintained. Furthermore, it is important to notice that the ratio considers only the direct monetary benefits assessed for hydropower and tourism sectors. The true societal benefits are substantially higher, particularly if the production, dissemination and use of the information is improved in all sectors of society.

Recommendations

DHMS is currently experiencing rapid modernisation which provides a good starting point for the near-future. However, to reach and maintain the level of services enabled by the modernisation, the following recommendations should be considered.

#1 24/7 OPERATIONAL FORECASTING SERVICE AND EARLY WARNING SYSTEM (EWS)

For efficient forecasting and especially EWS, the following recommendations are outlined: 1) to develop the capacity to start operational hydrological forecasting and warning service 2); to start issuing a 3-day weather forecast with 3-hour temporal interval and disseminate it to the public and relevant stakeholders; 3) to develop a 24/7 operational weather and hydrological forecasting service; 4) to produce a medium-range (5-6 days) weather forecast with freely available material and disseminate it as an early warning to relevant stakeholders (such as DDM) when considered beneficial; 5) to start the verification of the operational meteorological forecast; 6) to improve the cooperation between DHMS and different authorities and to make clear the responsibilities of different agencies regarding disaster risk reduction and management.

#2 STATION MAINTENANCE AND CALIBRATION OF THE INSTRUMENTS

To reap the long-term benefits of the substantial increase of the automatic meteorological and hydrological stations, station maintenance and instrument calibration have to be guaranteed and DHMS has to be prepared for likely situations of station malfunction. The recommendations are as follows: 1) a yearly maintenance visit to each station; 2) develop and implement a preparedness plan for situations of station malfunction; 3) regular (depends on the instrument) calibration of the instruments has to be ensured by purchasing required equipment or alternatively, be prepared for the cost of sending the instruments elsewhere for calibration 4) adjust the number of maintenance staff for the yearly maintenance and malfunctions.

#3 STAFF

The most urgent need for staff is in the IT section. When the upgraded station network is running, the need for skilled people to run and maintain data management systems becomes essential. Furthermore, the development of WRF into an operational forecasting model requires a skilled person. Two recommendations to achieve this are: 1) current staff members should be provided with continuing education on IT, and after such training should remain employed as dedicated IT specialists. This should be achieved before the new station network is running. 2) to increase the number of skilled people in DHMS, the need for IT specialists should be communicated to the Ministry of Economic Affairs or other relevant authority, to ensure that DHMS will receive IT specialists in the future. This will increase the labour cost, but is crucial for the successful implementation of the NAPA II project and the modernisation of DHMS.

To start and maintain the 24/7 operational forecasting service, it is necessary 1) to increase the number of meteorological and hydrological forecasters minimum to six, and 2) to increase the number of back-up technical IT specialists to respond to maintain the 24/7 operational system and especially respond to problem situation, which can initially be operated through an on-call duty system;

#4 DATA TRANSFER AND OVERALL DATA DEVELOPMENT

High speed internet and undisturbed electricity supply has to be guaranteed. This has to be done with the support of the Ministry and the telecommunication service providers.

#5 IT DEVELOPMENT

The IT section should be developed and modernised as the amount of data and stakeholder demand will increase. Two recommendations to achieve this are: 1) proper Data Management system for the observational data, hydrological and meteorological forecasting models and forecast products should be developed within the next few years. 2) the development, maintenance and product development of WRF should be guaranteed by having dedicated people with programming skills

#6 STAKEHOLDER INVOLVEMENT

The services offered by DHMS are valuable to society and different economic sectors only through successful outreach and use of the services offered. The interviews held during this study revealed that DHMS services have high potential demand but stakeholder involvement and information dissemination has to be improved. To achieve this, the following recommendations are given: 1) map potential customers and stakeholders (media, authorities) and determine what services they would need; 2) establish well-defined and sustainable relationship with the most important stakeholders within a couple of years and after successful implementation of these, extend to other stakeholders; 3) develop and implement a data dissemination policy to ensure efficient accessibility to information by all stakeholders; 4) collect systematic customer and stakeholder feedback;

5) hire a dedicated customer service officer.

#7 CLIMATE CHANGE

The majority of the interviewees mentioned the need for climate scenarios for Bhutan. To accomplish this, the following recommendations are given: 1) obtain the outcome of global climate models and scenarios; 2) to develop downscaling methods for the Bhutanese context and produce local climate scenarios; 2) to obtain the best possible use of them, contact relevant stakeholders and prepare climate scenarios for stakeholder needs.

#8 GENERAL RECOMMENDATIONS

Furthermore, some general recommendations are provided: 1) develop data quality control by the end of 2014 to prepare for the upgrade of the measurement station network; 2) improve the seasonal forecast process and dissemination as this is a very low-cost development measure and if successfully implemented, would bring substantial benefits 3) improve regional co-operation; 4) Conduct a follow-up socio-economic study by 2020.

1 Introduction

This chapter provides a brief overview of Bhutan, its climate and the Department of Hydro-Met Services (DHMS). Additional information can be found in Appendixes A, B and C. Chapter 1 also provides the aims and objective of this study, and an outline of the structure of the report.

1.1 Background

1.1.1 Bhutan

Bhutan is categorized as a least developed country. Its small population base (738,000 inhabitants in 2011), geographical size, and land-locked position pose significant development challenges. In 2012, the Gross Domestic Product (GDP) was approximately US$1.8 billion, corresponding to US$2400 per capita (World Bank).[2] Agriculture is the dominant source of employment for the majority of the population. Bhutan has significant hydropower resources, and the development of the hydropower sector has boosted the industrial sector, which is developing rapidly. Hydropower exports constitute a significant share to the GDP. Tourism activities are also on the rise.

Unique to Bhutan, socio-economic development is guided by the philosophy of Gross National Happiness (GNH), which advocates that socio-economic development will lead to the prosperity and happiness of the general populace only if there is an equitable balance between the four pillars of i) Sustainable and Equitable Socio-Economic Development, ii) Conservation of the Environment, iii) Preservation and Promotion of Culture and iv) Good Governance. (See Appendix A for a more thorough overview of the Bhutanese economy and society.)

1.1.2 Climate

The climate in Bhutan varies substantially due to dramatic variation in topography and elevation. Approximately 70% of the precipitation is generated by the monsoons, which appear from early June to late September, and approximately 20% of the precipitation falls in the pre- and post-monsoon period.

Bhutan is susceptible to multiple natural hazards. Earthquakes are the most imminent hazard, as evidenced by past seismic events. Another pertinent hazard, especially with regards to climate change, is the impending risk from Glacial Lake Outburst Floods (GLOFs). Furthermore, Bhutan is vulnerable to recurrent and seasonal hazards such as landslides, flash floods and windstorms, fire on human settlements and forest fires.

Climate change poses a pertinent concern for Bhutan as the impacts associated with the changing nature of the water resources pose significant threats to the country’s development. The projected loss of glaciers from the Himalayan peaks will affect water resources, resulting in an increased risk of flooding in the near future and decreased river flow in the long term. (See Appendix B for a more thorough overview of the climate.)

1.1.3 Department of Hydro-Met Services

The Department of Hydro-Met Services (DHMS) in Bhutan was established in December 2011 under the Ministry of Economic Affairs of Bhutan (MoEA). The first meteorological

[2] http://data.worldbank.org/country/bhutan

observations in Bhutan started in 1985, and the earliest hydrological measurements date back to the early 1950s. Currently, the services provided by DHMS consist of the provision of historical weather and hydrological data and a 24-hour weather forecast which is disseminated through the national TV station and newspapers.

DHMS operates 25 hydrological stations, 10 sediment sampling stations and 15 Flood Warning Stations, which monitor river levels. In 2008–2013, an operational, semi-automatic GLOF warning system in the Punakha-Wangdi valley was established. The meteorological monitoring network consists of 20 agro-meteorological stations and 76 climatological stations. Observations at most stations are conducted manually and the data is sent by conventional postal service to the head office. Eleven Automatic Weather Stations (AWS) transmit (near) real-time data to the head office. DHMS operates 10 wind masts. (See Appendix C for a more thorough overview of DHMS.)

1.2 Aims and objectives

This report forms part of a project entitled 'Strengthening Hydro-Meteorological Services for Bhutan', funded by the Ministry for Foreign Affairs of Finland. The aim of the report is threefold:

1) to provide a qualitative overview of the potential benefits to different sectors of Bhutan's economy by the provision of improved hydro-meteorological services;
2) to provide feedback for DHMS on the needs of their current and potential future stakeholders and services, and;
3) to provide an estimate of the costs and, where possible, monetary benefits of the future services provided by DHMS to the Bhutanese economy and society.

Due to the current structure of DHMS, as being *mostly* a data collector and raw-data distributor (a more thorough description of the current services is given in Appendix C), and the limitations due to the scarce observation network, the results of the valuation of the future services are based on a hypothetical situation and are therefore only an indication of the true value. The true benefits for Bhutan do not depend only upon the improvements in the services provided by DHMS, but also greatly upon how different sectors actually use and respond to this information.

Owing to the practical absence of prior useful economic information in conjunction with a limited timeframe, the cost-benefit analysis is based on expert interviews and best available expert estimates of the actual benefits. To obtain a more precise estimate and a cost-benefit ratio, a more detailed modelling of the considered sectors is required. This in turn requires adequate time series of production and resource use by sector, and daily local meteorological and hydrological data.

1.3 Structure of the report

The structure of the report is as follows: Chapter 2 briefly explains the analytical framework, approach, methodology and scope of this study. As the focus of this report is the benefits of improved hydro-meteorological services offered by DHMS in the future, these benefits differ substantially depending on the sector the services are applied to. Hence, to obtain a thorough understanding of the benefits, the current context in each sector and the future potential benefits are presented in chapter 3. Chapter 4 presents an estimate of the costs of the required investments needed to achieve the given level of services. Chapters 5 and 6 present the conclusions and highlight some recommendations for DHMS, respectively. Chapter 7 provides brief policy recommendations.

2 Analytical framework, methodology and scope

This chapter provides an introduction to the services offered by modern national hydro-meteorological services (section 2.1.1), further moving on to the analytical framework (section 2.1.2) and methodology used in this study to assess the benefits of the improved services provided by DHMS (section 2.1.3). Section 2.2 details the data collection methods and methodology, and section 2.3 details the scope of this study.

2.1 Analytical framework

2.1.1 Hydro-meteorological services

Information and services provided by modern national hydro-meteorological services (NHMS) can be divided into 7 categories (modified from Zillman, 1999):

1) Compilation and distribution of information on past weather and hydrological conditions (historical data/observations)
2) Provision of information on the current state of the atmosphere, air quality, ocean, land surface and surface water (current observations)
3) Provision of nowcasts of up to 6/12 hours (nowcasts)
4) Provision of forecasts of future conditions - general forecasts for the community at large and specialized forecasts for a range of users (forecasts)
   - Short-range forecasts
   - Medium-range forecasts
   - Monthly forecasts
   - Seasonal forecasts
5) Provision of warnings of hazardous weather, climate or hydrological conditions for the community at large and specialized warnings for a range of users (warnings)
6) Projection of future climate conditions (climate projections)
7) Provision of advice and research activities on meteorological, climatological, hydrological, or oceanographic science and its application to community needs (research & consultancy)

The extent to which an NHMS provides these services varies between countries and depends on many factors, such as institutional arrangements, organisational structure and financial situation.

The principal stages in weather service provision and the main activities per stage are summarized in Figure 1. Data acquisition and processing are based on international satellite data, global weather models, national observation system data and often some data from neighbouring countries. This basic set allows for production of a basic national forecast and/or a few regional forecasts (depending on the size and topography of a country), which in turn form the basis for more focused products for different user groups. The stages of dissemination and use follow information processing and production.

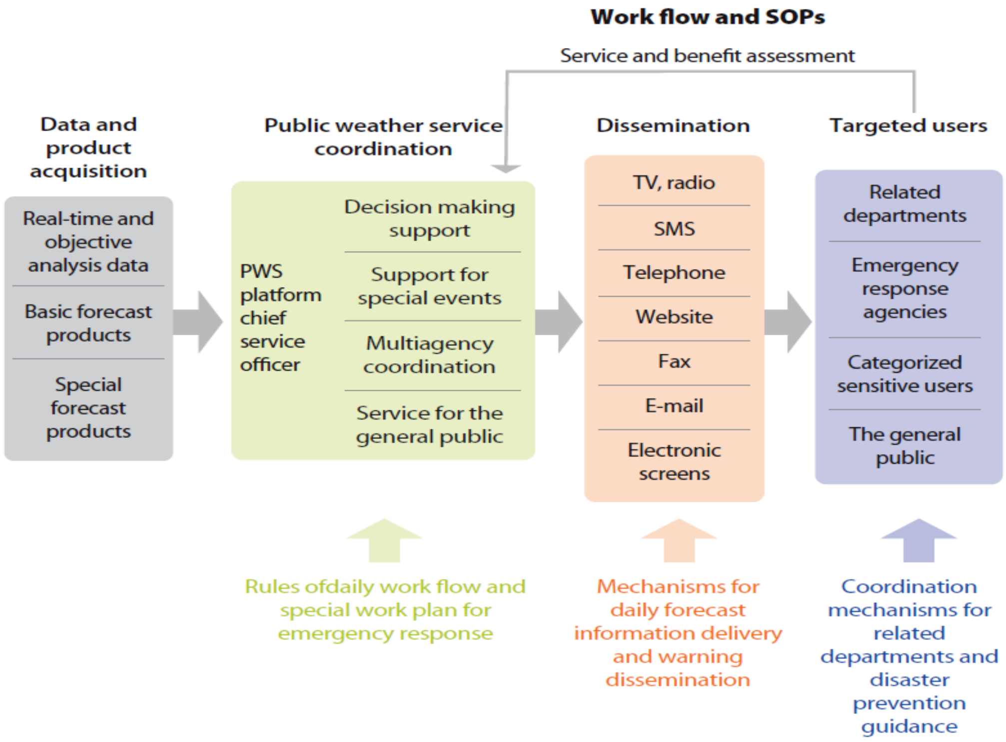

Figure 1. The weather information production and dissemination process (with emphasis on the role of NHMSs). PWS=Public weather service, SOP= Standard Operating Procedure (Rogers and Tsirkunov, 2013)

2.1.2 Valuation of hydro-meteorological services

In most countries, hydro-meteorological data, observations and forecasts are public goods. As such, this requires that hydro-meteorological information is produced by publicly funded organisations, whilst the information is made available without a charge or at a highly subsidized user cost. As hydro-meteorological information is a public good, there is no market to determine the equilibrium price under the forces of supply and demand. Thus, there is little or no market data for the information. (Lazo and Chestnut, 2002) Consequently, the benefits of such a public system cannot be straightforwardly calculated, yet a calculation – or at least estimation - is needed for the economic rationalization for the production of the information, meaning that the benefits generated by the use of the weather services to society need to be larger than the costs (i.e. public funds paid by the society) to justify the public system. (Nurmi et al., 2012)

Valuation of hydro-meteorological services tends to mainly consider the accuracy of meteorological forecasts as the basis for value creation. In principle, the methods and context can be extended to cover other types of services, such as climate services and hydrological information. Regarding weather information, the theory behind the valuation is explained in great detail for example in Katz and Murphy (1997). However, from an economic theory point of view, the scope of value creation is wider, including practically the whole range of weather, climate and hydrological service provision (Perrels et al., 2013a). Similarly, by looking at the difference that a hydro-meteorological service can make in decision making, valuation becomes possible in a less developed environment, where prior climatological or hydrological information is not necessarily available or it has not been used in decision making. In general, hydro-meteorological information can be understood as a factor in a decision process aimed at maximizing the value or utility of a considered process or activity. The value of information is derived from the difference in value or utility between a decision involving the use of information and a decision using only prior information or no information at all.

The value created by supplying meteorological information is depicted in Figure 2 (Perrels et al., 2013a). The first phase in the value addition (VA1) is mainly the responsibility of the NHMS and commercial weather services. Phase 2 (VA2) is the responsibility of different media channels through which information is disseminated. This can consist of e.g. the website of the NHMS or commercial provider, or external channels, mainly TV, radio or newspapers. Nowadays, mobile applications are an increasingly important information dissemination channel. The third value adding phase (VA3) is the key in the value addition. The actual value of the initial hydro-meteorological information stems from the use of the information and the extent to which the end users are able to interpret and use the information and transfer the benefits to other agents. A concrete example of value creation is when a farmer improves the timing of harvesting by using a weather forecast. This is usually outside the capability of the NHMS to affect upon. (Perrels et al., 2013a)

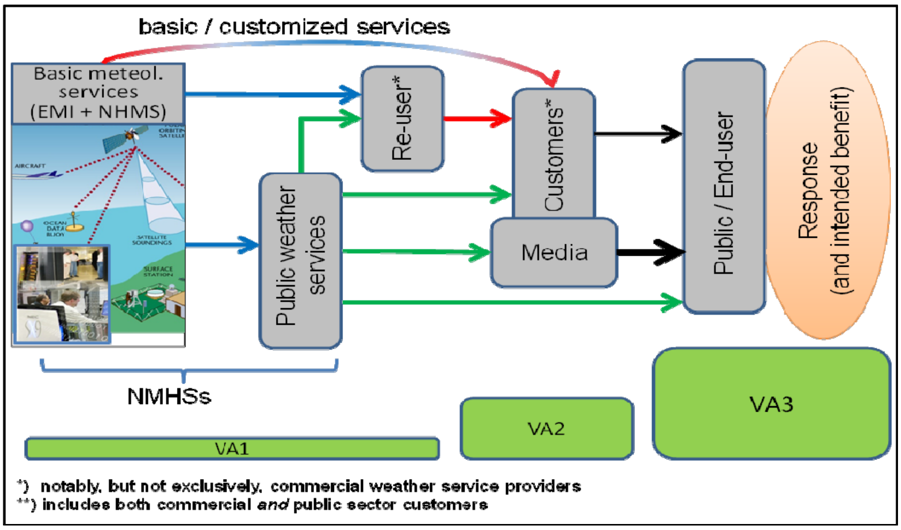

Figure 2. Principal stages in the provision of meteorological services and the related generation of value added by stage; VA = value added (by service stage 1, 2, 3) (Perrels et al., 2013)

A hypothetical maximum benefit potential of the hydro-meteorological services can be estimated, assuming that perfect initial information (e.g. perfect weather forecast or historical data series) is combined with 100% use among end users and 100% effectiveness of their responses. However, the drivers behind the actual level of realised benefits are the quality of the information, and the timeliness and ability of the involved users to respond to the information. With regards to the quality of the information, the average quality level in most cases should surpass some threshold level before potential users are willing to seriously consider use of the information. (Perrels et al., 2013a; WMO, 2013) This threshold effect is evident also for historical measurement data, as often a minimum length of time series is needed to reap the benefits.

The maximum attainable benefit may change over time, as the size (number of end users or size of the business) or functioning of the end user markets change. Furthermore, technical developments may decrease or remove the vulnerability of an end user sector to weather-related problems, decreasing the need for and benefit created by hydro-meteorological services. (Perrels et al., 2013a; WMO, 2013)

An important aspect in the approximation of the actual level of realised benefits is the information decay in the service chain (Figure 3). A framework to analyse the value of meteorological information and the information decay has been developed by the Finnish Meteorological Institute. Weather Service Chain Analysis (WSCA) (Nurmi et al., 2013; Perrels et al., 2013b) aims at accounting for the inadequacies in the dissemination and use of weather information. The method describes the decay of the benefit potential based on a decomposition of the information flow, ranging from information generation to benefit realization for the end-user and society as a whole. WSCA is comprised of seven steps, which assess the extent to which:

1) hydro-meteorological information is accurate;
2) information contains appropriate data for a potential end user;
3) the end user has (timely) access to the information;
4) the end user adequately understands the information;
5) the end user can respond/responds to the information to effectively adapt behaviour;
6) responses actually help to avoid damage or improve operations;
7) benefits from adapted action or decision are transferred to other economic agents.

