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Valuing Weather and Climate:
Economic Assessment of Meteorological and Hydrological Services

WORLD BANK GROUP

GFDRR
Global Facility for Disaster Reduction and Recovery

USAID
FROM THE AMERICAN PEOPLE

World Meteorological Organization
Weather • Climate • Water

WMO-No. 1153

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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at http://www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html. Acronyms may also be found at http://www.wmo.int/pages/themes/acronyms/index_en.html.

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PREFACE

From 1970 to 2012, 8 835 disasters, 1.94 million deaths and US$ 2.4 trillion of economic losses were reported globally as a result of weather-, climate- and water-related disasters, collectively referred to as hydrometeorological disasters. In the last four decades, the number of reported hydrometeorological disasters has increased almost fivefold, from about 750 in the period 1971–1980 to about 3 500 during 2001–2010.[1] Over the same period, cumulative economic losses have increased more than fivefold, from US$ 156 billion to US$ 864 billion[2] per decade.

Despite this increasing risk, which is due to a number of climatic and non-climatic factors (including population growth in high-risk areas), improvements in early warning systems and preparedness are making it possible to limit losses from hydrometeorological disasters. This would not be possible without the informed use of constantly improving meteorological, hydrological, oceanographic, social, behavioural and related information. As forecasting and modelling capabilities improve, some decisionmakers are going beyond risk mitigation to a more comprehensive risk management approach that includes adapting to anticipated changes to avoid damage altogether. Moreover, scientific, technological and social developments such as the Internet and smartphones have generated an ongoing revolution in the demand for and availability of weather, climate, water and related information services. Hundreds of millions of people and organizations are gaining access to these services and using them in decisionmaking with greatly enhanced public and private benefit.

Increased and diversified demand provides a great opportunity to improve and extend hydrometeorological services. However, it also poses new challenges for service providers in prioritizing investment in the underpinning infrastructure, advancement of knowledge and generation of understanding, versus designing and financing service delivery. Easier access to a growing volume of data and information requires higher reliability, targeting, understandability, and decision-support services to ensure information is used appropriately and with due regard to inherent limitations and uncertainties. To optimally invest and meet rapidly evolving demands, more rigorous and comprehensive methodologies for understanding user needs and evaluating the benefits of the enabling infrastructure and of the provided hydrometeorological and related services are needed.

National Meteorological and Hydrological Services (NMHSs), central governments and development agencies need to understand the full value of the socioeconomic benefits (SEBs) provided by hydrometeorological services, as well as the financial realities of maintaining modern operations and service delivery, so that adequate financing can be mobilized and invested strategically to ensure a significant impact of investment. This is particularly true in developing countries where many NMHSs are not currently able to fully provide basic services to help save lives and support economic development.

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1 World Meteorological Organization, Centre for Research on the Epidemiology of Disasters and Université Catholique de Louvan, 2014: *Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2012)* (WMO-No. 1123). Geneva, http://www.wmo.int/pages/prog/drr/transfer/2014.06.12-WMO1123_Atlas_120614.pdf.

2 Values not adjusted for inflation.

Since the 1950s, the interest in the economic valuation of hydrometeorological services has been growing in the hydrometeorological, climate and economics communities. As part of a process of improving the understanding of SEBs of hydrometeorological services, the World Meteorological Organization's (WMO) high-level international conference "Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate, and Water Services", held in Madrid in 2007, agreed on a Statement and Action Plan that sets out a comprehensive strategy for the enhancement, development and application of improved methodologies for evaluating the benefits from the operation of NMHSs. The present publication addresses the growing interest and need identified during this conference and in the years since it took place. It is directed at the hydrometeorological and socioeconomic research and service-provider communities, as well as officials from government and international development agencies; but the general public will also find an interest in understanding the role weather, climate and water information plays in their daily life.

The World Bank Group, with a current hydrometeorological investment portfolio of around US$ 500 million, estimates that globally improved weather, climate, and water observation and forecasting could lead to up to US$ 30 billion per year in increases in global productivity and up to US$ 2 billion per year in reduced asset losses.[3] This scale of improved productivity could be crucial to lifting out of poverty the millions around the world whose livelihoods are at risk of climate shocks. The recognition of these benefits and their contribution to sustainable development, poverty reduction and shared prosperity is motivating the development community to invest more holistically in modernizing hydrometeorological services[4] and ensuring that service providers are better connected with service users.

The review of all past and current SEB analysis performed for this publication indicates that properly planned investments in hydrometeorological services provide significant benefits relative to their costs. While the publication attempts to capture the currently available wealth of experience and expertise across different contexts, it is not the end point for developing global knowledge on SEB analysis of hydrometeorological studies. Indeed, as we move to implement new global commitments on sustainable development goals, climate change adaptation and disaster risk reduction, interest in knowledge, expertise and implementation of SEB studies for hydrometeorological services will continue to grow.

Further, the Global Framework for Climate Services (GFCS) – an initiative of the United Nations adopted by the World Meteorological Congress in 2012 after the call of the third World Climate Conference in 2009 – promotes better access and use of climate information by users; encouragement of global, free and open exchange of climate-relevant data as an international public good; and multidisciplinary partnerships. The implementation of GFCS facilitates the delivery of goods and benefits in key economic

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[3] Hallegatte, S., 2012: *A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning and Evacuation.* World Bank policy research paper No. 6058. Washington, D.C., World Bank.

[4] Rogers, D.P. and V.V. Tsirkunov, 2013: *Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services.* Directions in Development. Washington, D.C., World Bank.

sectors such as agriculture and food security, health, energy, disaster risk management, water resources management and urban environments. The present publication should provide strong analytical support for implementation of GFCS, providing a broader platform within which to use SEB studies to improve hydrometeorological services.

We hope this publication will be useful to make more evident and enhance the SEBs that NMHSs of the world deliver daily to society and will help mobilize and optimize financing to ensure NMHSs can fulfil their critical role in an even more effective way.

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* Participants at the 2013 meeting of the WMO "Forum on Social and Economic Applications and Benefits of Weather, Climate and Water Services", WMO, Geneva, Switzerland, 8–11 April 2013. These participants led the groundtruthing session that developed the concept of this publication.

EXECUTIVE SUMMARY

For more than a century, nations have equipped themselves to provide weather, climate and hydrological information, forecasts and, more recently, remotely sensed data and early warnings to the public and private sectors. These services, collectively referred to throughout this publication as met/hydro services, have increased the safety and efficiency of land, sea and air transport, helped communities prepare for and respond to extreme weather events, and facilitated improved decisionmaking in weather-sensitive economic sectors. Increasingly, it has become easier for people and businesses to access met/hydro information and products due to advances in the Internet and telecommunications.

Yet, as NMHSs strive to maintain and improve the quality, diversity, and coverage of their services, they face challenges similar to other public institutions in securing adequate and sustained funding. To compete for and optimize the use of scarce public investment resources, NMHSs may be required to demonstrate that the benefits of their services are significantly larger than the costs to produce and deliver them. Although there is not a single definitive study on the global benefits of met/hydro services, economic studies have consistently generated benefit–cost ratios (BCRs) of greater than one (see box). This publication is intended to help NMHSs and other providers of met/hydro services develop a basic understanding of economic valuation methods to enable them to design and commission studies. It further supports utilization of the results to improve service delivery through business optimization and communication with decisionmakers, users and the public.

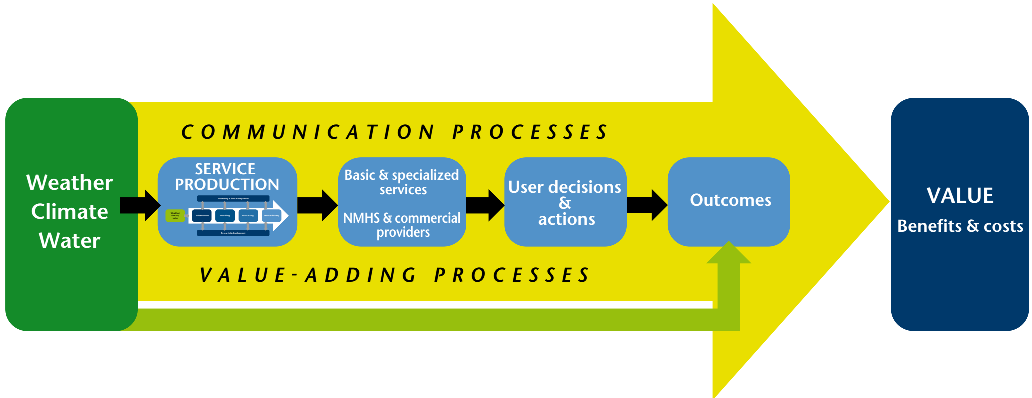
Illustrative economic assessments of met/hydro services

- NMHS improvements to reduce disaster losses in developing countries – BCRs range from 4 to 1 to 36 to 1
- Current and improved weather forecasts in the United States of America assessed for households – BCR of at least 4 to 1
- Drought early warning system in Ethiopia to reduce livelihood losses and dependence on assistance – BCRs range from 3 to 1 to 6 to 1
- El Niño early warning system in a five-state region of Mexico to improve decisionmaking in agriculture – BCRs range from 2 to 1 to 9 to 1

CREATING VALUE: LINKING PRODUCTION AND DELIVERY OF SERVICES TO VALUED OUTCOMES

Met/hydro services do not generate economic and social value unless users benefit from decisions as a result of the information provided, even if the services are of the highest quality. In addition, met/hydro services of similar quality provided in two countries can vary significantly in terms of their benefits depending on the relative nature of weather- and climate-related risks, the number and types of users and their capacity to take actions to avoid harm or increase economic output.

The generation of met/hydro services benefits can be depicted in a “value chain” linking the production and delivery of services to user decisions and the outcomes and values resulting from those decisions. The value chain presented in the figure below



(and featured in Chapter 2) can be used to illustrate the production and delivery of the entire suite of met/hydro services provided by NMHSs or to describe a single new or existing service. How the value chain is specified depends on the met/hydro services to be valued and the reasons for conducting the valuation study.

As is discussed in Chapter 3, the valuation study can be designed for the purpose of validating the current provision of individual or all met/hydro services, justifying new investments in those services, or demonstrating the value of met/hydro services in key sectors such as agriculture, aviation or energy.

PLANNING THE STUDY

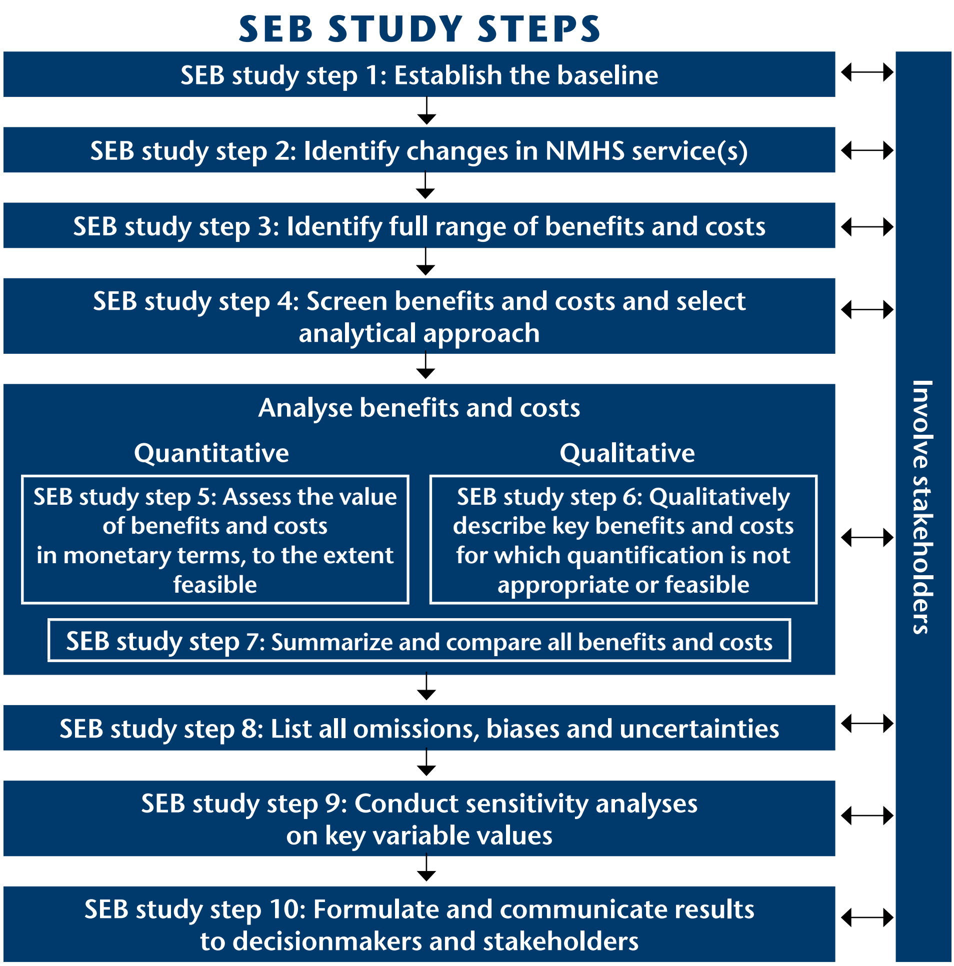
Chapter 4 provides a discussion of the process for planning, commissioning and conducting SEB studies. On the assumption by the authors that few NMHSs would conduct in-house economic studies, it is envisioned that a concept note will be prepared to secure resources for the study in terms of financing, expertise and access to the necessary information and data. The concept note will provide information on reasons for conducting the study, the services and user communities to be assessed, costs and time frame, valuation methods proposed and plans for disseminating the results of the study. Chapter 4 also describes the elements of a detailed scope of work required for procurement and to guide preparation of the study and dissemination of the study's results to decisionmakers and stakeholders.

CONDUCTING THE SOCIOECONOMIC BENEFIT STUDY

Socioeconomic benefit studies to support investment decisions will typically involve analysis of benefits and costs and a comparison of benefits and costs using the net benefits (benefits minus costs) or benefit–cost criteria. The diagram describes the 10 steps that are undertaken in conducting an SEB study.

Chapters 5 to 8 provide the reader with the essential economics material covering steps 3 to 9 in the diagram. For readers not conversant with economics, Chapter 5 provides an introduction to definitions and concepts needed to understand the discussions of benefits, costs and benefit–cost analysis (BCA) presented in Chapters 6, 7 and 8.

Chapter 6 provides an overview of the extensive variety of methods that have been used to assess the benefits of met/hydro services. The methods can be tailored to different users and benefit streams (avoided costs or damages, higher profits or increased social welfare). Some methods, particularly where more precise results are required, will involve extensive data collection, surveys of user preferences and willingness to pay (WTP) for services, or economic modelling, while other methods such as benchmarking and benefit transfer are reasonably inexpensive to apply. In collaboration with their SEB study implementers, NMHSs will need to select the benefits estimation method(s) most suitable to the services and types of users to be assessed, while accounting for resource and time constraints.



Given the experience of NMHSs in preparing budgets, the discussion of costs in Chapter 7 will be more familiar. However, some adjustments are required in converting budget information and expenditures, particularly for capital investments, into economic costs that can be compared to benefits. In addition, SEB studies may also require consideration of costs incurred by users to benefit from met/hydro services. Chapter 8 describes the criteria and methods that are used to compare benefits and costs and explains how these values are discounted and aggregated. Chapter 8 also provides some guidance on how to present benefit–cost results to demonstrate sensitivity to underlying assumptions and uncertainty.

Chapter 9 covers the important topic of communicating the results of SEB studies, the range of audiences and the types of messages to be delivered via radio, television, the print media, Internet, SMS text messaging and public meetings. Communication efforts as well as assessment of benefits should be part of a continuous process of education, outreach and review of the quality and uptake of met/hydro services. Internal communication to inform prioritization and business planning is also highlighted.

The publication also includes five appendices covering a glossary of met/hydro and economic terms, historical background on the global development of met/hydro services and progress in estimating benefits of these services, a survey of non-economics social science methods for assessing the quality of met/hydro services, and summaries of nine SEB studies.

As noted in the concluding chapter, there is still much work to be done to help NMHSs and other providers to make the financial case to sustain and increase the quality and coverage of met/hydro services. Chapter 10 also highlights the value that open-data and open-access approaches can add. There are significant gaps in the application of benefits estimation methods, regional coverage of studies (particularly in developing countries), and studies for key economic sectors. The authors hope the publication increases the understanding of the potential value of SEB studies and serves as a catalyst for future studies.

CHAPTER 1. INTRODUCTION

1.1 METEOROLOGICAL, HYDROLOGICAL AND RELATED SERVICES

Meteorological, hydrological and related conditions affect everyone on the planet. The variability of the atmosphere and of the underlying land and ocean, on timescales from minutes and hours to decades and centuries, exerts a major influence on the general public and national economies (see Figure 1.1).[5] Extremes in temperature, precipitation and wind and other natural hazards impact every country and every sector of society. Rarely does a day go by without news of a weather-related disaster somewhere in the world or new information on the expected impacts of human-induced climate change.

The informed use of meteorological, hydrological, oceanographic and related information can deliver enormous benefits to society. Reliable weather, climate and water information enables individuals, households, organizations, businesses and governments to take decisions which reduce the impacts of natural hazards, enhance the safety and convenience of daily life, increase business profitability, address the challenges of public health and poverty alleviation, improve productivity, strengthen national economies, protect the environment and provide a more secure basis for future planning on hourly to century timescales.

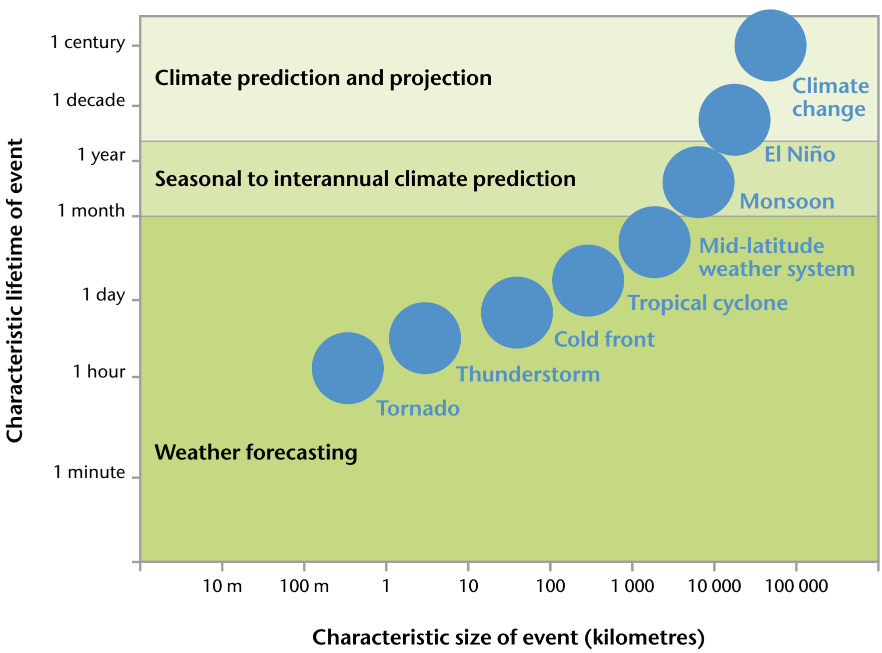


Figure 1.1. Time and space scales of weather and climate

Source: World Bank (2013*a*)

[5] See Figure 2.2 for a more detailed version.

The second half of the twentieth century witnessed innovation and expansion in the quantity, quality and availability of weather and climate information and the development of a wide range of meteorological, hydrological, oceanographic and other environmental services for individual social and economic sectors and for communities at large. The provision of state-of-the-art forecast, warning and advisory services for their national communities became a widely accepted responsibility of governments in both developed and developing countries. Numerous studies provided compelling evidence of the social, economic and environmental benefits of the services and the importance of continuing investment in national and international infrastructures and the scientific research on which they were based (WMO, 2014).

Internet, smartphone and other scientific, technological and social developments of recent decades have continued to increase the demand for, and availability of, weather, climate and related services. Billions of people are gaining access to these services and using them in decisionmaking with greatly enhanced public and private benefit. However, this is producing new challenges for the service providers in prioritizing their investment in the underpinning infrastructure and in designing and funding the services required. Easier access to the growing volume of data and information is providing special challenges in ensuring that the quality of the data and information is as high as possible and that they are used appropriately and with due regard to their inherent limitations and uncertainties. Improvements in the quality and coverage of these services, as well as the development of new services, has engendered additional costs and demand for new, more rigorous and more comprehensive methodologies for evaluating and demonstrating the benefits of the enabling infrastructure and of the meteorological, hydrological and related services provided.

This publication outlines a number of methods for evaluating and demonstrating the economic value of meteorological and hydrological services. First, however, it is necessary to introduce some basic concepts in meteorological and hydrological service provision, identify the challenges facing the major national organizations responsible for these services, and recall the rich history of earlier work on economic valuation on which this publication is built. The key meteorological, hydrological and economic terms are briefly explained when first introduced and the sense in which they are used in this publication is summarized in the glossary provided in Appendix A.

1.1.1 Meteorological services

Meteorological services consist of the provision of information and advice on the past, present and future state of the atmosphere, including information on temperature, rainfall, wind, cloudiness, air quality and other atmospheric variables, as well as the occurrence and impacts of significant weather and climate phenomena such as storms, flooding, droughts, heatwaves and cold waves. Meteorological services are usually regarded as falling into the two broad classes of "weather services" and "climate services" based on the characteristic timescales of weather (minutes to weeks) and climate (months to centuries), respectively, albeit with substantial overlap between the two, as well as with hydrological and oceanographic services.

Meteorological service provision is an inherently international activity requiring global coordination, worldwide observation networks and efficient international data exchange. Over the past 150 years, the global meteorological community has built up the scientific understanding and technical infrastructure needed to support the provision of comprehensive weather and climate services to both national and international users in every country (Daniel, 1973). The global meteorological service system is based on a strong tradition of voluntary cooperation through WMO, with every WMO Member country contributing what it can to the international effort and every country able to draw, according to its needs, on the global system to support the provision of essential services to its national community (WMO, 1990*a*). The role of WMO in international coordination of service provision is summarized in Appendix B (section B.13).

1.1.2 **Hydrological services**

Hydrological services consist of the provision of information and advice on the past, present and future state of rivers, lakes and other inland waters including streamflow, river and lake levels and water quality. These services focus mainly on the surface component of the hydrological cycle, through which the rainfall over a catchment is partitioned between storage, runoff and evaporation back to the atmosphere, which provides some of the moisture supply for producing clouds and further rain. They also include information on subsurface (underground) water resources.

The provision of hydrological services has historically been more closely linked with national and local arrangements for navigation, river management and water supply. Although there is a long tradition of cooperation within river basins in Europe and some other parts of the world, hydrological service provision lacks the strong tradition of voluntary global cooperation, which was a primary factor that shaped the development of meteorological services worldwide. Since 1975, WMO has served as the United Nations specialized agency for operational hydrology, and hence for hydrological service provision (WMO, 2003). Responsibility for scientific hydrology has in recent decades resided with the International Hydrological Programme of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

1.1.3 **National service provision**

Virtually all meteorological, hydrological and related services and the benefits they provide depend on the existence of an integrated observation, data processing, information production and service delivery system for the region or country concerned. Most countries have a long-established system based on the operation of a primarily government-funded National Meteorological Service (NMS) (WMO, 1999; Zillman, 1999). In those countries where the NMS also carries hydrological responsibilities, it is often referred to as a National Hydrometeorological Service, albeit with the same abbreviation, NMS (WMO, 2000). Many countries, however, operate a separate National Hydrological Service (NHS), usually in a natural resource or water-supply ministry (WMO, 2001). The abbreviation NMHS is used in this

Box 1.1: Important acronyms/abbreviations used in this publication

NMS	National Meteorological or Hydrometeorological Service
NHS	National Hydrological Service
NMHS	National Meteorological and Hydrological Service

publication to refer to an NMS or NHS. The abbreviation NMHSs, in the plural, is used by WMO as shorthand for NMSs and NHSs (WMO, 2000) (Box 1.1). The director of an NMS usually, but not necessarily, serves as the permanent representative of their country with WMO.

In addition to their NMHSs, most countries have a range of public and private service providers who draw to varying degrees on the basic national meteorological and hydrological observation and data-processing infrastructure and information to provide a range of basic (public) and special (user-specific) meteorological and hydrological services (WMO, 1990*b*). The essential arrangements for the production, delivery and application of met/hydro services are introduced in Chapter 2 and elaborated in greater detail in Appendix B.

Increasingly since the 1980s, one of the major issues of national service provision has related to the relative roles of the public and private sectors, especially in the commercialization of meteorological services. This issue was examined in depth in the context of the United States in the publication *Fair Weather: Effective Partnerships in Weather and Climate Services* (National Research Council, 2003), which triggered a decade of ongoing consultations amongst the public, private and academic sectors and the adoption of the concept of a national weather, water and climate enterprise.

1.1.4 Challenges facing National Meteorological and Hydrological Services

The rapidly growing demand for met/hydro services around the world presents major scientific, operational and public policy challenges for NMHSs that maintain and operate most of the more than US$ 10 billion in global infrastructure on which the quality and value of these services ultimately depends (Zillman, 2003). This increasing demand is diverse in nature and suggests the need for major investments in:

- Comprehensive, high-quality and robust observational networks;
- Efficient data collection and management, and rapid information exchange;
- State-of-the-art information technology and computing facilities;
- Sophisticated data-analysis schemes and powerful simulation and forecasting models;
- Improved understanding of meteorological and hydrological phenomena through ongoing scientific research;

– Effective tailoring of services to user needs;

– Efficient public and private service delivery arrangements;

– Effective communication of the science, including its limitations and uncertainties, and its applicability;

– Improved methodologies and algorithms for use of meteorological, hydrological and related information in decisionmaking.

In addition to these needs, NMHSs also face broader challenges associated with social and technological changes that affect the ways in which people and activities are vulnerable to weather, climate and water influences and how they use meteorological and hydrological information to reduce risks and vulnerabilities and seize opportunities. So the challenge facing NMHSs is much more than that of mustering resources and achieving stability of funding for their infrastructure – their leadership must also foresee and plan for a wide range of social and technological changes and their implications for service provision and realization of the benefits available from effective use of the services. The NMHSs in many countries face major challenges in ensuring their capacity to meet the ever-growing demand for their services, while maintaining the integrity of the science that is the basis for these services, as well as providing authoritative information and advice for decisionmaking by their national communities.

It has long been understood that investments in NMHSs provide countries with a greater return of more than an order of magnitude in economic benefits in addition to their vitally important, but less quantifiable contribution to human safety and well-being. This realization, which goes back to the 1960s, has been reinforced over the years by the wide range of studies summarized briefly in section 1.2. But the expenditure, both globally and for individual countries, has reached a scale that requires NMHSs to demonstrate the value of the public investment necessary to support the level of met/hydro services expected by their governments and national communities.

The challenges facing NMHSs have to some extent been exacerbated by the diversity of funding and operational models that have arisen due to pressure on public funds, commercialization, competition and the challenges of international data exchange (WMO, 1999). While the experience of the past decade suggests that it is possible to maintain the overall stability of the international met/hydro service system with a variety of national funding and operational models (WMO, 2013), many NMHSs have found that they are in urgent need of:

– Clearer demonstration of the importance of the underpinning observational and data-processing infrastructure and supporting research needed to provide essential public information, forecast and warning services to their national communities;

- More rigorous and widely understood demonstration of the SEBs, both public and private, of the services they provide;

- A more systematic basis for prioritizing the use of available funding for infrastructure and service development and improvement;

- Stronger economic evidence for the substantial additional investment in climate services infrastructure necessary to support national responsibilities under the Global Climate Observing System (GCOS), GFCS and the United Nations Framework Convention on Climate Change.

1.2 ECONOMIC VALUATION OF MET/HYDRO SERVICES

There has been substantial interest since the 1950s in both the meteorological/hydrological and economics communities in economic valuation of meteorological and hydrological services (Bijvoet and Bleeker, 1951; Gibbs, 1964; WMO, 1975, 1994*a*, 2009). This has been driven, in particular, by the promise of the enormous potential benefits from investment in the space-based observing and digital-computing technologies of the WMO World Weather Watch (WWW) instituted in 1963 (WMO, 1966; Thompson and Ashford, 1968).

The development and application of economic valuation methodologies accelerated in the 1980s and early 1990s in response to the increased pressure on the budgets of NMHSs and the end of the period of rapid growth in investment in international meteorological infrastructure that had fuelled the establishment of WWW and the Global Atmospheric Research Programme (GARP). The World Meteorological Organization sponsored three major international conferences focused on demonstrating and enhancing the benefits of meteorological and hydrological services – in the United Kingdom in 1987 (Price-Budgen, 1990), and in Geneva in 1990 and 1994 (WMO, 1990*b*, 1994*b*). The two Geneva conferences focused particularly on ways of bringing the systems and services of NMHSs of the developing countries up to or nearer the standards of those of developed countries (WMO, 1996).

The 1990s saw increasingly sophisticated national economic valuation studies (for example, Chapman, 1992; Anaman et al., 1995; Anaman et al., 1998) and the publication of a comprehensive book on the economic value of weather and climate forecasts (Katz and Murphy, 1997).

During the second half of the 1990s, the increased focus, in WMO circles, on providing a more secure legal, economic and policy framework for international meteorological cooperation generated renewed efforts to establish a systematic and economically rigorous approach for assessing the economic benefits of NMSs (Freebairn and Zillman, 2002) and an overall economic framework for meteorological service provision (WMO, 2002; Gunasekera, 2004). This placed particular emphasis on the characteristics of public good of most meteorological services (Samuelson, 1954;

Heilbroner and Thurow, 1994; Harris, 1995; Stiglitz et al., 2000) and led to renewed efforts to more clearly define the role of NMHSs in the provision of public and private met/hydro services.

Economic valuation studies were conducted over the following decade in many countries and through a number of WMO mechanisms including a WMO "Forum [initially task force] on Social and Economic Applications and Benefits of Weather, Climate and Water Services". This led to the convening of a high-level international conference in Madrid in March 2007 on "Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services". The Madrid Conference Statement and Action Plan (WMO, 2007, 2009) set out a comprehensive five-year strategy for enhancement of the applications and benefits of met/hydro services around the world, including a specific call, through its action 11, for the development and application of improved methodologies for evaluating the benefits from operation of NMHSs.