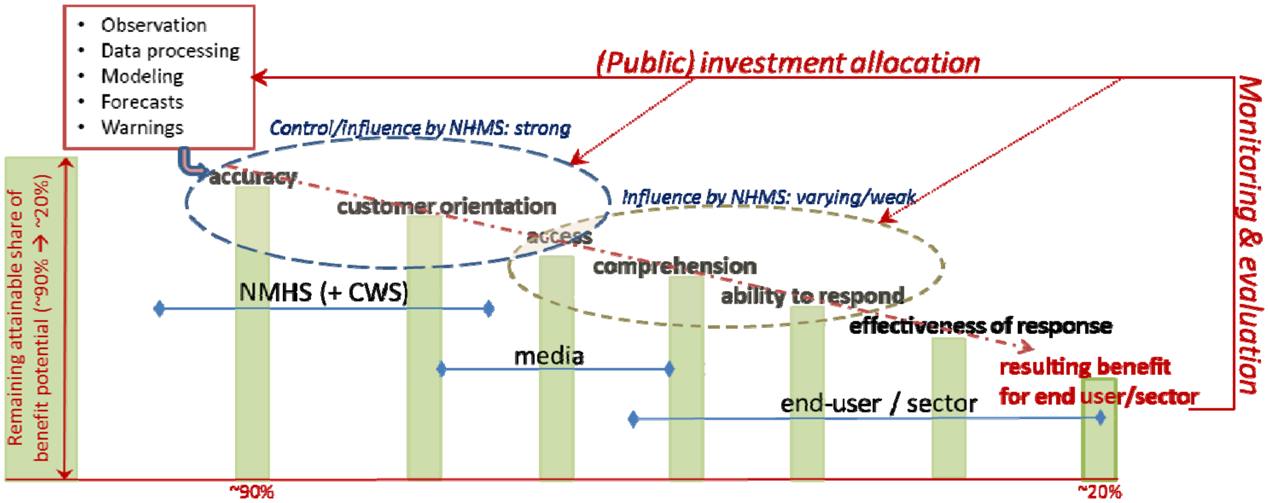

Figure 3. The weather service chain and its information decay and feedback possibilities for improving steps in the weather service chain (Perrels et al., 2013)

The information decay reflects that a decreasing fraction of the potential benefit addressed by a weather service can actually be exploited. Figure 3 presents an example of such a decay. It shows how, if the accuracy of the forecast was the only factor to affect the benefits, approximately 90% of the benefits would be realised. However, due to the decay process in the service chain, the potential 90 % benefit is turned into only 20 % final benefits after the filtering steps. The more professional and skilled the end-user is, the less the stages beyond forecast accuracy (steps 2-7) affect the attainable value added generated by the use of weather services. For the most professional users, better accuracy and lead-time of weather forecasts (step 1) might create a significant increase in the value (Nurmi et al., 2012). For less professional users, value creation may happen in other steps of the chain. Furthermore, Figure 3 illustrates that the valuation of the benefits is an iterative process which should be used to improve the functioning of the information service chain.

The method has been formalised mathematically (Perrels et al., 2013b), but in this report WSCA is used in a non-formal, qualitative way to evaluate the benefits and main hindrances in the value creation of different services provided by DHMS. Furthermore, the approach has been extended to cover also the benefits of historical climatological and hydrological information, and hydrological forecasts.

2.1.3 Social Cost-Benefit Analysis

Social Cost-Benefit Analysis (SCBA) is a tool to assess the gains (benefits) and losses (costs) of a given project to society as a whole, and is used to determine whether a given project is worth undertaking or not. Both costs and benefits are calculated on an annual basis for the entire lifetime of the project. Often, costs and benefits are not realized simultaneously. Therefore, they need to be accounted in a common currency of equivalent present terms, which is achieved by discounting the cumulative costs and benefits by an appropriate discount rate. An alternative to SCBA is a Cost-Effectiveness Analysis (CEA), which is especially useful if the benefits cannot be easily or not at all expressed in monetary terms. For example, CEA is often used to assess alternative methods for reducing the number of casualties and to assess alternative ways to achieve hard to monetize environmental objectives, such as preserving bio-diversity.

Full-blown SCBA (and CEA) often require a substantial amount of data and modelling, which was beyond reach in this project due to restricted data and time. Therefore, this report is mainly a qualitative assessment of the social benefits of improved services of DHMS. It is based on the workshop held and interviews with key stakeholders conducted in Bhutan, August 2013. To complement the material collected in Bhutan, earlier studies and expert judgement in Finland were also used.

2.2 Methodology

The report is based on five sources of information:

1) Preliminary information on the current use and value of improved services was received over a one-day workshop held on the 21st of August, 2013 in Thimphu (List of organisations which were represented is detailed in Appendix A);
2) Interviews with stakeholders were conducted to obtain an understanding of the value of the services and of the preferred dissemination method. The interviews took place within the 2-week mission to Bhutan between 19-29th of August, 2013 (List of organisations and people interviewed is detailed in Appendix B);
3) Statistics from different sectors have been used where possible.
4) A second workshop on the results of the socio-economic assessment was held on the 29th of January, 2014 in Thimphu. The preliminary results of the study were presented at the workshop and the stakeholders were given the opportunity to provide feedback.
5) Stakeholders who participated in the workshops (August, 2013 and January, 2014) and acted as interviewees were given the opportunity to provide feedback on a draft of the report.

2.3 Scope of the study

Taking into account the prospects of DHMS given in the 11th Five Year Plan 2013-2018 (see Appendix C.4), the following services have been identified as feasible and relevant to this study:

1. Compilation and distribution of information on past weather and hydrological conditions (historical data/observations)

Current historical data provided by DHMS is used in some sectors. However, there is a clear need for an improved station network. This deficiency will very likely be remedied to a large extent if the NAPA II project (NAPA: National Adaptation Programme of Action) is implemented successfully. In the context of the project, there is a plan to install 60 automatic weather stations (AWS) and 39 automatic water level stations (AWLS) through funding provided by UNDP-GEF (United Nations Development Programme – Global Environment Facility) (see more details in Appendix C.5). Therefore, the fixed costs of the AWS's and AWLS's will not be accounted for in the cost calculations, but the operation and maintenance of the stations is considered (an important requirement for providing reliable data in the long-term). Unless other source of funding is provided, this must be covered through the government's budgetary support to the public services. The benefits of the new AWS's and AWLS's are assessed until 2030.

2. Provision of information on the current state of the rivers (water level), flood information and atmospheric conditions (current observations)

Stakeholders in hydropower sector and other agencies who could be affected by floods, or changes in water level, could potentially benefit from this service.

3. Provision of forecasts of future conditions - general forecasts for the community at large and specialized forecasts for a range of users (forecasts)

DHMS plans to start issuing 72 hour forecast, possibly with a 3-hour time resolution, for the general public in the near future. In 2013, the first seasonal forecast for the monsoon season (June-September) was issued. This service is planned to be extended by forecasts related with the pre-monsoon (March-May) season. Furthermore, provision of flood forecasting services is being explored at the moment. The benefits of the forecast services are assessed until 2030.

4. Provision of warnings of severe weather, climate or hydrological conditions for the community at large and specialized warnings for a range of users (warnings).

As noted in section 1.1.2 and described more in detail in Appendix B.2, Bhutan is highly susceptible to different natural hazards. An effective multi-hazard Early Warning System (EWS) could improve the country's preparedness for the hazards and help in reducing the amount of financial losses and minimizing casualties and injuries. The benefits of the EWS are not assessed for any specific time range, as the benefits depend on the frequency and intensity of the weather event in question and this information was not available.

The pre-selection of sectors already using or potentially benefiting from the services is based on DHMS's assessment and literature. The key sectors identified by DHMS include the agriculture, hydropower, construction, disaster management, roads, public health, and aviation sectors. Furthermore, as an important source of foreign income, the tourism sector is expected to benefit from improved services. Additionally, the following sectors are covered: other small-scale energy generation, electricity distribution, insurance, and climate change monitoring. Gender aspects of improved hydro-meteorological services are also briefly elaborated upon, as women and children are often most vulnerable to hazardous weather events in developing countries (Neumayer and Plümper, 2007).

The benefits for each sector have been qualitatively assessed through the filtering steps of the WSCA, considering also the threshold level for the information quality. A brief overview of each sector (Chapter 3) is given first to obtain an understanding of the local context affecting the benefits and value.

3 Benefits for different sectors

This chapter describes the benefits of the services that DHMS is planning to start offering within 2013–2018. Each section starts with a brief introduction to the sector, subsequently describing the current use of DHMS services to provide a baseline for the assessment. The core of each section is the evaluation and in some cases assessment of the benefits of the future services, paying attention to the filtering steps of the Weather Service Value Chain (described in section 2.1.2).

3.1 Energy production

Background

Bhutan possesses significant natural resources suitable for electricity production, including substantial water resources, solar and wind potential and a vast forest cover (Alternative Renewable Energy Policy, 2013). The currently estimated theoretical potential of hydropower generation capacity is 30 000 MW (possibly even 40 000 MW) of which about 24 000 MW is techno-economically feasible. As of 2013, Bhutan has four large-scale hydro-power plants (HPPs) (see Appendix A.1 for more details). Additionally, four HPPs are under construction; the first planned to be operational in 2014 and remaining three by 2017. Feasibility studies have been conducted for four more plants. By 2020, 10 000 MW (38% of the currently evaluated capacity) will be installed, with the majority of the production to be exported to India, creating major revenue stream for Bhutan.

As means to reduce its dependence on imports of fossil fuels, Bhutan plans to further harness its abundant renewable energy (RE) sources. The Alternative Renewable Energy Policy, accepted in 2013, provides guidance and future direction of small-scale RE in Bhutan with regards to solar, wind, bio-energy, geo-thermal and small-scale hydropower plants (up to 25 MW) and waste-to-energy. Fossil fuel price volatility, coupled with the risks related to single energy source and the impending threat of climate change, hampers economic growth. Therefore, "*a reason to consider a more diversified and independent energy system that meets national energy needs while balancing energy security, environmental preservation and economic development potential*" exists (Alternative Renewable Energy Policy, 2013). As mentioned in the policy, the development of untapped hydropower potential is an integral part of Bhutan's development strategy. Furthermore, the policy sets out a preliminary minimum target of 5 MW electric capacity installed for both wind and solar energy by 2025.

3.1.1 Benefits for small-scale renewable energy production

Current use of hydro-meteorological services

Wind energy production is heavily location dependent, putting an increased pressure on reliable wind measurements and models. Crude wind and solar mapping, used by some foreign consultants, has been conducted by the National Renewable Energy Laboratory of America. However, the Department of Renewable Energy (DRE)[3] lacks adequate data required for decision-making related to the precise location choice of wind turbines, hence delaying the implementation processes. With this data, DRE would have a concrete plan and knowledge of the locations which would have maximum benefit in terms of services or cost-effectiveness.

[3] The mandate of the Department of Renewable Energy (DRE) is to diversify the use of energy resources in Bhutan.

Similar to wind energy, the assessment of **solar power** potential is not possible due to lack of sufficient data. Therefore, the projects have so far been based on approximations, resulting in inaccurate estimates of the generation potential and benefits. Solar hot-water-systems are also being promoted, and the lack of data is contributing to the challenges in implementing these initiatives.

Regarding **hydropower** design, the data situation is better. However, in some river basins hydrological data are entirely missing, making DRE dependant on crude estimates based on data from existing stations in other basins. Furthermore, the data DRE receives from DHMS often contains gaps. Without accurate hydro-meteorological data for each potential river basin, DRE faces major challenges in fulfilling its mandate. The most important parameter for the optimal design of a small-scale hydropower plant (HPP) in a country such as Bhutan is monthly discharge, as the variation in monthly rainfall is large. According to DRE, the lack of data and the use of secondary data are causing significant challenges to the design of micro HPPs.

The DRE has not used or considered using any weather forecasts to predict future electricity consumption; only the past patterns of consumption have been used.

Benefits of improved historical data

The investment costs of RE, even for small-scale generation, and particularly of wind energy, are large in the context of Bhutanese economy; hence difficulties arise in the promotion of their construction. Furthermore, if the realised generation is less than designed, people may lose faith in the system. Consequentially, the impact of wrong data on the design and uptake of such technologies could be significant and the uncertainty in the calculation of the potential production and value should be reduced to a minimum. In case of RE, reliable hydro-meteorological data is the most important factor. As the demand for electricity produced by RE has increased substantially, the lack of reliable data has become an increasing limitation for efficient planning. This challenge is further exacerbated in Bhutan, as the climatological conditions can change significantly over short distances.

The need for hydro-meteorological data is evident for proper planning of the **wind and solar power** installations. With the planned extension of the weather station network, DHMS may, within a few years, have relatively good data on the relevant parameters for wind energy planning. If this could be coupled with modelling the wind energy potential, micro-generation could be optimally designed and the benefits could prove to be significant. However, the set time limit for the installation (5 MW of solar and wind power by 2025) poses challenges to the selection of the right wind turbine locations and thereby to the benefit potential of the new AWS for wind power.

Based on an expert judgement, at least 1 year wind-mast measurements and 8-10 years of conventional wind measurement data to evaluate the climatological representativeness of the short-term mast measurement data are required to adequately estimate the generation potential. Therefore, the threshold effect might hinder the benefit creation at this point and the benefits would be realised only if more extensive RE plans for post-2025 are made. Furthermore, the locations of the wind measurement stations related to the potential locations of the wind parks affect the benefits. An alternative would be to assess the climatological representativeness of the one-year mast measurements with re-analysis data or to conduct longer mast measurements on-site, which are however often expensive and delay the planning process. The benefits of these are, however, beyond the scope of this study.

Assessing the solar power potential is challenging, particularly because of the difficulties related to cloud-cover assessments. Modern AWS measure solar radiation, but as the specifications for the AWS installed within the NAPA II project are not yet known, this is not further elaborated in this study. Similar limitations to wind measurements apply.

Furthermore, for new HPP design comparable provisos apply, although to some extent they can be overcome by using data from similar locations elsewhere. On the other hand, the benefits of the new hydrological stations will start to accrue approximately ten years after the installation. In addition, flood levels are needed to design the dams to sustain floods of certain frequency, increasing the need for long-term hydrological measurements.

Benefits of forecasts

A 72-hour weather and hydrological forecasts will be of value once the targets for small-scale production have been met and the power plants are operating. Temperature forecasts could be used for consumption estimations, whereas precipitation, wind, solar radiation and hydrological forecasts could be used for production estimations. Weather forecasts for demand and supply-side management will create some value as it can improve guaranteeing secure electricity supply.

For electricity production companies operating in a spot-market, weather forecast information is highly valuable as weather parameters are an important input in production and consumption predictions (e.g. Perrels et al., 2013b). Therefore in Bhutan, where the small-scale electricity producers do not operate in spot-markets, the value of the forecast will not necessarily reach the value of the forecast for electricity producers operating in a spot-market, where the future production and consumption needs to be predicted as accurately as possible. Furthermore, the HPPs are mostly slightly over-designed so they are able to produce the maximum energy amount most of the time, decreasing the need and value of hydrological forecasts. Wind forecasts, especially forecasts on strong gusts, will be of great importance for operating the wind turbines as damaged turbines are very expensive to replace.

3.1.2 Benefits for large-scale hydropower generation

Current use of hydro-meteorological services

Historical hydro-meteorological data are necessary for the planning and design of large-scale HPPs. The pre-feasibility studies, the design of the HPPs and the assessment of the potential generation capacity are heavily dependent on the quality of the hydro-meteorological data. The data is a key in determining the capacity to be installed, which is used to calculate the yearly energy production and eventually the profitability of the plant.

DHMS was originally established for hydropower purposes, implying that the hydrological station network in large rivers is relatively good. However, both the Department of Hydropower & Power System (DHPS)[4] and Druk Green Power Corporation (DGPC)[5] note that the current data quality is a problem – indeed, a good network does not mean that data are of good quality – and especially the information on data quality is lacking. For some streams, measurement data from existing stations need to be extrapolated to the streams without measurement stations, producing an additional source of uncertainty and consequent economic loss in the operational phase.

[4] Department of Hydropower & Power Systems (DHPS) is the policy and planning agency for energy production and responsible for the planning of macro-level hydropower production.
[5] Druk Green Power Corporation (DGPC) is a fully state-owned company operating the macro-scale HPPs (above 25 MW).

To optimise the operations of the HPPs, DGPC uses historical precipitation and water level data to plan operations. Weather forecasts are not used.

Large-scale Hydropower Plant Punatsangchu in Punakha.

Photo: Chhimi Dorji

Benefits of improved historical data

The most significant benefit of the optimal design of the HPPs is to obtain an accurate estimate of the revenue stream. An optimal set of good-quality hydrological data would include raw discharge data, water levels and flood analysis, evapotranspiration, sediment and glacier data. Flood levels are needed to design the dams to sustain floods of certain frequency.

The large-scale HPP projects in Bhutan are predominantly financed by the Government of India which provides the funding partly as a grant and partly as a loan. If the revenue stream during the operational phase is poorly assessed, the payback period of the loan may be longer than originally estimated, creating a substantial loss in terms of interest payments. Because the majority of the HPPs are run-of-the-river plants, excess rainfall cannot be utilised. Therefore, the largest problem is under-design of the plants[6]. Furthermore, over-design leads to overshooting the estimated payback period, as the expected annual generation and consequential revenue stream is not achieved[7]. After the loan has been paid back, the value of good measurement data comes from the revenue created from the exports to India.

As the hydropower sector is very likely a highly professional end user of the historical information, an extensive station network, proper data management and effective dissemination of the data could result in major improvements in the design of the HPP projects. The most pertinent issue is to guarantee the quality of the existing data (work which has already started at DHMS) as this could improve the design of the plants which are still in the planning phase.

The current meteorological and hydrological station network will very likely be extended with the help of the NAPA II project. The importance of data management increases substantially with the increase in the number of measurement stations. As with the design of the small-scale HPP, the new stations will create benefits only after approximately ten years. Before the time series of the new stations are long enough, proper modelling techniques to extrapolate data from existing stations are essential.

[6] Under-design: the actual generation is less than the potential offered by the river flow

[7] Over-design the plant does not reach its installed capacity as planned

To obtain a best estimate of the value of the extended station network for one HPP post-2025, the values from a water diversion scheme in Chukha Hydropower Plant (CHP) have been used[8]. The design discharges for the two streams of CHP, Tichhalumchhu and Lubichhu, are 2.5 and 3 cubic metres per second (m^3/s), respectively. However, the minimum recorded discharge has been 0.8 m^3/s and the maximum 1.5 m^3/s, implying that the HPP has been over-designed. In CHP, the problem was partly overcome by water diversion, which is expected to generate an additional 7 MW a day in winter creating an expected Nu 67 Million (approximately 790 000 Euro) yearly increase in the revenue generation. If it is assumed that the original design of the plant, especially under-design, could have been improved by proper hydrological measurements, and the impact would be of the same magnitude than of the water diversion, the direct benefits would be substantial. In the cost-benefit assessment in chapter 6, it is assumed that the same improvement would occur for four new large-scale HPP.

Assessment of the indirect benefits to Bhutanese society would require detailed modelling which is outside the scope of this study. However, as the hydropower sector is considered crucial in the development prospects of the country, it can be quite safely concluded that the overall benefits are substantial.

Benefits of observations and forecasts

Currently, the majority of the generated electricity is exported to India by DGPC. The tariff is negotiated and remains constant throughout the negotiated period. Therefore, the volume of river inflow, especially in the pre and post-monsoon period, has a major impact on the financial performance of the HPPs. Another issue affecting the performance is the number of outages: shutdown of power plant due to failure in the grid, planned maintenance, or breakdown of machines. Accurate real-time observations and hydro-meteorological forecasts would significantly improve the performance and help in short-term revenue forecasting. Furthermore, extreme weather events, especially floods and cyclones, are detrimental to HPP turbines. For instance, after cyclone Aila in 2009, most of the turbines in the cyclone’s path had to be changed. Therefore, flood and cyclone warning products would be of value to DGPC and tailored warnings could be designed for the purposes of hydropower production.

By assuming that the use of current observations, an accurate 72-hour forecast and timely early warning information increases the yearly average production of the three operating HPPs, which sell the majority of the generation to India, by 0.5% on average through optimised maintenance and reduced damage, the yearly value of the services with the current export tariff becomes Nu 65.8 million (approx. 771 445 Euro) (Table 1). The value of the forecast becomes substantially higher after the inauguration of the new HPPs.

[8] http://bhutanobserver.bt/2134-bo-news-about-chp_generates_more_power.aspx

Table 1. The value of current observations and a 72-hour forecast for hydropower operations

HPP	Annual average production	Export tariff Nu/ KWh	Production increase 0.5%	Annual value Nu	Annual value €
Chhukha	1800 GWh	2.0	90 GWh	18 million	212 000
Kurichu	400 GWh	1.89	20 GWh	3.8 million	44 455
Tala	4865 GWh	1.8	243 GWh	44 million	515 000
Total	7065		353 GWh	65.8 million	771 445

The long-term goal of DGPC is to join the Indian spot-market. This would increase the importance of reliable hydro-meteorological information, especially short and medium-term and seasonal weather forecasts, substantially, as any error in the production and consumption predictions create a loss to the company.

3.2 Electricity distribution

Background

Bhutan Power Corporation Limited (BPC) is the national electricity distribution company and providing the transmission capacity for power plants for domestic supply and export (BPC website)[9]. According to BPC, reliability of electricity supply in some areas is very poor, and power lines are often damaged by hydro-meteorological events. In winter, falling snow causes problems. During the monsoon period, lightning affects the reliability of distribution. Major problems occur when the distribution lines are washed away by a landslide. This damage takes usually months to restore. Tropical cyclones are not considered a major problem for the distribution network.

BPC is facing several challenges in repairing damaged power lines. Due to the challenging topography, accessibility to some areas is limited, especially during winter months. Transportation of repair items to the mountainsides is a significant problem, and inaccessibility can last up to six months due to high altitude and snow loads. BPC does not have helicopters at their disposal, meaning that the items have to be carried manually. In addition, shortage in man power adds to these problems.

Current use of hydro-meteorological services

Often, electricity distribution companies are one of the key users of weather information, especially short- and medium range weather forecasts. Weather forecasts are used in preparing for the expected repairs and also informing customers of possible black-outs. Furthermore, weather forecasts are used to estimate possible overload situations during extreme cold spells or heat waves. (Perrels et al., 2013b) However, BPC does not use any weather forecasts in its operations, but is responding to the weather-related problems after they occur.

[9] http://www.bpc.bt/

Benefits of improved historical data

Design and selection of sites for the lines and poles are partly affected by climatic factors. Wind zone factor is already taken into account, and this could be better optimised if more knowledge on this parameter would be available. Currently the uncertainty is, causing unnecessary costs for the structures.

Benefits of forecasts

Even though weather is causing problems for the power line infrastructure, significant benefits from the use of weather information do not necessarily occur due to the limitations to the operations mentioned above. However, a temporally improved weather forecast would most likely be of some benefit in much a similar way as in other countries. Intensity of snow is a key factor causing damage on power lines, implying that improved weather forecasts in terms of snow load and storms could lead to improved reliability of the network. In addition, already with the existing limitations, more accurate weather forecasts could be used to inform customers to improve their preparedness for the situation. Lightning forecast could be used to warn the public and the customers. Several different dissemination channels, such as radio, TV or SMS, could be used.

A useful service for BPC would be seasonal forecast which could be used in demand prediction. All the electricity which is conserved in Bhutan will be exported to India, and the importance of this to Bhutanese economy is indispensable.

3.3 Agriculture

Background

Agriculture is the second largest contributor to Bhutan’s GDP after hydropower. Rain-fed subsistence farming is the main source of employment for 60% of the Bhutanese. The aim in the agricultural sector is to develop in the direction of more intense farming practices and production for the market. This requires major investments in irrigation systems and increases the importance of proper planning and optimised farming.

Weather is often the most significant parameter in agricultural production, affecting the yields and prices. For instance, Pandey and Pal (2000) found that the regional variations in rice yield in India are mainly explained by the variations in rainfall. In Nepal, significant variation in crop production was the result of a drought in 2005–2006 and floods caused by heavy rains in 2007 (Malla, 2008). In Bhutan, Wangdi (2013) did not find a statistically significant correlation between two weather parameters; observed mean temperature and total rainfall; and agricultural yield. This is likely a result of the poor agricultural data availability and does not indicate that agriculture in Bhutan is not weather-dependant. However, total rainfall in June showed statistically significant relationship with rice yields, suggesting that the rainfall in June is highly important for the initial growing phase of the rice plant. (Wangdi, 2013).

According to the Ministry of Agriculture and Forests (MoAF), several programs on climate-smart agriculture have already been implemented in Bhutan. Mainstreaming of climate change on agricultural practices is becoming increasingly important, as weather patterns have already become more unpredictable than previously.

Current use of hydro-meteorological services

Agriculture has traditionally been an active user of meteorological information due to the sector’s weather dependency. The MoAF is using historical climatological information in the setting of the annual and cumulative targets for cereal production for the coming five years. The use of the current weather forecast by farmers was assessed through a historical event.

Benefits of improved historical data

Long-term planning of most suitable crops and a consequential increase in the average yield is highly important to the overall development of Bhutanese agriculture. The target setting by the MoAF would become more precise if the climatological data were more accurate. Furthermore, the seed choice in different locations could be better optimised when climatological information would be included in the decision making. The benefits of the new measurement stations for agricultural sector will therefore be significant, especially as the change into more commercial production is promoted.

As historical data are mostly used by professional users, the potential value of the historical data and new AWSs is significant. However, to reap the full benefits, farming practices should be altered substantially. As mentioned in the first workshop, current agricultural practices are based on traditional knowledge. The agricultural extension workers play an important role in training the farmers and educating them on new seed choices and farming practices.

Weather Index-based Insurance (WII) scheme is a financial tool being used to hedge against weather risks in locations where conventional crop insurance is not feasible due to large number of small-scale farmers or where insurance markets are undeveloped. One of the key requirements behind a well-designed WII scheme is a good coverage of weather stations. As a guideline, at least 20 years of historical daily data should exist, and missing data should not exceed 3% of the total daily dataset. (Dick et al., 2011) Furthermore, in most cases the observational network is required for monitoring the weather to define when payment is triggered[10].

In Bhutan, MoAF has recently started an initiative on a crop insurance policy. In the first phase, it covers human-wildlife conflicts, which are becoming a serious threat due to the strict conservation policy. WII has been considered but not yet initiated. However, a private Japanese insurance company has planned on starting a WII scheme in Bhutan. This will increase the importance of quality-checked historical data and further increase the immediate value of the new AWSs.

This report will not elaborate further on the possibilities of a WII scheme in Bhutan. However, based on experiences elsewhere, if the scheme can be developed successfully and is adopted by farmers, it can provide an efficient way for farmers to hedge against weather risk and improve the wellbeing of Bhutanese people.

Benefits of forecasts

The traditional way to use meteorological information in agriculture is the planning of the timing of seed planting and harvesting through a short to medium-range weather forecast. In Bhutan, a 72-hour forecast, disseminated to the farmers, would likely create benefits as well. Food security is not a serious issue, but subsistence farmers could decrease yield losses though a more accurate forecast. However, the value creation requires improvements not only in the accuracy of the forecast, but also in later steps of the WSCA, as demonstrated by the peripheral impacts of cyclone Phailin. The cyclone hit western Bhutan and the warning of abnormal rains did not reach the farmers. According to *the*

[10] In most cases, as satellite data can also be used to monitor rainfall.

Bhutanese[11], “most of the damage was caused due to paddy [rice] being left out in the fields to be dried, followed by damage to irrigation channels resulting in paddy being submerged by debris and overflow of water in the fields”. Areas which had not started harvesting, did not suffer from damage.

However, as elaborated more in Chapter 3.6.2, DHMS issued the forecast for rain resulting from the peripheral impacts of the cyclone through TV, but the message did not reach the farmers as they do not currently use the forecasts issued on TV. Therefore, due to the failure in step 5 (the extent to which a decision-maker can use/uses information to effectively adapt behaviour) of WSCA (see section 2.1.2), the estimate of the current value of the forecast is close to zero. In this case, the potential value of the forecast is the total loss and its indirect benefits to the farmers and the community. In general, efficient use of an accurate 72-hour forecast during the onset and ending of the monsoon period would create major benefits for both subsistence and commercial farmers.

To further improve the average yield, adaptation to yearly variations in rainfall patterns could be enhanced by seasonal forecasts. For instance, drought-tolerant crops could be used if the signal for drought from the seasonal forecast is strong. The importance of the seasonal forecast becomes greater as climate change progresses and alters the behaviour of the atmosphere, deteriorating the predictability of seasons based on historical averages (Perrels et al., 2013b).

Double cropping – cropping both during monsoon season and in winter – is feasible in some parts of Bhutan. Winter cropping is highly dependent on irrigation, which in turn depends on the monsoon season. If the monsoon season does not provide enough rain, winter cropping becomes challenging. Seasonal drought forecasts could be used to prepare for these situations.

The *ex-ante* value of seasonal forecasts for (semi-)professional agricultural systems has been studied quite extensively (a review of 58 assessments is given in Meza et al. (2008). Meza et al. (2008) conclude that the value of the forecast is generally positive but modest, and subject to “considerable controversy”, particularly for marginal rain-fed regions of the tropics with greatest vulnerability to climate risk. Meza et al. (2008) suggest that the true value of the seasonal forecasts can be determined only through rigorous *ex-post* impact studies, after *“forecasts have been widely communicated and supported adequately for a long enough period to allow learning, adaptation, and widespread adoption”.* If the skill of seasonal forecasts becomes good and farmers are able to change their farming practices, the potential value of the seasonal forecast is high.

The potential benefit of the forecasts for the agricultural sector is high. However, due to the high number of subsistence farmers, the economic value does not necessarily reach high numbers but the positive effect on society and wellbeing of people is significant. However, this requires not only improvements in forecast skill, but also improvements in other steps of the value creation, most importantly in the access and response to the forecast.

3.4 Tourism

Background

Alongside hydropower, the tourism sector is the second major sector contributing to the foreign source of income (see Appendix A.1 for more information). In 2012, Bhutan

[11] http://www.thebhutanese.bt/massive-impact-on-paddy-yield-in-paro/

received approximately 100 000 visitors, and in 2013 the estimated number is 150 000 (the number of visitors and tourism earnings shown in Figure 4). The current average yield per international tourist[12] per night is US$400. However, the aim of the Tourism Council of Bhutan is to increase it to US$700. It is clear that as the number of tourists increases and if the daily expenditure increases as is planned, the impact on the economy will be substantial.

Approximately 60-70% of the tourists arrive by air, the rest through the Indian border in the south. Trips to Bhutan are organised through local travel agencies, and the pre-booked tours have to be arranged in advance. All international tourists are accompanied by a local travel guide.

Figure 4. Total visitor arrivals (regional and international) and Tourism earnings from international leisure visitors in USD million (2007 –2012).

In October 2013, a private airline Tashi Air started operating alongside the state-owned carrier Druk Air. This has the potential to increase the number of visitors, as there has been seat shortage during peak tourist season.

Current use of hydro-meteorological services

Currently, there is no established collaboration between DHMS and the Tourism Council or the Association of Bhutanese Tour Operators.

Benefits of future hydro-meteorological services

Scott et al. (2011) have illustrated the potential use of weather and climate services in the tourism sector as shown in Figure 5. The figure shows that the sector could use almost all types of hydro-meteorological information.

[12] Citizens of India, Bangladesh and Maldives are exempted from visa requirements. All other nationalities are referred as international visitors or tourists, depending on the purpose of the visit.

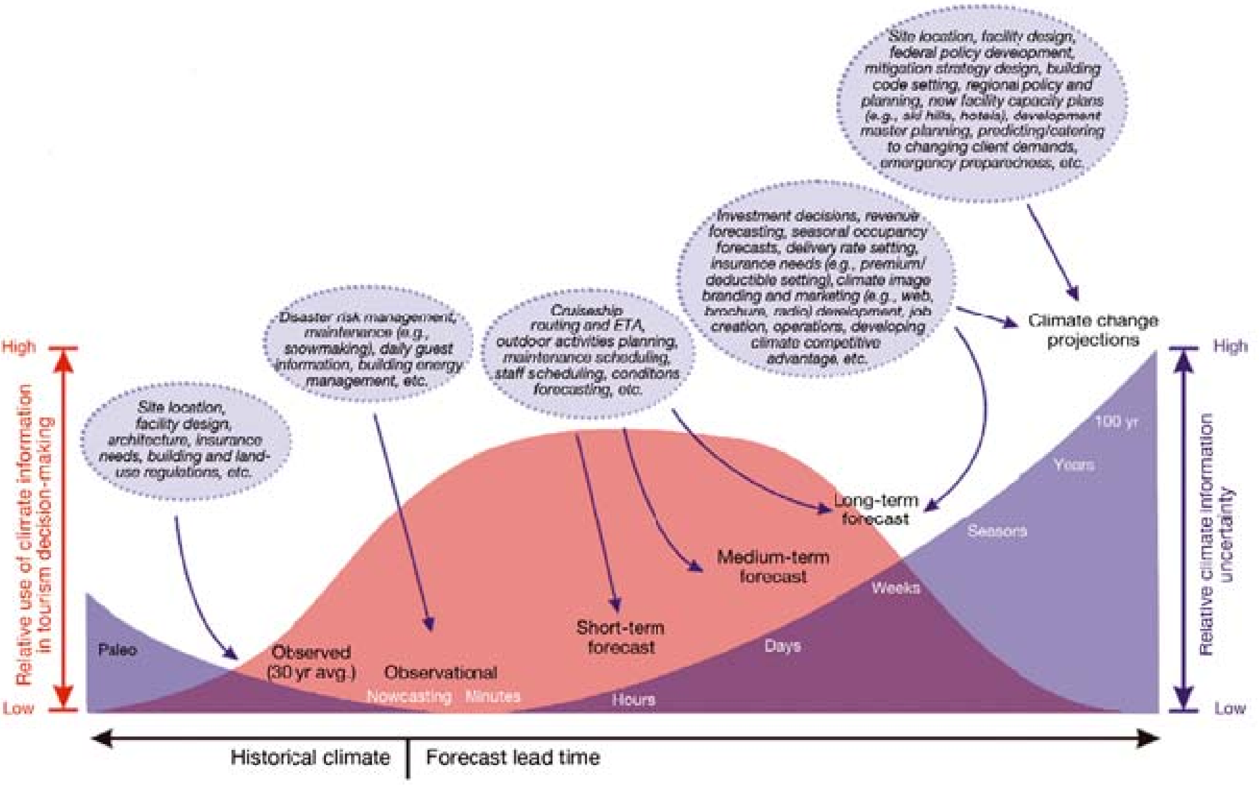

Figure 5. Potential uses of weather and climate information by tourism and travel planners. ETA: estimated time of arrival. (Scott et al., 2011)

Benefits of improved historical data

Bhutan has not managed to take full advantage of the most important global tourism seasons; winter and summer, as these are the low seasons in Bhutan. The client's perception on the climate is important in the global tourism market and reliable climatological data and proper marketing could be used by Bhutan tourism PR offices, located around the world, to market Bhutan as an attractive tourism destination during the off-season. This is particularly important in the eastern parts of the country as climate information, combined with marketing efforts, could help to distribute the arriving tourists more evenly throughout the country and across seasons. This could increase the number of tourists without imposing too much pressure on the current hot spots (Thimphu, Paro, Punakha), and to make tourism more environmentally and economically sustainable. Furthermore, even tourism flows can improve rural employment.

In 2012, the number of international tourists was approximately 43 900. By assuming that the use of climatological information in marketing the off-season would increase the number of the international tourists by 5% each off-season month starting from 2020, the number of additional tourists would be 500 a year. This would create per day US$101 200 income through the tourism tariff. By assuming that each tourist spends an additional US$200 per day, an additional revenue of US$101 200 per day would be created. By further assuming that each tourist stays the current average length of stay of 6.9 days (7 days), the estimated yearly value of the information would be approximately US$1.4 million (Nu 86 million; 1 million Euro). Assessment of the indirect benefits to Bhutanese society would require detailed modelling which is outside the scope of this report.

Benefits of forecasts and warnings

As a major part of tourism in Bhutan is outdoor tourism, weather plays a major role in the satisfaction of the tourists, and hazardous weather can be a major threat to the wellbeing and safety of the tourists. As tourists do not speak the local language, they do not necessarily know how to respond to a hazardous weather event.

All international tourists travelling in Bhutan have an itinerary, implying that the location of the tourists is fairly well known. Therefore, EWS could mitigate the impacts of hazardous weather on tourism effectively, as the warnings could be issued to the local tourism agents who are able to reach the tour operators accompanying the tourists. This would not only improve the safety and satisfaction of the tourists, but also the overall perception of Bhutan as a safe place to travel. This may raise tourist numbers depending on the extent the potential tourists are deterred by perceived lack of safety.

Particularly due to the rise in outdoor tourism, the value of forecasts and warnings is already high and further increasing in the future, as the number of tourists increases. The value of satisfaction and safety of the tourists is hard to quantify, but it is highly significant and potentially also increasing the number of tourists choosing Bhutan as their travel destination. A significant impact is potentially also arising from more equal distribution of tourism income in the country and between seasons, making tourism more environmentally sustainable and distributing income more evenly throughout the country.

Furthermore, seasonal forecasts could be communicated to the PR offices to further increase the number of tourists. Other means of disseminating the information before the tourist comes to Bhutan are websites and social media.

3.5 Aviation

Background

Bhutan’s only international airport is located in Paro, situated in very difficult terrain between high mountains in the altitude of 2 235 metres. It receives 3 200 international flights per year, with 8 scheduled incoming flights per day. In 2012, the number of passengers passing through the airport was 182 000; 60% of the passengers are tourists, 40% are national passengers. As mentioned in section 3.4, 60–70% of the tourists arrive in Bhutan by air. Additionally, passenger flights are operated from two domestic airports, Bumthang and Yongphula. Until recently, the only Bhutanese carrier was the state-owned Drukair, but in October 2013, Tashi Air, a privately owned carrier, started operating Bangkok-Paro route and plans to start operations on other routes. By 2030, the number of passengers at Paro is estimated to be 0.5 million, implying that the airport has not reached its maximum capacity.

In 2012, there were 3-4 cancellations on international flights and several delays due to snow, wind storms and poor weather conditions. Domestic air traffic is affected to a greater degree due to poor weather conditions, experiencing 7–8 cancellations each month. To date, no accidents have occurred. As noted by The Tourism Council, uninterrupted flights are an important aspect for the tourism sector.

Current use of hydro-meteorological services

The International Civil Aviation Organisation (ICAO) has defined a set of Standards, Recommended Practices and Procedures regarding meteorological services for international air navigation in the Appendix 3 to the Convention on International Civil Aviation. Without the meteorological services, no commercial aviation at the scale as we see today would exist. Therefore, there is little worth in calculating the total value of the current level of information. However, the value of improved observations and nowcasts could decrease the costs of unnecessary precautionary measures, and weather-related delays and cancellations could potentially be reduced. (Nurmi et al., 2012)

Currently, the Paro airport does not fulfil the requirements for an ICAO compliant airport. It has one ICAO compliant AWS and one smaller which acts as a back-up. No aviation forecasts are produced for air traffic in Bhutan; take-offs and landings are based on visibility. When pilots attempt to approach the airport during cases when the cloud ceiling is too low, they are forced to turn back to Kathmandu. At Paro, the cloud ceiling is the most important weather parameter, and low cloud ceilings cause most of the weather-related problems. All three airports have weather observers, but the only qualified meteorologist works at Paro airport. Aviation meteorology is not part of DHMS operations, but under the responsibility of the Department of Civil Aviation.

Benefits of improved historical data

Due to the challenging terrain, the airports suffer from physical damage due to weather events. For instance flood damage could be reduced with hydrological information on the historical flood levels and return periods for different floods.

Benefits of improved current observations

Improving the meteorological operations at Paro airport and later on at other domestic airports is crucial for the tourism sector and entire Bhutanese economy. The operating hours at all airports need to be expanded, which will increase the demand for quality-assured observations. The first improvement required is the installation of a ceilometer, which measures the height of the lowest cloud, at Paro airport and later at Bumthang airport, if it is to be upgraded to an international airport. The domestic airports would also need appropriate AWSs and the maintenance and calibration of the current AWS at Paro should be guaranteed.

Benefits of nowcasts

Airports in Bhutan are prone to convective weather phenomena; storms and lightning. These are usually detected and monitored in modern airports by dual-polarised Doppler radars. However, the benefits of these are not obvious in Bhutan due to the mountainous terrain. In Mäkelä et al. (2014), lightning location system (LLS) is suggested as an alternative way to detect convective events. The paper demonstrates the use of LLS at the Tribhuvan International Airport in Kathmandu and concludes that the benefits of the system for aviation are likely to be high. LLS would be a cost-efficient and suitable way to nowcast potentially dangerous events which would improve the safety of the aircraft. LLS and its costs are elaborated in greater detail in section 5.1.

The aviation sector is highly professional in using weather information, so the majority of the value would come from the accuracy of the observations and nowcasts.