The immediate follow-up to the Madrid Conference included the preparation of the publication *Primer on Economics for National Meteorological and Hydrological Services* (Lazo et al., 2009). Subsequent work on the role of the social sciences in enhancing the value of meteorological and related services and a range of studies associated with implementation of the new GFCS (Hewitt et al., 2012) and the Climate Services Partnership (CSP) (for example, Clements et al., 2013; von Flotow and Ludolph, 2013) has led to increased understanding of the many economic factors influencing the value of met/hydro services, including the diverse national policy frameworks within which NMHSs operate. Appendix C provides a short history of met/hydro economic valuation studies during the past 60 years and Appendix E provides summaries of 10 case studies.

The notion that the benefits of met/hydro services significantly exceed the costs to produce and deliver these services is not based on a single authoritative global study. For the purposes of this publication, more than 140 studies of the value of met/hydro services were reviewed (see Clements et al., 2013). Table 1.1 provides a representative sample of studies for which both benefits and costs were assessed. The studies cover assessments for "whole of services", and also a range of specific met/hydro services in developed and developing countries for individuals, households, and a variety of economic sectors. In Table 1.1, BCRs range from 2 to1, to 36 to 1, and in one study, in which the value of lives was quantified, a BCR of 2 000 to 1 was estimated.[6]

[6] There are numerous factors that influence the magnitude of benefits. Lower levels of benefits may be observed if there are significant lags in adoption of new services because of the time required to trust the product. Also, users may have limited capacity, especially in agriculture in developing countries, to take advantage of improved forecasts to avoid losses or increase profits. In addition, if there are significant resource and time constraints imposed on the SEB study, analysts may not consider all user communities or all types of benefits. The value of statistical lives, illness and morbidity are rarely quantified and can be a significant source of benefits. The level of benefits will also depend on the starting point or baseline for calculating changes. For example, a new met/hydro service will typically generate considerably more benefits than one that is improved in reliability. Ranges are often reported in SEB studies because assumptions must be made about the way that user communities respond to new or improved services. Analysts will often estimate benefits for alternative scenarios or assumptions to help decisionmakers and other audiences understand the sensitivity of results to alternative specifications.

Table 1.1. Illustrative economic assessments of met/hydro services

SEB study	*Geographic location*	*Sectors*	*Benefits methods/ measures*	*BCR*
Contingent valuation study of the public weather service in the Sydney metropolitan area (Anaman et al., 1998)	Sydney, Australia	Households	WTP survey of households	4:1
Economic value of current and improved weather forecasts in the United States household sector (Lazo and Chestnut, 2002)	United States	Households	WTP survey of households	4:1 +
Benefits of Ethiopia's Livelihoods, Early Assessment and Protection (LEAP) drought early warning and response system (Law, 2012)	Ethiopia	Households	Quantification of avoided livelihood losses and decreased assistance costs	3:1 to 6:1
Success of the United States National Weather Service (NWS) Heat Watch/Warning System in Philadelphia (Ebi et al., 2004)	Philadelphia, Pennsylvania	Households/ elderly	Regression analysis to determine lives saved; application of the United States Environmental Protection Agency's (EPA) value of a statistical life (VSL) estimate	2 000:1 +
The benefits to Mexican agriculture of an El Niño/ Southern Oscillation (ENSO) early warning system (Adams et al., 2003)	Five-state region in Mexico	Agriculture	Change in social welfare based on increased crop production with use of improved information	2:1 to 9:1
The value of hurricane forecasts to oil and gas producers in the Gulf of Mexico (Considine et al., 2004)	Gulf of Mexico	Oil drilling	Value of avoided evacuation costs and reduced foregone drilling time	2:1 to 3:1
Economic efficiency of NMHS modernization in Europe and Central Asia (World Bank, 2008)	Eleven European and Central Asian countries	Weather-dependent sectors	Sector-specific and benchmarking approaches to evaluate avoided losses	2:1 to 14:1

Table 1.1. Illustrative economic assessments of met/hydro services (continued)

SEB study	*Geographic location*	*Sectors*	*Benefits methods/ measures*	*BCR*
Benefits and costs of improving met/hydro services in developing countries (Hallegatte, 2012)	Developing countries	National level and weather-sensitive sectors	Benefits-transfer approach to quantify avoided asset losses, lives saved, and total value added in weather-sensitive sectors	4:1 to 36:1
Avoided costs of the FMI met/hydro services across economic sectors (Leviäkangas and Hautala, 2009)	Finland	Key economic sectors	Quantification of avoided costs and productivity gains; also used impact models and expert elicitation	5:1 to 10:1
Social economic benefits of enhanced weather services in Nepal – part of the Finnish–Nepalese project (Perrels, 2011)	Nepal	Agriculture, transport and hydropower	Statistical inference and expert judgement	10:1
Economic and social benefits of meteorology and climatology (Frei, 2010)	Switzerland	Transport, energy, aviation, agriculture, households	Benefit transfer, expert elicitation, decision modelling	5:1 to 10:1
Socioeconomic evaluation of improved met/hydro services in Bhutan (Pilli-Sihvola et al., 2014)	Bhutan	National level	Benefit transfer, expert elicitation, cardinal rating method	3:1

The ratio of benefits to costs in these studies supports the statement by M. Jarraud, Secretary-General of WMO in 2007: “Traditionally, the overall benefits accrued from investment made in the meteorological and hydrological infrastructures were estimated to be, in several countries, in [the] order of 10 to 1” (World Bank, 2013*b*).

The key conclusion is that met/hydro services provide significant benefits relative to their costs and SEB studies can play an important role in helping NMHSs make the case to sustain or increase public investments in these services.

1.3 OBJECTIVES OF THIS PUBLICATION

As a further and more comprehensive response to Action 11 of the Madrid Action Plan, and following increasing World Bank interest in the benefits available from increased investment in NMHSs (see, for example, Rogers and Tsirkunov, 2013; World Bank, 2013*b*, 2014), WMO and the World Bank, with support from USAID for the CSP through its Climate Change Resilient Development project, joined forces for the preparation of this publication. The main objectives of the publication are to:

- Assist NMHSs in evaluating, demonstrating and enhancing the benefits of the services they provide;
- Build increased understanding between meteorologists and hydrologists on the one hand, and economists and other social scientists on the other;
- Increase awareness of SEBs of met/hydro services within the current and potential user communities;
- Provide a rigorous basis and practical guidance for evaluating the economic benefits of individual services and components of the service-provision infrastructure;
- Assist in communicating the results of SEB studies to users and potential users of the services, to governments and other funding organizations, and to public and private decisionmakers at all levels of society.

The publication is addressed to all those in the met/hydro service-provider and user communities with an interest in evaluating the benefits and costs of the services provided and, especially, to the meteorologist/hydrologist and economics/social science staff or advisors of NMHSs charged with designing, guiding and conducting valuations.

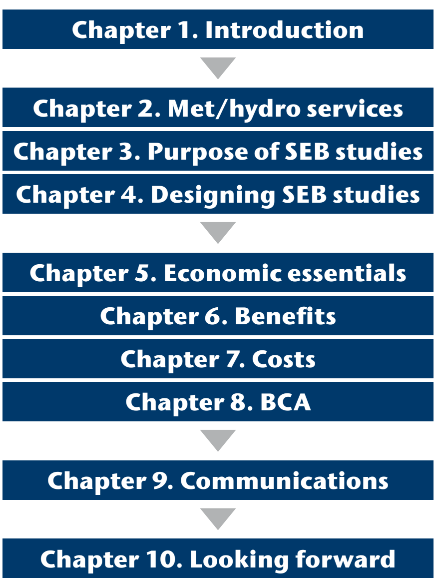


Figure 1.2. Chapter roadmap flow diagram

1.4 ROADMAP

The flow diagram[7] (Figure 1.2) describes the sequencing of topics in the publication. Chapters 2, 3 and 4 are designed to help the reader structure economic valuation and benefit–cost studies. Chapter 2 provides a brief introduction to the production and delivery of met/hydro services and the mechanisms through which they generate economic value for their user communities. Most of the material will be familiar to the service-provider community, but may provide useful background for those readers who have not previously been involved with the provision and use of met/hydro services. Chapter 3 explains the purpose of conducting SEB studies for met/hydro services and identifies the

[7] The chapter roadmap appears at the start of each of the 10 chapters to help guide readers through the SEB assessment/study process. See footnote 2 for more information on SEBs.

various audiences interested in the results of such studies.[8] Chapter 4 describes the steps involved in framing and commissioning an assessment, including the engagement of key stakeholders, detailed scoping of the study and other practical issues involved in getting the study underway and communicating the study's results.

Chapters 5, 6, 7 and 8 provide detailed discussion of economic terms, the types of benefits and costs, and methods for measuring them, and the process for conducting BCAs. Chapter 5 provides a summary of the economic essentials relevant to valuation studies and BCAs. It is aimed at providing the meteorological and hydrological service-provider community with the basic understanding of economic terms needed to guide the commissioning, conduct and use of economic valuation studies. Chapter 6 defines and characterizes the benefits achievable from the use of met/hydro services, describes the various methodologies already used and potentially available for their valuation, and provides case study examples to illustrate both the strengths and limitations of the various approaches. Chapter 7 explains concepts and methodologies used to define and measure costs incurred at different stages in the service production and delivery chain and by users of these services. Chapter 8 provides a simple workbook approach to the conduct of BCAs for met/hydro services.

Chapter 9 deals with the important issues involved in communicating the results of an SEB study to governments and other service providers, funder and user institutions and the general public. It is aimed at ensuring the effective use of the study analyses in public policy formation for the funding and operation of NMHSs.

Chapter 10 provides the summary conclusions of the group of meteorologists, hydrologists, economists and other social scientists who prepared this publication. The conclusions focus on the current state of knowledge and suggested priorities for future work on improved approaches for assessing the benefits and costs of meteorological, hydrological and related services.

There are five appendices (including Appendices A, B and C already introduced), as follows:

– Appendix A – Glossary of technical terms;

– Appendix B – Meteorological, hydrological and related services;

– Appendix C – A short history of studies of socioeconomic benefits of meteorological and hydrological services;

[8] Note that the term SEB assessment/study is used throughout the publication to refer to economic assessments, most of which involve estimation of benefits and costs, and range from quick-turnaround assessments to extensive studies. The emphasis on benefits relates to the view that the primary reason for undertaking economic assessments of met/hydro services is related to demonstrating their benefits vis-à-vis other types of public investment.

– Appendix D – Complementary roles for other[9] social science applications in socioeconomic benefit studies;

– Appendix E – Case studies (a summary of a representative set of economic valuation case studies which are used to illustrate the various methodologies outlined earlier in the publication).

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CHAPTER 2. THE PRODUCTION, DELIVERY AND USE OF MET/HYDRO SERVICES

Chapter 1. Introduction
Chapter 2. Met/hydro services
Chapter 3. Purpose of SEB studies
Chapter 4. Designing SEB studies
Chapter 5. Economic essentials
Chapter 6. Benefits
Chapter 7. Costs
Chapter 8. BCA
Chapter 9. Communications
Chapter 10. Looking forward

2.1 INTRODUCTION

The current organizational structure, functions and services of NMHSs are related to a guiding mandate, vision or mission and attendant goals and objectives (see Box 2.1 for examples). Apparent in the NMHS mission statements are the following principal motivations: safety of citizens and households, protection of property, and support for economic growth and efficiency. These objectives guide the production and delivery components of NMHSs and establish the priorities and broad parameters of the communities they are obliged and intend to serve.

Virtually all met/hydro services and the benefits they provide depend on the existence of an integrated system of observation, data processing and management, modelling, forecasting, research and development, and service production and delivery for the country or region concerned. An idealized and simplified version of this system is present in Figure 2.1.

This chapter provides a brief introduction to the production, delivery and use of met/hydro services. The scope and nature of met/hydro services are described and service delivery mechanisms are explained by elaborating upon elements of the diagram in Figure 2.1. Additional context and detail are provided in Appendix B. The conceptualization is then broadened into a general value chain to address the connections between the production and delivery of met/hydro services and the various user communities and to highlight important features of the value generation process.

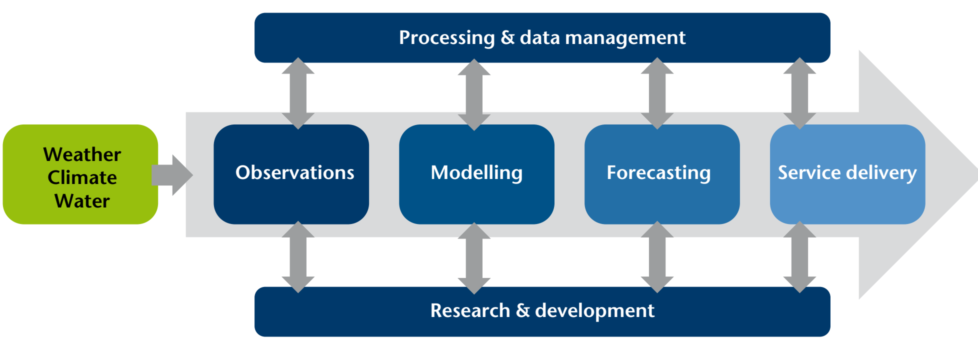

Figure 2.1. Components of the service production and delivery system of NMHSs

Box 2.1: Illustrative NMHS mission and vision statements

United Kingdom Met Office (2013)

The Met Office endeavours to meet its aim through provision of weather and climate services that help the United Kingdom Government, devolved administrations, other public and international bodies, the public and a wide range of commercial customers achieve goals. The Met Office's "Top Level Objectives" underpin this:

- Enabling protection – Protecting lives, infrastructure and the natural world;
- Improving well-being – Improving quality of life and well-being, now and in the future;
- Increasing prosperity – Enabling United Kingdom economic growth and international competitiveness.

Indian Meteorological Department (2013)

- To take meteorological observations and to provide current and forecast meteorological information for optimum operation of weather-sensitive activities such as agriculture, irrigation, shipping, aviation and oil explorations;
- To warn against severe weather phenomena such as tropical cyclones, nor'westers, duststorms, heavy rains and snow, cold and heatwaves, and the like, which cause destruction of life and property.

Kenya Meteorological Service (2013)

- Our vision: To become a leading, world-class operational forecasting centre and scientific institution that provides optimum contribution to improved quality of life;
- Our mission: To facilitate accessible meteorological information and services and infusion of scientific knowledge to spur socioeconomic growth and development.

MetService (Meteorological Service of New Zealand Ltd.) (2013)

MetService provides comprehensive weather information services, 24 hours per day, 365 days a year. Our national weather forecasts are vital to the public and we are constantly enhancing and improving their delivery. We provide groundbreaking products and services that give a competitive edge to local and international businesses in the energy, media, transport, resources, industry, infrastructure and retail sectors.

2.2 NATURE AND SCOPE OF MET/HYDRO SERVICES

In the broadest sense, meteorological services consist of the provision of information and advice on the past, present and future state of the atmosphere, including information on temperature, rainfall, wind, cloudiness and other atmospheric variables and their influence on weather- and climate-sensitive activities and communities. The physical phenomena responsible for such conditions are manifest at particular spatial and temporal scales, as depicted in Figure 2.2 and also earlier in Figure 1.1, and this has important implications in terms of observability, predictability and service design. For example, with respect to tornadoes or other phenomena that form and evolve at very fine spatial (tens to hundreds of metres) and temporal (minutes) scales, it is only possible with present knowledge to issue a location- and time-specific warning with about 20 minutes of advanced notice. Contrast this with a large tropical cyclone with a diameter of hundreds of kilometres that forms and matures over a period lasting from a few to several days prior to affecting land, thus permitting long lead times for warnings and attendant preparations. Beyond a couple of weeks, even large tropical storms cannot be confidently resolved with high temporal or spatial precision. However, as the frequency of storms and other hazardous events often correlates with indicators of larger scale atmospheric and oceanic circulation patterns or conditions, they can be statistically linked to predictions at long-range weather, seasonal and climatic scales (for example, annual basin forecasts of hurricane occurrence; large basin flood events; increased frequency/severity of storms under climate-change scenarios). Predictions or forecasts concerning tropical storms and tornadoes are representative of a particularly important subset of the information on future conditions ("forecasts" or "predictions") that consists of "warnings" or "early warnings" of hazardous or dangerous meteorological conditions and extreme weather and climate phenomena. This category also includes flooding, droughts, high winds, extreme heat and cold that pose an immediate or highly consequential threat to life, property or livelihoods (Zillman, 2014).

Hydrological and meteorological services overlap significantly largely because the atmospheric component is a critical part of the hydrological cycle – and thus both services are concerned by any hazards associated with too much or too little water. Flood warnings, therefore, are regarded as both meteorological and hydrological services. Hydrological services involve the provision of information and advice on the past, present and future state of rivers, lakes and other inland waters, including streamflow; river, lake and reservoir levels; water quality and so on. As with meteorological services, Figure 2.2 is also useful when considering the important

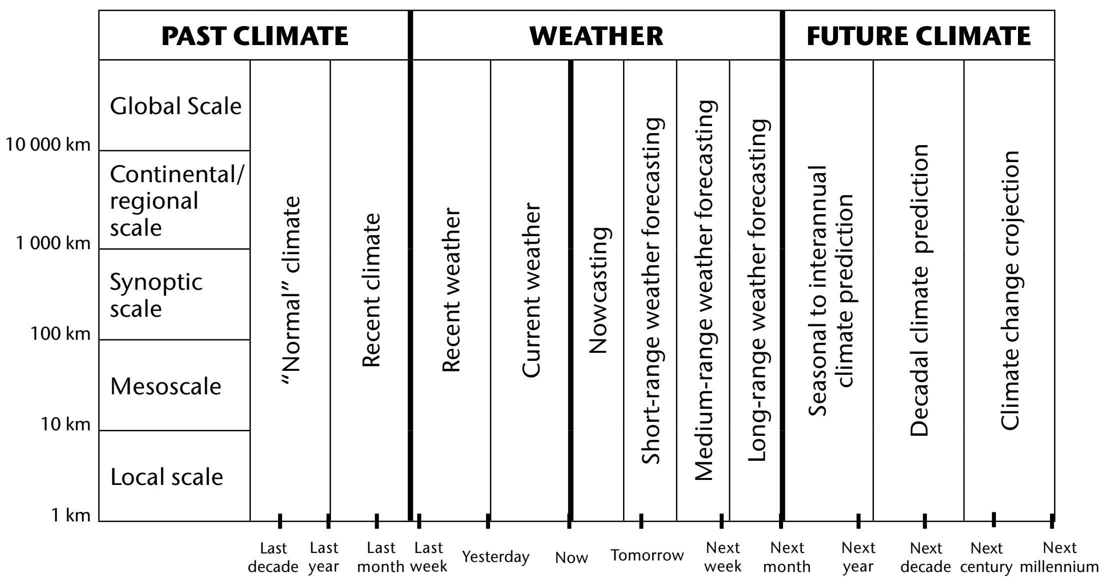

Figure 2.2. Characteristic spatial scales of weather phenomena (left-hand scale) and the approximate temporal terminology for weather and climate description and prediction (bottom scale)

time–space characteristics of hydrologic hazards and accompanying implications for services (for example, the potential precision of a prediction). For example, the lead time for a flood event warning at the outlet of a large (that is, 100 000 square kilometres or more) river basin is much greater (days) than that for a comparatively small watershed (that is, less than 100 square kilometres) – the latter are often referred to as "flash flood" events, with only minutes to hours of advanced warning potential. In all cases, the accuracy of the flood event is very much tied to the skill of those responsible for the precipitation forecast and predictions of other important antecedent factors (for example, saturation level of soils, snowpack, and the like).

Many national agencies also provide marine weather and climate services, covering hazards such as high waves, currents, storm surge/coastal inundation, and sea ice. While the accuracy of warnings for such hazards often depends on the skill of those responsible for forecasting meteorological conditions, oceanic observations and predictions (for example, temperature profiles and sea ice state) are fundamental inputs to long-range weather, seasonal and climate-scale forecasts.

Almost every meteorological and hydrological variable is of importance to some section of society, and hence part of a meteorological or hydrological service, whether in the form of long-term statistics or analyses (for example, for dam, bridge or building design), information on current conditions (for example, for air traffic management, runway selection and ground crew stoppages) or forecast conditions on timescales from minutes to months, years or decades (for example, for crop harvesting, electricity load planning or drought preparedness).

Most countries place the highest priority on the provision of warning services enabling communities to prepare for, and minimize the impacts of, extreme hydrometeorological phenomena such as tornadoes, storms, hurricanes, heatwaves, wildfires, floods and droughts. The warnings can take the form of general cautionary advice or detailed, location-specific, model-based forecasts of hazard evolution, expected impacts or consequences and precautions for particular vulnerable segments of society.

Virtually all weather and climate forecasts and warnings may be presented in words, numbers or graphical form; may be expressed in categorical or probabilistic terms; and are updated frequently – all according to the standard practices of the service agency, which generally reflect the needs and preferences of user communities. In many cases practices are coordinated and standardized through international organizations, for example WMO and the International Civil Aviation Organization for aeronautical needs and services (see http://www.wmo.int/pages/prog/amp/aemp/aeronautical-links_en.html).

The information can be developed and delivered by national forecast centres or through local meteorological and hydrological offices using guidance from the national centres. Some products may be derived directly from the output of numerical weather prediction, while many others go through post-processing and varying degrees of interpretation, adjustment and synthesis by forecasters and other practitioners. Forecasts and warnings can be examined and considered qualitatively by individual decisionmakers or they can pass directly into automated decision algorithms of various kinds.

Box 2.2: Example of the United Kingdom Met Office tailored services

The United Kingdom Met Office offers a range of special services tailored to specific road, rail, aviation, and marine transportation interests. Their road service applications include forecasts and training for route planning, optimization and maintenance (see http://www.metoffice.gov.uk/roads).

Working with Devon City Council and transportation consultants, the Met Office was able to streamline maintenance routes into groups with similar road weather hazards through an analysis of climatology, thus reducing the number of routes from 48 to 38 and saving £ 20 000 per route in terms of reduced mileage, fuel, fleet and labour costs (Met Office, 2011).

Since the 1980s, Members of the WMO community have found it useful to distinguish between two broad categories of services:

- **Basic services:** Those services provided at public expense to discharge a government's sovereign responsibility for protection of life and property, for the general safety and well-being of the national community and for provision for the essential information needs of future generations;

- **Special services:** Those services beyond the basic services aimed at meeting the needs of specific users and user groups and that may include provision of specialized data and publications, their interpretation, distribution and dissemination.

Many services, particularly special services, often go well beyond the simple dissemination of information to include consultative advice or scientific investigation into particular meteorological and hydrological phenomena and events or their impacts.

As apparent in Figure 2.2, information services extend across all timescales. While the emphasis and examples referenced in this section have related primarily to short- to medium-term forecasts and warnings, services also include retrospective products based on recent or long-term historical observations as well as future long-term predictions and projections.

2.3 SERVICE DELIVERY

The ultimate benefit from the use of met/hydro services depends at least as much on the effectiveness of the service delivery process as it does on the inherent scientific quality of the forecast or other information provided.

The 2011 World Meteorological Congress approved a detailed WMO Strategy for Service Delivery aimed at guiding the various participants in both the national and international meteorological and hydrological service provision system on ways of improving the overall quality of their services and the benefits from their application (WMO, 2014). The six "strategic elements" which provide the overall framework for the strategy are:

– Evaluate user needs and decisions;

– Link service development and delivery to user needs;

– Evaluate and monitor service performance and outcomes;

– Sustain improved service delivery;

– Develop skills needed to sustain service delivery;

– Share best practice and knowledge.

An implementation plan for the Strategy for Service Delivery was published in 2014 (WMO, 2014). The strategy represents an important initiative in support of the Madrid Action Plan (WMO, 2009), the WMO Strategic Plan (WMO, 2011) and the GFCS Implementation Plan (WMO, 2012) and can be expected to reinforce the focus on service improvement in all countries.

2.4 USERS OF MET/HYDRO SERVICES

The users of met/hydro services (especially meteorological services) include virtually every person on the planet (Zillman, 2014). The overall user community is often broken down into the general public, consisting of individuals, households and a wide range of government and non-government organizations, on the one hand, and specific user sectors and user communities on the other (Table 2.1).

Each of these major user sectors has specific requirements for historical, current and forecast meteorological and/or hydrological information and advice, and most of them have well-established consultation and coordination mechanisms for formulating user requirements and meeting user needs. That said, the individual actors, enterprises and institutions within these broad user sectors, and most definitely the general public, vary in terms of their desire and capacity to obtain, understand and utilize information – typically it is the larger organizations, businesses and agencies that are best able to leverage the value of information. Industry, professional, non-government associations

Table 2.1. Sector utilization of met/hydro services

Economic sectors		*Public safety*	*Natural resources*
– Services – Manufacturing – Energy – Insurance and finance – Tourism	– Agriculture – Transportation – Construction – Mining	– Defence – Emergency management – Health – Transportation safety	– Water supply – Natural resources management (forests, coasts, terrestrial and marine ecosystems)

and other advocates (such as WMO) often play the role of demonstrating the utility of incorporating met/hydro information into decisions among the underserviced communities.

While practice differs from country to country, the term "users" is usually taken to embrace the entire user community, albeit often with emphasis on the general public and other consumers of the "basic service". The terms "client" and "customer" have been mostly reserved for the users of specialized products and services, especially those provided on a commercial basis (Zillman, 1999).

2.5 GENERATING VALUE FROM SERVICES

Many actors and interactions are involved in the process that ultimately leads to generating value – those who conceive, create, develop, disseminate, translate, exchange, promote, receive, interpret, utilize and benefit from one or more products or services. The production and service-delivery elements described in Figure 2.1 capture important components of this process. However, it is also necessary to appreciate the roles of communication, perception and interpretation, decisionmaking behaviour, and actions taken by users – these, in turn, lead to outcomes and ultimately value. Figure 2.3 extends the service production and delivery process by incorporating these aspects into a comprehensive yet simple value chain that will be elaborated and referred to throughout the remainder of the publication.

The met/hydro service production system, including the operation of capital-intensive monitoring and modelling infrastructure and the production of information targeting broad public audiences, is typically managed within the domain of government-supported NMHSs. Outputs from this system are distributed through two streams, one delivering basic services through traditional or social mass media, emergency service organizations and public sector agencies; the other providing specialized services through private sector providers or commercial arms of NMHSs. Even when the focus is strictly on assessing an aspect of a public service, it is important to include and

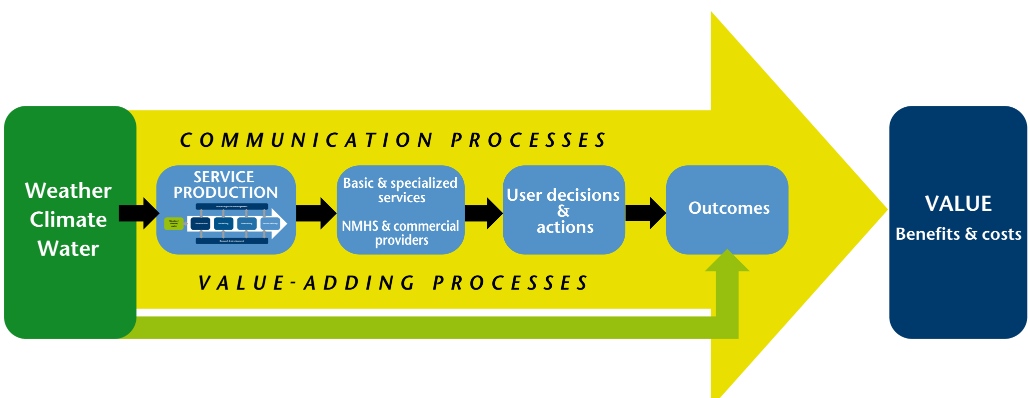

Figure 2.3. Simplified schematic of the met/hydro services value chain

consider the role of private sector players in the production and delivery of knowledge, as that may be an important vehicle for the creation of value.

Potential value is added at each link of the chain moving from left to right as services are received by users and incorporated into or considered in decisions. Decisions consist of three general types – strategic, operational and tactical (Davison et al., 2012) – and conveniently align more or less onto the spatial–temporal scales and categories of products and services (see Figure 2.2). Strategic decisions are typically infrequent and long-term commitments are often related to large investments and major infrastructure designs, which may be informed by interannual and climate-change scale prediction or projection information as well as analyses of long historical records (for example, streamflow statistics to justify the sizing and design of a hydroelectric power installation). Operational decisions are those required for the routine, continuous daily management of an organization or activity and are normally informed with forecast information in the order of minutes to one day, such as that used to allocate winter maintenance equipment, personnel and treatment technologies (for example, road ploughing and/or applications of de- or anti-icing chemicals and abrasives) to clear roadways during a particular winter storm. Tactical decisions lie between those at operational and strategic levels, are often repetitive but less frequent than operational decisions, and are usually informed with meteorological and hydrological information at daily to seasonal scales. Crop plant selection and advanced natural gas contract purchases are examples of tactical-level decisions. While the above examples and classification of decisions stems from organization management, the concept is portable to the general public where strategic decisions might relate to the choice of a place to live or work; operational decisions could include selection of appropriate clothing and accessories (for example, whether to be equipped with an umbrella) on a given day; and tactical decisions might involve booking a vacation or changing automobile tyres from summer to winter models.

Value-adding processes involve tailoring services to more specialized applications and decisions (that is, making the information more relevant and trustworthy) or expanding the reach of an information product to ever-greater audiences (more people, decisionmakers, clients). The efficacy of the information is highly dependent on communication processes that influence the ability of users to perceive, interpret and apply knowledge as intended by the service or information provider(s). Such processes operate throughout the production, delivery and use of met/hydro information and are significantly affected by psychological, social, cultural, political, economic, institutional and other non-weather factors. As a simple example, given warning of a pending storm, one is far more likely to cancel or defer a non-essential weekend trip rather than a commute to work, especially if the avoided work trip leads to a lost day of wages. Such non-weather factors are essential to understanding deviations from the behaviours expected (for example, staying off the roadways to reduce risk) by those issuing warnings and providing services.

The results of decisions taken or not taken, with or without the benefit of met/hydro services, are outcomes – the critical pieces that link met/hydro services to value. Beneficial outcomes may include losses avoided (typically reported as injuries, fatalities, displaced populations, property damage, environmental impact and various measures of costs, income and productivity) or additional profits realized due to improved decisions for weather events. Outcomes less commonly acknowledged and analysed, but no less important, include aspects of time (for example, delay), inconvenience and feelings or emotions (pleasure, stress, dissatisfaction, sadness, sense of place/community, and the like). When assessing the value of a service, one is really attempting to qualify and quantify the aggregate effects of changes in outcomes thought to result from the introduction, improvement or withdrawal of the service.