3.6 Disaster Risk Reduction and Management

Background

As described in Section 1.1.2 and more in detail in Appendix B.2, Bhutan is susceptible to several types of natural hazards. To enhance Disaster Risk Reduction (DRR) efforts, the Disaster Management Act of Bhutan was accepted in 2013. The Act identifies the relevant authorities for hazards of different severity according to the capacity of each authority to manage the hazard. The response to the most severe hazards, classified as ‘Type III disasters’, are the responsibility of The Department of Disaster Management (DDM). Type III disasters satisfy the following criteria: *“Severity and magnitude is so great that it is* *beyond available resources and the coping capacity of the Dzongkhag concerned"* (Disaster Management Act of Bhutan 2013). Less severe disasters are the responsibility of the Gewog (block) (Type I) or Dzongkhag (districts) (Type II)[13]. To establish an administrative framework for disaster management, the Disaster Management Rules and Regulations, 2013 is being promulgated.

In flood risk management, the key stakeholder for DHMS is the Flood Engineering and Management Division (FEMD)[14]. In Bhutan, especially in the low-lying areas in the southern Dzongkhags of the country, flooding is a frequent phenomenon. Some areas suffer damage annually, and the flood protection walls are rebuilt after every event. Socio-economic factors are a significant contributor to the flood impacts, but hydro-meteorological factors; discharge, rainfall and soil characteristics, also play a significant role. Budget constraints often hinder efficient flood protection, as building sufficient flood protection is unaffordable. Therefore, cost-efficient flood protection is essential. According to FEMD, no studies on cost-efficient protection have been carried out to date.

Early Warning Systems (EWSs) related to hydro-meteorological hazards are one of the main responsibilities of most NHMSs. Efficient EWSs with sufficient lead-time can aid authorities in preparing for two types of hazards: low-frequency high-impact hazards (such as tropical cyclones), and high-frequency low-impact hazards (such as floods).

A warning system for extreme hydro-meteorological events does not currently exist in Bhutan, and warnings are issued in an ad-hoc basis. However, the Disaster Management Rules and Regulations, 2013 defines a procedure for the establishment of EWS for potential hazards and emphasises the role of the responsible agency in monitoring the situation and issuing the warnings in consultation with DDM. Even though not identified in the document, DHMS can be assumed to be the responsible agency in hydro-meteorological hazards.

Glacial Lake Outburst Floods (GLOFs) are pertinent threats in Bhutan, but this report focuses on the value of floods and early warnings based on weather forecasts.

3.6.1 Flood risk management and response

Background

Current use of hydro-meteorological services

Currently, the FEMD does not utilise DHMS data for designing flood protection, whereas DDM is actively collaborating with DHMS.

Benefits of improved historical data

Flood frequencies or return periods should be used in the flood walls design to ensure that protection is set on a cost-efficient level. Therefore, the value of historical flood data is potentially of great value. However, it requires long-term data series and might not be feasible to obtain during the time frame (benefits assessed up to 2030) of this study.

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[13] Type I, if it can be managed with available resources and is within the coping capacity of the Gewog /Thromde concerned.
Type II, if it can be managed with available resources and is within the coping capacity of the Dzongkhag concerned.
Type III, if severity and magnitude is so great that it is beyond available resources and the coping capacity of the Dzongkhag concerned.

[14] Flood Engineering and Management Division (FEMD) is a unit under the responsibility of the Department of Engineering, created in 2012.

Dzong in Punakha, located at the confluence of Pho River and Mo River in the old capital of Bhutan and being one of the most historic buildings in the country.

Photo: Chhimi Dorji

According to FEMD, the assessment of the benefits of flood and hydrological information is not possible as damage data is not available. Conducting benefit assessments is also challenging based on the damage data on large-scale flood events (see Appendix B.2, Table B1), as flood protection may not be able to prevent damage occurring from major events. However, as floods are the most serious natural hazard threatening the lives and livelihoods, the benefits of cost-efficient flood protection are evident.

Historical hydro-meteorological data would be of benefit in hazard mapping of human settlements. Identifying flood-prone areas based on historical rainfall, geographical and socio-economic data would provide major long-term benefits in terms of reduced damage. The information should be used in land use and spatial planning to avoid building settlements and houses in flood-prone areas. Furthermore, flood risk management is also very important for Bhutan's unique cultural heritage, as many of the temples and other important sites are located on riversides (see photo on the next page). If climate change increases the risk of flooding, the benefits of proper hazard mapping will obtain greater value.

Benefits of improved flood forecasts and warnings

As flood protection does not prevent all damage, flood forecasting and EWS are key in damage mitigation and are indispensable in Bhutan, particularly with regards to fatality and injury prevention. The value of EWS is tightly connected to their functionality and reliability as false alarms or missed events quickly decrease their credibility and potential value. In the most flood-prone areas in the south of Bhutan, flood forecast and EWSs should be improved to meet the needs of the vulnerable communities. In terms of WSCA, the value of the flood EWS is further increased by building the disaster preparedness capacity of the vulnerable communities. These aspects are expected to be significantly improved due to the JICA-funded project described in Appendix C.5.2.

Subbiah et al. (2008) list three case studies on the assessment of the costs and benefits of flood EWS in Asian countries. The return of every USD 1 invested varies from US$0.93 for flood EWS in Sri Lanka to US$558.87 for Bangladesh over a 10-year period. The studies show that the cost-benefit ratio depends largely on the frequency of the hazard. The negative return on investment in Sri Lanka is explained by a low frequency of significantly damaging floods. To obtain a quantitative estimate for the cost-benefit ratio of flood EWS in Bhutan, detailed analysis would be required.

3.6.2 Management of other hydro-meteorological hazards

Current use of hydro-meteorological services

As mentioned in the previous section, DDM is actively collaborating with DHMS.

Benefits of improved historical data

As with hazard mapping of flood-prone areas, historical hydro-meteorological data would be of benefit in hazard mapping of human settlements and cultural heritage with regards to other hydro-meteorological hazards. Major long-term benefits, in terms of reduced damage, could result if the information would be used as guidance in land use and spatial planning to avoid building settlements and houses in hazard-prone areas, and to design contingency plans in highly vulnerable areas. Furthermore, records of extreme events should be stored to define threshold values for different extreme phenomena.

Benefits of improved forecasts and warnings

The key requirement for a successful EWS is an accurate short to medium-range weather forecast, yet seasonal forecasts can be used as early warning information to warn about impending droughts. In Bhutan, with the current 24-hour weather forecast, lead-time for responding to hazardous weather situations is not long enough.

In terms of WSCA, a qualitative analysis of the EWS in Bhutan is shown below.

1. *Spatial and temporal forecast accuracy*

The key in the value formation of EWS is the spatial and temporal accuracy of the weather forecast. According to DDM, a 5 to 6-day weather forecast is needed to mitigate the losses of extreme weather events most efficiently. This is naturally true, as a longer lead-time gives stakeholders greater time to prepare for the coming event. DHMS already has the capability to produce a 72-hour forecast, as the MetGIS used is producing a forecast three days ahead. However, the accuracy is unknown. For professional use, such as for DDM, a longer forecast could be produced with the help of forecasts freely available on the internet. This would not necessarily be disseminated to the general public, but if the authorities could be informed well in advance of potentially hazardous events, the efficiency of the preparedness and response measures would increase and much of the damage could be avoided or the recovery time reduced. This would however need capacity building of DHMS on producing the medium-range forecast of acceptable accuracy.

2. *Appropriate data for a potential user*

According to DDM, DHMS should provide warnings especially for heavy windstorm and cyclone events. Other disasters causing harm in Bhutan include lightning, which is a problem especially in the south, and forest fires (often caused by lightning strikes and triggered by extreme dry spells). Preparedness for forest fires could be improved by issuing drought warnings which requires the development of seasonal forecasting skill.

3. *(timely) Access to the EW*

Access to the EW is extremely important for an efficient EWS. Currently, two issues in this step might jeopardise the benefit creation. Firstly, DHMS does not have 24/7 operational meteorological service and data (satellite or radar images) to detect quickly approaching extreme events, hence some potentially disastrous events may not be warned. Secondly, the warnings are currently disseminated through TV, but the access by final beneficiaries should be improved by disseminating the warning through radio as well.

4. Understanding the EW

As the Disaster Management Rules and Regulations, 2013 emphasise, the EW message content and form shall be:

a) simple and brief;
b) user friendly and easily understandable by common people; and
c) suited to the needs of the community.

Preferably, clear warning criteria should be developed, and the warnings should be based on the potential impacts, as the impacts may vary significantly between locations.

5. Use of information to effectively adapt behaviour

EWS is valuable only if the official stakeholders and the public know how to react to the warning and can respond to it. According to DDM, a well-functioning response mechanism to large-scale disasters already exists. Mobilising the response forces works already well and with 3–4 day lead-time, e.g. evacuation response would be effective. In addition, an Incidence Command Centre could be established quickly after the warning to ensure efficient coordinated response.

Raising public awareness on the severity of the disasters and training the public to react is important. Media should be engaged to inform people how losses could be mitigated.

Benefits of an effective response to a cyclone warning were demonstrated in India, when cyclone Phailin hit Orissa and Andhra Pradesh states on October 12th, 2013. Nearly 1 million people were evacuated. Response to the disaster was highly effective, as the death toll was only 38, a sharp drop from the 10,000 people killed in a similar cyclone in 1999. The difference between the two events has been attributed to the accurate early warning issued to officials and people combined with efficient response measures.[15]

The importance of the steps 2-5 of WSCA was demonstrated on the 17th of October, 2013, when torrential rain caused by the peripheral impacts of cyclone Phailin hit the western part of Bhutan during the rice harvesting season. Based on a preliminary damage report, collected by the Dzongkhag and Gewog extension agents in Paro, 65 % of the rice was affected. The damage could have been avoided through a well-functioning EWS.

After the event, the Bhutanese newspaper *Kuensel* published an article titled "Why farmers weren't warned"[16] (Kuensel online), arguing that if the farmers would have received information on the coming event, the damage would have been significantly smaller. However, DHMS did monitor the track of the cyclone and due to the severity of the cyclone, issued the first bulletin, even though the cyclone had not made landfall and was tracking away from Bhutan. The bulletin was updated three times.

The bulletins were issued to Bhutan Broadcasting Services (BBS), Kuensel Newspaper and DDM. An insert of the first bulletin reads:

"*…Bhutan is not on the forecast track of the cyclone. However clouds and some light rain is expected in parts of Bhutan as the system dissipates in the next 24-48 hours"*

Insert on the Update 3 reads:

[15] http://www.worldbank.org/en/news/feature/2013/10/17/india-cyclone-phailin-destruction-preparation
[16] http://www.kuenselonline.com/why-farmers-werent-warned/#.Ul-hT9KnroA

"…According to the latest observation, under the influence of the system, light to moderate/rather heavy rainfall is expected over Thimphu, Haa, Paro, Chukha, P/ling, Samtse, Tsirang, Dagana, and Gasa and isolated light rainfall over rest of Bhutan over the next 24 hrs."

Despite the bulletins, significant damage occurred. After the event, two potential reasons were identified:

- Farmers had not trusted/took seriously the forecast, presented on TV after BBS news
- DDM had thought that it was a light rainfall and did not warn the farmers. However, the light rainfall at this period of season affected the rice harvest.

6. The extent to which responses actually help to avoid damage or improve the operations

On the 25th-26th of May, 2009, peripheral effects of cyclone Aila caused major humanitarian and financial losses in Bhutan (given in Table 2). The total cost caused by cyclone Aila was approximately Nu 722m. Most of the damage was to infrastructure and other assets, and could not have been avoided by an efficient EWS. However, the cyclone also caused the death of 13 people, which could have been avoided with an efficient EWS in place. Furthermore, some, or even all damage to livestock may have been possibly avoided with an EWS. No data on injured people is available but every avoided injury decreases the burden to the individuals and the healthcare system.

Table 2. The estimated reported losses of cyclone Aila in 2009 (Source: DDM).

Damage	**Estimated value million Nu**
Government infrastructure	544
Farm & Feeder Roads	47
Agricultural property	7.5
Bridges	56
Drinking water/irrigation	45
Livestock	15
Private Property	7

As mentioned in Section 3.3, the peripheral effects of cyclone Phailin damaged 65 % of the rice in Paro. The main reasons behind the damage (leaving the rice in the fields to dry, and rice being submerged by debris and overflow of water in the fields), could have been avoided with the help of an efficient EWS.

7. Benefits from adapted action or decision are transferred to other economic agents

A direct benefit of a well-functioning EWS is the prevention of loss of life. This has far-reaching indirect impacts on families and communities, and is beyond economic analysis. Avoided losses not only decrease the suffering of the individuals, but also decrease the need of food aid and support from the government when the disaster strikes.

As demonstrated in the previous example, the potential value of EWS is high. The benefit creation is not only a matter of improved forecast skill, but requires improvements in the subsequent steps of the WSCA as well. Hallegatte (2012) reaches a conclusion that depending on the circumstances, the cost-benefit ratio of investments on EWS ranges from 1:4 to 1:35.

Socio-economic development will both increase and decrease the value of warnings. In general, when people become wealthier and urbanisation increases, people become less vulnerable to natural disasters as they have access to better housing and they are less dependent on agricultural income. However, developed societies are often more vulnerable to natural disasters due to increased capital stock and the dependence on information technology.

3.6.3 Women and children

Evidence shows that women and children suffer more severe consequences of natural disasters compared to men (Neumayer and Plümper, 2007). Women also have a major role in disaster risk management, as they are often responsible for the children. Gender issues regarding GLOF EWS in Bhutan formed a part of the HKH-HYCOS project. According to a report (ICIMOD, 2013), the level of gender sensitivity in EWS projects is quite low, mainly due to the reason that the tangible value-added of including gender aspect in EWS and risk management projects is perceived to be low. As of now, DRR is not getting attention in the agencies advocating gender-rights.

According to the interview held with the National Commission for Women and Children (NCWC)[17], the gender issue has reached a relatively good status on a political level, as the 11th 5-year plan of Bhutan is almost entirely gender mainstreamed. This implies that all sectors of society have conducted a gender sensitivity analysis. The recent 'Disaster Management Act of Bhutan 2013' has a section on affirmative action, stating that

"Due care shall be taken to ensure that women are adequately represented on Disaster Management Committees established under this Act"

and

"Special care shall be taken of children, women, elderly persons and persons with disability during rescue, response and relief operations".

How this is implemented remains to be seen.

According to NCWC, several issues related to gender equality on a grass-root level are still problematic and relevant to DRR, especially in rural parts of the country. Rural-urban migration of men is on the increase, meaning that women become the sole supporter of the family, increasing their workload and responsibility of children. This leads to a situation where women are more likely to suffer larger effects of disasters and need a longer lead-time to react to the disasters than before.

Such issues should be taken into account in DRR efforts. Special attention should be given to the ability of women to respond to disasters, for instance when organising DRR trainings. If no special attention is paid to the gender distribution, it is possible that only the men of the families and communities participate, and particularly lone women are not able

[17] The National Commission for Women and Children (NCWC) is the national mechanism for coordinating and monitoring activities related to women and child rights, and reporting to treaty bodies.

to participate because they must stay at home. This and the overall situation of disaster preparedness could be improved by e.g. TV commercials.

Furthermore, the early warnings should be customised for women: warnings should also be issued through radio or targeted directly to women via mobile phones (most Bhutanese women have mobile phones). This is important particularly in communities where the majority of men have migrated.

Bhutan has not experienced any problems related to human trafficking after disasters, which has been reported elsewhere after major disasters. Attention must be paid to this issue for the situation to remain the same.

3.7 Transportation

Background

Major weather-related problems for roads in Bhutan are caused by snowfall (blocking roads), monsoon rains (washing away roads) and landslides. Large-scale landslides occur more than 20 times a year in landslide-prone areas. No information on the total number of road blockages was available. However, the Department of Roads[18] (DoR) noted that the number is significant. National highways do not suffer from considerable damage caused by weather events as they have been constructed to withstand such events. However, secondary highways still suffer from weather-related problems. The time period to clear the roads depends on the magnitude of the damage, but at maximum it is three days. In snowfall cases it is at most two days.

DoR has a dedicated team which is responsible for clearing road blockages. In most cases, this enables the roads to be cleared within 1–2 days. Areas which suffer from road blockages frequently have excavators used to clear landslides or snow in place throughout the year. Off-the-record estimate of the affected number of vehicles by a road blockage was 100 cars.

Current use of hydro-meteorological services

Globally, the road transportation sector is one of the key beneficiaries of weather forecasts. Vehicle drivers often use weather information to improve pre-trip decisions[19]. Choices are made to lower the risk of accidents or to ensure arrival on time. Bus and truck operators are more professional in the use of information, but require longer lead-times which allow them to reschedule, re-route, postpone or find safe-haven for vehicles or cargo. (Nurmi et al., 2012)

Weather information is crucial especially for road maintenance during winter. The benefits of accurate weather forecasts include effective use of personnel and chemicals, and a timely response to weather events to ensure a minimum level of service required. Based on literature, benefits of weather information often significantly outweigh the costs for winter road maintenance. (ibid)

To prepare for potentially damaging weather events, DoR is currently using the 24-hour forecast.

[18] Department of Roads (DoR) is the government body responsible for smooth traffic flows. It consists of four divisions: roads, bridges, investments, and development. The mandate of DoR is to maintain roads and ensure smooth traffic flow by e.g. clearing of bushes, resurfacing roads; maintenance of the roads and construction of new roads.

[19] Destination, mode, route and departure time

Benefits of improved historical data

Road sector would benefit from the use of historical rainfall information, which could be used for hazard mapping: to define vulnerable areas and threshold values for weather parameters causing problems.

Benefits of improved forecasts and warnings

According to DoR, improved weather forecast would reduce the impacts and costs of weather events significantly in two ways: 1) to inform people on the impending blockages and improve their preparedness; 2) to prepare for the situation and mobilise the workforce earlier. This could decrease the time until the road is accessible again. The current budget for clearing a single landslide is Nu 2.5 million (about 30 000 Euro). Weather forecast and early warning could help in reducing the cost of one landslide through more efficient response. More importantly, due to the topography and terrain, the benefits of accurate weather forecasts and EWS for road users are high because the road network in Bhutan does not have much redundancy.

Regarding the road users, the majority of the affected people on the secondary highways are commuters. Business traffic which mostly operates on the national highways is not as severely affected by weather-related problems. Therefore, the largest benefits of improved weather services would come from the reduced number of casualties and injuries (see the number of accidents, casualties and injuries in Figure 6). The number of accidents has risen drastically after 2009, which is likely due to the increase in the number of cars.

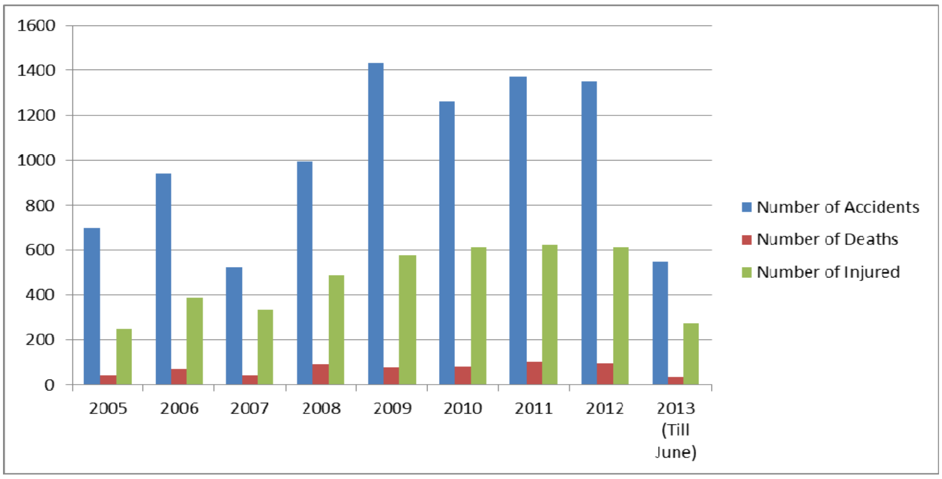

Figure 6. Road Crash Statistics (2005-July 2013). Source: Road Safety and Transport Authority

Due to the yearly frequency of the road crash statistics, it is not possible to estimate the number of accidents caused by weather events. To get an estimate of the benefits, secondary data is used. Based on a study conducted in Finland, 10% of the winter-time accidents could be attributed to bad weather conditions (Nurmi et al., 2012). Furthermore, "Strengthening the Hydrometeorological Services in South Eastern Europe" (Tammelin et al., p. 24) report cites a Finnish expert who notes that *"meteorological information and warning services offered to road users reduce by 1-2% the number of road accidents involving personal injury or death in public roads in Finland".* The low percentage is likely a consequence of the information decay related to the WSCA. For road users, Nurmi et al., (2012) form a best estimate of 14% of the final potential value of weather forecasts reached. Therefore, by assuming that 8% of the accidents in 2012 could be attributed to bad weather conditions, and 1-2 % of them could be avoided by an accurate weather forecast, the number of accidents is not reduced in practice at all. However, as the number of cars is likely to increase, the direct benefits are likely to become tangible. Furthermore, improving the quality of life of the people living in the vulnerable areas is an important aspect. It cannot be measured quantitatively in this study, but its importance should not be ignored.