2.6 CONCLUSIONS

Demonstrating the value of met/hydro services can be an important factor in supporting decisions to maintain or increase funding for these services. However, this is not a simple task for economics or other social sciences. In part this is because the relationships and actors within the value-creation process are dynamic and reflective – the value-creation process is iterative and interactive, as important feedbacks continuously connect outcomes back to the producers of information through formal and informal systems of verification and valuation.

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CHAPTER 3. THE PURPOSES OF SOCIOECONOMIC BENEFIT ASSESSMENTS OF MET/HYDRO SERVICES

Chapter 1. Introduction

Chapter 2. Met/hydro services
Chapter 3. Purpose of SEB studies
Chapter 4. Designing SEB studies

Chapter 5. Economic essentials
Chapter 6. Benefits
Chapter 7. Costs
Chapter 8. BCA

Chapter 9. Communications

Chapter 10. Looking forward

3.1 INTRODUCTION

Many NMHSs are seeking to improve and expand their services to meet new and increasing national needs. Others facing level or shrinking budgets need to ensure the best possible use of available funds to maintain their basic infrastructure and essential services to the highest possible standard. In all of these cases, NMHSs will be increasingly expected to document the quality of met/hydro services, the level of uptake by users, and the value of these services. This chapter provides an overview of the types of analysis that NMHSs might commission[10] to make the funding case, and describes several ways that SEB studies can be used to support arguments for sustained or increased funding.

3.2 EVALUATING MET/HYDRO SERVICES

A comprehensive evaluation of met/hydro services would cover verification of service quality, characteristics of service uptake by user communities and the economic value of services to user communities. Most NMHSs are continually evaluating the quality of their forecasts and other services (Mason, 2013). These evaluations might involve ex-ante or ex-post analysis (see section 6.2) of forecasts with actual weather data to generate routine verification scores and/or customer satisfaction surveys to assess perceptions of service reliability and access. Together, these analyses can be used to support service improvements and demonstrate reliability to funding authorities and user communities.

In addition to their utility in assessing service quality, customer satisfaction surveys are a tool used by NMHSs to understand who is accessing information, how that information is being used, and the experience of users in matching that information to their specific needs. In addition to their use for evaluating current products and services, surveys and focus group interviews can also be used to explore potential demand for new services.

There are numerous non-economic social science methods that can be employed to understand the uptake of met/hydro services. Non-economic methods can be used to reveal diverse information on the value of the service, including, for instance, the ability of users to access, understand and apply particular met/hydro services to their

[10] At the time of writing, most NMHSs do not have an on-staff economist. Even as met/hydro staff review this guide to SEB studies, the authors do not expect that NMHSs will be able to produce such studies without external support.

particular needs. Non-economic social science evaluation studies can also describe the capacity of users to incorporate met/hydro information into particular decision contexts, which are not quantifiable in strictly monetary terms. This will also help characterize the ease with which met/hydro information flows from an NMHS to intermediaries and on to the end users in question. Appendix D provides a more detailed description of the many applicable non-economic social science methods that can contribute to the evaluation of met/hydro services.

These assessments can be very useful as NMHSs work to understand their customers' needs, improve individual products and/or better tailor services to specific user groups. Non-economic methods also serve as important complements to economic methods, providing the context and background to help understand how economic studies should be designed in order to best reflect the value of a service and better understand the determinants of the pace and extent of uptake for current and future services.

While non-economic methods are very useful in illuminating the context in which services are provided and used, in many cases NMHSs will also need to determine and communicate the value of their met/hydro services in economic terms. Economic valuations can be very helpful as NMHSs make decisions about how to allocate resources – for example, allowing limited resources to be directed at specific needs to enable the organization to fulfil its central mission or role. It can be challenging for NMHS management to decide where best to invest their (usually scarce) financial and personnel resources (Rajasekaram et al., 2010). Too often, previous patterns of investment are maintained without their effectiveness being explored in any rigorous manner.

An SEB study can point the way to a more informed and evidence-based decisionmaking process in that it can identify elements of the organization that will produce the best return on resource investment. This can be a difficult process; any change in budget allocation that differs significantly from historical patterns will almost certainly present challenges within an organization. Nonetheless, decisions based on the outcomes of SEB studies are more likely to be beneficial for the organization in helping it to retain relevance than decisions made without reference to such studies; such decisions are also more defensible than those made without a similar level of analysis.

Economic studies are powerful tools in communicating with funders to help them understand the likely return on current and/or future investments in met/hydro services. In all cases, an NMHS that can plausibly demonstrate that it provides good "value for money" (whether societal or economic in character) is in a better position to argue for the retention of, or an increase in, its existing resources (see Box 3.1). The studies listed in Table 1.1 in Chapter 1 provide a range of examples for which benefits exceed costs by a substantial margin, whether the study focuses on the analysis of whole of services or individual services for all or selected user communities.

It should be considered that many other government agencies will be engaged in similar exercises to demonstrate the value of the services that they provide; an NMHS that cannot point to an SEB study to support its case for funding may find itself at a

Box 3.1: Target audiences for socioeconomic benefit studies

When considering why an SEB study should be commissioned, careful thought needs to be given to the audience to which the finalized assessment report will be targeted, and how that report will be communicated to that audience. While this topic is covered in depth in Chapter 9, those developing the study should, early on in the process, develop a clear idea as to the formats in which the results will be presented to the audience, for example, text narratives, tables, graphics, and the like. Different presentation formats will work best with different audiences. It would be unwise, for example, to present tables of detailed results to meetings of key users, whereas those in funding agencies or finance ministries may specifically require such details to aid them in their decisionmaking. The form of presentation should always be tailored to the specific audience if the message is to be communicated to maximum effect, and this has implications that reach right back into the specification and design of an SEB study.

serious disadvantage when the finance ministry and/or relevant donor comes to make its key decisions. It will not normally be sufficient to demonstrate that a positive economic benefit will derive from resource investment in an NMHS, as other agencies will have similar support to their applications; it is important to document the economic benefit in a way that can be supported by the study outcomes.

While these and other goals for SEB studies are dealt with in more detail in the following section, it is important that NMHSs come to view the valuation of met/hydro services not as a one-off project, but as a part of ongoing service development and delivery. Regardless of whether economic or non-economic methods are used, it is clearly beneficial for NMHSs to perform assessments on a routine basis to help them characterize the value of their service developments over time, similarly to the way that regular forecast verification helps to illuminate the extent to which forecast skills have evolved. A schedule of periodic assessment procedures, which could include economic studies, non-economic social science assessments, or a mixture of both, should be developed by each NMHS.

3.3 TARGET AUDIENCES FOR SOCIOECONOMIC BENEFIT STUDIES

As those working in NMHSs will know, when a forecast is issued to a specific user, it is usually tailored to the needs of that user. The more closely the forecast is tailored to user needs, the more likely it is to assist users in their decisions and generate value as users benefit from the decision. In an analogous manner, an SEB study should be conceived and carried out with careful consideration given to the needs it will fulfil.

Every SEB study should start with a question to be answered or a purpose to be met. The nature of that purpose will inform the type of study to be undertaken, its scale and scope, and the communication strategy that will be employed to ensure maximum exploitation of the study results. The purpose, of course, will be informed by relevant stakeholders and the target audience for the study, which may include government decisionmakers, public and sectoral users and staff, as detailed below. Figure 3.1 lists and characterizes the main types of NMHS operating models and describes the institutional context defining how they are financed and managed. This can help NMHSs that employ varying operating models understand relationships between the met/hydro service and an audience, funding agency, user, and the like.

3.3.1 Governing decisionmakers

Every NMHS exists within an institutional framework or structure, the details of which fundamentally inform the identification of an SEB study's target audience and communication strategy. Rogers and Tsirkunov (2013) reviewed the global landscape of NMHSs and concluded that five broad operating models are currently employed, summarized in Figure 3.1.

In practice, the majority of NMHSs are structured following one of the three least autonomous models, that is, departmental units, contract agencies and public bodies.

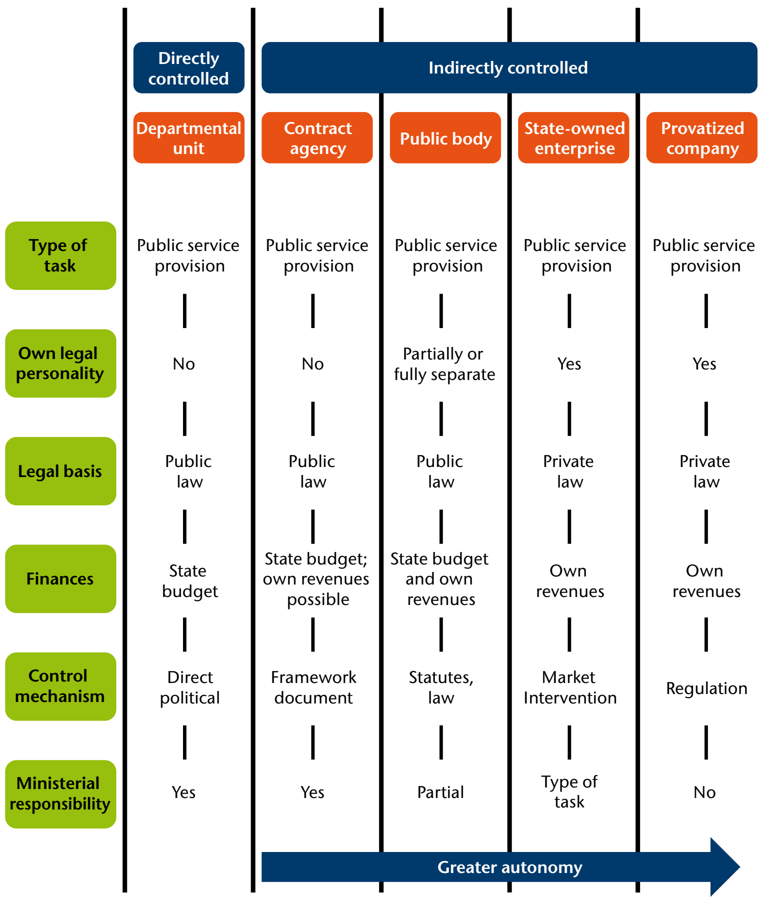

Figure 3.1. Five NMHS operating models in current use

Source: Rogers and Tsirkunov (2013)

For NMHSs that are fully part of the civil service of the country in question (as a part of the government department or as an agency reporting directly to a department or minister) the key decisionmakers may be in the parent department and/or in the finance or treasury ministry. Decisions may be at the administrative level or at the political level or, as is most usual, some mixture of the two. If, on the other hand, an NMHS is constituted as an agency with its own board of directors (for example, a state-owned enterprise or privatized company), then this board represents a key decisionmaking layer to which the SEB study must be communicated.

If an NMHS has some commercial freedom and can raise money for investment from private sources (for example, banks), the effective communication of the study outcomes will be essential in assembling the business case and preparing proposals for potential investors/lenders. Even within government, many investment funding decisions are now taken on the basis of competitive business cases. Frequently, it will not be sufficient to demonstrate a positive return on investment in an NMHS; the return may need to be demonstrably higher than other potential investments seeking funding from the same source of public funds.

3.3.2 **Public and sectoral users**

Almost all NMHSs will have, as a basic public task, the provision of forecast and warning services to the general public. These may be communicated directly to the public by an NMHS through its own staff or through partner organizations such as emergency management agencies and the media. In virtually all cases, there will also be online channels of communication, ranging from the traditional websites to social media. There may be differences in the relative importance of each of these media channels as well as in the transmission of weather information, but in general the weather message is tailored to each specific means of dissemination. In an analogous manner, it will be important to carefully tailor the communication of SEB study data for each of these specific media, exploiting their individual strengths and avoiding their individual weaknesses. Additional strategies to reach the media and external audiences will be examined in more detail in Chapter 9.

Sectoral users, including agencies, organizations and private companies, can be both contributors to and consumers of SEB studies. Government agencies reliant on met/hydro services may contribute data and information and even help advocate on behalf of NMHSs by promoting their SEBs, while they and other agencies may also be competing for the same public funding. In both cases, the agencies form a key audience for SEB studies. Agencies and companies that pay for met/hydro services will most likely be interested in SEB analysis to inform their relationship with NMHSs, for example to gauge the fairness of the fees they are paying. International donors and financiers will of course be interested in understanding and determining the expected socioeconomic returns of their investments, and may require an SEB analysis as a condition of funding.

3.3.3 National Meteorological and Hydrological Service staff

It will be highly desirable that all members of an NMHS staff are engaged in the SEB study, understand the process of analyses and play a role in implementing the resulting decisions to ensure that these analyses are fully and effectively utilized. Depending on the scope of the study, some staff will most likely be highly engaged in the process, or will at least contribute key information. All relevant staff should be aware from the beginning of the reasons that management has for pursuing such analysis, and be informed of the process and results at regular intervals. Studies should not only be communicated to staff as a static audience; opportunities must be provided for questioning, feedback and deeper engagement if so desired.

A compelling reason why the staff of an NMHS will have a deep interest in the results of an SEB study is that the results should help to confirm to them a sense of the significance of the work that they perform, and thus support and promote morale in the organization. Everyone wants to feel that they do useful work and tangible evidence of the value of an NMHS and its products will, in most cases, raise the confidence levels of the individuals working within the organization and contribute positively to both individual and corporate self-esteem.

3.4 REASONS TO CARRY OUT A SOCIOECONOMIC BENEFIT STUDY

There are many possible purposes or needs that may inform the decision to conduct an SEB study with a focus on met/hydro services. The impetus may come from outside the NMHS – perhaps from the parent government ministry or the treasury. It may come from a board of directors or a council of users if such formal structures exist. Alternatively, the initiative may come from the management of the NMHS, either to provide them with quality evidence on which to base management decisions or evidence to assist them in advocating for improved resources from the public purse.

While each NMHS will have its own unique circumstances and challenges, this section attempts to describe and summarize some of the more common needs that underlie the requirement to conduct an SEB study and suggest some of the characteristics of studies that might address those diverse needs, together with appropriate examples. These needs include, but are not limited to, validating the provision of existing or proposed new services, determining the contribution of met/hydro services to user goals in strategic sectors or among members of the general public, and assessing the allocation of NMHS resources to specific services.[11]

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[11] The final purpose – assessing the allocation of NMHS resources – only entails analysis of costs. As SEB studies are designed to evaluate benefits, it would not provide a motivation for such SEB studies. However, SEB studies often focus on both benefits and costs. By determining how to use resources more cost-effectively, which will reduce total costs, this can increase net benefits (the difference between benefits and costs). Furthermore, the determination of lower-cost strategies to provide services can complement SEB analysis results and make a more compelling case to provide financial support for NMHSs.

The specific purpose or need will inform the type of valuation that should take place, in that it should deliver the precise metrics that support the particular need. The manner in which SEB study results are to be employed and communicated will also need to be considered at this early stage; the study results will not exist in isolation but will typically feed into a wider process of decisionmaking. In addressing this point, the concept of framing the study will need to be taken into account. In the communications literature, "framing" (see, for example, Scheufele, 1999; Entman, 2004) refers to the creation of a common understanding of the purposes of the intended study plus the mode of presentation.

3.4.1 Validating the provision of basic met/hydro services

While politicians and other opinion formers sometimes argue against public sector spending on the grounds that a well-resourced government is a contradiction to a healthy economy, it is government spending that creates the conditions for businesses and communities to prosper. Governments fund transportation and energy infrastructure, ensure fair business practices, educate and train a large fraction of the workforce and contribute significantly to keeping it healthy. They also provide the resources to cope with crises created by natural and man-made hazards. National Meteorological and Hydrological Services contribute significantly to the latter and provide routine services that facilitate efficiencies in for-profit weather-sensitive industries and for the economy as a whole.

In the latter context, NMHSs are viewed by some governments as entities that can provide a return on capital or can support some fraction of their own infrastructure costs, thereby subsidizing any public sector investment. While this approach may be politically attractive, it undermines the essentially public-good role of NMHSs and, if accompanied by inadequate financing, contributes to a decrease in a country's ability to cope with climate- and weather-related fluctuations. Documenting the value of basic met/hydro services helps to justify basic investment in NMHSs.

The primary audience for those SEB studies that aim to validate the existence of the publicly funded NMHS is normally the owner of the NMHS, usually the responsible

Box 3.2: Validating whole-of-service investments

The Finnish Meteorological Institute was one of the first NMHSs in Europe to conduct an economic valuation of its met/hydro services. The study was designed to demonstrate the value of all services, but focused only on major sectors and user groups: transportation, construction and facilities management, logistics, energy, and agricultural production. The authors used existing data, impact models, and interviews to determine the current level of use of met/hydro services, how individuals and organizations change their decisions in response to this information, and how decisionmakers and other users benefit from it. Estimated annual benefits for the sectors studied were US$ 359 million–US$ 390 million, about five times the annual costs of providing all FMI met/hydro services (US$ 68 million–US$ 82 million). Case study 7 in Appendix E provides additional detail on the FMI study.

Source: Leviäkangas and Hautala (2009)

Box 3.3: Validating current investments in specialized met/hydro services

In 2014, MeteoSwiss analysed the benefits of the terminal aerodrome forecasts (TAFs) it provides to Switzerland's domestic airlines. Specifically, interviews were conducted with airline representatives and a normative, economic decision model was applied to quantify the economic value of TAFs in terms of avoided fuel and flight-deviation costs. Results of the study indicate that the annual economic benefits of TAFs are between US$ 14 million and US$ 22 million at Switzerland's two main airports. The study helped to validate past investments in TAFs, and also allowed MeteoSwiss to assess options for improving TAFs to increase economic benefits. Case study 6 in Appendix E provides additional detail on the MeteoSwiss TAF benefit study.

Source: Frei et al. (2014)

ministry or the treasury. However, it should be stressed that these whole-of-service studies can be difficult to scope out, can be very time-consuming and typically require considerable resources to conduct (a more in-depth discussion of such studies can be found in Chapter 6). More limited studies, focusing on a particular sector, geographical region or major client, are recommended as a starting point for organizations developing an SEB study for the first time.

3.4.2 Validating past and current investments in specialized met/hydro services

Many NMHSs are called on, from time to time, to justify their continuing operation and especially the substantial investment of public funds to support their basic infrastructure and their entire suite of services. And most NMHSs frequently find themselves needing to validate investments in specific programmes and/or services provided to a particular sector. The NMHS may be interested in determining if a particular service that has been provided in the past should be maintained or discontinued. There may be interest in understanding which sectors benefit from specific types of services. In comparison to the whole-of-service study described in the section above, this type of SEB study typically will have a more narrowly focused scope of work and may be more manageable in scale and less costly and time-consuming to conduct.

For instance, SEB studies that focus on specific user sectors (for example, agriculture or transport) can illustrate the value of met/hydro services to specific actors (Frei et al., 2014). The valuation of the benefits associated with early warning systems also fall into this category. In Hong Kong, China, for instance, it has been shown that early storm warnings ensure that people have the time to return safely to their homes using an adaptive public transport system that is responsive to the warnings. Timely warnings, effective communication and response ensure the safety of Hong Kong citizens and permit the economy to rebound quickly from such natural hazards (Rogers and Tsirkunov, 2011).

While these studies focus on the economic benefits associated with specific activities, they can also be a means to explain the value of NMHSs to their respective governments and to improve the availability of financial resources to invest in this sector.

3.4.3 **Justifying new investments in met/hydro services**

In general, a well-established NMHS can reasonably expect that its annual budget allocation will bear some close relationship to the allocation levels in recent years, being adjusted up or down in line with the prevailing economic health of the country (amongst other considerations). Seeking an additional allocation of funds for new activities or investments is, however, a more challenging scenario and will typically require a robust illustration of the benefits to be realized by the new allocations sought.

The economic assessments employed in this case are necessarily pragmatic, with the aim of determining the likely SEBs of enhanced services provided through the new activities or new facilities of the NMHS. One of the difficulties in this case is that potential users of these new services are likely to be unaware of the new opportunities and benefits that might ensue. Therefore, there is a risk that the beneficiaries will undervalue the potential benefits of modernization or improvement, or require significant time to adjust their decisions to the new or improved information.

To mitigate this, economic assessments aim to estimate the potential aggregate benefits that would accrue to national business activities from an improved quality (accuracy, timeliness and reliability) of met/hydro information and services. The approach used in these studies focuses on estimating potential countrywide losses from high-impact met/hydro hazards, while assuming that the potential benefits of modernization will be realized over several years. There are a number of complex aspects to this approach, notably the absence of systematic recordings of damage/losses (both in physical and value terms) incurred by the economy, sectors of society and the population as a whole as a result of met/hydro hazards. As a result, it is also necessary to apply additional approaches (World Bank, 2008).

Box 3.4: Justifying new investments in met/hydro services

The World Bank, working with a number of NMHSs in Europe and Central Asia, has conducted 11 studies to evaluate the benefits associated with existing weather and met/hydro services, as well as the benefits that large-scale NMHS modernization might achieve. The studies employed two assessment methods:

- A sector-specific method to estimate the economic benefits of met/hydro services in weather-dependent sectors using available in-country data and expert surveys;
- A benchmarking method to assess the losses caused by prior weather events involving the estimation of reduction in losses from weather events that could be achieved with improved services.

Results of the World Bank studies indicate that improving met/hydro services and information would result in significant economic benefits. For example, results for Kyrgyzstan indicate that the benefits (avoided damages) of investments to improve met/hydro services are 2.4 to 3.2 times the costs of these investments. Case study 1 in Appendix E provides additional detail on the sector-specific and benchmarking studies that the World Bank has conducted in countries in Europe and Central Asia.

Source: World Bank (2008)

Box 3.5: Informing strategic policy decisions

User-tailored climate services can generate significant SEBs in the agricultural sector; for example, by early warning systems which trigger preventive measures to avoid or reduce crop losses. This potential was explored by the Peruvian National Service for Meteorology and Hydrology (SENAMHI) and MeteoSwiss in a pilot case study estimating WTP for specific early warning systems in the Peruvian region Cusco. The study applied the stated-preference method (see sections 6.5.1, 6.5.3, 6.5.4 and 7.6), an econometric approach based on face-to-face interviews with more than 60 individual farmers. The results indicate SEBs for coffee and maize cultivation over a period of 10 years of about of US$ 10 million for the Cusco region and well over US$ 100 million for Peru as a whole. Considering only coffee farmers, the estimated WTP corresponds to up to 1% of Peru's coffee export value. The study shows clear evidence for the need and utility of tailor-made climate services for the agricultural sector, hence underscoring the essential role NMHSs can play, for instance in ensuring food security or improving farmers' incomes. It thus demonstrates the importance of climate services as a basic element for national climate change adaptation strategies in climate-sensitive sectors.

Source: MeteoSwiss and SENAMHI (2014)

This approach also draws attention to the fact that, in many cases, measurable social and economic benefits will accrue only after substantial investment to transform ill-equipped and nearly obsolete NMHSs. Over 100 NMHSs in developing countries are considered to be in need of substantial investment to bring their services to a level at which they can provide timely, reliable and accurate forecasts of high-impact weather to the public and to national economic sectors (Rogers and Tsirkunov, 2013).

3.4.4 Determining the value of NMHSs to user goals

While an NMHS will normally be focused primarily on its routine forecast and warning operations, it has the capacity to inform and contribute to larger strategic goals that may be national or even international in scale. Examples of national goals might be those linked to the safety and security of citizens (civil protection), to food and nutrition (agricultural development and food security), to public health (air quality) or to climate adaptation. International goals might include those policies that are aimed at opening up public data sets for use by third parties, for example, the European Union's Directive on Infrastructure for Spatial Information in the European Community (INSPIRE) relating to the reuse of public sector information in the European Union (de Vries et al., 2011), and similar initiatives in Australia (Office of the Australian Information Commissioner, 2011). This special category of SEB studies can help to determine how an NMHS, operating at the national level, can contribute to the realization of these larger strategic sectoral goals.

3.4.5 Prioritization or reallocation of resources

Decisions regarding how to allocate resources are normally internal to an NMHS. A decision may be required as to where investment should be focused to improve the overall quality and range of services provided to the public and specialized users. For example, choices may need to be made between investments in ground-based or space-based observation systems, or perhaps between investments in observation systems or forecast systems. Choices may need to be made between allocating monies to tangible assets (equipment, computers), or to capacity-building activities, including training and other activities.

A particular example of this type of choice faced by many NMHSs includes whether resources devoted to weather modification (for example, hail suppression) might not be better allocated to improved forecast and warning services. An analysis of cost-effectiveness can be useful in determining whether the current or improved quality and level of met/hydro services is achieved at lowest cost.[12]

The context of this category of need or purpose is usually a national one, whereby a public audit office or similar institution carries out a study of a publicly-funded institution to ascertain whether or not public monies have been used in an optimal manner. However, an NMHS could, on its own initiative, embark on a study of this type to illustrate to the public that it is using tax revenues prudently. This type of study may also be required to support cost estimates provided to a regulator, for example in the aviation industry, where the costs of support services are determined by regulation and passed on to the users – in this case the airlines and, ultimately, the travelling passengers.

3.5 CONCLUSIONS

The articulation of the purposes of SEB studies provides the impetus for developing studies to answer one or more questions about the value of met/hydro services and renewing or expanding political, financial and public support for NMHSs. This initial realization of the importance of the benefits of met/hydro services represents the beginning of a process of SEB study approval, resource mobilization, study design and implementation and communication of results that is the focus of the next six chapters.

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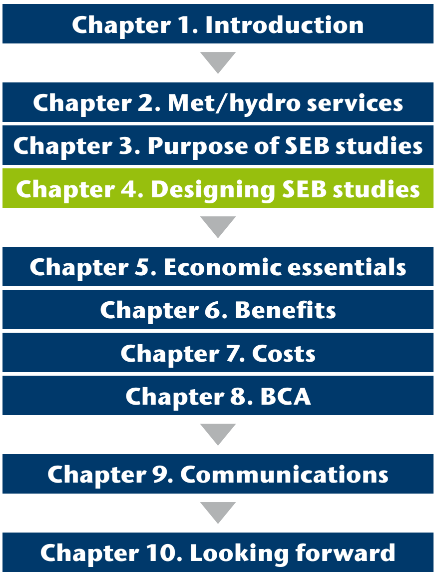
CHAPTER 4. DESIGNING AND COMMISSIONING SOCIOECONOMIC BENEFIT STUDIES



4.1 INTRODUCTION

As noted in Chapter 3, there are several motivations for studying the costs and benefits of NMHSs. Studies might be designed to support one or more of these motivations. The purpose of this chapter is to help met/hydro service providers undertake the groundwork necessary to conduct and commission an SEB study covering the analysis of benefits, costs (cost-effectiveness analysis), or BCA, and communicate study results to decisionmakers and stakeholders.

While NMHSs may have the capability to conduct non-economic studies on the importance of their services (for example, user surveys to assess quality and uptake) or apply simplified methods such as the benchmarking approach developed by the World Bank (see section 6.5.3 for a detailed description) to provide order-of-magnitude benefit estimates, it is assumed that few NMHSs will prepare in-house SEB studies. Thus, this chapter is organized according to a five-stage process to help NMHSs design and commission SEB studies. The stages and main outputs for SEB studies are described in Figure 4.1.

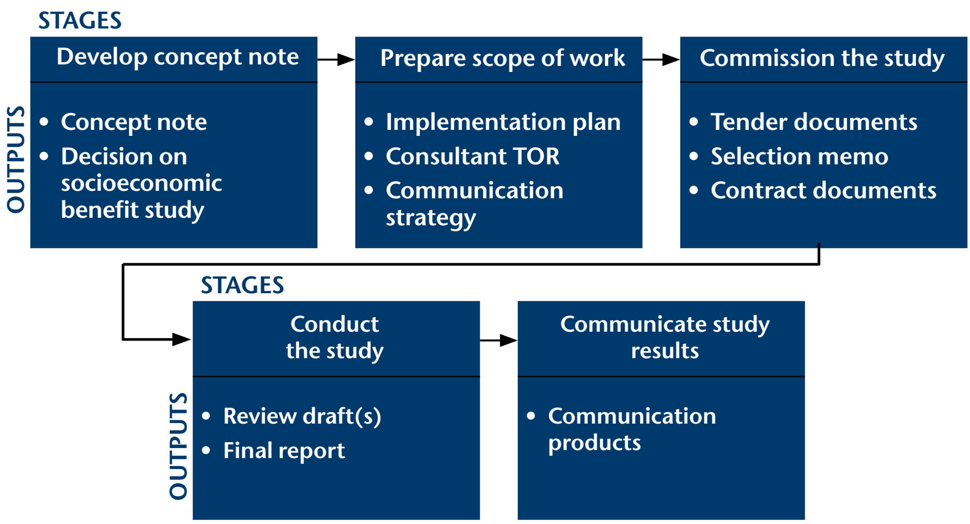


Figure 4.1. Process of designing and commissioning socioeconomic benefit studies

4.2 STAGE ONE – DEVELOP THE CONCEPT NOTE

The first stage concerns the preparation of a concept note that will enable high-level government or NMHS management to take a decision to provide financial support for the SEB study, agree to consider the results of the study in terms of resource allocation and understand other potential uses of study results. The concept note should also anticipate the types of questions that decisionmakers will ask related to the study's purpose(s), intended audiences, content, financial and staff resource requirements, and management of the preparation, review and communication of the results of the SEB study.

The purposes of SEB studies were enumerated and discussed in Chapter 3. In most cases, their primary purpose is related to financial and staff support for NMHSs, the operation of their infrastructure or the specific met/hydro services they provide. For decisions related to budgets, the study will help decisionmakers determine if public expenditure on NMHSs is highly valued vis-à-vis other investments that government can make by applying BCA. Less frequently, studies may focus only on an assessment of the costs of alternatives for producing and delivering a specific type or level of met/hydro services using cost-effectiveness analysis. In addition to funding and allocation decisions, SEB study results can be used to educate the public about the value of services or increase awareness and uptake of services by user communities.

Box 4.1: Contents of the concept note

Description of the study

- Purpose of the study
- Met/hydro services to be assessed
- Sectors to be assessed
- Benefit–cost methods

Budget and financing

- Costs of the study
- (Potential) sources of financing

Timeframe

- Design and procurement
- Study preparation and dissemination of results

Roles and responsibilities for:

- Management oversight
- Procurement (if necessary)
- Preparation of the study
- Dissemination of results

The concept note should include a description of the study, provide information on budget and financing, the timeframe to design, commission and conduct the study, and describe roles and responsibilities that will be likely divided between the NMHS, consultants, and other stakeholders. In Box 4.1, an illustrative description of the contents of the concept note is provided. Even if a concept note is not required to make a decision on whether to conduct an SEB study, the contents described in the box will be useful in preparing a briefing for decisionmakers, external funding agencies, or NMHS senior management, and will provide the framework and a summary of the content to be included in the study's scope of work in stage two.

In most cases, an NMHS will provide management oversight for the study, but if the study is required to be viewed as truly independent, oversight might be provided by a steering committee comprised of multiple agencies and representatives from user communities. Audiences for SEB studies depend in part on the purpose of the study and the desire of an NMHS to exploit results with the public and user communities.

Table 4.1 provides a list of primary audiences for SEB studies undertaken for each of the purposes described in Chapter 3. The concept note should also provide an outline of the review process and plans for sharing results with the various audiences described in Table 4.1. This element of the concept note should describe how and at what stages in the process stakeholders are to be engaged.

The study may be conducted by a single individual, single organization or a consortium. Potential organizations involved in conducting the study might include the NMHS, other agencies, non-governmental organizations or universities, or a private firm. If, for example, the prime purpose is understood by the key stakeholders as providing evidence for the urgency of a supplementary investment programme aimed at reinstating and refurbishing observation and localized weather service capacity (where these have been allowed to deteriorate), a report from a widely respected – possibly international (and hence more neutral) – expert organization is a good option (see, for example, World Bank, 2008). Alternatively, if the NMHS aims to provide input for a well-founded state or ministerial budget allocation, the recommended course would be to engage national independent experts with background guidance from a broadly based advisory group and have them deliver a report (for example, Met Office, 2007). For the purpose of prioritization of public spending, the coordination of SEB studies across comparable actors from other sectors can often be useful, especially in case of joint benefits, such as those related to traffic safety or to public health.

The concept note should also provide an outline of the review process and plans for sharing results with the various audiences described in Table 4.1. This element of the concept note should describe how and at what stages in the process stakeholders are to be engaged (Box 4.2).

Table 4.1. Primary audiences for socioeconomic benefit studies

Audiences	*Purposes*			
	Validating the provision of basic met/ hydro services	*Validating the provision of specialized met/ hydro services*	*Supporting investments in new met/ hydro services*	*Determining the value of NMHS services to user goals*
Governing decisionmakers (ministry, treasury, boards of directors, and the like)	✓	✓	✓	✓
NMHS leadership	✓	✓	✓	
Sectoral ministries and partner agencies		✓	✓	✓
External funding agencies			✓	✓
User communities	✓	✓	✓	✓

Box 4.2: Stakeholder engagement in socioeconomic benefit studies

Stakeholders play a key role in the engagement process of an SEB study. Met/hydro stakeholders include government and non-governmental organization staff, users of met/hydro services, and the public. Before a study begins, stakeholders should be consulted to help those managing the study to set goals. For some NMHSs, this may require beginning with market research to determine user groups.

Alternatively, involvement of stakeholders can be implemented at the later stages of the study – during review of the scope of work, review of study results, and communication of the SEB study to various audiences. Stakeholder engagement must be driven by well-researched and strategic information, as well as communicated with a clear message that provides examples of the enhanced quality of services and improved accountability of decisionmaking as a result of the SEB study. Stakeholders may be engaged by NMHSs through formal written commenting rounds, information provision, semi-structured interviews, workshops and advisory groups. Interactions can be technical, overarching or results-based.

Depending on the country that the SEB study covers, varying consultation mechanisms may be chosen. The form of consultation may be guided by legislation on transparency, accountability and divisions between provision and reviewing of public services; this highlights the importance of due diligence. Stakeholder involvement in the SEB study is valuable because it communicates performance and thus provides accountable, transparent and independent updates about services.

Three other points regarding the content and presentation of the concept note may assist in informing decisionmakers. First, it may be useful to combine other types of analysis with SEB analysis. For example, NMHSs may propose to conduct an analysis of the technical quality of NMHS services and products and provide results to decisionmakers on customer satisfaction.

Second, it may be useful to view the SEB study as one analytical element of an ongoing process of assessment, given that NMHSs will likely need to justify resource allocations on a sustained basis. The concept note might discuss the strategy of the NMHS for updating the study on a regular basis.

Third, given the novelty of the commissioning of SEB studies by NMHSs, particularly in developing countries, it might be useful to provide decisionmakers with evidence from SEB studies in other countries that show that similar assessments yield significant benefits and that the proposed methods are based on international good practices. An inventory of case-studies is provided by WMO on its website (http://www.wmo.int/pages/prog/amp/pwsp/SocioEconomicCaseStudiesInventory.htm) and Appendix E of this publication describes a selection of SEB case studies. In addition, input from user groups, including those with economic activities in multiple countries, can be very valuable or even indispensable in improving the scope and accuracy of estimated benefits and cost.

4.3 STAGE TWO – PREPARE THE SCOPE OF WORK

Once a favourable decision on the SEB study has been taken, a detailed scope of work should be prepared that includes the following components: (a) motivation/context for the study (from the concept note); (b) roles and responsibilities for management oversight, study preparation and review, and communicating the results; (c) plan for conducting the study; (d) budget and timeline; (e) communication strategy. As few NMHSs have capabilities to conduct an in-house SEB study, the detailed scope of work will be required as one of the documents to guide responses to a competitive procurement.

The first two components will help bidders for this work to understand policy questions to be informed by the SEB study and how the study will be coordinated, including the commitment of staff resources that the NMHS will provide and the proposed processes for engaging stakeholders and distributing the draft report for review.

The plan for conducting the SEB study is the key component of the detailed scope and will help to determine funding requirements and the timeline for completing the study. Figure 4.2 below provides a basic flow chart that summarizes the preparation of the study as a sequence of 10 steps (referred to as SEB study step 1, and so on) and Table 4.2 briefly describes each step and directs the reader to more detailed discussions of each step.

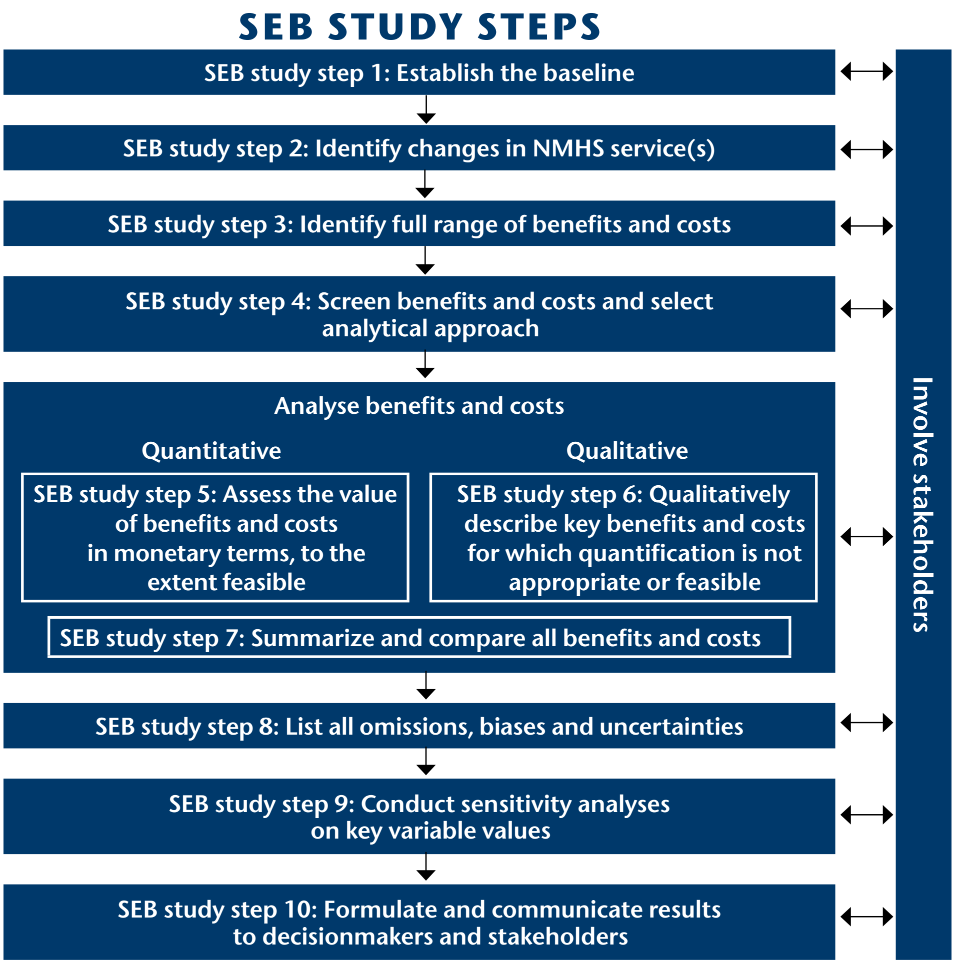


Figure 4.2. Steps in conducting a socioeconomic benefit analysis

Table 4.2. Summary of socioeconomic benefit study steps

Step 1:	**Establish the baseline** – The baseline for the study is the current situation and provides a point of reference for changes in the met/hydro services to be evaluated (section 4.3.1)
Step 2:	**Identify changes in NMHS service(s)** – These changes can involve the introduction of new services or products, expanded geographic coverage of existing services, improvements in services, and the like (section 4.3.2)
Step 3:	**Identify the full range of benefits and costs** – This step focuses on reviewing the baseline and service changes to enumerate benefits to user communities and costs incurred under both scenarios; it is useful to characterize the various user groups in terms of number, types, and locations of different users in case the analysis will only focus on a sample of users or user communities (sections 6.3 and 7.3)
Step 4:	**Screen the benefits and costs and select the analytical approach** – This step is critical in sizing the study and selecting estimation methods. Costs and time constraints may limit the types of benefits or costs that can be analysed as well as the estimation methods. At this step, data needs and availability would also be determined as required for the estimation methods selected for the SEB study (sections 6.4 and 7.4)
Steps 5 and 6:	**Analyse benefits and costs** – Benefits and costs are analysed in quantitative and qualitative terms to facilitate determination of net benefits (benefits minus costs) (sections 6.5, 6.6, 7.5, and 7.6)
Step 7:	**Summarize and compare all benefits and costs** – This step involves the comparison of benefits and costs using economic criteria to determine if the change in services results in benefits that are greater than costs (section 8.3)
Step 8:	**List all omissions, biases and uncertainties** – This is important in helping NMHSs and funding authorities understand the limitations due to data limitations, funding constraints, and uncertainties inherent in assumptions and future values (section 8.4)
Step 9:	**Conduct sensitivity analysis on key variable values** – This analysis follows directly from step 8 and involves methods for presenting benefit and cost results for a range of assumptions on uncertain variables (section 8.5)
Step 10:	**Formulate and communicate results to decisionmakers and stakeholders** – Once the study is completed, the results will be reviewed and formulated into results to be shared with various audiences. The communication strategy will guide the development of messages and mechanisms for delivering results to audiences (sections 9.4–9.7)

The plan for conducting the SEB study can vary in detail. If there are regulations that mandate specific types of estimation methods, this information should be communicated in the solicitation for proposals. In some cases, the NMHS may want to provide bidders with some flexibility to propose detailed approaches for conducting SEB study steps 3, 4, 5 and 6.

The budget for the study can be difficult to determine until the plan for conducting the study has been developed. If bidders have discretion to propose estimation methods, the range of proposed project costs could vary significantly across proposals. The cost of the SEB study depends on several factors. Simple and focused studies may require only several person–months input, whereas wide-scoped, in-depth studies covering multiple economic sectors may demand various person–years of input, plus significant coordination costs and staff time in the NMHS. In some cases, the study will have to be tailored to available resources, particularly if data are lacking or of poor quality. This may preclude a comprehensive SEB study covering all users and benefit streams and necessitate the use of certain types of valuation methodologies such as "benefit transfer", involving the use of intermediate or final results from one or more other comparable studies (see section 6.5.4). As a general rule it will be easier to justify comprehensive SEB studies and larger budgets when they are designed to inform decisions on large investments in met/hydro services or demonstrate the whole-of-service value of an NMHS.

The timeline for conducting the study should account for the time to collect data, carry out surveys, conduct the study and draft and finalize the report. In addition, the timeline should be adjusted to ensure adequate time for stakeholder consultations and mandated provisions for public review of the draft SEB study. If the SEB study is coordinated with other analyses and will be presented to decisionmakers as a package, the timeline for the SEB study should be aligned to the timelines for these other analyses.

4.3.1 **Socioeconomic benefit study step 1: Establish the baseline**

The assessment of benefits and costs focuses either on the current suite of services (whole of service or specific services) or a change from one suite of met/hydro services to an alternative configuration of services. The current or status-quo situation is viewed as the base case or baseline. To establish the baseline, the study team characterizes the services that are currently offered and the outcomes observed for the current situation. The baseline represents the level and quality of service against which changes are measured from the proposed NMHS programme. It is important to define the scale and timing of the impacts of the baseline, articulate what problems the proposed programme is intended to resolve and be explicit about assumptions.

When considering the different levels of information quality, the NMHS should also recognize the importance of data and forecast quality and developing and maintaining a good verification system. While standard verification measurements (for example, 500-millibar skill scores) do not translate directly to economic value, if the NMHS cannot or does not measure the quality of its forecasts in standard meteorological terms it will be a much less convincing process to develop economic measures of the value of that information.

In general, when evaluating the output of an NMHS, the value of specific products or programmes and changes in the quality of available forecasts and services is of greatest interest. Economists consider this to be determining the value at the "margin" or valuing a “marginal” change in the services or products being provided. This would usually involve a relatively small change when compared to the total set of products and services provided by an NMHS.

Valuing the NMHS in total (that is, whole of services) is a conceptually different problem than valuing changes in met/hydro services, and doing so would be difficult in situations where it is unreasonable to assume that the alternative to the baseline would be no services or products from the NMHS. The total value of an NMHS would be the difference between current information and either persistence or climatology (whichever it is assumed that the end users would rely on if the NMHS were not providing any services). In some cases, the baseline information without the NMHS may be the information provided by another NMHS (for example, from a neighbouring country).

4.3.2 Socioeconomic benefit study step 2: Identify change(s) in National Meteorological and Hydrological Services

To determine what is being valued, consider the primary options and what reasonable or potential alternatives should be included in the analysis. Options often of interest to NMHSs include changes or improvements in:

- Observation systems;
- Data assimilation;
- Forecasting models;
- Computer facilities and capacity;
- Forecast dissemination.

Extending the traditional realm of many NMHSs may involve improvements or implementation of new or better uses and responses to information, including improved:

- Forecast communication;
- Development of decision support tools;
- Emergency response activities for severe weather.

4.4 STAGE THREE – COMMISSION THE STUDY

In most cases, NMHSs will contract with outside organizations to prepare the SEB study. Even if an NMHS has in-house economic expertise, it may still be better to contract with an independent organization to emphasize the impartial nature or enhance the credibility of the study. The NMHS can identify potential contractors via open tendering procedures or through targeting of a limited number of pre-qualified organizations. National and often international guidelines will indicate the tendering procedures to be followed by the NMHS. For medium- and large-sized studies, open tendering will often be required. For smaller studies, tendering on invitation could be considered so as to reduce administrative burden.

In addition to the detailed scope, the tendering documentation should describe eligibility requirements, requirements for project staffing, experience in conducting similar studies, guidance on the preparation of the cost proposal, criteria that will be used to evaluate technical and cost components of proposals, and instructions for submitting proposals. The NMHS is expected to follow rules for reviewing proposals, selecting the successful bidder and informing all bidders of their decision. If possible, the NMHS should engage a selection committee that includes at least one member with economic expertise.

4.5 STAGE FOUR – CONDUCT THE STUDY

The implementation of the study should align with the detailed scope and timeline. It is encouraged that NMHSs meet frequently with the project team beginning with project inception. In addition to the importance of these meetings to monitor progress and address problems that may arise, these meetings will also present an opportunity for the NMHS to become better versed in understanding economic concepts and the methods used by the contractor, as the NMHS will later be responsible for communicating results to decisionmakers and other audiences.

Even as the review process develops alongside the actual assessment and several interim checks are usually built in, the overall process should allow for a formal review phase of the entire output of the SEB study prior to the draft being made final. The entire output should be evaluated against the requirements of the contractual agreement with respect to contents (methods, results and interpretation of results) and presentation (that is, clarity and tailoring of the message to the relevant audiences).

4.6 STAGE FIVE – COMMUNICATE THE STUDY RESULTS

After the final study results and reporting are approved, the NMHS will engage in internal and external communication of the SEB study results. This phase of the study is described in greater detail in Chapter 9, but a couple of points are provided in this section. First, as noted earlier, the NMHS should begin thinking about communicating SEB study results at the stage of preparing the detailed scope to ensure that staff responsible for communicating results will begin to identify audiences and messages

Box 4.3: Communication – A crucial role in the socioeconomic benefit study process

As noted in Box 3.1, a communication strategy is an essential element in the design of an SEB study. Even though the communication element of the exercise will be primarily focused towards the end of the process (communicating the results of the assessment to key stakeholders), the communication needs should inform all aspects of the design of the study. A strong story encompassing clear results will not necessarily flow from an SEB assessment automatically – it needs to be planned for through the design and commissioning stage. Chapter 9 provides more detail about how to approach communication planning and strategy throughout the SEB study.

early in the process and have the opportunity to interface with the project team to understand study methods and expected results.

Second, while communication is the final step in the SEB study design, there may be considerable effort undertaken prior to the study's completion. It may be useful to conduct focus group interviews or other stakeholder consultations to test alternative ways to communicate economic messages to different audiences. The NMHS may want to meet with media outlets and user communities to brief them on the study while it is underway. In addition, some preliminary communication materials may be released to make audiences more aware of NMHS services and products and NMHS efforts underway to assess service quality, options for strengthening or expanding services and financing these investments.

4.7 CONCLUSIONS

This chapter has described the basic five-stage process to be undertaken in designing, commissioning, implementing and communicating the results of an SEB study, with only a brief introduction to the methods and analysis that are actually used to conduct the study. The next four chapters provide additional details that will enable NMHSs to gain an understanding of economic terms, benefit and cost assessment concepts and methodologies, and options for comparing benefits and costs needed to prepare the concept paper and scope of work, and work effectively with economic consultants in supervising the study, managing reviews, and communicating the study results.

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CHAPTER 5. ECONOMIC ESSENTIALS

Chapter 1. Introduction
Chapter 2. Met/hydro services
Chapter 3. Purpose of SEB studies
Chapter 4. Designing SEB studies
Chapter 5. Economic essentials
Chapter 6. Benefits
Chapter 7. Costs
Chapter 8. BCA
Chapter 9. Communications
Chapter 10. Looking forward

5.1 INTRODUCTION

Of the five stages described in Chapter 4 to design an SEB study, the preparation of the detailed scope of work is likely to be the most challenging for non-economists unfamiliar with methods of measuring and comparing benefits and costs. The next four chapters are designed to help NMHSs and other service providers gain a basic understanding of the economic methods used to enable them to commission SEB studies and communicate the results to decisionmakers and other audiences. This chapter introduces the reader to essential economic concepts that are discussed in greater detail in Chapter 6 (benefits), Chapter 7 (costs) and Chapter 8 (BCA). Appendix A includes definitions of economic terms used in the publication. Basic economics textbooks (for example, free, online options: Kling, 2002; Amos, 2014) cover most of the economic concepts (see also the intermediate text: McAfee, 2009) that are used. The reader may also find it useful to consult a public finance textbook (Johansson, 1991; Cornes and Sandler, 1996; Conservation Strategy Fund, 2014) for more detailed discussion of topics such as public goods and BCA.

5.2 MET/HYDRO SERVICES INFORM DECISIONS

Met/hydro services generate net economic benefits through an integrated process described in Chapter 2 as a value chain. The costs of producing met/hydro services are associated with observations, modelling, forecasting and service. Once basic met/hydro services are produced, they may undergo repackaging and tailoring into more specialized products by the NMHSs or other service providers before they are consumed by user communities. Figures 5.1 and 5.2 (previously presented as Figures 2.1 and 2.3) summarize, respectively, the production and delivery of services and the full value chain that covers basic production and tailoring of services, plus the uptake by users in making decisions and taking actions to produce outcomes that can be valued in the study. To understand the economic benefits of met/hydro services, one may consider how those services help to make better decisions. Aviators know better when to cancel flights; farmers may avoid crop losses; and emergency officials might be able to avert flood damages. Not all costs can be averted, of course, but some can; and in other cases, met/hydro services create opportunities to benefit from situations. A high snowpack estimate, for example, is often welcome news for downstream water resource managers.

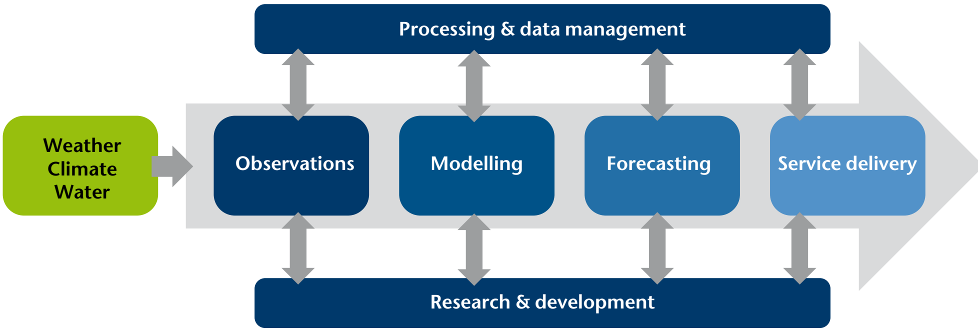

Figure 5.1. Components of the service production and delivery system of NMHSs

In the value chain, costs are incurred to produce, tailor and disseminate met/hydro services to users (first two purple boxes in Figure 5.2). However, there are also costs involved when users make decisions and take actions based on those decisions. While each link in the value chain can add to the value of met/hydro services, it is more practical to determine the benefits of services once users have responded to the information provided by NMHSs and other providers.

Economists speak of the economic benefits of met/hydro services as an example of a "value of information". Given the pace of innovation in information technology, questions concerning the value of information are of great interest to economists. Precisely what makes met/hydro services valuable is a complex issue because information services are technically sophisticated and because of the sheer number and variety of decision applications. As mobile Internet devices become more prevalent, the number and economic value of potential met/hydro service decision applications increases. One peculiarity of information as an economic service is that one cannot know its value with certainty until after it is produced. While accuracy is

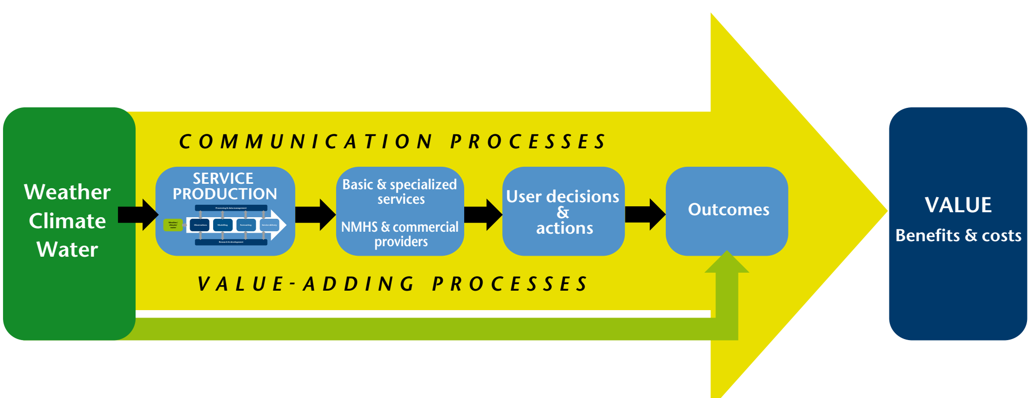

Figure 5.2. Simplified schematic of the met/hydro services value chain

desirable for observations and predictions in the geosciences, accuracy alone does not guarantee that information will be useful.

It is difficult to know the value of a specific piece of information unless considering its use in a specific decision context. What a flood warning might be worth, for example, is hard to say unless it is known when it will occur, how many people might be affected, and if and how they could protect themselves. In this situation, not even a very good warning can be expected to enable all damages to be avoided. The benefits of the warning will thus be less than the expected total loss in the absence of the warning. More generally, the economic benefit of met/hydro services is based on the expected outcome from an improved, service-assisted decision compared to the expected outcome of the decision without the service (see also section 5.3).

The benefits that met/hydro services create – depending on the related decision circumstances (for example, crops grown, resource conditions and technology) – have become important public policy concerns. Basic met/hydro services are mainly provided by the public sector. Estimating the economic benefit of met/hydro services can help show if their improved provision and dissemination would offer greater value to society than other investments, such as improvements in public health services.

5.3 ADDING UP ECONOMIC VALUE: BENEFITS AND COSTS

In economics, a cost is anything that lessens the well-being of the entire society, or societal welfare; if resources are used to produce a particular good or service, they are no longer available for other purposes. Most readers will be familiar with the concept of cost as the value of the inputs needed to produce any good or service, measured in some units or numeraire, generally money. Note that the resources sacrificed to produce met/hydro services may or may not be directly associated with a cash flow. For example, the use of a computer may not require any additional expenditure but would count as a cost if it displaces other possible uses for the computer. Since multiple met/hydro services tend to be developed and provided jointly, finding the incremental cost of an individual met/hydro service can be challenging. In addition to provision costs, any use of a decisionmaker's time or other resources is also considered a cost associated with the met/hydro service enterprise.

In contrast to a cost, a benefit is anything that increases societal welfare or represents a gain from taking an action (Tietenberg and Lewis, 2014). The benefits of met/hydro services result from users taking decisions at least in part based on the weather, water and climate information that is provided. Farmers may earn higher incomes by tailoring their planting or harvesting decisions to a seasonal forecast. A power company may be able to better plan and reduce fuel costs for the winter heating or summer cooling season based on such forecasts.

For both costs and benefits, economists distinguish between the total and incremental values. In economics, incremental cost (benefit) is the change in the total cost (benefit) when the quantity produced changes by one unit. It is the cost (benefit) of producing one more unit of a good. Essentially, total and incremental values address different questions. Total costs and benefits will be the focus of the SEB study when evaluating the full suite of services of the NMHS, while incremental costs and benefits will be the focus when assessing individual or a subset of NMHS met/hydro services or in assessing improvements in services.

Perspective is crucial to understanding costs and benefits. Avoided flood damages that represent a service benefit to an urban dweller, for example, may be seen as a lost opportunity, or cost, by a builder. Since the builder is still able to pursue other projects, his cost may be less than the benefit to the urban dweller. There are few actions that are taken in response to met/hydro services, or more generally the provision of any type of public service or policy, where there are not winners and losers. Some additional discussion of the types of decision rules that are used in this case is provided in Chapter 8.

The benefits of met/hydro services, minus their costs – which economists refer to as net benefits – represent the societal value or worth of met/hydro services. Whether and how much public funds should be devoted to met/hydro services are important public policy questions. Economics contributes to policy discussions an ability to quantify changes in society's well-being stemming from changes in the condition or availability of met/hydro services. Improving our knowledge of economic net benefits of met/hydro services can inform decisionmaking in at least two ways: first, it can identify or at least approximate what the best economic choices may be; second, it can reveal the economic importance of previous choices.

Often, met/hydro services must be processed or translated so that they more directly address the needs of a particular decision application (for example, farming) or region. The met/hydro services must then be interpreted by decisionmakers, who must decide how to respond to the information. If the information, over time, results in higher incomes or lower production costs the improvement would represent an economic benefit. Any deficiency at one of the links in the met/hydro service value chain can reduce benefits. For example, when users in developing countries take actions, even though they know what decision they should make, their opportunities may be limited and thus the benefits of a forecast may be reduced. For example, if farmers cannot purchase more drought-resistant seeds or shift to crops that require less water, they may not benefit from an accurate forecast. This means that other factors besides the met/hydro service will be important in determining their benefits.[13]

5.4 SCARCITY AND OPPORTUNITY COST

What are the reasons for an NMHS to know the economic costs and benefits of met/hydro services? Estimating economic values is difficult and, at times, contentious. Yet

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[13] Attribution of benefits to met/hydro services can be a complex problem when other types of information are required by users to make decisions. For example, in the case of farmers' efforts to respond to drought, they may also require production and market information as well as access to seed and other farm inputs to take advantage of the forecast and the understanding of the drought's severity.

NMHSs are frequently asked if they are making the best use of time and resources. Economic costs and benefits demand the attention of those managing the met/hydro process because the availability of resources such as land, labour and capital are scarce relative to the demands placed on them. No society has the necessary productive resources to fulfil all human wants and needs. Trade-offs exist and a sense of priorities is essential. Because met/hydro services are costly to produce but can inform the use of scarce resources, the decision to offer met/hydro services is partly an economic one. Economics can inform policymakers about the costs and benefits of alternative and, in some cases, competing uses of economic resources.

If met/hydro services such as flood and extreme weather forecasts were available for everyone in any quantity, no economic problem would exist. But infrastructure such as automatic weather stations and Doppler radar are scarce, and expenditures on this infrastructure implies that some other resource demand will go unmet.

In public policy, NMHSs must frequently make choices. Because of this, NMHSs should consider which resource uses are most highly valued. The key notion here is what economists refer to as opportunity cost, the idea that the resource-use choices NMHSs make will restrict or preclude other opportunities. In identifying trade-offs, economics gives NMHSs a needed reminder that normally resource demand outweighs resource availability.

5.5 MET/HYDRO SERVICES AS PUBLIC GOODS

Basic met/hydro services are different from most goods and services; they can be provided at the same cost of production to a thousand or a million users. Unlike most goods and services, one person's consumption/use of the met/hydro services does not reduce the availability of the services to others. This is important from the perspective of justifying met/hydro service provision because benefits increase with the number of users, whereas costs of production remain constant.

Many met/hydro services fall into an important category that economists refer to as public goods. The key attribute of public goods that distinguishes them from private goods is a property referred to as "non-rivalry" by economists. Non-rivalry means that once a basic met/hydro service is provided for one person, it is available for all to use.[14] One surprising implication of non-rivalry is that the optimal price to charge for a public good, such as many met/hydro services, is zero. The intuition behind this puzzle is that, once a basic met/hydro service, for one and all, has been provided, society benefits if more people use it, and charging a price would only deter use of the public good.[15]

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[14] Even though the cost to provide the good to additional users is zero, users will still incur costs to access the information on television, radio, or a cell phone.