3.8 Public health

Background

Outbreaks of diseases are a complex phenomenon which is affected mostly by socio-economic factors. However, in less developed countries, weather and climate phenomena are still a major contributing factor and anomalous events can explain serious outbreaks, as is reported in the Annual Health Bulletin 2013 of Bhutan (See Appendix A.2 for more information on the health sector):

"Malaria cases significantly declined from about 87 cases per 10,000 in the year 2000 to only 1 case per 10,000 in the year 2012. Similarly, the number of deaths caused by malaria had also been remarkably contained with only 1 death in the year 2012 as compared to 15 deaths in the year 2000."

"Significant results could be attributed to various preventive measures such as information dissemination, increasing use of insecticide treated bed nets, early diagnosis system and effective treatment. However, Bhutan experienced abnormal outbreak of malaria in the year 2009 with 972 positive cases. This was mainly attributed to abnormal rainfall patterns *coupled with high infection rates across the border in India. " [emphasis added]*

In Bhutan, vector-borne diseases are exhibited by distinct seasonal patterns, outbreaks occurring right after the end of the monsoon season. Figure 7 shows an indication of the relationship.

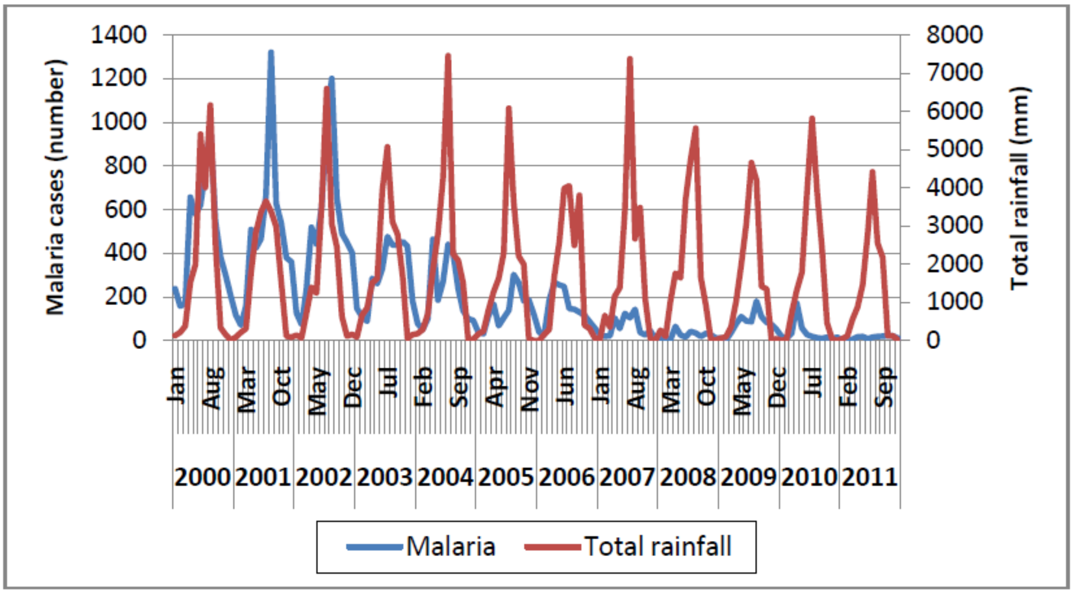

Figure 7. Monthly malaria cases and total rainfall of the seven endemic districts over the analysis period (2000 to 2011) (MoH and WHO)

Current use of hydro-meteorological services

The public health sector is using historical hydro-meteorological data to study the outbreaks of different diseases, and the role of weather in the outbreaks.

Benefits of improved historical data

Improved management of historical data would improve the studies conducted, as missing data and the uncertainty related to the representativeness of the measurement stations are creating problems in the assessments of the outbreaks, due to the fact that there is no clear knowledge and understanding of how well the available station data represents the area under study.

Public Health sector will benefit from the improved station network, but as with other sectors, the climatological representativeness takes minimum 10 years before proper assessments can be conducted.

Benefits of improved forecasts and warnings

Reliable weather services, particularly seasonal outlook on unusual rainfall patterns (especially the ending of the monsoon) would enable the health authorities to prepare for mass outbreaks and to enable a quick response. Currently, no preparedness measures are taken and response plans are done only after the outbreak has occurred. Furthermore, the vulnerable communities could also be informed in advance if a forecast/warning would be issued.

The benefits of the current and potentially improving seasonal forecast could be substantial, if the forecast would help the public health sector to prepare for the outbreak and the vulnerable communities would be informed on the measures needed to decrease the risk of the outbreaks.

Bhutan experiences harsh winter conditions, causing common cold and respiratory diseases. A potentially beneficial service could be a warning on extremely low temperatures, which could be used to warn the vulnerable population, such as people who suffer from chronic respiratory diseases.

Health workers operating at the community level would be an efficient way of communicating the warnings. More directly, as with other kinds of weather information, radio stations and TV channels which reach the vulnerable communities would be a good way to disseminate the information. In the future, the internet could also be used as a dissemination channel.

3.9 Construction industry

Benefits of improved historical data

The construction industry could benefit from historical and recorded meteorological data on freezing conditions and rainfall as construction companies could design appropriate concrete or design parameters or plan activities based on the local weather conditions.

Furthermore, construction companies and regulators usually maintain a register called *hindrance register* at the site, which is basically a rain/no-rain or snow/no-snow record with some approximate time of rainfall/snowfall. Later, the contractor uses this with the employing agency to extend the date of completion as rainfall/snowfall days are considered as hindered days. This is a very crude and unsystematic system, being also expensive. DHMS could provide the rainfall/no-rainfall record for all places to concerned contractors where meteorological stations exist.

Benefits of improved forecasts and warnings

A 72-hour weather forecast could help construction industry to plan their works where workers are engaged in the open air.

3.10 Insurance sector

Background

Two insurance companies operate in Bhutan, of which Royal Insurance Corporation of Bhutan Limited (RICBL) has a 70–80% share of the market. RICBL insures most major hydropower and road construction projects. According to RICBL, they are increasingly aware of the damages caused by hydro-meteorological disasters because floods, inundation and landslides potentially affect the major infrastructure projects of the country.

Current use of hydro-meteorological services

Currently, the RICBL does not utilise DHMS data.

Benefits of improved historical and observational data

Reliable hydro-meteorological information would be of great benefit to the insurance sector in the risk assessment. DHMS services could also be used in advising customers on the protection measures and damage mitigation measures e.g. in hazard-prone areas. Furthermore, the possibility for using historical climatological data to adjust premiums exists.

As explained in section 3.3, weather index-based insurance (WII) has great potential in improving farmers' risk management. WII would increase the need of historical meteorological information substantially. Furthermore, WII does not work without a reliable observational system.

3.11 Natural resource use

Background

The Natural Resource Development Corporation Limited (NRDCL) is responsible for sustainable management of Bhutan's stone quarries and forests, which are governed by a constitutional mandate stating that 60% of the land area must be covered by forest.

Current use of hydro-meteorological services

Currently, the NRDCL does not utilise DHMS data.

Benefits of improved forecasts and warnings

Monsoon season is the riskiest season especially for quarrying. Flooding and landslides affect the safety of the workers and damage easily movable machines and property. According to NRDCL, the operations in the quarries and forests could be better optimised with the help of forecasts and warnings. Warning services would help to save lives and property and help in preventing accidents occurring due to landslides in the roads leading to the quarry. Furthermore, if no market for the stones emerges, they are dumped close to the crushing plant. In case a flood occurs soon after the dumping, the stones erode causing environmental problems. This could be prevented through a warning.

After the forest has been cut, three years is given for natural regeneration. If it does not succeed, the area is reforested. Dry spells or excessive rainfall and flooding during the monsoon season may hamper the reforestation efforts. A seasonal forecast or reliable medium-range forecast could be used to plant the trees accordingly to ensure better growth.

3.12 Watershed and water resources management

Background

Bhutan is highly dependent on its water resources. Therefore, sustainable use of water resources is the key to the development of Bhutan’s economy. Currently, an Integrated Water Resource Management (IWRM) project is being conducted, with an aim to ensure that water resources are used efficiently. The purpose of the IWRM is to identify the existence of drinking water shortages, to protect water resources and to study the competing use of resources for irrigation and hydropower.

Current use of hydro-meteorological services

Currently, the Watershed Management Division[20] and The National Environment Commission Secretariat (NECS)[21], responsible for the IWRM, are using DHMS data as an input in their studies. Furthermore, DHMS expertise is used in measuring new sources and streams.

Benefits of improved historical data

Water resource management would benefit from improved hydrological and climatological data, which are basic requirements for any water resource management activities. For instance,

- Hydrological data plays a key role in National Water Resource Inventory. This information is mostly available for major rivers, but is not available for small rivers.
- Historical climate series are important for climate change impact studies.

According to the Watershed Management Division, the potential benefits of future DHMS data for managing the water resources are substantial as this information could serve as the basis for studies and actions for water resource management.

During the implementation of the IWRM project, NECS recognised the importance of close cooperation. The existing and future hydro-meteorological station data could be used in conducting the IWRM.

3.13 Climate change

Background

Climate change is a pertinent concern for Bhutan (see Appendix B.3). The production of regional or local climate scenarios is often conducted in universities and other research institutes, and the role of an NHMS is the provision of historical data series, which is the focus of this report.

In Bhutan, the National Environment Commission Secretariat (NECS) is the focal agency for coordinating all climate change activities. It is also the designated national authority to the United Nations Framework Convention on Climate Change (UNFCCC) and provides feedback to the Royal Government of Bhutan on climate change issues. NECS does not

[20] Watershed Management Division is one of the six functional divisions under Department of Forests and Park Services with primary responsibility of managing watersheds throughout Bhutan.

[21]National Environment Commission Secretariat (NECS) is the regulatory authority on Environmental Protection with the mandate to issue guidelines and frame environmental policies. NCES is responsible for e.g. drinking water quality standards, water quality monitoring, water inventories and the National Integrated Water Resource Plan.

produce climate scenarios for Bhutan.

The World Wildlife Fund (WWF) is an active player in the climate change field in Bhutan. WWF has a 30-year history in Bhutan working with nature conservation issues: climate change, fresh water and river basin management. The aim of the WWF Bhutan's climate change activities is to increase awareness of climate change, capacity building related to adaptation, and mainstreaming adaptation into the management of conservation and protected areas. Wangchuk Centennial Park, the largest national Park in Bhutan, is the first national park co-managed by WWF and the Royal Government of Bhutan. The first activity to mainstream climate change adaptation into the park management was to conduct a Climate Change Vulnerability Assessment for the park. (WWF Bhutan, 2011)

Benefits of improved historical data

Advanced data processing and analysis based on high-quality hydro-meteorological observations ensure accurate results for the analysis of climate change or climatological conditions. Many of the sectors covered above noted that historical hydro-meteorological data is important for climate change monitoring and impact studies.

WWF has taken climate change activities and the use of meteorological information one step further. According to the Vulnerability Assessment (VA), the ecosystem and the communities of the park are highly vulnerable to the potential impacts of climate change. To increase knowledge on the vulnerability, close collaboration between WWF Bhutan and DHMS was initiated. As the VA states, *"…early detection and study of the changing climate and its impacts on hydrological, ecological and social systems becomes a priority"* (WWF Bhutan, 2011). During the course of the park management, six AWSs have been installed. WWF has been responsible for purchasing the equipment and DHMS is responsible for the installation and maintenance. The park staff has been trained to collect data from AWSs and record rainfall, temperature and river flow measurements. The information is sent to DHMS. Simultaneously, the staff is monitoring biodiversity, creating a possibility to jointly assess weather parameters and biodiversity. The benefit of the AWSs is clearly stated in the VA: "

"Data from existing meteorological stations should be further analysed and additional hydrometeorological stations established. The data collected would be exceptionally useful for follow-up studies on climate and water resources and could serve as inputs to (future) environmental flow conditions to be maintained by the planned hydropower dams. "

More AWSs will be installed as WWF is expanding the project to cover areas in the southern part of the country as well.

The value of good-quality, long-term climate data series for climate monitoring is high. The standard period for determining the climatological normal of different weather parameters is 30 years, which is not feasible in Bhutan with the current length of the historical time series. However, the current quality-controlled observational data possessed by DHMS can be used to determine 10-year average parameter values (World Meteorological Organisation, 2011). The new weather and hydrological stations installed through the NAPA II Project will be of value ten years after the installation at the earliest. Regular maintenance and calibration of the stations must be assured.

The majority of the interviewees mentioned the need for local climate scenarios for Bhutan. The benefits of the scenarios are not assessed in this report, but climate scenario production should be kept in mind in the future.

4 Costs

This chapter assesses the costs to achieve the services assessed in this report and to maintain the level of services in the future. Although aviation meteorology is not currently part of DHMS services, the cost of upgrading the services at Paro airport are included in the calculation to obtain a better understanding of the cost of the overall improvements in hydro-meteorological services.

4.1 Lightning Location System

Due to the challenging topography of Bhutan, weather radar would most likely not be a profitable investment, taking into account the mountainous terrain, and high initial cost and maintenance. As an alternative, Mäkelä et al. (2013) demonstrate the use of lightning location systems (LLS), which provides lightning location data practically in real time in examining the characteristics of thunderstorms. LLS is especially suitable for countries "*in which a nation-wide network is difficult or even impossible to establish because of a complicated terrain or of poor economical situation*" (Mäkelä et al., 2013). As in neighbouring Nepal, where the benefits were demonstrated, Bhutan fulfils both of these arguments.

LLS data could be used a first guess or a proxy for intense convective precipitation which include lightning (Pessi and Businger, 2009), which is usually the cause for landslides and flash floods in Bhutan. Therefore, benefits of using LLS could be substantial. Furthermore, if detrimental cyclones involve lightning, they could be tracked and forecasted more accurately. However, this applies only to phenomena which develop outside the country. Forecasting local events requires a proper weather forecast model.

The cost of a national LLS depends on the size of the area covered and the number of sensors. In Bhutan, the cost could reach up to one million euro. The cost of Vaisala Global Lightning Dataset GLD360[22], which provides real-time lightning coverage but does not require any equipment or maintenance, is only a few thousand Euro. Mäkelä et al. (2014) conclude that "*developing countries can get large benefits from receiving long range lightning location data. A national lightning location system owned by an NHMS is an excellent and efficient tool for observing thunderstorms, but it needs continuous maintenance, analysis and suitable and safe installation sites for the sensors; these may be difficult to fulfil which may lead to a network of decreasing performance. We suggest that developing countries should first use long range LLS data to get hands-on experience on the data and its usefulness in different fields of meteorology, and afterwards make plans regarding a national medium-range network*."

C-band weather radar would cost 1.5-2 million euros.

4.2 Ceilometer

The installation of a ceilometer to improve the capacity of Paro airport for real-time measurement of the height of the cloud ceiling costs approximately 22 000 Euro.

4.3 Upper Air Sounding

During 2014, DHMS will obtain a radiosonde to conduct upper air soundings (a description

[22] http://www.vaisala.com/en/products/thunderstormandlightningdetectionsystems/Pages/GLD360.aspx

of the project is given in Appendix C.5.4). The first three years of the project implementation will be free-of-charge for DHMS, implying that in the costs will start to accrue in 2018. The current yearly cost of operating a radiosonde in Bhutan will be approximately 65 000 Euro.

4.4 Data management

As the number of hydrological and meteorological stations will very like increase substantially, the requirements for proper data management will also increase. This request also came up in most interviews, and is clearly one of the biggest challenges DHMS is currently facing. This section is based on an FMI expert mission to Bhutan, and a preliminary gap analysis regarding data management at DHMS.

The most important development needs regarding proper data management are twofold: 1) storing all observational data on a database, where it is quick to access and disseminate; 2) recruiting skilled IT engineers to handle all IT services.

The first development need would require purchasing servers to operate the database. According to the FMI experts, 4 servers is the minimum requirement for a reliable system with redundant servers. The average cost of one server is 2000-3000 euros. DHMS is in the process of obtaining some basic equipment and training on a database software Climsoft with the support of the World Meteorological Organization.

Human capacity in the IT segment should be built hand-in-hand with the technical capacity. Proper data management and other IT services would require at least 4-6 skilled IT-engineers. This cost analysis includes only the cost of labour, not the cost of educating the engineers.

WRF is an open access "next-generation meso-scale numerical weather prediction system designed to serve both atmospheric research and operational forecasting needs"[23]. It is already partly in use at DHMS. To use WRF to its full potential, DHMS should develop and maintain the forecast model and develop useful products for its potential customers. This requires dedicated staff with programming skills.

4.5 Station maintenance and instrument calibration

DHMS is currently employing 114 technicians. In five years, after the NAPA stations have been installed, the total number of maintenance staff is increased by 24 people. Hence, there will be altogether 138 staff members maintaining the AWSs and AWLSs.

A fully equipped calibration laboratory is a costly endeavour, reaching up to 50000 – 100 000 Euro investment cost. However, an initial, sufficient calibration instrumentation can be purchased with an investment cost of maximum 20 000 euro and calibration can be taken care of during the regular maintenance. The funding for this must covered either from public funds or should be a priority of donor funding. In the cost assessment, purchase of the calibration instruments is assumed to take place in 2016. After the initial cost, calibration requires mostly maintenance staff.

4.6 Forecasting and warning services

The number of operational forecasters (1 meteorologist and 3 technicians) is sufficient in

[23] http://www.wrf-model.org/index.php

the current environment. However, to guarantee timely access to (early) warnings, the number of hydrological and meteorological staff should be increased to six, which is the minimum requirement for a 24/7 operational forecasting service at the Finnish Meteorological Institute. Preferably, one meteorologist, hydrologist and a technician should be present at all times. The 24/7 service will increase staff costs, as additional staff members should be hired. Furthermore, ICT technicians are needed to take care of the system. Initially it can be operated through an on-call duty system.

4.7 Funding

The hydro-meteorological network is currently going through substantial expansion due to several projects funded by international donors. The JICA project will focus also on improving the hydrological forecasting and warning capacity of DHMS. Therefore, little funding at this point is required from the public funds. However, the operational cost of the DHMS staff, data management cost and maintenance of the measurement stations must be provided through public funds. As the public budget of Bhutan is small and there are many competing development goals, the funding for the DHMS services must be well justified. This report shows that the socio-economic benefits of the future services provided by DHMS are very high, particularly when the costs of the international projects are excluded.

The general weather forecast should be publicly funded and be free-of-charge. However, the historical data is of economic value to several sectors and could in the future provide revenue to DHMS to cover part of the operational costs. During this study, large-scale hydro-power, tourism, construction and insurance sectors indicated that they have willingness-to-pay (WTP) for good-quality historical data. However, public funds are needed to achieve the level of quality required. Before the sectors would pay for data, it must meet quality standards and efficient dissemination. This requires proper data management facilities and guaranteed maintenance and calibration of the upgraded and new automatic measurement stations.

Tailored weather forecasts and warnings are economically valuable to some sectors (e.g. large-scale hydro-power, tourism) and some of these sectors may also have WTP for reliable, accurate forecasts and warnings.

5 Conclusions

This chapter outlines the conclusions, the summaries of the benefits of each service, and costs to achieve the level of services assessed in this report. Chapter 5.3 presents the conclusive benefit-cost analysis.

5.1 Summary of the benefits

The benefits of each service are assessed, where possible, for each sector directly. In most cases there was no possibility to derive monetary estimates. Furthermore, the overall benefits to society stemming from each service in the sectors are assessed on a scale of +…+++++. The higher the number of + -signs, the higher is the benefit to society. If the +-signs are in brackets, the benefits are conditional on factors which are mostly not under the control of DHMS.