[15] In practice, some degree of rivalry may exist in the use of some met/hydro services, and in those cases the service is referred to as a congested public good. The met/hydro service can be shared, but only on a first come, first served basis. One example would be an extreme weather warning that can only be accessed via a slow Internet connection (United Nations Industrial Development Organization, 2008).

Another attribute ascribed to public goods is "non-excludability", suggesting that once the public good is provided, it should be available to all. For many public goods, it may be technically possible to exclude users. For example, companies can exclude households from accessing satellite television and users can be charged for information that can only be accessed on the Internet. Unless there is public funding available to finance the production or provision of met/hydro services or other public goods, it may be necessary to require payment for the service in order to finance the costs of the public good. Clearly, satellite television will not be provided by private companies unless they can cover their costs, and some NMHSs will charge for specialized products to cover the incremental costs of their production if there is no funding support from the government for such specialized services.

Met/hydro services become less costly on a per user basis when the service can be offered to a greater number of users. Since providing met/hydro services costs largely the same, in total, regardless of how many persons use them, less populous nations tend to pay much higher costs per user to provide the services. Similarly, a more populous nation will often be able to provide more numerous and varied met/hydro services since the provision costs can be allocated across a larger number of users. The decline of unit costs for each met/hydro service with the expansion of the number of the services offered is termed by economists as an economy of scale. An NMHS that already provides daily temperature forecasts may find it can also provide hourly temperature forecasts at little additional cost. The exception is the case of geographically larger countries that pay most per user, since the cost of operation is strongly linked to the area over which networks must be maintained. In those cases, diseconomies rather than economies of scale are observed. When met/hydro service provision costs decline as the variety of services rises, economists say that service provision is characterized by "economies of scope".

5.6 ADDING UP OVER TIME: DISCOUNTING AND PRESENT VALUES

The economic costs and benefits of met/hydro services must be aggregated over individuals, sectors and regions to arrive at national totals. In addition, benefits and costs will vary in magnitude over time, and an analysis that only considers their magnitude in the current year will present an inaccurate estimate of the value of met/hydro services. On the cost side of the ledger, the development of a new service or expansion of an observational network will entail significant upfront investment outlays; design and calibration of a new decision support system will involve high costs initially, with lower costs in later years, while costs may increase over time because of inflation. The benefits of a new met/hydro service will tend to increase over time as a result of the learning curve or lagged adoption. For example, it may take time for users to trust the new service enough to make economic decisions or determine how to best respond to it. The other problem with using current-year benefits relates to the probabilistic nature of benefits, especially those related to user responses to services that help them understand and respond to extreme events such as droughts. In the year of the analysis, if weather is uneventful a drought early warning system will be less valuable than if it had been a drought year. Similarly, if benefits are expressed as reduced damages to tropical storms and floods due to an improved forecast, current year benefits, whether there is a flood or not, will either overestimate or underestimate typical benefits observed over several years.

When calculating total benefits and costs over time, two interrelated factors – inflation and the "time value of money" need to be accounted for in comparing these economic magnitudes from one year to the next. When inflation is included in recording or projecting values over time, it is said that the values are in "nominal" terms. Many financial analyses are conducted in nominal terms. For economic analyses, though, it may be more appropriate to use "real" (that is, inflation-adjusted) monetary units (hereafter, United States dollars (US$) are used in examples). The use of real, inflation-adjusted costs and benefits can result in significantly different calculations in countries experiencing serious inflation. In real United States dollars, a dollar today has the same purchasing power as a dollar 10 years from now, regardless of the rate of inflation.

In addition to inflation, SEB studies must account for the fact that most people prefer a dollar today to a dollar available in the future. Most also prefer to use that dollar to consume today or to invest to yield more than a dollar in the future. This preference for near-term consumption over deferred consumption is called the "social rate of time preference" or the "time value of money". This social rate of time preference is the real (that is, inflation-free), net-of-tax and risk-free rate of interest that would need to be paid to a person to entice consideration of the delayed receipt of a real dollar. The rate used for converting future values to current value is referred to as the "discount rate" and it is expressed as a per cent per year (for example, 3% per year). It is similar to an interest rate. The greater the preference for immediate benefits (time preference) or the greater expected rate of return on other investments today (known as the "opportunity cost of capital"), the greater the discount rate. For instance, a value of US$ 100 to be realized in five years ($t = 5$) discounted at a 3% rate of interest ($r = 0.03$) would be considered as being worth US$ 86.26 in present value (PV) ($t = 0$):[16]

$$\text{PV (time 0)} = \frac{\text{Future value (time } t)}{(1 + r)^t} = \frac{\$100}{(1 + 0.03)^5} = \$86.26$$

Alternatively, the same US$ 100 to be realized in five years ($t = 5$) discounted at a 10% rate of interest ($r = 0.10$) would be considered as being worth only US$ 62.09 in PV ($t = 0$):

$$\text{PV (time 0)} = \frac{\$100}{(1 + 0.10)^5} = \$62.09$$

The discount rate can be expressed in either nominal or real terms. A real discount rate is the nominal discount rate minus the inflation rate. Here, the key is to use a real

[16] In the examples, the dollar symbol ($) is used simply to indicate a monetary measure. The analyst should use the unit of currency relevant to his/her decisionmaking process.

discount rate when analysing dollars in real terms and a nominal discount rate when analysing values in nominal terms.[17]

The net present value (NPV) of a met/hydro service is simply the sum of its benefits minus its costs, all expressed in PV terms. Alternatively, NPV of benefits and costs may be summarized as a ratio (that is, the BCR) or as an implied return on investment funds (that is, the internal rate of return). These measures use the exact same benefit and cost measures as in the NPV approach but summarize them a little differently.

5.7 VARIABILITY, UNCERTAINTY AND RISK

Far more is known about the benefits and costs of met/hydro services in the current year than is known in the future. The nature of imprecise future values is due to two factors: variability – the natural variations in an estimation resulting from its properties or the forces acting on it – and uncertainty about the estimated value that arises from lack of knowledge about what will happen, what decisions will be taken, and how significant will be the magnitude or timing of changes in key variables that are critical in determining the estimated value.

Parameters such as temperature and precipitation will vary in magnitude over different timescales; these parameters might be characterized by constructing probability distributions based on historical data and using expected values in the SEB analysis. For example, historical data may be used to determine the frequency and magnitude of droughts, floods, frost, or extreme heat events and apply this information in estimating future benefit streams. For example, if the benefits of a drought early warning system in years where droughts occur can be estimated and assumptions can be made on the probability of a drought (assuming away the problems of droughts varying in magnitude for the purposes of illustration), expected benefits can be estimated for future years by multiplying benefits by the probability of a drought.

Uncertainty relates to the lack of knowledge about the true value of a key variable or parameter both in the present and future. For example, in SEB studies, it is difficult to determine beforehand how individuals or business will respond to weather and climate forecasts in any given year. Similarly, the damages of a particular class of tropical storm are difficult to determine because many factors come into play, such as the time of day that the storm first makes landfall, local meteorological conditions and tidal information, as well as characteristics of the geographical area (rural, urban, megacity, residential, industrial, agricultural, and the like). There are many sources of uncertainty that may need to be accounted for in SEB studies, such as market forces and inflation, innovation and technological change, political unrest, climate change and sea-level rise.

For most of these sources of uncertainty, probabilities cannot be assigned to different outcomes and the uncertainty is carried over into benefit and cost estimates in SEB

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17 Additional discussion on determining the appropriate discount rate to use in SEB studies is provided in section 8.2.2.

studies. However, "risk" is a form of uncertainty where, while the actual outcome of an action is not known, probabilities can be assigned to each of the possible outcomes. In the case of the more common types of uncertainties, sensitivity analysis can be conducted for benefit and cost estimates to determine how significantly SEB study results are sensitive to different values of uncertain parameters.[18] The challenge in conducting sensitivity analysis is in selecting the range of parameter values that will be acceptable to decisionmakers and other audiences. Different methods for selecting parameter values include: (a) establishing deviations (for example, + 15%) from an historical value; (b) selecting values from simulation models; (c) relying on stakeholder or expert judgment (the Delphi process) to select parameter values.

5.8 MET/HYDRO SERVICES ENTER THE MARKET PLACE – SUPPLY AND DEMAND

Met/hydro services are produced and consumed in the market place. Costs are incurred by NMHSs as buyers of labour, energy and equipment. In turn, a diverse customer base of aviation, agricultural and other interests uses met/hydro services. To estimate the costs and benefits of met/hydro services, we turn to the market place, where most buying and selling occurs. The net benefit of met/hydro services is simply what they are worth to their clients, based on their demand, minus the cost to NMHSs of supplying the services. Demand is simply how much of a good or service consumers wish to buy at various prices. Similarly, supply is simply how much producers offer at various prices.

We usually think of the economy in terms of market economic values such as spending, sales, output, income, employment and tax revenues generated. However, the economic values observed in markets may well be conditioned by others not directly transacted in markets. Met/hydro services, for instance, are seldom allocated using market prices, although they may indirectly generate a great deal of market-based economic activity in transportation, agriculture and tourism. Both market and non-market values are important in determining which alternative uses of economic resources will yield the greatest net gain to society. Who receives that gain is also important. Economists separate market values and non-market values into two categories, according to the group receiving the value, consumers or producers.

Economic methods are available for evaluating changes in the quality or availability of natural resources, whether or not the uses of resources are commonly transacted in markets. If the resource uses are traded as goods or services in markets, well-established empirical techniques (for example, multiple regression or computer simulation models) exist for measuring changes in individuals' well-being or welfare (Chapter 6). Economists use directly observed information from market transactions to evaluate consumer and producer surpluses as approximations of the satisfaction that society derives from the good or service. Consumer surplus is the excess of what

[18] For modelling risk, methods such as Monte Carlo simulations may be employed in economic valuation. Additional discussion of Monte Carlo methods is provided in Chapter 8.

consumers are willing to pay over market price. Producer surplus is the excess of market price over and above production costs.

How much better off would we be if a new met/hydro service improved the productivity of agriculture or improved decisions in other economic sectors? Chapters 6–8 will examine this essential question in more detail. Economics provides methods and tools to help evaluate questions about the use of services by comparing economic surplus — the sum of consumer surplus and producer surplus — with and without the service. Economics can help determine if met/hydro services are highly valued, in comparison with alternative investments, and worthy of designation as priorities.

5.9 CONCLUSIONS

Met/hydro services are costly to provide, but create SEBs when user communities make decisions and take actions based on the information they generate. While the budgetary costs of met/hydro services may be apparent enough, the economic benefits produced and how NMHSs should compare those benefits with budgetary costs are not as widely appreciated. Public officials with limited budgets and competing needs need to know the economic contribution that met/hydro services make. To show the economic principles underlying the concepts of economic costs and benefits for met/hydro services, this chapter has provided a basic overview of economic terminology, covering supply, demand, scarcity, opportunity cost, public goods and discounting, as well as terms such as risk and uncertainty that are important factors that can influence the magnitude and confidence in estimates of benefits and costs.

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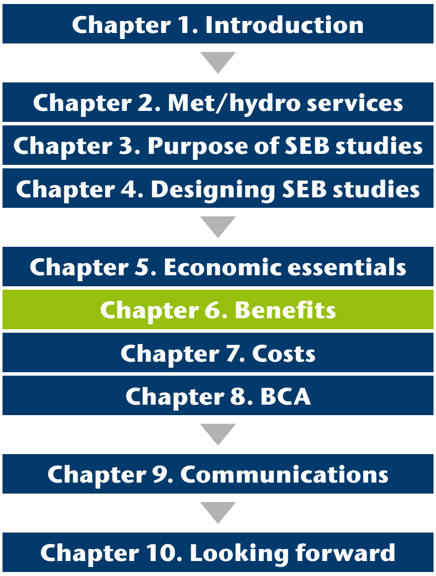
CHAPTER 6. DEFINING AND MEASURING BENEFITS



6.1 INTRODUCTION

The earlier chapters have provided the groundwork needed to frame an SEB study in terms of questions to be answered, the specification of met/hydro services and user communities to be assessed. Building on that groundwork and the introduction of key economic concepts in Chapter 5, Chapter 6 provides guidance on the processes and methods that can be used to assess the benefits of met/hydro services. Specifically, the following sections outline a general process for conducting benefit analysis, based on the following steps:

– Understand the value chain;

– Identify the full suite of economic, social and environmental benefits associated with met/hydro services and programmes;

– Quantify and monetize the value of benefits identified;

– Qualitatively describe and analyse benefits that cannot be feasibly monetized;

– Deal with uncertainty surrounding benefit estimates.

Within this framework, specific methods and models are described that can be used to estimate the benefits of met/hydro services. An overview of general issues and limitations that must be considered when assessing benefits is also provided. The aim of this chapter is to provide a baseline understanding of key economic principles and methods rather than a prescriptive approach for valuing specific benefits.

To value the benefits of met/hydro services, the analyst must understand and characterize the potential users of the service and its impact on their decisions. This concept is discussed in Chapter 2 through the introduction of the met/hydro services value chain and is briefly addressed here within the context of benefit analysis.

6.2 UNDERSTAND THE VALUE CHAIN

Ultimately, the value of met/hydro services is determined based on how (and whether) potential users receive and interpret met/hydro information, and how that information impacts or changes their decisions and actions. The outcomes associated with these decisions/actions are then compared to the outcomes that would have occurred in the

Box 6.1: Value added by met/hydro services in agriculture

While each link in the met/hydro services value chain can add value, it is often difficult to measure the added value at intermediate points in the delivery of services. For example, in agriculture, farmers may base decisions on observation data, but it is likely that the observation data will provide inputs into the development of forecasts or other products and that these will be used by farmers in making cultivation decisions.

absence of the service. Thus, when assessing benefits, it is essential that the analyst understand the relevant components of the value chain within the context of the service being evaluated.

As described in Appendix D, different social science methods such as customer surveys can be employed to assess how users have made, or will make, decisions when presented with new met/hydro information and services. However, in many cases it will be necessary to make assumptions about users' responses. This often requires expertise or understanding with respect to specific users (for example, households, agriculture, water resource management and energy sector users) and appropriate authorities should be consulted to elicit their views on how users might respond to met/hydro information.

When evaluating benefits at an aggregate level (for example, for a sector or nationwide), it will also be important to evaluate or make assumptions about the rate of adoption of specific services (that is, the percentage of targeted people/businesses that use the service), as this will affect the magnitude of benefits realized. Economists speak of anticipated met/hydro service adoption as an example of demand forecasting. Demand forecasting involves both informal methods, such as expert judgment, and quantitative methods, such as the analysis of historical usage data or survey data. Demand forecasting may be used in pricing decisions, in assessing future capacity needs, or in deciding whether to offer new or improved met/hydro services. In some cases adoption may be close to 100% (for example, the use of weather forecasts by households). For many sector-specific services, however, the rate of adoption may be much lower, particularly in developing countries where communication of services may be challenging or users have fewer options to act on improved or new met/hydro services. Factors that may impact the behaviour of potential users and the rate of adoption of the met/hydro service being valued include:

Box 6.2: Framing the benefit analysis

Considerations in framing the analysis and identifying benefits of met/hydro services might include:

- Understand the climate services value chain;
- Identify potential users and how climate service information impacts their decisions (typically requires working with users);
- Apply a triple bottom line (TBL) approach to identify the full suite of financial, social and environmental benefits;
- Consider whether the climate service will result in non-marginal changes or downstream impacts;
- Identify all benefits regardless of to whom, when or where they accrue.

– How well the service is communicated to the user;

– Characteristics of the service (for example, accuracy or lead time);

– Decisionmaker characteristics (for example, risk aversion, or prior knowledge of information);

– Decisionmaker environment (for example, government programmes and policies that might affect adoption of services, community norms);

– Availability of resources and management options for changing behaviour in response to information.

Although it may be difficult to incorporate many of these factors into the benefits assessment, it is important to recognize how they might impact the outcome of the analysis (for example, identifying whether these factors lead to an overestimation or underestimation of value). Performing sensitivity analyses surrounding these assumptions (see section 8.5) can also help to quantify the potential impact of these different factors. For example, many studies of the benefits of met/hydro services assume that the service includes a perfect forecast. However, the benefits of the service may vary considerably based on the conditions that actually occur and how they differ from the perfect forecast scenario. To assess the range of potential benefits associated with a given service, it is advisable to evaluate two or more scenarios under which forecast accuracy varies.

In addition, as discussed in Chapter 3, studies of the benefits of met/hydro services can include ex-ante or ex-post assessments. In ex-ante assessments, the value of climate services is forecast in advance of their provision. In practice, people must make choices and reveal values ex ante before they know which state of the world will actually prevail. Ex-post studies cannot capture what people may be willing to pay to avoid risk but, to their advantage, are based on actual data regarding the historical or current use and value of existing met/hydro services. To estimate service value ex post requires assumptions regarding what would happen without met/hydro services.

Ex-ante studies typically assume that baseline decisions taken by users are based on perfect knowledge of historical climate data or on the forecast available at the time. The value of these baseline decisions is then compared to the value of simulated, and presumably more beneficial decisions than would be taken in the baseline case. Simulations are typically based on historical (that is, retrospective) conditions, especially if an improvement in met/hydro services is to be evaluated. For ex-ante studies of new services, an analysis of decisionmaking behaviour, including attitudes towards risk, might be undertaken to specify simulation assumptions about behaviour. These analyses might include discussions with experts or surveys and/or focus group interviews with potential users.

In relationship to this chain, ex-ante studies are extremely important for providing insight into the potential value of climate services prior to their implementation. However, the necessary assumptions associated with these studies introduce some uncertainty into the analysis. For example, in studies related to agriculture, crop simulation models are used to represent how crop output might change in response to decisions made with and without the met/hydro service being evaluated. These models are assumed to match on-the-ground conditions, but do not account for many aspects of human behaviour. In reality, even if a farmer does adopt a specific management strategy, it may take several years before he or she begins to see returns. The farmer may also choose to implement a different strategy, or may not have the resources to change farming techniques at all. He or she may also decide to pursue other means of income for the season. These types of behavioural effects are not included in most models and studies.

Resolving this issue completely would require extensive ex-post studies conducted after forecasts have been widely communicated and adopted for a sufficient period to allow for learning and widespread adoption (Meza et al., 2008). However, ex-post studies are often very expensive and time-consuming to conduct. Studies that combine qualitative social science methods for understanding the determinants of the use of forecasts and value with modelling approaches that can realistically incorporate this information can help to reduce the uncertainty associated with ex-ante studies (Meza et al., 2008).

6.3 SOCIOECONOMIC BENEFIT STUDY STEP 3: IDENTIFY THE FULL RANGE OF BENEFITS

The point of departure for this discussion is provided by SEB study steps 1 and 2 (see Figure 4.2) concerning establishment of the baseline scenario and identification of the change in services to be valued. Step 3 focuses on determining the types of benefits associated with the met/hydro service(s) to be evaluated. As described below, it is recommended to apply a TBL approach to identify the full suite of financial, social and environmental benefits, including those that can easily be quantified and monetized and those that are more amenable to qualitative evaluation.

As detailed above, to identify potential benefits, NMHS staff should consider how the climate service will be used and how the use of the service will change outcomes associated with a specific decision or action (vis-à-vis the value chain). For example, agricultural users of met/hydro services might alter crop management decisions in response to new met/hydro information, which would result in increased profits or reduced losses in the event of extreme weather phenomena such as droughts. Households and businesses may make more informed decisions about preparing for an extreme event if early warning systems were improved, resulting in additional lives saved and less property damage. Users of met/hydro services in the energy sector may be able to optimize hydropower operations based on improved streamflow information. This would result in increased revenues and, potentially, a more reliable supply of energy.

Triple bottom line benefits

To determine the total economic value of met/hydro services, it is important that all benefits be identified, regardless of to whom they accrue or where they might be realized. This includes the financial benefits (for example, increased revenues) of a given service or programme, as well as any environmental and social benefits that may result (for example, lives saved, improved recreational experiences, minimization of the release of toxic substances, and the like). The inclusion of environmental and social values in the economic analysis process is often referred to as TBL accounting.

Table 6.1. Examples of the triple bottom line benefits of met/hydro services

Social	– Avoidance of loss of life and/or injuries/illnesses from natural disasters
	– Safety and security of the travelling public
	– Improved information and data to the scientific community
	– Contribution to the day-to-day safety, comfort, enjoyment and general convenience of citizens, including:
	  – Recreation
	  – Travel and commuting
	  – Preparation for severe weather
	  – Home improvement decisions
	  – Other direct and indirect forms of societal benefits
	  – Event management
	  – Avoided climate-related illnesses (for example, heat-related illnesses, vector-borne diseases that are worsened by climate such as malaria)

Environmental	– Long-term monitoring of basic indicators of the state of the environment – Minimization of release of toxic substances and other pollutants – Management of local environmental quality – Support for addressing major global environmental issues – Water savings – Reduced runoff from fertilizer application, resulting in improved water quality
Economic	– Avoidance of crop losses from frost, hail or drought – Increased farm production and sales – More efficient scheduling of the use of agricultural machinery – Reduced transportation fuel consumption through route planning – Improved scheduling of flight arrivals and departures – Minimization of airline costs from aircraft diversions – Minimization of search and rescue costs – Minimization of drought-relief costs – Efficient scheduling of ship loading facilities – Avoidance of unnecessary shutdown of offshore oil and gas operations – Avoidance of weather damage to personal property – More efficient planning of energy production and delivery

Source: Lazo et al. (2009)

The TBL approach accounts for the fact that the benefits of services extend well beyond the traditional financial bottom line that portrays only cash flows (that is, revenues and expenditures), or other benefits that are more easily monetized. As providers of met/hydro services, NMHSs and commercial weather services also need to consider their stewardship and other responsibilities and to thus account for how they may generate values that contribute towards the social and environmental bottom lines. Section 6.5 discusses methods employed by economists to monetize social and environmental benefits (which often include "non-market" benefits) associated with met/hydro services.

In the current context, the TBL approach provides an organizing framework within which the broad array of benefits associated with climate services can be portrayed and communicated. This TBL approach should include those outcomes that can be quantified and monetized (including both market and non-market benefits described below), as well as outcomes that are less amenable to reliable valuation and instead require qualitative discussion.

Table 6.1 provides several examples of different types of social, environmental and economic benefits often associated with met/hydro services. Many of these benefits can be analysed at the individual or household level (for example, improved crop yields experienced by an individual farmer), as well as at the sector (for example, avoidance of unnecessary shutdown of offshore oil and gas operations), or national levels (for example, impacts across multiple sectors of the economy). Figure 6.1 provides an illustration of a comprehensive review of the potential range of benefits from an actual study (Lazo et al., 2009).

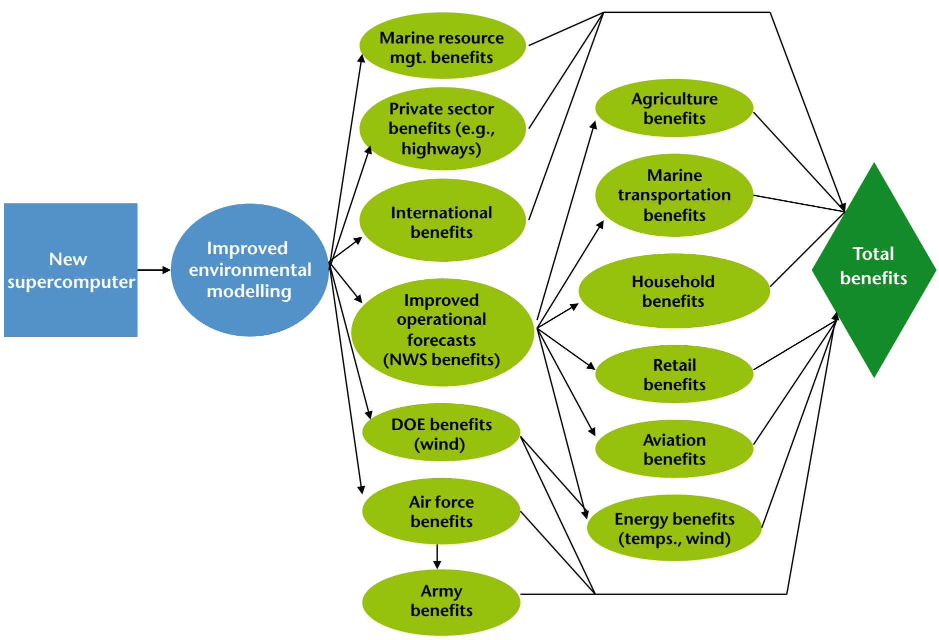


Figure 6.1. Benefits of improved weather modelling

Note: NWS = United States National Weather Service; DOE = United States Department of Energy.
Sources: Lazo et al. (2009); Lazo et al. (2010)

6.4 SOCIOECONOMIC BENEFIT STUDY STEP 4: SCREEN THE BENEFITS AND SELECT THE ANALYTICAL APPROACH

Once the financial, social and environmental benefits have been identified, the next step is to screen the benefits to determine their relative importance (for example, in terms of magnitude) and assess which are most likely to be amenable to quantitative assessment and those that will be difficult to assess, except in qualitative terms. Once this screening has been completed, methods for assessing benefits can be selected. Additional discussion of methods is provided in sections 6.5 onwards.

As shown in Table 6.1, outcomes associated with met/hydro services may include increased crop yields (yield per hectare), lives saved, reduced illnesses due to climate-related disease, energy savings (and associated reduction in carbon emissions and other greenhouse gases, water savings and increased recreational visitor days, among others. The quantification of the value of these outcomes can involve extensive modelling efforts and often requires expertise in relevant fields. It is therefore often very important to work closely with experts in health, agriculture, water-resource management, energy and other sectors to complete this stage of the analysis. The principal role of the economist at this stage is to ensure that the information provided is useful for the subsequent economic valuation models that may be used later in the benefit analysis. The analyst should give special care to ensuring that the outcomes evaluated are appropriate for use in benefits estimation. Effects that are described too broadly, or that cannot be linked to human well-being, will limit the ability of the analysis to capture the full range of a policy's benefits (United States EPA, 2010). It is also important to determine to what extent the benefits can be fully attributed to the met/hydro service. For example, most users will consider a range of information in making decisions on the met/hydro service. Farmers deciding whether to plant drought-resistant seeds or shift to alternative cultivation will take into account production and market information before planting their crops.

6.5 SOCIOECONOMIC BENEFIT STUDY STEP 5: ANALYSE THE VALUE OF BENEFITS – QUANTITATIVE

Building on the efforts described above, the next step in the analysis is to assign value to the benefits identified and quantified, where feasible and practical. Economists employ various demand-side methods to estimate the value of information (such as forecasts provided by NMHSs), including:

- Directly asking users of the information to subjectively assess the value of the data: this method must be carefully designed and executed, using standard economic approaches or the results may not be credible;

- Inferring the value of the service based on observations of people's behaviour and the costs they voluntarily bear: with this method, economists can use data collected from subjects or respondents to develop proxy prices for the information. This data may include actions taken to avoid the impacts of weather- and climate-related events, or the additional costs that people bear to recreate in areas that have better forecast information;

– Economic (decision) modelling of the situation in which the information is used: economic modelling involves formulating mathematical relationships to represent decisionmaking and the value (or cost) outcomes that result, both with and without information. This makes it possible to calculate the value increase attributable to the information;

– Applying findings from similar studies: original studies to estimate the values associated with the use of met/hydro services can require a significant amount of time and financial resources. For this reason, researchers often use the benefit-transfer approach to estimate these values. Benefit transfer involves the transfer of existing economic values estimated in one context or study to estimate economic values in a different context;

– Data analysis, in which historical records are analysed or surveys conducted to determine the actual difference made by that information (ex post): data analysis requires that the data span a period of time, or space, or circumstances in such a way that the information was available for some, but not all, of the situations represented by the data.

Table 6.2 provides an overview of the various methods that can be used to value met/hydro-related services, including non-market valuation techniques, economic modelling approaches, avoided-cost assessments and benefit transfer. Each of these methods is discussed in more detail below.

6.5.1 Non-market valuation techniques

As noted above, there are no market prices for many of the key outcomes associated with the use of met/hydro services. Assigning monetary values to these outcomes will therefore require the use of non-market valuation methods, including revealed-preference and stated-preference approaches. As noted in Table 6.2, these methods rely on primary data collection to assess benefits.

Stated-preference methods

Stated-preference methods rely on survey questions that ask individuals to make a choice, describe behaviour, or state directly what they would be willing to pay for the non-market good being evaluated. The methods that use this type of data are referred to as stated-preference methods because they rely on survey data that are stated in response to hypothetical situations, rather than on behaviour observed in actual markets.

Stated-preference methods are based on the notion that there is some amount of market goods and services (which people buy with their income) that people would be

Table 6.2. Valuation methods

	Method	Description
Non-market valuation – Stated preference	Contingent valuation (CV)	– Survey-based elicitation of individuals' preferences and values (for example, WTP)
	Conjoint analysis	– Similar to CV, except respondents are surveyed about a set of choices instead of a single WTP question
Non-market valuation – Revealed preference	Averting behaviour	– Determines values based on expenditures that would have been made to reduce impacts of weather or climate events, but were avoided because of improved met/hydro information
	Travel cost or expenditure modelling	– Uses observed tourist and recreational trip-taking behaviour to determine whether people pay more to visit sites for which forecasts are available – Can rely on other expenditures or costs incurred to search for or obtain met/hydro information
	Hedonic analysis	– Uses observed housing, property, or labour market behaviour to infer values for quality changes
Economic modelling	Decision analysis	– Analyses decisions and resulting values when people have access to met/hydro services and when they do not – Typically paired with business or production models
	Equilibrium modelling	– Examines changes in supply and demand, and price effects associated with use of met/hydro services – Measures resulting gains/losses for producers and consumers
	Econometric modelling	– Examines statistical relationships to determine specific outcomes associated with the use of met/hydro services – Regression analysis is the most common form of econometric modelling
Avoided-cost assessment		– Evaluates benefits based on avoided costs of weather and climate events due to better met/hydro information, including avoided asset losses, lives saved, and avoided morbidity impacts
Benefit transfer		– Applies results of existing valuation studies and transfers them to another context (for example, a different geographic area or policy context)

Advantages	Disadvantages
– Estimates use and non-use values – Incorporates hypothetical scenarios that closely correspond to policy case	– Time intensive and expensive to implement – Challenging to frame survey questions that elicit valid responses – Potential response biases
– Uses observed data to conduct ex-post analyses – Tailored to specific policy case – Expenditures easy to estimate through surveys	– Values interpreted as lower bound estimates because averting expenditures only capture a portion of an individual's WTP to avoid a particular harm
– Uses observed data to conduct ex-post analyses – Tailored to specific policy case	– Measures use values only – Collecting adequate data is often expensive and time intensive
– Uses observed data to conduct ex-post analyses – Tailored to specific policy case	– Measures use values only – Requires extensive market data – Assumes that market prices capture the good's value
– Useful to examine decisions and expected outcomes at household or firm level – Can be relatively simple to perform depending on model employed	– Can be time and data intensive, depending on model employed – Requires sector expertise (for example, agriculture, transport) – Often assumes perfect information as a simplifying measure
– Partial equilibrium modelling useful to examine benefits of met/hydro services for a specific sector	– Time and data intensive – Expensive to implement – Requires significant expertise
– Uses observed data to conduct ex-post and ex-ante analyses	– Can require significant amounts of data and expertise
– Can be applied in ex-post and ex-ante analyses – Relatively easy to implement	– Only represents partial value (for example, it does not take into account benefits of met/hydro services associated with increased productivity and enjoyment)
– Relatively simple and inexpensive – Accepted as a suitable method for estimating order-of-magnitude values for use and non-use benefits, in ex-post and ex-ante analyses	– Can generate potentially inaccurate and misleading results – Limited number of original studies

willing to trade off so they can benefit from a non-market good. This is often measured in terms of WTP for a non-market outcome, although the methods have also been used to assess how much compensation people would be "willing to accept" to give up a non-market good they already benefit from.