5.1.1 Historical data

The socio-economic benefits of historical data stem from three different sources and two time scales.

Sector	*Current network; quality-controlled data; 2015–2030*	*Successfully extended network, 2016–2030*	*Successfully extended network; 2020/2025-2030*
Small-scale energy production	Improved design of small-scale hydropower plants +	Improved design of small-scale hydropower plants +	Improved design of wind, solar and hydropower plants (++++)
Large-scale hydropower	Improved design of hydropower plants ++	Improved design of hydropower plants ++	Estimated yearly value Nu 67 Million (790 000 Euro) per HPP +++++
Agriculture	Long-term planning of most suitable crops, weather index -based insurance scheme ++	Long-term planning of most suitable crops, weather index -based insurance scheme +++	Long-term planning of most suitable crops, weather index -based insurance scheme +++++
Tourism	Marketing to increase the number of tourists, especially during lean seasons ++	Marketing to increase the number of tourists, especially during lean seasons ++	Estimated yearly value Nu 86 Million (1 million Euro) (starting 2020) ++++
DRR	Hazard-mapping, land-use and spatial planning +++	Hazard-mapping, land-use and spatial planning ++++	Hazard-mapping, land-use and spatial planning +++++
Public Health	Assessment of outbreaks ++	Assessment of outbreaks ++	Assessment of outbreaks +++

Insurance	Risk assessment, pricing, weather index -based insurance scheme +	Risk assessment, pricing, weather index -based insurance scheme ++	Risk assessment, pricing, weather index -based insurance scheme +++
Water resource management	National Water Resource Inventory +++	Management of water resources +++	Management of water resources ++++
Climate Change	Climate change monitoring +++	Climate change monitoring +++	Climate change monitoring ++++

The benefit summary shows that the provision of historical hydro-meteorological information is vital for practically every sector assessed in the report. However, to reap the full benefits of the historical observations, data management, maintenance and calibration of the AWSs and AWLSs are crucial. It is a costly endeavour but guarantees that economic sectors which are highly important for the Bhutanese economy, most notably hydropower production, agriculture and tourism, can plan their operations better and improve their performance in the long run. Furthermore, high benefits occur from efficient risk management in every sector and in society. The insurance sector plays also a key role in risk reduction and recovery.

5.1.2 Current observations

The only sector greatly benefiting from current observations is the aviation sector, which would not operate without the service. This is highly important for the Bhutanese economy, as the majority of the tourists arrive by plane. Furthermore, current observations have clear indirect benefit stemming from the use in weather forecasting and particularly when weather forecast information is turned into early warning in hazardous weather situations when the progress of the phenomenon can be monitored with observations.

5.1.3 Forecasts

The potential socio-economic benefits of weather and hydrological forecast and the seasonal outlook are assessed for 2015–2030.

Sector	***72-hour forecast; 2015/2020–2030***	***Seasonal forecast; 2015–2030***
Small-scale energy production	Consumption and production estimations, secure electricity supply (starting 2020), aid in operation ++	Production estimations +
Large-scale hydropower	Production estimation, improved maintenance, yearly value Nu 65.8 million (771 445 Euro ++	Production estimations +
Electricity distribution	Prepare for damage, inform customers (++)	

Agriculture	Improved farming practice ++++	Adaptation to yearly variation in rainfall patterns +++++
Tourism	Expand tourism areas currently without forecast, Nice-to-know information +	Increase the number of tourists, Improved planning and preparedness +
Aviation	Benefits from nowcasts +++	
Public Health		Prepare for outbreaks, inform the public ++
Road Transportation	Prepare for road blocks and mobilise the workforce earlier, inform the public ++	Improved planning and preparedness +
Natural Resource Use	Optimise the operations in the stone quarries and forests ++	Optimise the operations in the stone quarries and forests ++

Forecasts were not the most important service requested by DHMS, as the majority of the sectors considered historical information more important. However, the benefit summary shows that potentially there are major benefits from the 72-hour and seasonal forecasts. In particular, for the professional users, the benefits would further increase if the temporal resolution of the forecast would be increased to 3 hours, and if the forecast is continuously monitored and, if necessary, updated. However, the value creation requires improvements not only in the accuracy of the forecast, but also in later steps of the WSCA. For instance education and training of farmers and the general public is necessary before the benefits start to accrue.

5.1.4 Early Warning System

Bhutan is highly susceptible to natural hazards. Therefore, the potential value of a reliable, well-functioning early warning system (EWS) is high. The direct benefit of a EWS is the prevention of loss of life, decreased number of injured people and affected livestock. This has far-reaching indirect impacts on families and communities, and is beyond economic analysis. Avoided losses not only decrease the suffering of the individuals, but also decrease the need of food aid and support from the government when the disaster strikes.

EWS would greatly benefit the hydropower sector in terms of avoiding the damages to the infrastructure by improved operation of the gates. EWS can also prevent physical harm to tourists. As all international tourists travelling in Bhutan have an itinerary, the location of the tourists is fairly well known and early warning services could mitigate the impacts of hazardous weather on tourism effectively. This would improve the safety and satisfaction of the tourists, and the overall perception of Bhutan as a safe place to travel. This may raise tourist numbers depending on the extent the potential tourists are deterred by perceived lack of safety.

In current circumstances, the benefit creation of a multi-hazard EWS in Bhutan is not only a matter of improved forecast skill, but requires improvements in the dissemination and use of the warning (subsequent steps of the WSCA). The potential economic value of a EWS was not assessed in this report. However, Hallegatte (2012) reaches a conclusion that depending on the circumstances, the cost-benefit ratio of investments on EWS ranges from 1:4 to 1:35.

Socio-economic development will both increase and decrease the value of warnings. In general, when people become wealthier and urbanisation increases, people become less vulnerable to natural disasters as they have access to better housing and they are less dependent on agricultural income. However, developed societies are often more vulnerable to natural disasters due to increased capital stock and the dependence on information technology.

5.2 Summary of the costs

Table 3. Summary of the costs in million Euro

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Project Costs	3.99															
Operational Cost & calibration 2016	0.23	0.26	0.25	0.39	0.4	0.42	0.44	0.46	0.48	0.5	0.52	0.54	0.56	0.59	0.61	0.64
TOTAL EURO	4.22	0.26	0.25	0.39	0.4	0.42	0.44	0.46	0.48	0.5	0.52	0.54	0.56	0.59	0.61	0.64

Table 4. Summary of the costs in million Nu

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Project Costs	336															
Operational Cost & calibration 2016	19	22	21	33	34	36	37	39	40	42	44	46	48	50	52	54
TOTAL EURO	355	22	21	33	34	36	37	39	40	42	44	46	48	50	52	54

Note: 5% cost escalation assumed..

5.3 Cost-Benefit Analysis

The cost-benefit analysis shows that the investments in the development of the hydro-meteorological services in Bhutan will yield high long-term monetary benefits (see fig. 8).

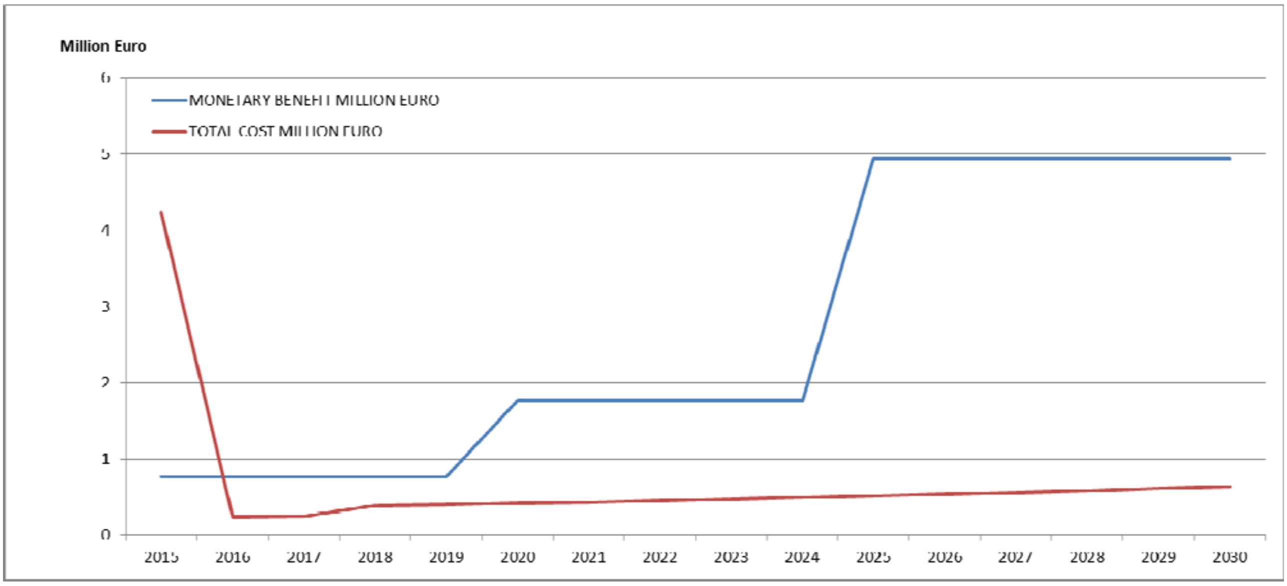

Figure 8. Summary of estimated cost and benefit flows of improved hydro-meteorological services in Bhutan in 2015-2030

The overall *net present value* cost-benefit ratio is 3.1, taking into account the high initial costs of modernising DHMS. However, these costs are covered by international co-operation. Excluding the project costs in the beginning of the assessment period increases the net present cost-benefit ratio to 5.5. The yearly benefit ratio increases substantially in 2025, up to 8-9, when the benefits of the historical data start to accrue. However, this requires that the NAPA II project is successfully implemented and the station network maintained. Furthermore, it is important to notice that the ratio considers only the direct monetary benefits assessed for hydropower and tourism sectors. The true societal benefits are substantially higher, particularly if the production, dissemination and use of the information is improved in all sectors of society.

6 Recommendations

This Chapter provides recommendations for DHMS to improve its infrastructure and services and reach the goal of becoming a modern hydro-meteorological service. Due to international donors, DHMS is currently experiencing rapid modernisation which provides a good starting point for the near-future. However, to reach and maintain the level of services enabled by the modernisation, the following recommendations should be considered.

#1 24/7 OPERATIONAL FORECASTING SERVICE AND EARLY WARNING SYSTEM (EWS)

For efficient forecasting and especially EWS, the following recommendations are outlined: 1) to develop the capacity to start operational hydrological forecasting and warning service 2); to start issuing a 3-day weather forecast with 3-hour temporal interval and disseminate it to the public and relevant stakeholders; 3) to develop a 24/7 operational weather and hydrological forecasting service; 4) to produce a medium-range (5-6 days) weather forecast with freely available material and disseminate it as an early warning to relevant stakeholders (such as DDM) when considered beneficial; 5) to start the verification of the operational meteorological forecast; 6) to improve the cooperation between DHMS and different authorities and to make clear the responsibilities of different agencies regarding disaster risk reduction and management.

#2 STATION MAINTENANCE AND CALIBRATION OF THE INSTRUMENTS

To reap the long-term benefits of the substantial increase of the automatic meteorological and hydrological stations, station maintenance and instrument calibration have to be guaranteed and DHMS has to be prepared for likely situations of station malfunction. The recommendations are as follows: 1) a yearly maintenance visit to each station; 2) develop and implement a preparedness plan for situations of station malfunction; 3) regular (depends on the instrument) calibration of the instruments has to be ensured by purchasing required equipment or alternatively, be prepared for the cost of sending the instruments elsewhere for calibration 4) adjust the number of maintenance staff for the yearly maintenance and malfunctions.

#3 STAFF

The most urgent need for staff is in the IT section. When the upgraded station network is running, the need for skilled people to run and maintain data management systems becomes essential. Furthermore, the development of WRF into an operational forecasting model requires a skilled person. Two recommendations to achieve this are: 1) current staff members should be provided with continuing education on IT, and after such training should remain employed as dedicated IT specialists. This should be achieved before the new station network is running. 2) to increase the number of skilled people in DHMS, the need for IT specialists should be communicated to the Ministry of Economic Affairs or other relevant authority, to ensure that DHMS will receive IT specialists in the future. This will increase the labour cost, but is crucial for the successful implementation of the NAPA II project and the modernisation of DHMS.

To start and maintain the 24/7 operational forecasting service, it is necessary 1) to increase the number of meteorological and hydrological forecasters minimum to six, and 2) to increase the number of back-up technical IT specialists to respond to maintain the 24/7 operational system and especially respond to problem situation, which can initially be operated through an on-call duty system;

#4 DATA TRANSFER AND OVERALL DATA DEVELOPMENT

High speed internet and undisturbed electricity supply has to be guaranteed. This has to be done with the support of the Ministry and the telecommunication service providers.

#5 IT DEVELOPMENT

The IT section should be developed and modernised as the amount of data and stakeholder demand will increase. Two recommendations to achieve this are: 1) proper Data Management system for the observational data, hydrological and meteorological forecasting models and forecast products should be developed within the next few years. 2) the development, maintenance and product development of WRF should be guaranteed by having dedicated people with programming skills

#6 STAKEHOLDER INVOLVEMENT

The services offered by DHMS are valuable to society and different economic sectors only through successful outreach and use of the services offered. The interviews held during this study revealed that DHMS services have high potential demand but stakeholder involvement and information dissemination has to be improved. To achieve this, the following recommendations are given: 1) map potential customers and stakeholders (media, authorities) and determine what services they would need; 2) establish well-defined and sustainable relationship with the most important stakeholders within a couple of years and after successful implementation of these, extend to other stakeholders; 3) develop and implement a data dissemination policy to ensure efficient accessibility to information by all stakeholders; 4) collect systematic customer and stakeholder feedback; 5) hire a dedicated customer service officer.

#7 CLIMATE CHANGE

The majority of the interviewees mentioned the need for climate scenarios for Bhutan. To accomplish this, the following recommendations are given: 1) obtain the outcome (data) of the global climate models and scenarios prepared for the 5th Assessment report of the Intergovernmental Panel on Climate Change; 2) to develop downscaling methods for the Bhutanese context and produce local climate scenarios; 3) to obtain the best possible use of them, contact relevant stakeholders and prepare climate scenarios for stakeholder needs.

#8 GENERAL RECOMMENDATIONS

Furthermore, some general recommendations are provided: 1) develop data quality control by the end of 2014 to prepare for the upgrade of the measurement station network; 2) improve the seasonal forecast process and dissemination as this is a very low-cost development measure and if successfully implemented, would bring substantial benefits 3) improve regional co-operation; 4) Conduct a follow-up socio-economic study by 2020.

7 Policy Recommendations

DHMS is currently going through quick modernisation which provides it a good starting point for the near-future to develop itself into a well-functioning hydro-meteorological service which can improve the wellbeing of Bhutanese people, viability of economic sectors and contribute to sustainable development. Excluding the project costs, the net present cost-benefit ratio is 5.5. The yearly benefit ratio increases substantially in 2025, up to 8-9, when the benefits of the historical data start to accrue.

The following recommendations at a policy-making level which are needed to improve and maintain the hydro-meteorological infrastructure and services in Bhutan should be considered:

1) The status and responsibilities of DHMS should be clearly defined and adopted at national level.

Hydro-meteorological services are an important part of modern, well-functioning society. Giving an official status to DHMS will improve the possibilities of DHMS to improve its services.

2) DHMS budget should be adjusted to the improved and more extensive level of infrastructure and operations.

A considerable amount of money is currently being invested in the modernisation of DHMS. The long-term benefits of these investments will be reaped only if the new infrastructure is properly maintained and DHMS has the capacity to use the infrastructure to its full potential. If DHMS will not receive any donor or project funding after all the current projects have been completed, the yearly operation and maintenance cost is approximately Nu 22 million. If DHMS has the capacity to improve the level of its services assessed in this report, this investment will yield three times more benefits only in hydropower sector at first. In 10 years, the benefit potential is up to nine times higher compared to the required public funding.

3) Education of IT specialists, meteorologists and hydrologists should be guaranteed; DHMS should be provided an adequate number of IT specialists, meteorologists and hydrologists.

The operations of DHMS are clearly suffering from the lack of adequate amount of educated staff in these disciplines. This deficiency will increase in the future due to the on-going modernisation of DHMS.

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Appendix A Overview of economy and society

A.1 Economy

Bhutan is categorized as a least developed country. Its small population base (738 000 inhabitants in 2011), geographic size, and the fact that it is a land-locked country pose significant development challenges (see Figure A1 for the demographic map and major roads of Bhutan).

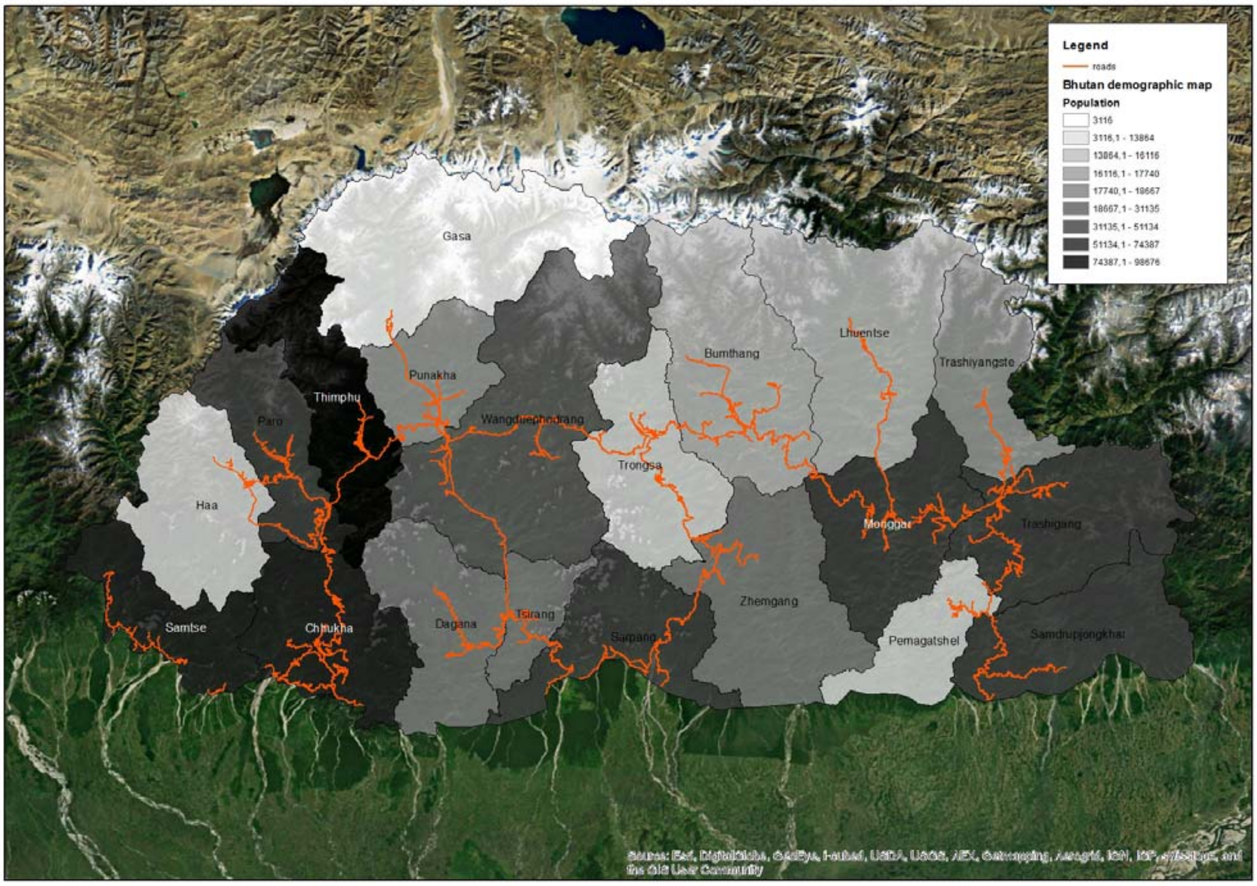

Figure A1. The demographic map and major roads of Bhutan

Between 2005 and 2010, the economy of Bhutan grew at an average of 8.7% per year and is fuelled mainly by investments in hydropower projects. The most important sectors in the economy are the hydropower, construction, agriculture and service (incl. tourism) sectors. Fuelled by the development of hydropower, Bhutan's industrial sector is developing rapidly; the industrial production growth rate is 12.4%, being 9th highest in the world (CIA World Factbook)[24]. Hydropower exports to India provide a substantial part of Bhutan's Gross Domestic Product (GDP), and has a significant implication for the development of Bhutanese economy, and towards achieving the overall national goal of poverty reduction. Tourism activities are also on the rise. In 2012, GDP was US$ 17 million, corresponding to US$ 2400

[24] https://www.cia.gov/library/publications/the-world-factbook/geos/bt.html

per capita.[25]

As of 2013, Bhutan has four large-scale hydropower plants (HPPs) (see Table A1 for details). During the monsoon period, almost 90 % of the production is exported to India, due to low domestic consumption. However, during winter Bhutan experiences problems with electricity self-sufficiency. This problem is expected to be solved due to installation of HPPs, of which the first is planned to be operational in 2014 and remaining three by 2017. Feasibility studies have been conducted for four more plants. By 2020, 10 000 MW (38% of the currently evaluated capacity) will be installed, with the majority of the production to be exported to India, creating major revenue stream for Bhutan.