The advantages of stated-preference methods include the ability to estimate both use and non-use values and to incorporate hypothetical scenarios that closely correspond to the policy case through the use of a well-designed survey. The main disadvantage of stated-preference methods is that it may be subject to systematic biases that are difficult to test for and correct (United States EPA, 2010). Stated-preference methods typically require the assistance of experts with experience in survey design and economic modelling. These can be time intensive and expensive to implement.

The most widely used stated-preference technique has traditionally been the CV method, where respondents are presented with information about a non-market good or service (or changes in quality of the good or service) and asked to indicate how much it would be worth to them. Contingent valuation surveys can ask respondents to state directly what they would be willing to pay (open-ended CV), or whether they would be willing to pay a specified amount (referendum CV, where the specified amount varies across respondents). Another form of CV is to provide the respondent with a series of dollar values and ask them to indicate which of the options represents the maximum they would be willing to pay for the good or service being evaluated (payment-card CV).

More recently, "choice experiments" have begun to be used more extensively to estimate WTP. This is largely due to the potential biases associated with CV methods and the lack of easily implemented procedures to mitigate these biases. In choice experiment surveys consumers are presented with two or more options for a good or service and are asked to state which option they prefer. By examining consumer preferences for the attributes and prices associated with their preferred option, WTP can be inferred by the analyst.

In the context of met/hydro services, several published studies have assessed household WTP using stated-preference methods (mostly CV). For example, Anaman and Lellyett (1996*a*) conducted a survey in the Sydney metropolitan area to estimate the economic value households attach to basic public weather forecasts and warnings. Results indicated that the average annual WTP for these services was about $A 24 (about US$ 19) per person. In a similar study, Lazo and Chestnut (2002) found the median household WTP for current weather forecasts in the United States to be US$ 109 per year. As described in more detail in Appendix E (case study 8), Lazo and Croneborg (forthcoming), conducted a CV study to assess the potential benefits associated with a proposal to improve weather services in Mozambique. Results of the study indicated a mean annual WTP of about US$ 0.09 per individual for improved weather forecast information. Aggregation of results across the Mozambican population over a 50-year benefit lifespan suggested total PV benefits of over US$ 50 million – significantly more than the projected fixed costs of the project of about US$ 21 million.

Several studies have also assessed WTP for met/hydro services by businesses or sectors. Rollins and Shaykewich (2003) used CV to estimate benefits generated by an automated telephone answering device that provides weather forecast information to commercial users in Toronto, Canada. Average value per call varied by commercial sector from US$ 1.58 for agricultural users to US$ 0.44 for institutional users, with an overall mean of US$ 0.87 per call.[19] With roughly 13.8 million commercial calls annually, benefits were estimated to be about US$ 12 million per year. Anaman and Lellyett (1996*b*) also surveyed cotton producers to determine WTP for an enhanced weather information service tailored to the cotton industry. At the time of the survey (a drought period), average WTP for the service was about US$ 175. In addition, producers indicated they were willing to pay an average of US$ 204 annually for the use of the service during a period of good rainfall. Makaudze (2005) investigated the value of seasonal forecasts to farmers in Zimbabwe via CV surveys. Results showed that WTP for improved seasonal forecasts ranged from US$ 0.44 to US$ 0.55. Households in wet districts revealed consistently lower WTP than those in drier districts.

Stated-preference methods typically provide average per-person or per-household estimates for the survey respondents, which can be extrapolated to the wider population to provide an indication of the total non-market benefits or costs of a policy option. This requires making assumptions about the extent of the population that will be affected by the policy change and whether people who chose not to respond to the survey would also value the outcomes.

Revealed-preference methods

Willingness to pay can also be inferred from choices people make in related markets. Methods that employ this general approach are referred to as “revealed-preference methods” because values are estimated using data gathered from observed choices that reveal the preferences of individuals. For instance, although there may be no markets in which to buy and sell days of outdoor recreation, individuals often incur costs to undertake direct recreational-use activities. For these types of uses, incurred costs can be assessed to develop proxy “prices” for the activity. That information can then be used to determine the demand curve for recreation-related services for which value can be estimated. This approach uses observations of people’s behaviour or their associated expenditures as indications of revealed preferences for the service.

The most common revealed-preference methods are “hedonic pricing”, “travel cost” and “averting behaviour”. Within the context of met/hydro services, the hedonic-pricing and travel-cost methods have limited application. Hedonic pricing can be used to value a wide variety of factors that influence observed prices. For instance, in theory it would be possible to infer the value of a weather forecast by comparing the price difference between two newspapers, one that contained a forecast and one that did not, with the papers being identical in every other attribute (should such a situation ever occur).

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[19] Values converted from Canadian dollars to United States dollars based on an average 2003 exchange rate of 1.375 Canadian dollars.

The travel-cost method accepts as a maintained hypothesis that economic demand functions for recreation are revealed by the choices people make to travel to a particular location. The essence of the method is recognition that users pay an implicit price by giving up time and money to take trips to specific areas for recreational activities (United States EPA Science Advisory Board, 2009). In relation to met/hydro services, travel-cost methods could be used to estimate how much more people pay to take recreational trips to areas that provide better forecasts.

The averting-behaviour method is more directly applicable to assessing the benefits of met/hydro services. This method infers values from defensive or averting expenditures (for example, actions taken to prevent or counteract the impacts of weather or climate events). Because better weather forecasts may make such expenditures unnecessary, this approach can measure the benefits of improved forecasts. This could include, for example, installing storm shutters or temporary levee materials around a home to avert impacts from potential flooding. These expenditures are relatively easy to estimate through surveys.

Averting-behaviour methods can be best understood from the perspective of a household production framework. To the extent that averting behaviours are available, the model assumes that a person will continue to take protective action as long as the expected benefit exceeds the cost of doing so. If there is a continuous relationship between defensive actions and reductions in risks, then the individual will continue to avert until the marginal cost just equals his/her marginal WTP (or marginal benefits) for these reductions. Thus, the value of a small change in risk can be estimated from (a) the cost of the averting behaviour or good, and (b) its effectiveness, as perceived by the individual, in offsetting the loss in environmental quality (United States EPA, 2010).

The averting-behaviour method typically generates values that may be interpreted as lower bound estimates because averting expenditures only capture a portion of an individual's WTP to avoid a particular harm and generally does not take into account the loss of utility from pain and suffering. The most common application of averting-behaviour models has been the estimation of values for morbidity (illness) risk.

6.5.2 Economic decision modelling

Various economic modelling approaches can also be used to assess the benefits of met/hydro services and information. These models can rely on primary and/or secondary data as inputs to model decisionmaking and the value (or cost) outcomes that result, both with and without information. Within the context of met/hydro services, economists use models to determine the value of information for single agents or entities (referred to here as decision analysis), as well as to determine how the broad use of met/hydro services can impact local, regional or national economies (through the use of equilibrium modelling). The following paragraphs describe these two modelling approaches.

Decision analysis

Studies that employ economic decision models typically analyse a single agent or entity that is responsible for making a decision(s) to maximize (or minimize) an objective (for example, represented by a utility function, production function, cost–loss model of two alternatives or other economic model). These studies assume that the decisionmaker makes decisions based solely on the effect of the decisions on his/her payoffs (Rubas et al., 2006).

In the context of met/hydro services, these studies often assume that decisionmakers have some level of prior climate knowledge. Without updated climate information, the decisionmaker uses his/her prior knowledge to make decision(s). If updated information is provided, the decisionmaker will use this information to make optimal choices. The value of met/hydro information is then equal to the difference between the benefits when the information (that is, updated knowledge) is used, compared to the benefits when prior knowledge or no forecast is used (Rubas et al., 2006).

The use of decision models is appropriate when the choice of a decisionmaker or entity cannot affect an outcome for another decisionmaker. For example, a single agricultural decisionmaker interested in adopting seasonal forecasts would have little impact on supply or demand and would therefore have little impact on price (Rubas et al., 2006). Decision models are typically paired with business or production models (for example, crop growth simulation models or fisheries management models) to identify optimal decisions under alternative forecast scenarios.

Many studies have used some form of decision model to estimate the value of met/hydro services. For example, in the agricultural sector, Meza and Wilks (2004) estimate the value of perfect sea surface temperature anomaly forecasts for fertilizer management in Chile to be US$ 5 to US$ 22 per hectare for potato farmers, compared to a no-forecast approach. In the transportation sector, Berrocal et al. (2010) found that the use of probabilistic weather forecasts for predicting ice conditions reduced costs for the Washington State Department of Transportation by 50% relative to the use of deterministic forecasts.

In the energy sector, Hamlet et al. (2002) evaluated the use of long-lead streamflow forecasts in the management of hydroelectric dams on the Columbia River in north-west United States. The authors found that use of these forecasts could increase energy production by 5.5 million megawatt hours per year, resulting in a US$ 153 million increase in net revenues (compared to shorter lead time snowpack forecasts). For this study, the authors assume that monthly prices are "unaffected by the relatively small shifts in energy production from spring to fall examined here" (Hamlet et al., 2002, p. 98, as cited in Rubas et al., 2006). Several studies in the fisheries sector make similar assumptions (for example, Costello et al., 1998; Kaje and Huppert, 2007).

While it may be acceptable to assume that the decisions taken by a single economic agent or small number of businesses will not affect prices, it is inappropriate when considering a large number of producers or a large impact on the supply and demand conditions of the process. In these cases, other methodologies must be used (Rubas et al., 2006).

Macroeconomic or equilibrium models

Equilibrium models recognize that the choices of different decisionmakers are interlinked. For example, in the agricultural sector, if one producer uses seasonal forecasts, prices will not change because the production of a single producer is very small relative to total (for example, regional) production. However, as the number of producers using seasonal forecasts increases, the change in total production will cause price changes, which will result in changes in supply and demand – and prices – for related goods and services. Producers who do not anticipate this change may not make optimal choices (Rubas et al., 2006). Equilibrium models take these effects into account, providing estimates of consumer and producer surplus as a measure of the benefits to society.

Box 6.3: General equilibrium theory

In economics, general equilibrium theory attempts to explain the behaviour of supply, demand, and prices in a whole economy with several or many interacting markets, by assuming that a set of prices exists that will result in an overall (or "general") equilibrium. General equilibrium theory is distinguished from partial equilibrium theory by the fact that it attempts to look at several markets simultaneously rather than a single market in isolation.

When looking at how users respond to improved or new information, we are typically limited to partial equilibrium as opposed to general equilibrium analysis (see Box 6.3). Typically, general equilibrium models have not been used to value climate services, likely due to their complexity and extensive information requirements. However, several studies have used decision analysis and partial equilibrium models to examine the value of met/hydro information for specific sectors (Rubas et al., 2006). For studies related to agriculture, analysts have used crop-growth simulation models in conjunction with decision theory models to develop producers' production responses from forecast use. The analysts then apply partial equilibrium models to develop aggregate supply relationships. Changes in aggregate supply caused by the use of met/hydro information affect price, which is taken into account by individual producers (represented in the model) when making decisions (Rubas et al., 2006).

As reported by Rubas et al. (2006), a series of related studies have examined the effect of ENSO-based climate forecasts on the agricultural sector using a previously developed model of United States agricultural production. Chen and McCarl (2000) and Chen et al. (2001) report that producer surplus decreases by using ENSO-based forecasts (due to decreased prices associated with increased production), but consumer surplus increases enough that overall social welfare increases. Chen et al. (2002) report that using the five-phase ENSO definition almost doubles social welfare gains compared to the more standard three-phase definition (Rubas et al., 2006).

Using a similar model, Adams et al. (2003) report the value of an ENSO-based system to be US$ 10 million annually for Mexican agriculture. Mjelde et al. (2000) use a previously developed dynamic model to show that use of seasonal forecasts in the production agricultural sector will affect machinery manufacturers, food processors and retailers, and the financial sector (Rubas et al., 2006).

In the water sector of Taiwan Province of China, Liao et al. (2010) developed a partial equilibrium regional water economic model to evaluate the economic impacts of ENSO events on a regional water market with and without the use of ENSO information. Results showed that a water-management strategy based on transferring water among different groups could potentially increase social welfare by as much as US$ 11.6 million when ENSO information was provided.

6.5.3 Avoided cost/damage assessments, including avoided mortality and morbidity impacts

Avoided costs can be an important part of valuing the range of benefits likely to be generated by climate services largely using market information. For instance, these benefits accrue from reducing or eliminating expenditures related to power generation (for example, power companies increasing their production in anticipation of high temperatures) or reduced evacuation costs. These costs can also be deferred to later years. Using NPV analysis (discussed in more detail in Chapter 8) allows us to compare benefits accrued in different years on a similar basis. The analyst must be alert to potential issues, however, when using avoided costs as a proxy for benefits values. Avoided costs can be used as measures of benefits when they would actually be incurred in the absence of the climate services (for example, a power company increases production to err on the safe side, but improved forecasting would have changed that decision).

Several studies have calculated avoided costs associated with the use of met/hydro services. For example, Considine et al. (2004) used a probabilistic cost–loss model to estimate the incremental value of hurricane forecast information to oil and gas producers in the Gulf of Mexico. Results showed that the value of a 48-hour forecast amounted to US$ 8.1 million annually in terms of avoided costs and foregone drilling time. Frei et al. (2014) found that the use of meteorological (weather) services by the transportation sector in Switzerland would result in US$ 56.1 million to US$ 60.1 million in avoided governmental spending. As detailed in Appendix E (case study 6), von Grünigen et al. (2014) applied a simple decision model to assess the avoided fuel and flight deviation costs for airlines due to the use of terminal aerodrome forecasts (TAFs). Anaman et al. (2000) also studied the benefits of TAFs, conducting an (ex-post) econometric analysis to assess avoided fuel costs associated with the use of TAFs for Qantas Airways Limited. Results indicated that the abandonment by the airline of mandatory requirement for aircraft to carry alternate fuel in 1985, in favour of carrying such extra fuel based on weather forecasts, saved between US$ 19 million and US$ 30 million per year in reduced fuel consumption (in 1993/1994 United States dollars).

The World Bank conducted a series of studies to assess the avoided costs associated with large-scale modernization of NMHS services in 11 countries in Europe and Central Asia (see Appendix E, case study 1). These studies rely on simplified approaches, specifically sector-specific and benchmarking approaches, developed by the Bank to compare order-of-magnitude benefits of reducing damages from weather-related events to the costs associated with improving met/hydro services.

The sector-specific method values the economic benefits that would accrue in weather-dependent sectors from modernization of NMHS agencies. This method relies on available country data and surveys of national experts from NMHS agencies and weather-dependent sectors to (a) estimate current sectoral losses from weather events, and (b) determine the potential reduction in losses that modernization would achieve. The World Bank also uses surveys to determine the costs associated with actions taken by organizations and entities to prevent weather-related losses, both with and without modernization. The Bank uses this information to compare the benefits of modernization, expressed as the additional prevented losses from hazardous events and unfavourable weather, to the costs associated with modernizing the NMHS and implementing preventive measures. This comparison (that is, the incremental reduction in weather-related losses compared to the costs of modernization) represents the "economic efficiency" of met/hydro improvements, as defined by the World Bank.

The World Bank has used the sector-specific approach to estimate both the direct and indirect economic losses that would occur as a result of unfavourable weather events, with and without modernization. Direct economic losses are those that are caused by direct destruction, breakdown or damage to any types of property and tangible assets. Indirect economic losses include losses that a business entity or economic sector suffers because of decreased revenues or additional expenditures on production cycles.

Similar to the sector-specific approach, the benchmarking method assesses the losses caused by earlier events and estimates the reduction in losses that could be achieved with improved services. However, the benchmarking method provides a way to address limited sector-level data and expertise on weather-related losses. This method relies on expert opinion and readily available data to assess the vulnerability of the country's overall economy to weather-related events and obtain results about direct damages caused by weather impacts.

Benchmarking is carried out in two stages:

- **Determining benchmarks:** Using data and estimates from other countries and expert judgment, the authors define and adjust the following two benchmarks for each country:
    - The level of annual direct economic losses caused by met/hydro hazards and unfavourable weather events, expressed as a share of gross domestic product (GDP);
    - The level of annual prevented losses, with and without modernization, expressed as a percentage of the total level of losses;
- **Correcting benchmarks:** In this stage, data are adjusted to benchmarks according to country-specific estimates of weather and climate conditions, structure of the economy and other factors.

For the countries in Europe and Central Asia, the World Bank determined the level of annual direct losses and annual prevented losses based on findings from studies conducted in several countries (unlike the sector-specific approach, the benchmarking approach only considers direct damages caused by weather impacts). These studies showed that the mean annual level of direct losses from met/hydro hazards and unfavourable events varies between 0.1% and 1.1% of GDP.[20] The studies also showed that the share of prevented losses may vary from 20% to 60% of total weather and climate-related losses. Based on these parameters, the World Bank studies in the countries covered yielded BCRs of between 1.8 and 9.2 for investments in improved met/hydro services.

To assess the value of these basic parameters for a specific country, the Bank makes adjustments to the average values based on in-country characteristics, including: the weather dependence of the economy; meteorological vulnerability; the current status of met/hydro service provision; national climate; agency capacity; and national economic structure. These factors, and the extent to which they influence the benchmarks, are estimated based on quantitative data and expert assessments. The adjusted benchmarks are used to assess the marginal efficiency of met/hydro services, with and without modernization.

The World Bank developed the sector-specific and benchmarking approaches to help NMHS agencies provide understandable results to decisionmakers with limited time and resources. However, these methods are severely limited in that they rely primarily on expert opinion and data from other countries to determine the current level of weather-related losses, the additional reduction in weather-related losses that modernization would achieve, and the costs associated with mitigation options. Thus, the results of the analysis are subject to potential biases and knowledge limitations of the experts involved in the study. In addition, there is a limited amount of data available to support expert findings. Despite these limitations, the World Bank finds this method useful for providing order-of-magnitude estimates that help NMHS agencies justify increasing public funds to support their services.

Several studies have used more detailed approaches to value the avoided costs associated with the use of early warning systems for disaster management, including the number of lives saved as a result of these systems. Economists often use the VSL to estimate the monetary benefit of reducing premature mortality risk. For example, Ebi et al. (2004) (see Appendix E, case study 3) determined that the use of early warning systems during extreme heat events in the city of Philadelphia prevented 117 premature deaths between 1995 and 1998. The dollar benefit of these prevented deaths was estimated to be US$ 468 million, based on the EPA estimate of VSL at the time the study was conducted.

When applying the VSL estimate, the key point is that a dollar value is not being placed on any specific individual's life per se. Instead, the values reflect information about how individuals value modest changes in low-level risks of premature fatality. In other words, VSL estimates represent WTP (or the willingness to accept) for small changes in

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[20] These figures represent the mean annual level of losses for a fairly long period of observations. Losses for some specific year in some specific country may be well beyond the range given.

very small risks that are spread over a large population. Currently, EPA recommends a default central VSL of US$ 7.9 million (in 2008 United States dollars) to value reduced mortality for all programmes and policies.

Avoided cases of illnesses can also be an important benefit associated with met/hydro services (for example, heat-related illnesses and vector-borne diseases such as malaria can be largely predicted based on climatic conditions). Willingness to pay to reduce the risk of experiencing an illness is the preferred measure of value for morbidity effects. As described in Freeman III (2003), this measure consists of four components:

- Averting costs to reduce the risk of illness;
- Mitigating costs for treatments such as medical care and medication;
- Indirect costs such as lost time from paid work, maintaining a home and pursuing leisure activities;
- Less easily measured but equally real costs of discomfort, anxiety, pain and suffering.

Researchers have developed a variety of methods to value changes in morbidity risks. The three primary methods most often used to value morbidity are stated preference, averting behaviour and cost of illness. Hedonic methods are used less frequently to value morbidity from environmental causes (United States EPA, 2010).

Some methods measure individual WTP to avoid a health effect. Others can provide useful data, but these data must be interpreted carefully if they are to inform economically meaningful measures. For example, cost-of-illness estimates generally only capture mitigating and indirect costs and omit averting expenditures and lost utility associated with pain and suffering. Methods also differ in the perspective from which values are measured (for example, before or after the incidence of morbidity), whether they control for the opportunity to mitigate the illness (for example, before or after taking medication) and the degree to which they account for all of the components of total WTP.

6.5.4 **Benefit transfer**

Original studies to estimate stated preferences, avoided costs or other values associated with the use of met/hydro services can require a significant amount of time and financial resources. For this reason, researchers often use the benefit-transfer approach to estimate these values. Bergstrom and De Civita (1999, p. 79) offer the following definition of benefit transfer:

> Benefits transfer can be defined practically as the transfer of existing economic values estimated in one context to estimate economic values in a different context … benefits transfer involves transferring value estimates from a "study site" to a "policy site" where sites can vary across geographic space and or time.

There are numerous challenges and cautions to consider when using benefit transfer. While it is relatively simple to develop a benefit transfer-based monetary value estimate of many types of benefits (for example, there is a relatively large amount of literature on economic values for the impact of seasonal forecasting on agricultural productivity), the approach can generate potentially inaccurate and misleading results, even when a well-intentioned and objective analysis is being attempted. Obtaining accurate and credible findings using the benefit-transfer method can be challenging in that important differences often exist among the types of conditions studied in the primary empirical research (that is, the study context for the published monetary estimate) and the climate services context to which an NMHS may be trying to transfer the results.

One such challenge is defining the appropriate "market" for the particular site. For example, what are the boundaries for defining how many households are assigned a benefit transfer-based value such as dollars per year to improve traveller safety? Another challenge arises from the frequent need to attribute a benefit transfer estimate to a large outcome (for example, avoiding a hurricane evacuation) using an estimate of a fractional benefit to the whole (for example, the marginal mile of evacuation that was avoided).

Despite these challenges, when implemented correctly with the recognition that the estimates are not intended to be precise, benefit transfer is accepted as a suitable method for estimating use and non-use benefits associated with climate services. When time and resources allow, however, primary research specifically tailored to the issue and site at hand is broadly considered a far better alternative.

There is a well-developed literature on how to correctly apply benefit transfer (for example, Rosenberger and Loomis, 2003; United States Office of Management and Budget, 2003; United States EPA, 2010). The following steps are recommended when conducting benefit transfer (Lazo et. al., 2009; United States EPA 2010):

- Describe the issue, including characteristics and consequences and the population affected (for example, will impacts be felt by the general population or by specific subsets of individuals such as users of a weather forecast product?);

- Identify existing relevant studies through a literature search;

- Review available studies for quality and applicability: The quality of the study estimates will determine the quality of the benefit-transfer analysis. In assessing studies for applicability, determine whether available studies are comparable to the issue at hand. Guidelines for evaluating the usefulness of a particular study for benefit transfer for a particular situation (based on guidance provided in United States EPA, 2010) include:

    - Assess the technical quality of the study: The original studies must be based on adequate data, sound economic and scientific methods and correct empirical techniques;

   - Ensure that the expected changes in site conditions are similar in magnitude and type in the project being appraised and in those projects from which the data are obtained;

   - Use studies that analyse locations and populations similar to those of the project being evaluated if possible;

   - Carefully consider the cultural and economic differences between the project location and the data source;

- Transfer the benefit estimates: This step involves the actual transfer of benefits over the affected population to compute an overall benefit estimate. The transfer may simply involve applying a value to an average household as derived from a primary study, or a more complex transfer of the benefits function derived empirically by the original researchers. The transfer can also derive from a meta-analysis of multiple studies (see Box 6.4 for information on the different approaches for transferring values from study cases to the policy case);

- Address uncertainty: In addition to reporting the final benefits estimates from the transfer exercise, the analyst should clearly describe all key judgments and assumptions, including the criteria used to select study cases and the choice of the transfer approach. The uncertainty in the final benefits estimate should be quantified and reported when possible. Clearly describe all the judgments and assumptions inherent in benefit transfer, as well as any other sources of uncertainty and assess their potential impact on final estimates.

A limited number of published studies have used benefit-transfer techniques to estimate values associated with climate services. Most notably, Hallegatte (2012; see Appendix E, case study 4) estimated the potential benefits of providing early warning systems in developing countries based on a study of benefits for similar services in Europe. Taking into account differences in population, increased hazard risk due to climate and geography, as well as increased exposure to weather due to the state of infrastructure, the author estimated that upgrading early warning capacity in all developing countries would result in between US$ 300 million and US$ 2 billion per year of avoided asset losses due to natural disasters. In addition, it was estimated that early warning systems would save an average of 23 000 lives per year (valued at between US$ 700 million and US$ 3.5 billion per year using the Copenhagen Consensus guidelines (Copenhagen Consensus Center, 2014)) and would add between US$ 3 billion and US$ 30 billion per year in additional economic benefits.

Other studies have used benefit transfer to evaluate specific benefits. For example, Weiand (2008) estimated the value of improved ocean observing data to recreational fishermen in Florida using estimates of WTP for recreational fishing (per fish caught) from existing literature. Costello et al. (1998) also used estimates from the literature to determine the value associated with improved in-stream fishing in the United States Pacific Northwest due to improved fishery (coho salmon) management with the use of ENSO-based forecasts. Frei (2010) used benefit transfer to estimate the value for a

Box 6.4: Benefit-transfer approaches (United States EPA, 2010)

Unit value transfers are the simplest of the benefit-transfer approaches. They take a point estimate for a unit change in value from a study case or cases and apply it directly to the policy case. The point estimate is commonly a single estimated value from a single case study, but it can also be the average of a small number of estimates from a few case studies. Unit value transfers are useful for obtaining order-of-magnitude estimates of benefits, as point estimates reported in study cases are typically functions of several variables, and simply transferring a summary estimate without controlling for differences among these variables can yield inaccurate results.

Function transfers also rely on a single study, but they use information on other factors that influence value to adjust the unit value for quantifiable differences between the study case and the policy case. This is accomplished by transferring the estimated function upon which the value estimate in the study case is based to the policy case. This approach implicitly assumes that the population of beneficiaries to which the values are being transferred has potentially different characteristics, but similar tastes, to the original one and allows the analyst to adjust for these different characteristics (United States Office of Management and Budget, 2003).

Meta-analysis uses results from multiple valuation studies to estimate a new transfer function. Meta-analysis is an umbrella term for a suite of techniques that synthesize the summary results of empirical research. This could include a simple ranking of results to a complex regression. The advantage of these methods is that they are generally easier to estimate while controlling for a relatively large number of confounding variables.

Structural benefit transfer is a relatively new approach to benefit transfer that can accommodate different types of economic value measures (for example, WTP, willingness to avoid, or consumer surplus) and can be constructed in such a way that certain theoretical consistency conditions (for example, WTP bounded by income) can be satisfied. This can be applied to value transfer, function transfer, or meta-analysis; although applications to function transfer are the most common. Structural transfer functions that have been estimated have specified a theoretically consistent preference model that is calibrated according to existing benefit estimates from the literature.

number of selected sectors (households, agriculture, energy) from weather services in Switzerland to be in the region of hundreds of millions of United States dollars.

6.6 SOCIOECONOMIC BENEFIT STUDY STEP 6: ANALYSE THE VALUE OF BENEFITS – QUALITATIVE

For some types of benefits, expressing their value in quantitative or monetary terms may not be feasible or desirable. It is always important, though, to describe these non-quantified benefits in a meaningful, qualitative manner. One way to do this, in part, is by using a simple scale that indicates the likely impact on net benefits. For example, an NMHS can qualitatively rank impacts on a five-point scale to reflect non-quantified relative outcomes that span from relatively very small to very positive (for example, a “1” may signify an outcome with small non-quantified benefits and a “5” may represent a high level of non-quantified benefits). Qualitative ratings should be accompanied by descriptions of the impact and should be explicitly carried through the analysis.

6.7 CONCLUSIONS

This chapter describes the processes and methods that can be used to assess the benefits of met/hydro services, including the general process for conducting benefit analysis and methods and models used to quantify and monetize benefits. The information provided in this chapter on the different approaches for estimating benefits helps to provide a foundation for appropriately framing a benefit analysis. There is a well-established toolkit of economic valuation approaches that can be used to value non-market goods and services, including climate services.

When conducting benefit analysis, it may be necessary to apply several different methods, particularly when conducting whole-of-service analyses. Different methods often address different subsets of total benefits. In addition, the use of multiple methods can provide for comparison of alternative measures of value when applied to the same category of benefits. In many cases, NMHSs will not have the resources or expertise to complete an original benefit study that relies on primary data collection and/or extensive modelling. In these instances, benefit transfer can be a valuable tool that can be used to provide reasonable estimates. "Double counting" is a significant concern when applying more than one method, and any potential overlap should be noted when presenting the results (United States EPA, 2010).

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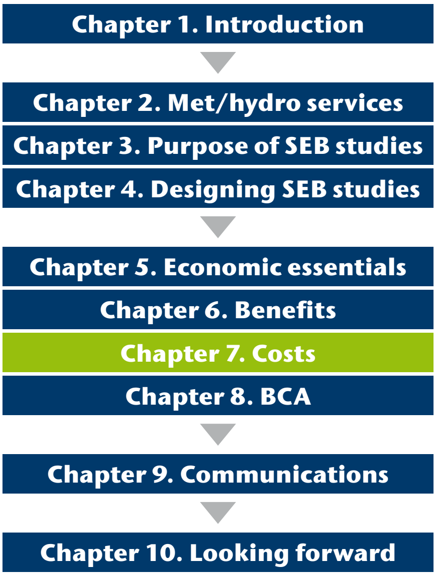
CHAPTER 7. DEFINING AND MEASURING COSTS



7.1 INTRODUCTION

The concept of opportunity cost, introduced in the previous chapter, provides the basis for evaluating the resources used in the production of met/hydro services. Most SEB studies will include an analysis of costs to provide a basis of comparison to benefits in order to inform decisions on the net benefits of met/hydro services. In addition, NMHSs may conduct cost-effectiveness analyses to determine the preferred investment option in providing a specific type and quality of met/hydro service.