Table A1. Existing large-scale hydropower plants in 2013

	Installed capacity	**Mean annual energy production**	**Other information**	**Domestic tariff**	**Export tariff Nu**
Basochhu Lower	24 MW	105 GWh		1.2 Nu /kWh (until 2008)	-
Basochhu Upper	40MW	186 GWh		1.2 Nu /kWh (until 2008)	-
Chhukha	336 MW	1800 GWh	Most of the generated energy is exported to India		2.0 Nu/ KWh
Kurichhu	60 MW	400 GWh)	During the peak power generation season, over 60% of the power generated from the Plant is being exported to India.		1.89 KWh
Tala	1020 MW	4865 GWh			1.80/KWh

With ever expanding rural electrification and with urban and industrial growth, (e.g. the commissioning of the Ferro-Silicon factory at Motanga/Rabtenling Industrial estate in Samdrupjongkhar), domestic electricity consumption is increasing rapidly, resulting in revenue decreases for DGPC and Bhutanese economy (DGPC website)

[25] http://data.worldbank.org/country/bhutan

Agriculture –mostly rain-fed - is the dominant sector providing livelihood, income and employment to more than 60% percent of the total population[26]. Whilst tourism's role in Bhutan's economy is on the rise, agriculture is still the second largest contributor to Bhutan's GDP after hydropower. The most important crops are paddy rice, maize and wheat. Commercial farmers are engaged in horticulture (citruses, apples), which generates direct income as the majority of the horticulture products are exported. The aim in the agricultural sector is to develop in the direction of more intense farming practices and production for the market.

Alongside hydropower, the tourism sector is the second major sector contributing to the foreign source of income. Most nationalities coming to Bhutan need a visa; only citizens of India, Bangladesh and Maldives (referred as 'regional visitors') are exempted from the visa requirement. All tourists who need the visa (referred as 'international visitors') are required to pay a daily tourism tariff, which is US$250 for high season and US$200 for off-season during the monsoon (June-Aug) and winter (Dec-Feb). The tariff includes accommodation in minimum a 3-star hotel, meals, local ground transportation, guides and trekking. US$65 of the tariff is given to the Royal exchequer. The tariff was introduced in January 2012 and there are no plans to increase it. According to the Tourism Council, the tourism sector employs 28 982 people.

Based on the statistics of the Tourism Council, the main reasons to visit the country are festivals, Buddhism way of life (monasteries, temples...), trekking and nature. On the rise are adventure tours, bird watching, flora & fauna; and according to the Tourism Council, the aim is to increase wellness & spa tourism and business meetings. Tourism is heavily concentrated on the western part of the country. Main sites are located in the triangular Paro, Thimphu and Punakha. Main reason behind the popularity of these places is access, as Bhutan's only international airport is located in Paro in the western part (see section 3.5). Recently the growth in other parts of the country has started to show signs of increase. Sustainability of the tourism industry in Bhutan has been a subject of debate in the country.

Bhutan is experiencing rapid development and urbanisation. In 2012, 21% of the population was using the internet (in 2000, Bhutan had only 500 internet users)[27]. 23.2% of the population live under the national poverty line, but only 1.7% lives under the global USD 1.25 poverty line. The total literacy rate of 15-24 year olds is 74.41%. Primary education is well developed; 94% of pupils starting grade 1 finish their last grade of primary education. [28]

Unique to Bhutan, socio-economic development is guided by the philosophy of Gross National Happiness (GNH) promulgated by the king of Bhutan, His Majesty King Jigme Singye Wangchuck. The GNH philosophy advocates that socio-economic development will lead to the prosperity and happiness of the general populace only if there is an equitable balance between the four pillars of: i) Sustainable and Equitable Socio- Economic Development , ii) Conservation of the Environment, iii) Preservation and Promotion of Culture and iv) Good Governance. To emphasize the importance of using GNH as the guiding philosophy for all plans and programs of the country, a GNH Commission (GNHC) was established in 2008 as the apex body for planning in Bhutan.

[26] http://data.un.org/CountryProfile.aspx?crName=Bhutan
[27] http://www.internetworldstats.com/stats3.htm#asia
[28] https://sdbs.adb.org/sdbs/index.jsp

Bhutan has taken climate change mitigation actions via the constitutional mandate to maintain 60% of land as forest, develop renewable energy infrastructure and implement various targeted environmental legislation and policies. To guide future action for Bhutan to fulfil its pledge to remain carbon neutral, “green growth” is promoted and forms a central part of Bhutan’s Economic Development Policy and Carbon Neutral Strategy.

A.2 Weather-related health issues

Weather-sensitive diseases are known to be leading causes of death in developing countries and are expected to become more common due to climate change. Weather fluctuations are also known to affect the most vulnerable section of the population, such as poor individuals, infants, young children, and the elderly.

Outbreaks of vector-borne diseases, such as malaria and dengue-fever, are affected by warm temperature and heavy rainfall which accelerates the breeding of mosquitos spreading the diseases. In Bhutan, vector-borne diseases are exhibited by distinct seasonal patterns, outbreaks occurring right after the end of the monsoon season. The total number of malaria and dengue cases is shown in Figure A2.

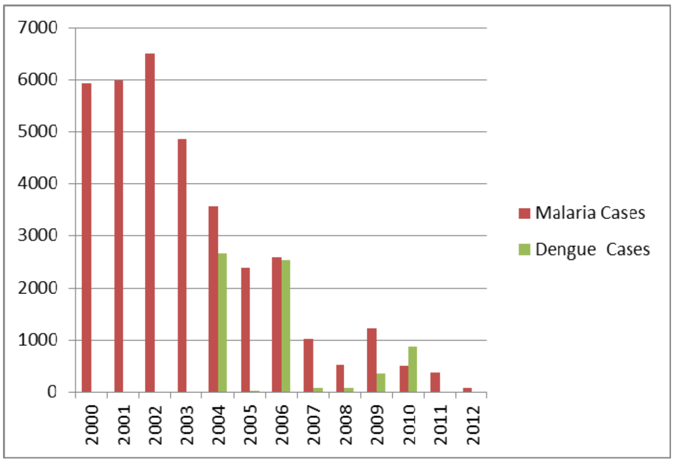

Figure A2. The number of Malaria and Dengue cases. Source: DoPHE

As Figure A2 shows, malaria cases in Bhutan are close to elimination. According to the Department of Public Health Engineering (DoPHE), malaria is mostly a problem in the southern Dzongkhaks, close to the Indian border.

More common are the persisting weather-related health problems related to water-borne diseases. They are caused by heavy rainfall and consequential flooding, which contaminates drinking water and increases the risk of diarrhoea and dysentery outbreaks. Diarrheal diseases continue to be a major problem in Bhutan, affecting especially the survival of children under five years of age. According to the Annual Health Bulletin 2012, diarrhoea incidence per 10,000 under five children in the year 2007 was recorded at 3 296 and 2 257 in 2011 (see Figure A3 for the number of diarrhoea and dysentery cases).

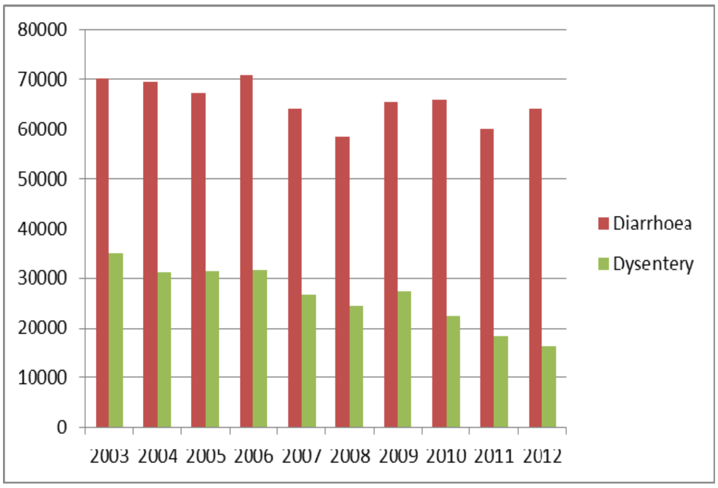

Figure A3. The number of diarrhoea and dysentery cases.

The majority of typhoid cases, caused by the bacteria *salmonella,* occur during the monsoon season, and the proximity of a river increases the risk of being infected. Typhoid fever occurrences are increased during flooding, and the transmission and distribution of typhoid infections are reported to be affected by rainfall, vapour pressure and temperature. (Dewan et al., 2013) The yearly number of typhoid cases in Bhutan is shown in Figure A4.

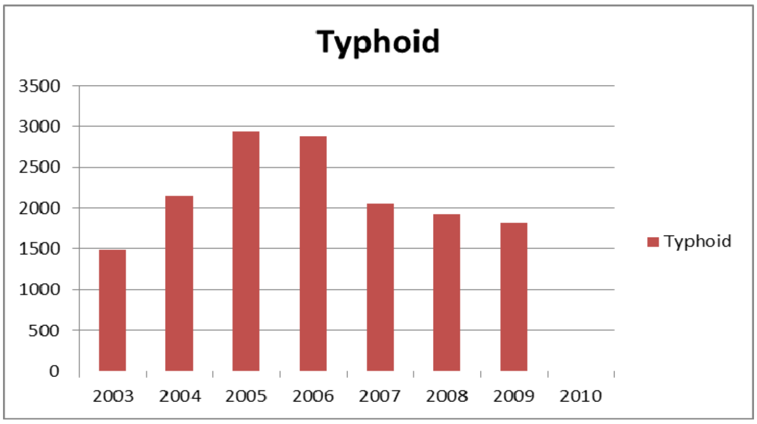

Figure A4. The number of typhoid cases

Appendix B Climatological overview

B.1 Climate

The climate in Bhutan varies substantially from one Dzongkhag (district) to another due to dramatic changes in the topography and elevation. Bhutan’s climate is generally dominated by monsoon winds with dry winters and a wet summer monsoon period. The factors that govern the climate are the altitude, latitude, prevailing wind conditions, local winds and orientation of the mountain ranges.

Bhutan is comprised of three climatic zones that are distinguished by their altitude:

- The southern belt is made up of the Himalayan foothills with an altitude ranging from under 200m to approximately 2000m. It has a subtropical and tropical climate characterized by high humidity and heavy rainfall. In this climatic zone, the average temperature ranges from 15 °C to 30 °C all year round.

- The central belt consists of the main river valleys with altitude ranging from approximately 2000m to 4000m and is characterized by cool winters and hot summers with moderate rainfall. The temperature ranges from 15 to 26 °C during the monsoon season (June through September) and -4 to 15 °C during the winter season.

- The high Himalayan region in the north encompasses many snow-capped peaks and alpine meadows with an altitude ranging from 4000m to peaks reaching over 7 351m. The zone is characterised with extremely cold winters and cool summers.

Around 70% of the precipitation in Bhutan is generated by the summer monsoons (from early June to late September), and approximately 20% of the precipitation falls in the pre- and post-monsoon period. The majority of lightning occurs during the pre-monsoon period. The annual precipitation ranges widely in various parts of the country. The northern region experiences around 40 mm of annual precipitation, mostly in the form of snow. The temperate central valley experiences a yearly average of around 1000 mm of rainfall, whilst the southern region sustains approximately 1 500 mm of rainfall annually (NSB, 2007).

B.2 Natural hazards

Bhutan is susceptible to multiple hazards. It is located in eastern Himalayas, one of the most seismically active regions of the world. Earthquakes are the most imminent hazard in Bhutan, as evidenced by past seismic events. Another pertinent hazard, especially with regards to climate change, is the impending risk from Glacial Lake Outburst Floods (GLOFs). As evidenced by studies conducted by the Department of Geology and Mines (DGM), in collaboration with various regional and international agencies, 25 of Bhutan’s 2 674 glacial lakes have been identified as potentially dangerous. Climate change is expected to exacerbate the situation.

Furthermore, flash floods and Landslide Dam Outburst Floods are a constant threat to lives, livelihoods and property in Bhutan (see Table B1 for the major GLOF and flooding incidents in Bhutan since 1957). The first, and to date only, flood warning system was implemented in Punakha-Wangdi Valley in 2008–2013 to provide warnings concerning impending GLOFs.

The overall cost of the project was US$ 8 273 million, which included the installation of equipment to measure the water level reduction in one of the lakes in the glacier and installing an automatic GLOF measure system, and increasing community awareness of impending disasters. A warning system with four automatic water level stations (AWLS) and two combined AWS and AWLSs has been installed; including 17 sirens to warn the communities. DHMS is responsible for the maintenance of these stations.

Table B1. List of Major GLOF and Flooding incidents (Source; DDM)

	Event and Date	Areas Affected	Loss and Damages	Remarks
1	1957 GLOF	Pho-chu sub basin		
2	1960 GLOF	Pho-chu sub basin		
3	1994 GLOF	Lunana	20 fatalities, more than 1,700 acres of agriculture and pasture lands, a dozen houses, and 6 tonnes of food grains damaged. washed away five water mills and 16 yaks	Caused by partial burst of Lugge Tsho in Lunana
3	August 2000 Floods	Phuentsholing		Flooding caused by Doteng chu
4	2004 Floods	Six eastern Dzongkhags	9 fatalities, 664 acres of wet and dry lands destroyed, hundreds of tons of crops lost and affected 1,437 households	Caused due to heavy monsoon
5	2005 Floods	Phuentsholing/ Pasakha	More than 200 people lost their properties	Caused due to heavy rainfall
6	May 2009 Floods	Almost all 20 dzongkhags affected	13 fatalities and properties worth Nu.766 million damaged	Caused due to heavy rains precipitated by cyclone Aila

Furthermore, Bhutan is also vulnerable to recurrent and seasonal hazards such as landslides, and windstorms (see Table B2), fire on human settlements (see Table B3) and forest fires. These hazards not only cause damage and loss to the economy, infrastructure and the environment on a continuous basis, but also affect the livelihoods of the people, especially the subsistence farmers in rural Bhutan.

Table B2. Damage caused by windstorms in 2011 by dzongkhags (Source: DDM)[29]

	Dzongkhag	**Rural Homes**	**Lhakhang**	**Chorten**	**School/ NFE**	**BHU/ ORC**	**RNR**	**Gups Office**	**RBP Outpost**
1	Gasa	3							
2	Thimphu	11	3	1	1	1			
3	Paro	137	6	1	1				
4	Haa	28	4	1	1	1			
5	Wangdue	17	3						
6	Chukhha	59	3	4	4				
7	Tsirang	34							
8	Dagana	170	4	7	7	1	1	2	
9	Trongsa	2							
10	Zhemgang	300	21	9	9	5	3	1	
11	Mongar	378	6	8	8	4	1	1	
12	Trashigang	401	7	13	13	2			
13	T/Yangtse	200	5	1	1	1			3
14	P/gatshel	433	9	4	4	5	1		
15	Sarpang	161	2	5	5				
16	Samtse	1	1	1	1				
17	S/jongkhar	89	3	2	2	1			
		2424	**77**	**4**	**57**	**21**	**6**	**4**	**3**

Table B3. Recent Fires and their impacts on Human Settlements (Source –DDM)

	Date	**Dzongkhag**	**Casualties**	**Damages**	**Families Affected**
1	2002	Yangthang, Haa		25 houses completely burnt down	
2	Dec. 2005	Zhapong, Trashigang		5 houses burnt down	
3	Nov. 2005	Chamkhar, Bumthang		7 shops burnt down	
4	8 Oct. 2010	Wamrong, Trashigang		14 houses (includes 9 hotels, residential houses and shops)	
5	26 Oct. 2010	Chamkhar town, Bumthang	2 dead, 1 injured	55 structures* – completely burnt 3 structures – partially burnt	64 families (267 individuals) affected
6	18 Feb. 2011	Chamkhar town, Bumthang	2 injured, 1 dead	18 structures – completely burnt	36 families (107 individuals)
7	27 May 2011	Chamkhar town, Bumthang		30 structures – completely burnt 3 structures – partially burnt	56 families (173 individuals)

[29] Lhankhang = monastery, Chorten = stupa, NFE= Non-Formal Education, BHU/ORC = health care units, Gup = headman of a gewog council. RBP= Royal Bhutan Police.

**Structure – Permanent/Semi-permanent houses, shops, offices.*

B.3 Climate Change

The IPCC's Fourth Assessment Report confirms that geographical distribution, intensity and frequency of hydro-meteorological hazards are significantly altered by climate change. Furthermore, changes are occurring in the amount, intensity, frequency and type of precipitation. This raises a concern regarding the preservation of water resources in Bhutan. The impacts associated with the changing nature of Bhutan's water resources pose serious threats to the countries development; hence the establishment of institutional arrangements in the region towards effective communication and sharing of knowledge on water resources and infrastructure are indispensable. The establishment of strong cooperation and development of appropriate technology is important between sectors, citizens, and countries, and as such the adaptive and preventive measures of preserving and maintaining fresh water resources should be responsibly shared between all members of society in the region.

Loss of glaciers from the Himalayan peaks is a strong indicator of climate change. The region has the largest area covered by glaciers outside the Polar Regions, and represents one of the largest reservoirs of fresh water on the planet. The major concentration of glaciers are spread across 12 mountain ranges forming the headwaters of almost all the major rivers in the central, south and south-eastern Asian mainland. With rising temperatures caused by climate change, the melting of glacier ice is projected to increase in the Himalayas. This will affect water resources resulting in an increased risk of flooding and decreased river flow as glaciers recede.

Warming in the Hindu Kush-Himalayan region has been greater than the global average warming. The decreasing trend in rainfall and increasing temperature anomalies are observed distinctly in Bhutan. Data on climate projections is extremely limited in Bhutan, in terms of historical record or the spatial coverage required providing adequate baseline assessment of the climate. However, an analysis of observed data from 2000–2009 shows an increasing trend for both maximum and minimum temperatures, but no apparent trends in precipitation patterns. Future periods were modelled using ECHAM5 and HadCM3Q0 climate models forced by IPCC SRES A1B scenario. As compared to the 1980–2009, mean annual temperature is projected to increase by 0.8° C to 1° C in 2010–2039 and by 2°C–2.4°C in 2040–2069. Summer temperatures may increase by up to 0.8°C in 2010–2039 and by 2.1°C in 2040–2069. (NCE, 2011)

The hydrological regime in changing climate is characterized by low flow in winter periods with small precipitation and low temperature resulting in accumulation of snow at high altitudes. The summer flows are predicted to be high which is caused by high precipitation and melting of glacier ice and snow. (Eldring, 2011)

Appendix C Department of Hydro-Met Services

C.1 Background

Prior to the establishment of DHMS, the former Hydro-Met Services Division operated under the former Department of Energy. The first meteorological observations in Bhutan started in 1985, and the earliest hydrological measurements, water level and rainfall, date back to the early 1950s; both conducted by different agencies.

A hydro-meteorological network covering the whole country was established as a part of the Bhutan Power System Master Plan project in 1991. The network and data collection system were primarily designed for hydropower planning. However, with the up-grade of the Hydro-Met Services Division to a fully-fledged department in 2012, the new Department of Hydro-Met Services (DHMS) has become a technical agency for national hydro-meteorological services.