This chapter provides a detailed discussion of various cost terminology, covers the topics of attribution and aggregation of costs, and examines different costing approaches that are used in SEB studies. A basic understanding of cost types and terminology will help NMHSs to more effectively develop SEB scopes, work with consultants, and communicate SEB results to decisionmakers and other audiences. The chapter covers SEB steps 3 to 6 in the 10-step approach (see Figure 4.2) for conducting a study.

7.2 CONCEPTS FOR DEFINING, MEASURING, ATTRIBUTING AND AGGREGATING COSTS

This section presents different perspectives on how costs can be defined and categorized. For many readers, terms such as costs, expenditures and outlays may seem fully interchangeable, but there are important differences in their meanings.

Costs

Costs have already been defined in Chapter 5, but the concept is further detailed in this chapter. Costs refer to the total amount of sacrifices made to accomplish a task or produce a product or service. It can encompass purchased goods and services, labour effort (working hours), use of goods from inventory, use of equipment, models and buildings (capital stock) and use of public goods and non-monetized resources (for example, the environment). Capital goods illustrate the distinction between expenditure and cost. A capital good is purchased in one year and recorded as an expenditure, but over time the capital good declines in quality or is depreciated and this depreciation (often calculated as the initial cost divided by the capital good’s expected useable life) is an annual cost.

In organizations in which the basic tasks are funded from fixed annual budgets, there is often a tendency to regard only efforts and purchases outside the basic task portfolio as costs (that need commensurate extra funding from whatever source) or to regard only purchases as costs. This supposition should be avoided in BCA. In BCA, either the incremental cost or the total cost with respect to a considered bundle of services should be included, regardless of whether these are covered from a basic budget or from another source.

Expenditures

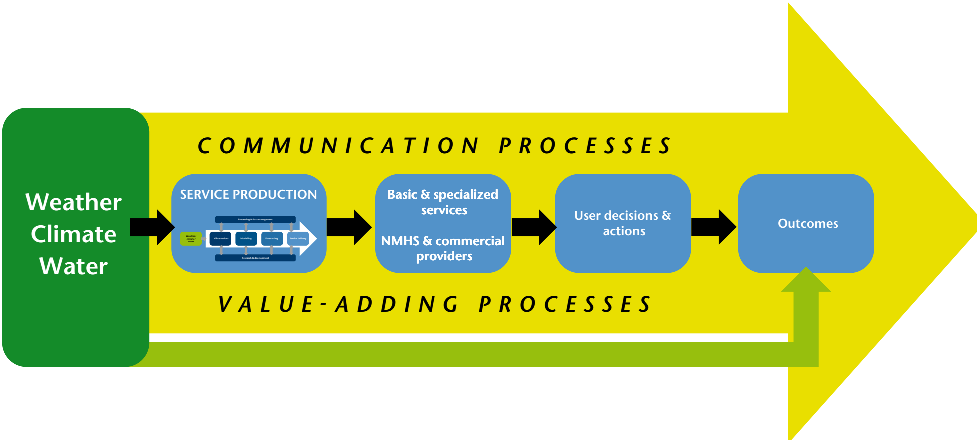
Expenditures refer to actual payments made with respect to the production of a good or service during a certain time span. If a BCA only considers expenditures, not all costs will necessarily be accounted for, either because some costs did not entail payments or because costs were incurred outside the considered period. In practice there may also be the inclination to only consider expenditures incurred by the organization in producing met/hydro services, whereas the considered service production may also entail expenditures elsewhere. For example, if purchases of an NMHS include subsidized goods, the related costs of the government should be accounted as well. The term "outlay" has the same meaning as expenditure.

Losses

Losses are another term closely related to costs. Losses are unintended costs; for example, in case of damage to equipment or buildings. If the costs of production of a good or service are not fully covered by revenues or by a budget, losses are incurred. This means that somehow additional resources have to be found to compensate the losses. Within an NMHS, it would mean that parts of a budget that were originally allocated to other activities must be used to balance a loss.

7.3 SOCIOECONOMIC BENEFIT STUDY STEP 3: IDENTIFY THE FULL RANGE OF COSTS

For the purposes of SEB studies, costs of met/hydro services can be distinguished according to who incurs the costs. Regardless of whether met/hydro services are provided to end users without charge, the society, that is, the national economy, incurs cost when producing these services. These costs, inside the NMHS and elsewhere, have to be identified. For met/hydro services, costs can be grouped by organizations (NMHSs and commercial weather services) that produce basic and specialized services and the various types of user communities that receive these services, process and interpret the information and take decisions. User communities may include individuals, households, businesses and other organizations. The costs incurred to produce met/hydro services are familiar to NMHSs and commercial weather services, but the costs of users may be significant and will need to be accounted for in BCA at



NMHS service production costs	*Commercial weather service provider costs*	*User costs*
– Infrastructure investment (especially observation systems) – Observations and data management – Modelling and forecasting – Information retrieval and processing cost (for example, satellites) – Research and development – Service delivery	– Information retrieval and processing (for example, NMS, satellites) – Modelling and forecasting – Service delivery – Product development and research – Data management – Infrastructure investment (for some commercial weather services)	– Information retrieval (and data processing – for some users) – Interpretation of met/hydro information – Modelling and decisionmaking – Costs of taking actions based on met/hydro information

Figure 7.1. Costs associated with the value chain

the national level. Figure 7.1 illustrates the types of costs that may be incurred by producers and users of met/hydro services.

The listing in the table in Figure 7.1 provides a tentative idea of the prominence of cost items (in descending order). However, due to diversity in – among others – organizational status and size, product portfolio, and technological skill levels, costs shares can vary appreciably within the groups of NMHSs and commercial weather services, respectively.

Almost without exception, NMHSs have their own observation systems, implying the need for investment and maintenance. The large amount of observation data added every day requires advanced data management systems for NMHSs. Furthermore, both commercial weather services and NMHSs acquire data from third parties, which also incurs cost, even if the data as such are free. Both NMHS and commercial weather services incur costs for running forecast models. Both types of actors often also have research and development activities, even though for NMHSs a more significant share may go to research, whereas commercial weather services will spend a (much) larger share on product development. Service delivery is important for NMHSs, but crucial for commercial weather services. Most commercial weather services do not have a significant amount of observation infrastructure, but some do. End users may incur costs to retrieve and process information provided by NMHSs and commercial weather services even if the information as such is free (see Figure 7.1).

7.3.1 National Meteorological and Hydrological Service and commercial weather service costs

The costs associated with NMHSs and commercial weather services, listed in the table in Figure 7.1, can be further differentiated according to the purchase of a variety of goods and services, plus capital expenditures:

- Labour (salary cost and additional cost of own employees), often subdivided into:
  - Direct labour (working hours clearly attributable to production tasks);
  - Overheads (labour in supporting services such as administration);
- Purchased information services (for example, remote sensing and meteorological data):
  - Fees for international cooperative bodies can be a significant share of the total cost of NMHSs (for example, greater than 10%);
- Purchased materials, energy, water, sanitation, and waste disposal services, fuel for vehicles (typically consumed in one year);
- Equipment and buildings/furnishings (for example, monitoring equipment, communication equipment, computers and other IT equipment, vehicles, and the like).

Next to overhead costs, which cannot be directly attributed to any productive activity, there are so-called joint costs, which are attributable to a collection of productive activities. Since joint cost is an important feature in NMHS costs, we will return to the attribution issue in section 7.5.3. Other costs incurred during service generation, but not observed by the NMHS, will be discussed in sections 7.5.4 and 7.5.6. Table 7.1 gives an example of annual cost statements of the Royal Netherlands Meteorological Institute.

Usually, the production of any product or service entails both variable and fixed costs. Variable costs vary according to the volume of production, whereas fixed costs remain at the same level regardless of the output level. The classification is sensitive for the period considered. For example, for periods up to a year, building costs are usually constant. If, however, an entire project lifecycle is to be considered, some constant cost items may show stepwise developments – for example, if an organization expands,

Table 7.1. Example summary of an annual cost statement of an NMS – the Royal Netherlands Meteorological Institute (€ millions)

Cost items	*2012*	*2011*
Staff	32.98	33.21
Material cost and services purchased, of which:	*26.98*	*24.32*
– Outsourcing	1.03	0.98
– Maintenance and operations	4.03	4.28
– Rent and lease	3.36	3.29
– Contributions (international)	13.07	12.00
– Remaining	5.49	3.76
Interest	0.28	0.21
Depreciation	2.75	2.32
TOTAL	**62.98**	**60.05**

Source: Royal Netherlands Meteorological Institute – Annual Report (2012)

building costs will rise by discrete levels. Similarly, the relation between variable cost and production level may be more or less linear, but also non-linearity is possible – for example, in the case that there are economies of scale in production. In meteorological services there are also economies of scope, which means that the production of an additional second type or new service has a lot of commonality in production.

7.3.2 **User costs**

User communities will incur similar types of costs as those of producers of met/hydro services, particularly related to labour and purchased materials, energy, and the like. Individuals and households using services may incur some of the same types of costs, but on a smaller scale than businesses and other types of organizations. Businesses may incur significant costs to take decisions based on met/hydro services. If the acquisition and use of the information contained in a weather service product requires dedicated equipment, labour effort and knowledge, these costs may deserve inclusion in the SEB analysis of costs. For example, if favourable growing conditions are forecast, farmers may decide to grow higher valued crops for which input costs are also higher than for the crops they would grow in normal or drought years. Without the capacity to respond to the forecast, the user would not be able to generate any benefit. This type of cost is clearly more difficult to estimate than the costs to supply met/hydro services.

Another potentially large cost for users relates to access to met/hydro services. For example, an internal assessment of road traffic weather service effectiveness in the FMI covering the total annual cost of related media use in Finland was estimated at almost

€ 1 million (Nurmi et al., 2013). The information content of weather services reaches the users via a multitude of media channels. For individuals and households, some of the mechanisms for accessing met/hydro services may be free (for example, radio, television, specific displays in hotels and public places), while others may involve quantifiable costs (for example, newspapers, SMS messages, cell phone and tablet applications, e-mail subscriptions for tailored data and products). The charging for access to information recently relates less to the public or private nature of the provider and more to the degree to which the information is personalized or tailored to the user. The business model of non-personalized media is based on advertisement income and at times on annual subscription fees. For personalized media it is easier to charge a fee. At the same time, a rise of new media use has been observed, with a higher share of personalized delivery options (Elevant, 2010; Perrels et al., 2013*a*; Harjanne and Ervasti, 2014).

Even if the services are available free of charge, their costs will be reflected in the costs of the production and dissemination of this information by NMHSs, commercial weather services, and television and radio stations. Where access to information is available for a fee, there is the potential for double counting of these costs (incurred by both the producer and user) and the analyst should avoid including the costs of services incurred by users if accurate information is available on the costs of producing and disseminating met/hydro services information and products.

There are other types of costs that should be identified even if they are not easily quantified or are limited in magnitude. These might include:

- Use of public goods (for example, use of state-owned land for observation sites – within the government, access to these lands may be free of charge, but there is an opportunity cost associated with the availability of these lands for these purposes to the exclusion of others);

- Opportunity cost of time for non-commercial users to acquire, learn how to interpret and use met/hydro services information;

- External costs – these are costs caused by certain actors imposed on other actors, without the latter being compensated (sometimes a non-priced natural resource, such as a river, functions as intermediate). The production of met/hydro services usually do not generate external costs. However, the way that individuals, households, or businesses respond to information could impose costs on others.

7.4 SOCIOECONOMIC BENEFIT STUDY STEP 4: SCREEN COSTS AND SELECT THE ANALYTICAL APPROACH

The starting point in screening costs to be assessed in SEB studies is to recall the purpose of the study as described in the study step 2. If the SEB study is focused on whole of services, it will likely consider the full range of costs for providers and users described in SEB study step 3. When the study concerns changes in existing services or new services, only the incremental costs to produce and disseminate the improved or new services will be considered. For example, if an observation network is improved by adding new stations, incremental costs may include construction costs, costs of new monitoring and communication equipment, labour to operate and service new stations and additional costs to manage the higher volume of monitoring data.

While this may be a straightforward budgeting exercise for the NMHS or commercial weather services, estimating incremental costs for user communities can be quite challenging because the analyst must understand the types of actions that will be taken by users and the scale of use of the improved or new service. The estimation of incremental user costs will often require the analyst to make assumptions about user decisions and uptake of the improved/new services and possibly consider a range of assumptions in sensitivity analysis performed once benefits and costs have been evaluated and compared (see Chapter 8).

For most cost items, estimates can be made of per-unit costs of the element; for example, the unit cost of labour (per hour, day, or the like). When the total production costs and output volume (for example, number of warnings of a given type) are known, the unit costs of a certain service can be established. The unit costs may serve as a basis for establishing a charge for that service. If costs and output are not 100% proportional, the unit cost will change when the level of output changes, and therefore one should be cautious when a charge is based on the unit cost. The unit cost of the service can also be regarded as the average cost of that service.

7.5 SOCIOECONOMIC BENEFIT STUDY STEP 5: ANALYSE THE VALUE OF COSTS – QUANTITATIVE

Some economic studies require more precise estimations of costs than others, depending upon the questions to be answered by the analysis. Studies that are applied at a high aggregation level or that are of an explorative nature usually do not require a high precision of costs. With regard to justification of investments, the need for precision increases when the decisionmaking proceeds towards well-specified concrete alternatives. If accounting systems are adequate, precision should not create major problems in case of retrospective studies. In the case of acquisition of new equipment, due attention should be paid to maintenance costs in addition to the initial investment cost and expected performance level.

The challenge is to arrive at an acceptable representation of the costs of the selected met/hydro service(s) at each production or delivery link in the value chain. Since some costs may be shared with other service products or even with the entire organization, the locally mandated accounting system will determine in part how precisely costs can be allocated to selected services. Also the way state-owned facilities, such as office buildings, are charged – if at all – to public organizations affects the costing picture.

The legal status of an organization affects the way costs are reported. Private companies with share capital have to follow international and national rules on accounting practices. Public organizations are subject to national rules on accounting in public organizations, while European Union regulations (or those of other transnational agreements) may also affect accounting practices of public organizations. For example, in many countries the cost of public sector products within an NMHS is assumed to be "competition neutral", meaning that it should exactly reflect the costs of the efforts made to produce the public sector product and avoid overstating or understating of joint costs (see section 7.5.3).

7.5.1 **Treatment of capital costs**

In many public sector organizations, capital investments are budgeted as a one-off cost, that is, the acquisition is paid for in the first year. In this case, no capital accounting is applied and as a consequence there is no depreciation (reflecting the aging and upcoming need for renewal of equipment). As acquisitions are funded from the annual budget, the SEB analyst has to decide whether depreciation should still be reflected in the assessment or instead the actual budget cash flow should be presented in the cost calculation (see Box 7.1).

The capital stock can be valued in different ways. Common approaches are historical cost (that is, the original purchase cost) and replacement cost (the amount needed to replace the equipment by a current up-to-date version). Similarly, stocks can be valued in different ways, for example, based on the average value or based on the historical values when bought, or based on current or expected prices. The choice of the valuation base depends firstly on the available accounting data, but also on the purpose of the study (investment appraisal or judging past performance), and on methodological choices in the BCA (Chapter 8).

7.5.2 **Treatment of prices**

It is common practice in socioeconomic valuations to correct for inflation. In other words the analysis is often carried out in real prices. The uncorrected (inflated) prices are called nominal prices. The use of real prices means that all costs (and benefits) are expressed according to a price level of one particular base year – usually referred to as constant prices adjusted to a specific, typically recent year. Correction for inflation is not the same as discounting towards a certain base year (see Chapter 8).

In forward-looking valuations, including investment appraisal, real prices are also used. Apart from more detailed investment appraisal, forward-looking valuations can often simply assume away inflation and apply constant prices. However, in countries where high inflation rates and/or notable differences in inflation rates between product groups are assumed to persist, it is better to start with nominal prices.

The inflation rate is also relevant for the financing cost of new equipment, when funded by a loan or from a reserve (a kind of accumulated savings), which otherwise – in principle – could produce a yield. A loan means that the debt gets smaller in real terms, when there is inflation. Furthermore, in the case of a fixed long-term nominal interest rate, inflation may imply that the real interest costs are low or are decreasing over time. Short-term nominal interest rates tend to follow the inflation rate.

If a part of NMHS costs are due to purchases or service fees abroad, the behaviour of the exchange rate can significantly influence the costs. In principle the same applies to revenues, but generally, for most NMHSs, sales abroad tend to be much smaller than purchases abroad. If the national currency depreciates, the costs of purchases abroad increases for the NMHS. Some countries with heavily regulated foreign exchange practices may also apply differentiated exchange rates. Variation in exchange rates constitutes a risk over and above other cost overrun risks of investment projects.

Box 7.1: Assessing the costs of a new observation network in Nepal

The capacity-building project for the Nepalese Department of Hydrology and Meteorology, funded by the Finnish Ministry of Foreign Affairs, required a preliminary appraisal of the costs and benefits of modernizing the observation system. This project included installing 101 automated observation stations and three Doppler radars over the course of nine years. The summary of the cost build-up is shown below. During the project, it was emphasized that the network would need maintenance, including recalibration, as well as more support for data processing services. Both activities would require notable and lasting labour input, as is shown in the table. Labour cost data and labour force requirements were established in cooperation with the Nepalese Department of Hydrology and Meteorology. For the depreciation of the equipment (in NPV), a lifetime of 10 years is assumed. The costs are expressed in constant prices of 2011. The procedure to calculate NPV is explained in Chapter 8.

Preliminary cost assessment of modernization of the Nepalese Department of Hydrology and Meteorology (millions of Nepalese rupees)

	2013	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
Operational costs									
Met services	1.08	1.62	2.16	2.70	2.70	2.70	2.70	2.70	2.70
Maintenance	0.75	1.19	1.31	1.44	1.59	1.76	1.93	2.23	2.53
Data management	0.54	0.81	1.08	1.35	1.35	1.35	1.35	1.35	1.35
Total operational costs	**2.4**	**3.6**	**4.5**	**5.5**	**5.6**	**5.8**	**6.0**	**6.3**	**6.6**
Number of stations	5	17	29	41	53	65	77	89	101
Annual number of new stations	5	12	12	12	12	12	12	12	12
Investment costs									
Automatic stations	25	60	60	60	60	60	60	60	60
Radars			100		100		100		
Total investment costs	**25**	**60**	**160**	**60**	**160**	**60**	**160**	**60**	**60**
Depreciation costs	2.5	8.5	24.5	30.5	46.5	52.5	68.5	74.5	80.5

Source: Perrels (2011)

7.5.3 Attributing joint costs

Joint costs refer to costs made for facilities, which are serving multiple weather information production chains. Examples include the costs of the weather observation system, costs of weather data processing and modelling, costs of maintenance services, costs of buildings and of general supporting staff (for example, administration, catering, transport, and the like). Joint costs are an important feature in the costing of weather, climate and hydrological services.

Fees for international cooperative bodies (such as the European Organization for the Exploitation of Meteorological Satellites) are a special kind of joint cost, as the fee may also reflect a member country's ability to pay and/or reciprocity regarding both the use and supply of data. The total costs for an NMHS for all these international cooperative bodies together can be significant. For example, according to the financial statement of 2013 of FMI, a share of 6% (approximately € 4.5 million) of the total budget was allocated to these costs. This cost item can be treated in the same way as other joint costs.

Joint costs constitute an important characteristic in the cost structure of met/hydro services. A significant part of the overall costs of basic services has to do with the observation system, data processing and basic (multi-purpose) modelling, of which the output is serving many products of the NMHS directly or indirectly. On top of that, there are the typical overhead costs related to administration. Cost attribution can be based on:

– Volume flows (share in the number of messages, maps, and the like);

– Value flows (share in direct costs);

– Expected profit contribution;

– Cost carrying capacity (that is, a compromise solution which aims to minimize effects on service product use across a portfolio of information products); it may also be related to welfare maximization of the supply of a collection of weather services ("Ramsey pricing").[21]

The allocation of joint cost can be based on operating hours of certain services, on some kind of generalized output unit, on the share of direct total costs of an activity as part of all direct costs of a department or service package, or on the share of value added for a particular service. The first two attribution approaches can be calculated

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[21] Ramsey pricing is a pricing policy used to determine prices charged by monopolistic firms or public service providers, such as telecommunications or met/hydro services. Rather than a government requiring providers to charge only the marginal cost of their services, which may not be financially feasible due to economies of scale, joint costs, and other issues, when Ramsey pricing is applied individual service prices are raised above marginal cost based on the service's price elasticity of demand. Price increases over the marginal cost are lower for services with more elastic demand, and higher for services with more inelastic demand (also called the inverse elasticity rule). This approach seeks to maximize social welfare without diminishing the financial well-being of the relevant firm or service provider (Oum and Tretheway, 1988).

Box 7.2: Analysing costs to improve efficiency in Haiti

Met/hydro services in Haiti are currently fragmented across several institutions in charge of collecting, storing, processing, analysing and disseminating data. These include the National Center for Meteorology, the National Service for Water Resources, the National Observatory on Environment and Vulnerability, the National Center for Geographical and Spatial Information and the National Coordination for Food Security. With support from a number of partners including the World Bank Group, WMO, the Inter-American Development Bank, the European Union, USAID and the United Nations Development Programme, the Government of Haiti is aiming to reform, strengthen and user focus the weather, climate and hydrological services. As a component of the World Bank Group's investment analysis, it was determined that by consolidating the currently disparate observation systems into a coherent national network, optimization would lead to reduced operations, maintenance and data management costs. With current network operations constituting some 85% of total costs, reducing these even by a limited degree will have a substantial impact on cost efficiency. While the value of services will also be increased, it was recognized that without financial planning to adequately cover annual operations and maintenance costs (which are in fact greater than the network's capital value), the impacts of reform and investment will not be sustained (World Bank, forthcoming).

Similarly, cost assessment can also reveal economic efficiencies to be gained through regional cooperation. For example, through cross-border data sharing, technology transfer and capacity-building in the Mekong River Basin, individual NMHSs such as the Lao People's Democratic Republic Department of Meteorology and Hydrology could reduce investment needs for modernization by up to 40% (World Bank et al., 2013).

rather straightforwardly; for example, a particular joint cost item may represent an input to four different types of warnings. For a volume flow-based approach, cost is attributed to each type of warning as a simple proportion of the number of warnings, or adjusted if one or more warnings would likely involve a smaller or larger share of inputs and costs. A value-based attribution is similar, but depends on the relative cost share of each type of warning included in total costs. The latter two approaches, expected profit contribution and cost carrying capacity, require more elaborate background work.

7.5.4 Assigning prices to public goods and subsidized goods

For all costs, the first option is to use observed prices for purchases and reported costs for labour. However, if products are subsidized, the actual costs to society are higher than the observed price. Examples relevant for service chains are energy and the shared use of land. The difference between the paid charge and the actual market price (or a realistic estimate of the opportunity cost) should be added to the social cost of the met/hydro service chain.

The co-use of land is quite often a contentious issue in the costing of meteorological and hydrological observation networks in as far as observation stations are located on land owned by a third person. In this case, it is helpful to recall the opportunity cost principle introduced in Chapter 5. If the owner of the land has arguably valuable alternative use opportunities for the land parcel used for observations, compensation for foregone value may be justified.

Another phenomenon is cross-subsidization. This may mean that an organization is using surplus income from sales in a certain product group to compensate for losses in another product group. Cross-subsidization may be observed when (a) a supplier can charge high prices for certain products when there is no competition, and/or (b) a supplier is allowed to apply (joint) cost attribution in a way that allows keeping prices for some products quite low, while raising those of others.

7.5.5 **Opportunity costs of public funds**

If new services require significant investments, the method of financing the investments can also affect the eventual cost to society and must be considered. Financing frameworks can affect (a) the time profile of funding and payback period of a project; (b) the applicable interest or discount rate; (c) the opportunity cost of public funds. The time profile and the applicable discount rate are not cost items per se, and depend on many organizational and institutional characteristics of the project – the NMHS, the ministries involved and the credit rating of the country. The third factor, the opportunity cost of public funds, is relevant if a new project implies an additional claim on public finance resources. A government can fund additional public expenditures by a loan, by raising taxes and by raising non-tax revenues such as royalties from mining. All these options will affect a country's macroeconomy and thereby result in costs to society. A loan means that interest has to be paid, and if taxes are not raised this may mean that some other part of the state budget has to be reduced. If the investment is truly productive, tax revenues will go up in the long run and thereby the reduced budget segment can be recouped. Yet, at least temporarily, the loan has a negative effect on the macroeconomy. Furthermore, if the government is already heavily indebted, interest rates may go up, which would harm the economy in general. Extra taxation generally reduces economic growth. Raising non-tax revenues, such as royalties, is in principle the least harmful for a country up to the point where companies would start to rate the resulting profitability as too low. The acknowledgement of the opportunity cost of public funds should not be understood as a general plea against raising public revenue. Publicly funded services such as basic schooling and health care increase welfare. Nevertheless, the opportunity cost of additional public revenue raising merits being weighed against what it may reduce elsewhere in the economy.

Altogether the opportunity costs of public funds are rated as being quite high, both in Organization for Economic Cooperation and Development (OECD) countries (Massiani and Pico, 2013) and in developing countries (Auriol and Walters, 2012), in which a given sum spent in public funding may demand a multiple of 1.2 or 1.3 of that sum (or more) from the economy. The cited authors warn in both cases, however, that these are multi-country and multiannual averages. Country- and project-specific estimates may result in quite different estimates (both up and down). Opportunity costs are high within the public sector, especially in developing countries. Even though BCRs are often high for improvements in meteorological services of developing countries (World Bank, 2008; Perrels et al., 2013*b*), they are equally high when spent on public health care, sanitation or basic education. In other words, the opportunity cost of public funds is one reason that a BCR well above 1 is necessary to attain support for higher expenditure/investment levels (see Chapter 8).

7.5.6 Substituting capital for labour (automation)

Modernization usually brings about significant changes in the type and amount of labour used as well as in the relation between labour and capital. In the long run, such modernization generates significant extra benefits for the society at large, but there may be social costs to be accounted for as a result of changes in the types of labour required and the locations where labour is situated. For example, a transition from labour-extensive to automated observation systems will likely eliminate jobs requiring less skilled labour in rural areas, and replace them with fewer, higher skilled jobs in central locations. Thus, the modernization of the NMHS and its employment consequences fits into a larger picture of urbanization in developing countries and a concomitant migration flow from rural to urban areas (see, for example, Revi et al., 2014).

The transition of manual weather and hydrologic observation stations to automated ones implies a significant loss of paid work for station assistants, unless the assistants are re-educated for other tasks or quickly find other work of at least equal pay. So far, this aspect is not, or is minimally, discussed in socioeconomic project assessments of modernizations of NMHSs. Within the scale of NMHS projects, it seems nevertheless justified to pay attention to this potentially significant socioeconomic effect, even if it diminishes after several years.

To meaningfully represent the employment effects as costs in a socioeconomic valuation, it should become clear to what extent:

- Employees lose their jobs (without quickly finding employment with comparable pay);
- Employees are offered other jobs (with differentiation in possible income losses);
- Employees are trained for new jobs and tasks (in the NMHS);
- New jobs are created (with differentiation by skill and wage level);
- Decrease and increase of employment in the NMHS is spatially segregated.

And also:

- The estimated duration of unemployment;
- The average level of the (monthly) unemployment benefit paid out by the state or local authority or another semi-public agency. Also early retirement schemes and lay-off compensations paid by the NMHS should be considered, if clearly related to the project.

Eventually the societal cost of employee redundancy can be represented in terms of the cost to public funds of (a) unemployment fees paid out (n persons × m months × fee level); (b) early retirement schemes (n persons × y years × pension); (c) re-schooling costs. An alternative approach is to assess the sum of all incurred (net) income losses attributable to the project.

7.5.7 Uncertainty

Even though uncertainty is usually a larger problem for the valuation of benefits, cost figures can be uncertain as well. Investment costs tend to be underestimated. Also the opportunity costs (see section 7.5.5) of public funds can be mentioned, as these cannot be assessed precisely. Furthermore, in the case of a long-term project, changes in technology, regulations and in the labour market typically introduce uncertainty in the cost estimates. A typical solution is the use of sensitivity analysis, by deviations based on historical observations (for example, +/- 15%). The latter type of margin can also be obtained through an expert elicitation process such as a Delphi approach. For truly large projects a scenario approach could be chosen, for example, exploring different extents and timetables of deployment in conjunction with different evolutions in the foreseen use of the new services.

7.6 SOCIOECONOMIC BENEFIT STUDY STEP 6: ANALYSE THE VALUE OF COSTS – QUALITATIVE

For some types of costs, expressing their value in quantitative or monetary terms may not be feasible or desirable (as per the screening in SEB study step 4). It is always important, though, to describe these non-quantified costs in a meaningful, qualitative manner.

One approach involves the specification of a simple scale that indicates the likely impact on net project costs. Impacts can be qualitatively ranked on a 5-point scale, ranging from –2 to +2, to reflect unquantified relative outcomes that span from very negative to very positive (for example, a " –1" may signify an outcome with moderate unquantified costs and a " + 2" may represent a high unquantified cost). Qualitative ratings should be accompanied by descriptions of the impact and should be explicitly carried through the analysis. For costs or benefits that may have a significant positive or negative effect on decisions on the net benefit of a project, additional analysis could be taken to better characterize or even quantify those impacts. For instance, non-market valuation techniques (stated preference), stakeholder interviews, or expert elicitation (for example, through Delphi consultation rounds or group elicitation and decision support systems), may help to shed further light on the societal significance of the cost effect. Chapter 8 presents more information on those methods.