C.2 Mandate and structure

The Department of Hydro-Met Services (DHMS) (see organogram in Figure C1) is Bhutan's national centre for weather, climate and water resources. Its mandate is to provide reliable and timely hydro-meteorological information, needed by various agencies, for:

- Natural resources policy formulation and planning for effective management of water resources for domestic, agricultural, commercial, industrial, recreational, and ecological uses.
- Hydropower planning, development and operation, as well as for other water related infrastructures;
- Planning for the agricultural, construction, tourism, health and other environmental sectors
- The provision of information and services for disaster risk reduction;
- Weather and climate forecasting, flood forecasting and warning services to minimize the loss of life and property as a result of hydro-meteorological related hazards (such as floods, droughts, windstorm, snow avalanches, GLOF etc.);
- The establishment of institutional linkages and coordination with international organizations;
- The maintenance of national, bi-lateral, regional, and international cooperation related to hydro-meteorology, including the exchange of data;
- The development of a resource pool of qualified professionals/specialist/experts in the field of hydrology and meteorology;
- Planning, coordination and research related to hydrology, meteorology, climatology, water resources, snow, glaciers, and climate change.

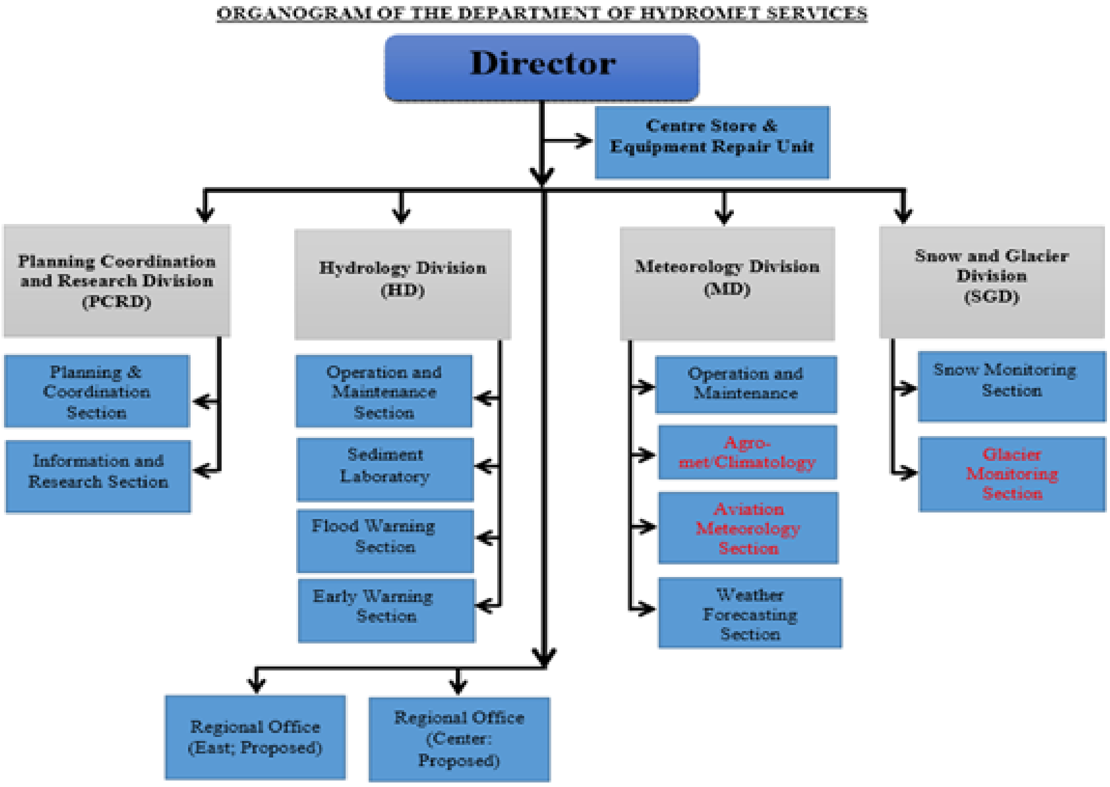

Figure C1. The organogram of DHMS

C.3 Current services and station network

DHMS currently provides the following services: the provision of historical weather and hydrological data, and a 24-hour weather forecast which is disseminated to the national TV station and newspapers.

Temperature forecast is done in Excel, and uses as inputs Meteogram provided by the Indian Meteorological department, historical climate data, and real-time data collected at 3 PM from all Dzongkhags. As there is no Meteogram developed for Bhutan, Meteograms from nearest Indian states are taken as reference (i.e., Meteogram for Gangtok for higher altitudes and Guwahati for lower altitudes). Mean temperature from the Meteogram is inserted into the Excel format. For featuring different types of precipitation, extreme weather events and other weather outlooks, a MetGIS application is used along with references from other regional meteorological websites. The forecast for the following day is based on MetGIS software ran by the University of Vienna, Austria, along with references from other regional meteorological websites. The forecast covers the 20 Dzongkhags of the country, and its accuracy is limited.

DHMS does not have flood forecasting capacity. Flood information is obtained via manual observations of river levels, and is communicated to various parts of the country and to neighbouring Indian States. With the assistance of the Danish International Development Agency, a set of servers, computers and flood modelling system (HEC HMS) has been established. However, the system is not utilized for flood modelling or forecasting due to lack of technical competency.

Most hydrological data are received by conventional postal service, checked and entered manually into HYDATA, a hydrological data management system. Some other information and meteorological data are stored in excel, whereas a new database is in MySQL. Operational data processing is minimal. Basic data quality control system exists.

DHMS operates 25 hydrological stations. River gauge measurements at these stations are collected by cableway or traditional float methods. 10 sediment sampling stations are in operation. 15 Flood Warning Stations monitor river levels across the country. The river level data is communicated through wireless VHF systems. In 2008-2013, an operational GLOF warning system in the Punakha-Wangdi valley was established. The meteorological monitoring network consists of 20 agro-meteorological stations, which are measuring air and soil temperature, humidity, rainfall, wind and solar radiation, and 76 climatology stations,, which are measuring temperature, humidity and rainfall, covering the whole country. Observations at most stations are conducted manually (twice a day), and the data is sent by post to head office in Thimphu. Some automatic weather stations (AWS) have loggers to record information which is downloaded every month. Currently, 11 automatic AWS transmit real-time (near real-time) data to the head office on pre-set time intervals through GSM/GPRS/satellite telemetry. AWSs measure the same parameters as agro-meteorological stations and also pressure. The location of the meteorological stations is shown in Figure C2.

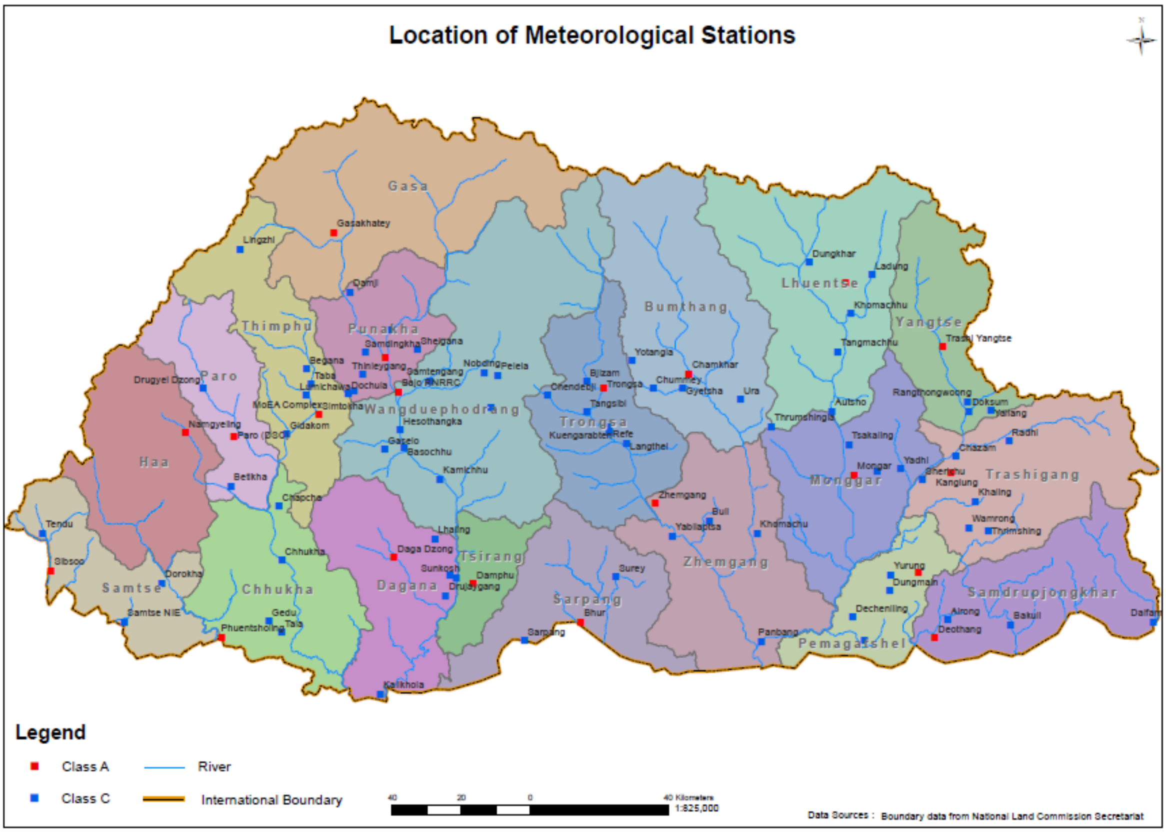

Figure C2. The location of meteorological stations.

In addition, there are 10 wind masts (nine 20m mast and one 50m mast) which have been installed to study and assess the feasibility of wind power generation in Bhutan[30]. The wind sensors are fixed at 10m and 20 m height for the 20m mast, and 10m, 20m and 50 m for the 50m mast. Most wind stations were installed between 2008 and 2010. In addition, solar radiation, relative humidity and pressure sensors were also installed at 2m height on the same mast for meteorological purpose. The data is recorded into the logger every 10 minutes, and is downloaded every three months.

C.4 Future prospects

For securing human lives and to ensure sustainable development of Bhutan's society and economy, developing real-time hydro-meteorological network and Early Warning System (EWS) merit urgent attention. Hydro-Meteorological Information System and Database Management also play a key role in data collection, processing and analysis.

The 11th Five Year Plan for the Department of Hydro Met Services (July 2013–June 2018) describes the development targets for DHMS. It consists of two programs, namely Program 01 *Enhancing Hydrological Network for Water Resources Assessment and Improvement of Flood Information/GLOF Early Warning System* and Program 02 *Strengthening Meteorological Network Coverage and Enhancing Weather and Climate Information Services.*

More specifically, Program 01 involves:

- Establishing Hydrological Monitoring Network and Infrastructures;
- Establishing Flood Warning Network and related Infrastructures;
- Establishing the Sediment Sampling networks and Laboratories
- Installing the Flood/GLOF Early Warning System in selected river basins
- Improving Hydrological Modelling Capacity and initiate Glacier Mass Balance studies in Bhutan and Database
- Publishing a Data book

Program 02 involves

- Strengthening of Institutional framework for National Hydro-Met Services
- Establishing Meteorological Network stations and Infrastructures
- Enhancing the provision of useful information to public and socio-economic development sector by use of WRF & MetGIS Models
- Improving hydro-meteorological information management system
- Education and awareness on hydro-met services
- Institutional collaboration + technical assistance, Research & Development.
- Research, Publication & dissemination of hydro-meteorological information

[30] Via the funding of an Integrated Energy Management Master Plan (IEMMP) project.

C.5 Relevant projects

C.5.1 Establishment of a regional flood information system in the Hindu Kush-Himalayan region

DHMS is implementing phase 1 of the project “Establishment of a regional flood information system in the Hindu Kush-Himalayan region (HKH-HYCOS)” through International Centre for Integrated Mountain Development (ICIMOD) with funding from the Government of Finland. Nine automatic hydro-meteorological stations will be installed to provide flood information to the downstream communities in neighbouring countries. The total committed funding for Bhutan is US$208 000 and the project runs until 2014.

C.5.2 Capacity Development of GLOF and Rainstorm Flood Forecasting and Early Warning

DHMS recently initiated a Project on Capacity Development of GLOF and Rainstorm Flood Forecasting and Early Warning, funded by Japan’s JICA. The main purpose of the project is to enhance capacity of the Department of Hydro-Met Services and relevant line agencies on emergency response against GLOF/rainstorm flood to develop disaster resilient society against natural disasters such as GLOF and rainstorm flood for Climate Change Adaptation in Bhutan. The budget of the 3-year project is € 1 million. The following are main outputs of the project:

a. Capacity of National Weather Flood Forecasting and Warning Centre (NWFFWC) on GLOF/rainstorm flood risk assessment, flood forecasting and warning as well as emergency information sharing among relevant agencies is enhanced.

b. Early Warning System (EWS) for GLOF/rainstorm developed and maintained in the pilot basins of the Mangdechhu and Chamkharchhu.

c. Emergency response capacity against GLOF/rainstorm flood at central and local level is enhanced in the pilot basins.

C.5.3 NAPA II project

A total of sixty weather and climate monitoring stations (i.e. Automatic Weather Stations - AWS) are proposed to be installed across Bhutan under the NAPA II project (National Adaptation Programme of Action). The 34 existing “Class C” Manual stations will be up graded to AWS while 26 new stations (AWS) will have to be installed at new locations. The plan is to install 47 real time AWS, 11 AWS with snow gauging facility and 2 off-line AWS. Hence the total estimated cost for installing these meteorological stations will be approximately Nu 103,085,950.00 (2 million USD). Furthermore, a total of 39 automatic water level monitoring stations (AWLS) are proposed to be installed across Bhutan. 11 stations will be up-gradation of existing manual stations while 28 are newly proposed sites. About six proposed sites are to be incorporated with cable system for discharge measurement. Discharge measurements stations are proposed at critical sub-basin outlets to help flood forecasting and modelling works. The estimated cost of the enhancement of the hydrological network is Nu 72,418,902 or approximately 1.3 million USD.

C.5.4 SAARC STORM Program

Installation of 10 AWS for monitoring and studying life cycle of severe thunder storms in SAARC region. Installation will be done first in Bhutan, The equipment have already reached Thimphu and planned to be installed tentatively by Oct 2013. One upper air sounding station will be installed with costs covered fully by donors until 2017.

Appendix D Workshop I participants

Name	Designation	Agency/Department
Pratigya Pradhan	Head, P&DD	Druk Green Power Corporation
Wangmo	AE	Druk Green Power Corporation
Thinley Choden	E.E	FEMD,DES, MoWHS
Tsheten Dorji	SS&LEO	NSSC, DoA, MoAF
Rada Dukpa	Program Officer	DoPH, MoH
kunzang Gyeltshen	EE/RM	Royal Insurance Corporation of Bhutan Limited
Jamyang Phuntsho	Sr. MO	WMD, DoFPS
Phurba lhendup	Po	World Wildlife Fund
Yeshey Lotay	Dy. EE	Department of Disaster Management
Sherab Jamtsho	Dy. EE	DRE, MoEA
Nima Dolma Tamang	Asst. Evn. Officer	NRDCL
Kuenzang	AE-II	FWS, DHMS, MoEA
Pema Dorji	Policy Specialist	UNDP
Aku Dorji	Principal Engineer	CDB
Tshering Tshi	Dy. EE	Ministry of Health
Tayba B Tamang	Sr. Meteorologist	MD, DHMS, MoEA
Tashi Dukpa	Dy. Chief	Civil Avation
Pema Tshoki	Reporter	BBSC
Thuji Pem	Tourism Officer	Tourism Council of Bhutan
Riikka Suhonen	UNV	SNDP
Thsewang Lhamo	E.O	NECS
Dawa Zam	Dy.CEO	DoR, MoWHS
Sonam Dagay	AEO	NECS
Nima Wangdi	Reporter	Kuensel
Rajesh Rai	Reporter	Kuensel
Tshering Lhamo	Civil Engg.	Royal Insurance Corporation of Bhutan Limited
Sonam Dorji	Meteorologist	MD, DHMS, MoEA
Wangmo	AE	HDD, DHPS, MoEA
Trashi Namgyel	EE/RM	DHMS, MoEA
Singay Dorji	Chief	MD, DHMS, MoEA
Tshencho Dorji	Engineer	MD, DHMS, MoEA
Tshewang Rinzin	Engineer	PCRD, DHMS, MoEA
Ugyen Chophel	Statistical Officer	PCRD, DHMS, MoEA
Sherub Phuntsho	Dy. EE	SGD, DHMS, MoEA
Phuntsho Namgyel	Chief	PCRD, DHMS, MoEA
Chhimi Dorji	Project Manager	DHMS, MoEA
Jenni Latikka	Project Manager	FMI

Appendix E Workshop II participants

Name	***Designation***	***Agency***
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Kinley Dem	FR	WMD
Tashi Phuntsho	Dy. Engineer	CDB, MoWHS
Namgay	Meteorologist	DCA, Paro Airport
Jigme Chogyal	PO	DDM, MOHCA
Chime Wangmo	Engineer	DRE, MoEA
Sonam Rabten	Engineer	MD, DHMS, MoEA
Sonam Lhaden Khandu	Sr. EO	NEC
Kuenzang Choden	Engineer	FEMD, MoWHS
Tshering Yangzom	AE, Civil	DGPC
Jamyang Phuntsho	Sr. MO	WMD, DoFPS
Nima Dolma Tamang	Astt. Env. Officer	NRDCL
Sangay Dorji	Chief	RICBL
Bikash Pradhan	Engineer	DHMS, MoEA
Tshering Wangchuk	Engineer	SGD, DHMS, MoEA
Tsewang Dorji	Dy. Chief Lab	NSSC
Sami Tornikoski	WWF Officer	WWF Living Himalayas
Pema Dori	Prog. Officer	UNDP
Dema Yangzom	Engineer	PCRD, DHMS, MoEA
Ugyen Chophel	Statistician	PCRD, DHMS, MoEA
Pema Yeshi	Reporter	BBS
Singay Dorji	Chief	DHMS, MoEA
Towchu Rabgay	Sr. LO	DoL, MoAF
Wangmo	AE	DGPC
Sangay Tenzin	AE, Civil	DHMS
Kristina Santti	Account Manager	FMI
Reija Ruuhela	Head of Climate Service	FMI
Karoliina Pilli-Sihvola	Researcher	FMI
Chimi Wangda	AMO	DHMS
TETSOR FUKUI		JICA
Phuntsho Namgyal	Chief	PCRD, DHMS
Tayba Buddha Tamang	Sr. Meteorologist	MD, DHMS
Sonam Dorji	Project Manager	MD, DHMS
Sonam Tashi	Forecaster	DHMS
Pema Yeshi	Reporter	BBS

Appendix F Stakeholders interviewed

Organization	Officials
Department of Renewable Energy	Mr. Sherab Jamtsho, Dy. Executive Engineer
Druk Green Power Cooperation	Mr. Tashi Dorji, Hydropower Specialist Ms. Pratigya Pradhan, Head of Planning & Design Department Mr. Lam Dorji, Head of Operation & Maintenance Department, Ms. Tshering Yangzom, Civil Engineer Ms. Wangmo, Civil Engineer
Department of Hydropower & Power System	Ms. Tashi Pem, Dy. Executive Engineer Mr. J.B Basnet, Executive Engineer Mr. Sagar Ghimirey, Engineer Ms. Dechen Wangmo, Assist. Engineer
Tourism Council of Bhutan	Mr. Phuntsho Gyeltshen, Tourism officer Ms. Thuji Pem, Tourism Officer
Department of Public Health Engineering	Mr. Rinchen Wangdi, Chief Engineer Ms. Rada Dukpa, Program Officer
Flood Engineering & Management Division, Department of Engineering Services	Ms. Thinley Choeden, Executive Engineer Mr. Kinley Dorji, Engineer
Department of Roads	Mr. M.B Mongar, Chief Engineer Mr. Dilip Thapa, Dy. Executive Engineer
Department of Civil Aviation, Paro	Mr. Tashi Drukpa Dy. Chief (Aviation Meteorology Unit)
Department of Disaster Management	Mr. Yeshey Lotey, Dy. Executive Engineer
Ministry of Agriculture and Forests	Mr. Tenzin Chophel, Chief Planning Officer, PPD
National Environment Commission Secretariat	Mr. Karma C Needup Environmental Specialist Mr. Jigmi Nidup Head Water Resources Coordination Division
Bhutan Power Corporation	Mr. Gorab Dorji, General Manager Engineering, Design & Contracts Department
National Commission for Women & Children	Ms. Tshewang Lhamo, Program Officer
WWF – Bhutan	Mr. Vijay Moktan, Conservation Director Mr. Phurba Lhendup, Program Officer

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