7.7 CONCLUSIONS

The identification and quantification of costs of met/hydro services production and dissemination is in general familiar to NMHSs and commercial weather services and thus relatively easy to undertake in an SEB analysis. Nevertheless, the analysis of costs provides challenges related to the treatment of investment costs, joint costs, public and/or subsidized goods or services, and the treatment of costs related to, for example, the automation of certain aspects of met/hydro services delivery such as observations. User costs, especially when SEB studies focus on ex-ante assessments of improved or new products, can be particularly challenging and may require the analyst to make assumptions about user responses that can be carried forward to sensitivity analysis of benefit–cost results.

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CHAPTER 8. BENEFIT–COST ANALYSIS

Chapter 1. Introduction
Chapter 2. Met/hydro services
Chapter 3. Purpose of SEB studies
Chapter 4. Designing SEB studies
Chapter 5. Economic essentials
Chapter 6. Benefits
Chapter 7. Costs
Chapter 8. BCA
Chapter 9. Communications
Chapter 10. Looking forward

8.1 INTRODUCTION

Benefit–cost analysis is a method for comparing the benefits and costs of a project, programme or investment over time and determining whether or not it improves or diminishes societal well-being. This economic information can then be considered as one of several factors that will help NMHSs or funding authorities take funding decisions on met/hydro services. Benefit–cost analysis involves a systematic appraisal of a programme (whole of services or specific met/hydro services) in order to quantify the full range of social, economic and environmental benefits and costs in monetary terms. The analysis can also be used for choosing among alternative approaches to achieving programme goals.

Building on concepts introduced in Chapter 5, Chapter 8 provides an expanded discussion of BCA decision criteria and the selection of discounting rates. Following this discussion, the remainder of the chapter focuses on SEB study steps 7, 8 and 9 in conducting an economic analysis (see Figure 4.2).

The primary reason for undertaking a BCA is to implement an accepted and unbiased economic analysis that considers all of the positive and negative impacts (characterized as benefits and costs) of a planned or potential investment or planned expenditure to support decisionmaking. In some countries or jurisdictions a BCA may be required by law for evaluating investments exceeding a certain financial threshold. Such an analysis can also be used as a framework for understanding and fully articulating those benefits and costs using a systematic approach that helps the analyst identify uncertainties and biases about the impacts of an investment.

8.2 BENEFIT–COST ANALYSIS CONCEPTS

8.2.1 Benefit–cost analysis decision criteria – Net societal benefit

For evaluating policy options, the fundamental principle of BCA is "choose the alternative with the greatest net societal benefit". This must include the possibility of "doing nothing" or not implementing any project in the case where the costs outweigh the benefits for the investments under consideration. Two key questions in implementing this principle are (a) what does "net societal benefit" mean, and (b) how do NMHSs measure it?

Net societal benefits

Net societal benefits are generally defined as the total benefits minus the total costs. But as discussed in the theory of economic valuation, benefits and costs are measurements of underlying utility at an individual level and thus aggregating to a societal level requires relating changes in welfare across all individuals. This presents a quandary as it is fundamentally impossible to measure utility changes on the same scale across all individuals (utility is subjective and means something different to each individual). Therefore, BCA proposes and uses rules for aggregating utility changes across individuals.

The rule used initially for BCA stated that the programme improves the welfare of society if it makes at least one person better off and no one worse off. This approach is unfeasible because there are very few programmes that leave no one worse off (for example, in the case of meteorological programmes paid for through taxation, some tax payers may be worse off if they never use meteorological information yet are still taxed in part to pay for met/hydro services). A more operational decision rule states that a programme has positive net benefits if the gainers could compensate the losers and still be better off. This rule is often called the Kaldor-Hicks compensation test.[22] This rule does not require that compensation should actually be made to losers, but only that the net benefits would be positive even if losers were compensated for their losses.

Criticisms of the use of BCA for decisionmaking when some individuals lose and others gain are usually related to ethical issues about the aggregation and comparison across individuals – or distributional issues. Building on results from BCA, policymakers quite often balance societal and distributional considerations beyond those captured in a BCA. Recognizing that BCA may only be one part of the decisionmaking process, it is important to explain the approach commonly used during the analysis. This focuses on the summation (adding up) of benefits and costs across the time frame of the programme and thus involves a process called "discounting".

8.2.2 Selecting the discount rate

As discussed in section 5.6, the benefits and costs of providing met/hydro services often vary from year to year. The discount rate is used to adjust these uneven future streams to the present to facilitate calculation of PVs to account for inflation and rate of time preference between the present and future magnitudes. This section provides a brief discussion of the process of selecting a discount rate to use in SEB studies.[23]

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[22] See Just et al. (1982) for a discussion of the Kaldor-Hicks compensation test, also known as the Kaldor-Hicks compensation principle.

[23] Some of the concepts and decisions related to the discount are technical issues critical to undertaking a valid BCA and may require further guidance from governmental or policy authorities or qualified economists. This is especially true for very long time horizons such as may be involved with climate change decisionmaking. See, for instance, Goulder and Williams (2012).

Economic theory suggests that in a world with no inflation, no taxes, no financial transaction costs, and zero risk, there would be a clear signal about what discount rate to use. If consumption today came at the expense of investments in the future, the opportunity cost of capital should be used to discount the stream of future benefits and costs. In that case, the discount rate should be equal to the rate of return that could be earned by investing the money. For example, if inflation is expected to be 4% in the future, and there is a 3% risk-free real return on capital, the real discount rate would be 3% and the nominal discount rate would be 7% (3% + 4%). But if the use of funds or resources today predominantly displaces future consumption (instead of investments), a social rate of time preference will be more suitable as the discount rate.

There are often regulatory and other practical aspects to the choice of discount rate, and economists and policymakers do not always agree about the correct discount rate to apply to project valuations. For BCAs of NMHSs, which are generally investments made for broad public benefit, it may be most appropriate to use a real, net-of-tax, social rate of time preference as a real discount rate to convert all values to their present worth. But justifications can be made for a range of rates, from a zero discount rate to a rate that reflects the private costs of capital.

Some argue for a zero discount rate, believing that discounting underestimates project benefits or costs that may occur far into the future (affecting future generations), or that include irreversible outcomes (for example, species extinctions). In a highly publicized British Government study (*The Economics of Climate Change: The Stern Review* (Stern, 2007)) the author argues for powerful and urgent actions to mitigate climate change, such as carbon pricing, on the premise that the future economic costs of unabated climate change (roughly 5% of global GDP annually) will far exceed the costs of climate change mitigation actions in the present (roughly 1% of global GDP annually). Importantly, his calculation is based on using a discount rate of just 0.1%, which places virtually equal value on costs and benefits accruing to both present and future generations.

Some leading economists, such as W.D. Nordhaus of Yale University, dispute the use of such a low discount rate, arguing that it is not consistent with current market place real interest and savings rates, and thus cannot be used to justify the high level of climate change mitigation expenditures proposed by Stern (Nordhaus, 2007).

Similar to Nordhaus, many economists suggest that the discount rate should reflect prevailing interest rates on low-risk bonds, because such risk-free, net-of-tax rates best reflect the rate of social time preference. This might be reflected by the real cost of capital to municipal agencies in raising capital through bonds, or by the cost of long-term federal government bonds. Some advocate using the private cost of capital, believing that the project's funds might be otherwise invested in private ventures, and that therefore, this measure reflects the true opportunity cost.

Due to differing viewpoints on the correct discount rate and how it should be best calculated, discount rates tend to vary widely among different countries and lending institutions. Zhuang et al. (2007) surveyed the discount rates used for public projects in 14 countries around the world, finding rates as low as 2%–3% in developed nations such as the United States and Germany, and as high as 12%–15% in developing countries such as Pakistan and the Philippines.

Multilateral development banks also apply variable discount rates that generally tend to fall more closely in line with the higher rates used in developing countries. The World Bank provides guidance on calculating the discount rate in its *Handbook on Economic Analysis of Investment Operations* (Belli et al., 1998). The Bank notes that it has traditionally used a notional discount rate of 10%–12%, but its task managers may use a rate outside this range as long as it is justified in the country assistance strategy.

The Asian Development Bank specifies its discount rate policy in its *Guidelines for the Economic Analysis of Projects* (Asian Development Bank, 1997). Similar to the World Bank, rates used at the Asian Development Bank may vary across sectors, countries and timescales, but tend to be 10%–12% at minimum. The other major multilateral development banks (the Inter-American Development Bank, the African Development Bank and the European Bank for Reconstruction and Development) also tend to use rates in the range 10%–12% (Zhuang et al., 2007).

There is a broad and growing literature on appropriate discount rates and functional forms to use for discounting that are especially relevant to long-term decisionmaking (for example, intergenerational decisions, as may be relevant to climate change issues). This publication does not examine that literature but readers may find the following papers of interest: Aalbers (2009); Gollier and Weitzman (2009); Baum and Easterling (2010); Weitzman (2012).

8.3 SOCIOECONOMIC BENEFIT STUDY STEP 7: SUMMARIZE AND COMPARE ALL BENEFITS AND COSTS

Following SEB study steps 5 and 6 (discussed in Chapters 6 and 7), the analyst has all the quantitative and qualitative information on the stream of costs and benefits that have been estimated for the change in met/hydro services. Step 7 involves two distinct calculations. First, all costs and benefits must be adjusted and aggregated into PV terms employing a discount rate specified in regulations or agreed to by the NMHS and government decisionmakers. Second, the analyst will compare the two PV terms, typically by applying the net benefits or the BCR decision criterion. This section provides detailed discussion of the development of PV sums and the comparison of quantified benefits and costs, followed by discussions of qualitative benefits and costs, and distributional issues.

8.3.1 Net present value and project decision criteria

Most investments or planned expenditures will involve costs that vary from year to year and an uneven stream of benefits. Whether a single investment, or multiple investments with varying temporal profiles of costs and benefits are to be evaluated, the discount rate is used to adjust future values to the present to determine the investment's PV of costs and benefits. If both benefits and costs are involved, the NPV of the investment is determined by subtracting the PV of the costs from the PV of the benefits. If the NPV of a project is greater than zero, the PV of the benefits is greater than the PV of the costs. The NPV of different projects can be compared if they are adjusted to a standard monetary basis, for example, 2010 United States dollars. Assessment of NPV of different projects allows direct comparisons of project values regardless of possible differences in the timing of benefits and costs for each project.

The Kaldor-Hicks compensation test can be stated in NPV terms: if the NPV is positive, the project is acceptable and should be undertaken; if the NPV is negative, it does not provide an improvement in societal well-being and should not be pursued.

Table 8.1 presents a simplified numerical example of discounting and calculation of NPV. The dollar values for benefits and costs shown are entirely made up for illustrative purposes only to show the impact of the use of different discount rates. The first column indicates the year during which benefits and costs are projected to occur. The next two columns under the heading "Discount rate = 0%" indicate the temporal flow of annual benefits and costs estimated at the current year dollar. Implicitly presenting these as undiscounted is the same as using a discount rate of 0%. Then, the discounted benefits and costs for each year are shown using discount rates of 3% and 7%, respectively. These are calculated using the following formula for benefits:

$$PV\ benefits_t = \frac{B_t}{(1+r)^t}$$

where *PV benefits* is the PV of the benefits from year t, B is the dollar value, and r is the discount rate. For instance, referring to Table 8.1, using the PV of year 5 benefits using a discount rate of 3% is:

$$PV\ benefits_t = \frac{50}{(1+0.03)^5} = \frac{50}{1.1593} = \$\,43.13$$

The PV of costs in year t (*PV costs*) is calculated using costs, C, rather than benefits:

$$PV\ costs_t = \frac{C_t}{(1+r)^t}$$

In Table 8.1, the total discounted value of benefits and costs are summed and recorded in the row "Total PV". The NPV is then calculated by subtracting the total PV costs from the total PV benefits and this is recorded in the row labelled "NPV".

Without discounting, it can be seen that for $r = 0\%$, the NPV is US$ 35.00. When applying a discount rate of 3%, this NPV decreases to US$ 20.08. At a rate of 7%, the NPV becomes US$ –8.16. Using the criteria that a positive NPV indicates that a project is worth doing and a negative NPV indicates a project should not be undertaken, this

Table 8.1. Simplified example of discounting

	Discount rate = 0%		*Discount rate = 3%*		*Discount rate = 7%*	
Year	*Benefits*	*Costs*	*PV benefits*	*PV costs*	*PV benefits*	*PV costs*
0	0.00	100.00	0.00	100.00	0.00	100.00
1	25.00	50.00	24.27	48.54	22.68	45.37
2	50.00	10.00	47.13	9.43	41.16	8.23
3	50.00	10.00	45.76	9.15	37.35	7.47
4	50.00	10.00	44.42	8.88	33.89	6.78
5	50.00	10.00	43.13	8.63	30.75	6.15
Total PV	225.00	190.00	204.71	184.63	165.84	174.00
NPV		35.00		20.08		–8.16

example shows the importance of the choice of the appropriate discount rate. In this case, with identical constant dollar benefits and costs, an increase in the discount rate from 3% to 7% would change the decision on whether or not to undertake this project.

As can be seen in Table 8.1, whether an investment will yield positive net benefits may depend on the choice of discount rates used in the analysis. The analyst is advised to undertake sensitivity analysis as described later in this chapter to examine the impact of different rates of discount on the decision. If positive net benefits are observed over a reasonable range of discount rate, the analysis can be considered to be robust with respect to choice of discount rates.

As a final note on discounting, the formula for NPV is simply the sum of the difference in PV of benefits and costs:

$$NPV = NP\ benefits - NP\ costs = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t}$$

The symbol Σ (Greek letter sigma) means that the benefits and costs are added up over all time periods from the present year, denoted $t = 0$, up to and including the final year in which benefits and costs are estimated, $t = T$.

In the preceding discussion, it was indicated that NPV is the appropriate measurement for decisionmaking in BCA. Alternative ways of summarizing the outcome of a BCA include BCRs and internal rates of return (IRRs). These measures use exactly the same benefit and cost measures as in the NPV approach but summarize them a little differently.

For the BCR, simply divide the present value of benefits by the present value of costs (rather than subtracting the present value of costs from the present value of benefits as in NPV):

$$BCR = {NP\ benefits}\Big/{NP\ costs} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} \Bigg/ \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$

A decision rule for use of the BCR is that any project with a BCR larger than 1.0 is worth undertaking (that is, improves societal welfare) and any project with a BCR less than 1.0 is not worth pursuing. As an example, using exactly the same benefit and cost flow indicated in Table 8.1, Table 8.2 shows the calculation of the BCR (for just the 3% discount rate example). In this case the BCR is calculated to be approximately 1.1.

A limitation to use of the BCR is that is does not indicate the magnitude of the investment. If only BCR measures are used to choose between investments, the investment with the highest BCR may be a small, low-cost investment and generate insignificant benefits to users. However, when there is a budget constraint on public investment funds, BCR will facilitate comparisons between investments in met/hydro services as opposed to other public investments.

Alternatively, the IRR is the rate of discount (*r*) such that the NPV of the project is zero (if such a rate exists). Thus, we solve the following equation for the rate (*r*) that will make NPV equal to zero. In some sense, the IRR represents the return on the investment. If the IRR is greater than the societal rate of time preference the project is said to increase societal benefit (that is, it is a good investment for society):

Table 8.2. Example of benefit–cost ratio

	Discount rate = 3%	
Year	*PV benefits*	*PV costs*
0	0.00	100.00
1	24.27	48.54
2	47.13	9.43
3	45.76	9.15
4	44.42	8.88
5	43.13	8.63
Total PV	204.71	184.63
BCR	204.71/184.63 = 1.109	

$$NP\ benefits - NP\ costs = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} = 0$$

A limitation of the IRR is that in some projects it is possible to have multiple IRRs that will make the equation equal to zero and it is not clear which IRR to use for decisionmaking. Similarly to the BCR, the IRR also does not indicate the absolute magnitude of the project.

In general, it is recommended at a minimum to report the NPV from the analysis. The BCR can also be reported as this number is often used by policymakers and may be easily understood by individuals unfamiliar with the concept of NPV.

8.3.2 **Reporting qualitative benefit and cost information**

In addition to reporting the results of the analysis of benefits and costs using one or more of the three decision criteria presented in the previous section, the analyst should also present a listing of those benefits and costs that have not been quantified in the SEB study. In some cases, not all benefits will be quantified with government decisionmakers. These non-quantified benefits will generally fall into two categories: (a) benefits that would normally be monetized but are not for the SEB study because of limited resources or time constraints; (b) benefits that are difficult to monetize. In terms of costs, estimation of the costs of NMHSs is straightforward but costs for users to take actions based on met/hydro services may entail resources and time that are unavailable for the SEB study. Some benefits estimation methods, such as CV methods, attempt to elicit net benefits information, reducing the need to have benefits and costs information available for user communities. In addition, estimation of external costs resulting from user community decisions will typically be beyond the scope of the SEB study.

For all of the non-quantified benefits and costs, the analyst should provide an assessment of their likely magnitudes and if possible a ranking of all terms, and indicate how the various terms, if quantified or quantifiable, would likely impact on the net benefits, BCR, or IRR calculations that have been presented for the SEB study.

8.3.3 **Distributional issues**

The methods used for BCA described so far are based on the approach that adding benefits and costs to derive NPVs reaches a socially optimal outcome regardless of who bears those costs or realizes the benefits. In essence this approach is blind to the conditions of the affected individuals or of social norms about equity and distributional issues. Often, regulatory analysis or BCA studies take this approach (Robinson et al., 2014). However, it is important to consider that benefits or costs may accrue to specific groups, sectors or regions and such differences would not be considered "fair". For instance, a tax may be imposed on all people in a country to support an improved met/hydro service, but the benefits may only accrue to a smaller portion of the population that has access to forecast information (for example, has televisions) and the ability to use that information to improve their well-being or profits.

If distributional or equity considerations are to be considered in the SEB study, they should at a minimum be qualitatively identified and described so that decisionmakers are aware of them when using the information from the BCA. More advanced approaches to distributional issues can include applying different "weights" to benefits or costs depending on to whom they accrue. For instance, if high-income individuals are most likely to benefit at the expense of poorer people, weights inversely proportional to income (for example, as a ratio to average income) may be applied to the benefits and costs in the aggregation process. Taking our prior formula for calculating NPV, we can incorporate individual weights, $\left(\frac{\bar{Y}}{Y_i}\right)$, which is average income divided by the individual's income. This is then multiplied by each individual's benefits and costs and added up across all individuals (that is, the additional summation from $i = 1$ through $i = I$):

$$NPV = NP\ benefits - NP\ costs = \sum_{i=1}^{I}\sum_{t=0}^{T}\left(\frac{\bar{Y}}{Y_i}\right)\frac{B_{it}}{(1+r)^t} - \sum_{i=1}^{I}\sum_{t=0}^{T}\left(\frac{\bar{Y}}{Y_i}\right)\frac{C_t}{(1+r)^t} = \sum_{i=1}^{I}\sum_{t=0}^{T}\left(\frac{\bar{Y}}{Y_i}\right)\frac{B_t - C_t}{(1+r)^t}$$

There are a number of equity issues involved in choosing a correct set of weights to use in such distributional BCAs that should be very explicit, as the choice of such a weighting approach can be easily manipulated to reach some desired outcome that may not be consistent with public policy processes.

8.4 SOCIOECONOMIC BENEFIT STUDY STEP 8: LIST ALL OMISSIONS, BIASES AND UNCERTAINTIES

In this step, all omissions, biases and uncertainties associated with the estimated benefits and costs are explicitly documented. Omissions will mainly relate to user groups for which benefits and costs have not been quantified. The analysis may have been truncated to include a subset of user communities. For those not included in the analysis, it would be useful to list the user communities omitted and the types of decisions and actions they might take in response to service information. As discussed in Chapter 6, there are a number of potential biases associated with benefits methods such as CV. Whenever possible, the analyst should describe the nature of the bias and how it may have affected the analysis and calculation of benefits.

The analyst should also document key assumptions that underlie the estimate of benefits or costs. For example, for a new met/hydro service, assumptions may be required about the rate of adoption of the new service, as well as the types of decisions that users would be expected to take in response to it. Since benefits of new services will typically lag behind investments to develop the services, the rate of adoption would be expected to rise over time. Assumptions may also be required to determine how benefits are to be attributed to the change in services as opposed to other types of information as users will often consider multiple types of information before taking actions.

These types of assumptions, combined with omissions and biases, will engender uncertainty about the magnitude of benefits and costs estimates. In addition to highlighting uncertainties and their sources in the SEB study results, the analyst may provide analysis indicating whether different uncertainties are likely to result in underestimates or overestimates of benefits and costs. By explicitly identifying and analysing these uncertainties (by conducting sensitivity analysis (SEB study step 9, below)), analysts will often deflect potential criticism of the BCA by honestly recognizing the limitations of the analysis.

8.5 SOCIOECONOMIC BENEFIT STUDY STEP 9: CONDUCT SENSITIVITY ANALYSES ON KEY VARIABLE VALUES

Sensitivity analyses on key variables of benefit and cost estimates is conducted with the aim of exploring and communicating the impact of assumptions, uncertainties, or natural variability in the SEB study results. Sensitivity analyses are used to identify which assumptions or uncertainties have the largest impact on the outcome of the analysis (for example, to identify which assumptions might change the net benefits of an option from positive to negative or to alter the ranking of options in terms of their relative net benefits).

Two potentially significant sources of imprecision in value estimates should be noted. One is variability – the natural variations in an estimate resulting from its properties or the forces acting on it. For instance, met/hydro services never predict weather perfectly and thus there will be imprecision in the value of information simply due to the natural variability in the atmosphere. Thus, no valuation study should indicate the value of "perfect information" except as a potential upper-bound estimate of the value of information. The other source of imprecision is uncertainty about an estimate that arises from our lack of knowledge about the true value (for example, is the value of improved weather forecasts US$ 25 per household or is it US$ 250?). Both variability and uncertainty can lead to imprecise estimates and both are reasons why estimates should be represented with a range of values instead of just a single value. Although a single "best estimate" or mean value can be used, sensitivity analysis will help to identify and explore the range of possible values. Using a range of values instead of only a single estimate can avoid any perception that the analysis is tilted towards a desired outcome. It will also help to indicate how certain NMHSs are about the results of the analysis (for example, a narrow confidence interval as opposed to a very broad confidence interval around the central estimate of the NPV).

In many cases it is important to explore the impact of uncertainties or key assumptions (such as the choice of discount rates or the use of benefit transfer-based estimates – or even whether an NMHS programme will improve the quality of information that users receive) using sensitivity analysis. Using this approach, the value of a key input variable can be systematically changed to see how it affects the outcome of the analysis. The change in results can illuminate how important the impact of uncertainty in a particular variable is to the outcome. Sensitivity analysis is often performed by varying a particular input by equal amounts greater to and less than the current value.

For example, if we choose a discount rate of 9% for the main analysis, we might vary that value in increments of 3 percentage points from 0% to 15% for the sensitivity analysis. Table 8.3 shows an example of a sensitivity analysis for the discount rate applied in this fashion to the range of benefits and costs. Other key variables should also be considered in sensitivity analysis. For instance, if it is uncertain whether or not a particular forecasting method will work, or how well, the BCA sensitivity analysis evaluates NPV under different potential outcomes of the forecasting method.

Sensitivity analysis (also called "scenario analysis" [24]) is an important tool for helping met/hydro services understand the effect of uncertainty. By examining different conditions with different values from the range of uncertainty for key variables, we can determine whether the uncertainty in the underlying variables is important to the ultimate outcome of the analysis or the decisions to be made based on the analysis. This knowledge can help us focus future research efforts on the most productive

Box 8.1: Monte Carlo method

The Monte Carlo method is useful in situations where multiple sources of variability or uncertainty can have profound impacts on estimates of benefits, risks, costs, or all three. The Monte Carlo method can be applied when the range and likelihood of plausible values for the key variables are understood well enough to characterize those values with a probability distribution. The Monte Carlo method can easily be used to reproduce the analysis in a computerized algorithm and can be especially useful when multiple variables can potentially interact to establish the true character of the risk being studied.

In Monte Carlo analysis, one should start by characterizing probability distributions for key input variables using data and knowledge developed through experience. For first approximations, it is often sufficient to assume relatively simple distributions for many types of phenomena (for example, uniform, triangular, normal or log–normal distributions). The distributions of any two variables, however, are usually treated as independent of each other. If the variables always move together – either in the same or opposite directions – the variables may not be independent and their joint relationship must be accounted for in the analysis. The Monte Carlo method uses computers to draw a large number (for example, more than 1 000) of random samples for each possible combination of variable values. The random draws are guided by the probability distributions, such that more probable outcomes are drawn more frequently than less probable outcomes. The analysis is then replicated for each sample draw of input variables and a final output is obtained for these inputs. When the final outputs for all sample draws are gathered together, the result is a probability distribution of the final output, based on the combined probabilities of each of the underlying input values. This result can give decisionmakers useful insights about the likelihood of a given outcome (for example, what the probability is that a project's NPV will be positive when the NPV outcome is influenced by several variables whose values are uncertain).

Source: Black et al. (2009)

[24] Scenario analysis is more common in financial analysis for investments. Some definitions indicate that scenario analysis involves setting uncertain variables as maximum values and assessing the outcomes – essentially evaluating the worst and best case scenarios.

Table 8.3. Sensitivity analysis applied to discount rate

Discount rate (%)	*PV monetized benefits**	*PV costs**	*Monetized net benefit (as NPV)**
0	49 000–51 500	30 000	19 000–21 500
3	39 500–41 700	26 000	13 500–15 700
6	29 500–34 000	22 000	7 500–12 000
9	15 950–21 300	16 000	(50)–5 300
12	8 500–14 000	11 000	(3 500)–3 000
15	2 500–8 000	8 000	(5 500)–0

* Thousands of US$.

topics, improving the BCA at the same time. The example in Table 8.3 looks at the sensitivity with respect to a single uncertain variable (in this case the discount rate). Often, however, several variables in the analysis may be uncertain and should be evaluated together in terms of their joint impact on potential outcomes. One useful approach to the case of multiple variable uncertainty, the Monte Carlo simulation or analysis, is outlined in Box 8.1.

Sensitivity or scenario analysis is somewhat different from evaluating different projects or courses of action. As mentioned previously, if the agency has the option (or potential) of either supporting ongoing operations and maintenance costs or not supporting them, this could significantly impact the long-term flow of benefits from a project. While this may often be evaluated under the rubric of sensitivity analysis, it may really be a situation of evaluating two different future conditions or essentially different programmes.

Sensitivity analysis generally involves replicating the analysis under different conditions of potential outcomes of key variables. These are generally characterized with some degree of probability and thus involve risk as opposed to uncertainty. For instance, it be may be unclear how much a new radar facility will improve forecast quality in a certain region of a country and thus different values of the potential improvements (for example, low, medium, and high values of the improvements) should be evaluated with sensitivity analysis. Uncertainty is defined as not knowing the probability distribution of potential outcomes or not knowing what the whole range of outcomes may be. For instance, in an ideal situation, data would be available for statistically estimating confidence intervals for benefit or cost estimates. Statistically estimating confidence intervals, however, may not be possible. When data are available to make this possible, ranges are developed for an estimate by stating the upper and lower bounds. When bounding of an estimate is not possible, we can at least characterize uncertainty qualitatively by describing the sources of uncertainty and stating whether an estimate developed is likely to over- or underestimate the true value.

It may also be useful to use sensitivity analysis to determine at what level of a key variable the decision outcome would change (for example, the level of forecast improvement related to a new radar at which the NPV changes from positive to negative). Expert judgment may then be used to evaluate how likely in the real world that level of the key variable will be.

8.6 CONCLUSIONS

The comparison of benefits and costs represents the final major step in conducting the SEB study and provides the decisionmaker with an economic measure of the value of the proposed investment to society. As noted, careful selection of the discount rate to be applied in calculating net values for benefits and costs can have a major impact on the outcome of the BCA. In general, with high discount rates, for investments with significant front-end costs it will be more difficult to demonstrate net benefits. The presentation of the quantitative results, listing and analysis of non-quantified benefits and costs, discussion of omissions, biases, assumptions and uncertainty, and analysis of sensitivity of results to alternative specification of uncertainties, affords the decisionmaker an opportunity to determine how robust the results are and will help NMHSs communicate the SEB results to a range of audiences.

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CHAPTER 9. SOCIOECONOMIC BENEFIT STUDY STEP 10: COMMUNICATING THE RESULTS OF SOCIOECONOMIC BENEFIT STUDIES

Chapter 1. Introduction

Chapter 2. Met/hydro services
Chapter 3. Purpose of SEB studies
Chapter 4. Designing SEB studies

Chapter 5. Economic essentials
Chapter 6. Benefits
Chapter 7. Costs
Chapter 8. BCA

Chapter 9. Communications

Chapter 10. Looking forward

9.1 INTRODUCTION

The benefits provided to society through meteorological and hydrological services are widely accepted as being substantial, and are especially evident in extreme weather, climate and river conditions. However, they are not usually expressed numerically following a rigorous economic valuation exercise. Thus, there is a particular need to devise a specific communication strategy around the preparation and execution of an SEB study. Even before the study begins, this strategy should be designed to ensure that the results of the study are communicated effectively internally as well as externally to the relevant decisionmakers, a wide variety of stakeholders and to the public. The overall communication objective is to create a strong and consistent message coming from the NMHS that gains or maintains public support as well as generating greater diffusion of weather-related information from the met/hydro services. Chapter 9 covers the final step of the 10-step process – formulating and communicating results to decisionmakers and stakeholders.

This chapter, a follow-up to guidance on designing the SEB study in Chapter 4, will focus on the different elements of a communication strategy, from identifying the most appropriate audiences to working with the various communication media to greatest effect, as well as ensuring that the SEB study lessons learned are best employed.

An NMHS communication strategy should focus first on practicalities – what message is to be conveyed related to the SEB study implementation and results, who is to be reached, what sort of delivery channels are to be used and how are these to be best utilized. Although communication strategies are discussed in the penultimate chapter of the publication, these should be developed in parallel with the detailed scope of work to ensure they are timely and appropriate at each step in the SEB study implementation and outreach.

9.2 USER INTERACTION, SATISFACTION AND VALUE

As outlined in Chapter 3, rather than attempt a whole-of-service study, in many cases it will be easier to both measure and illustrate the economic value generated by forecast, warning, and other information and advisory services that are provided to a specific client or a specific sector. The benefits and costs from a forecast or a warning are easier to define than those associated with the range of decisions also affected by met/hydro services. Following an SEB study, therefore, there exists an opportunity to tell a comprehensive story about the economic benefits that derive from weather information in these circumstances. By storytelling, or translating the study's data into narratives, a greater success in reaching your intended audiences can be created. However, for an NMHS to use these instances as an example of their beneficial outcome presupposes an excellent working relationship between the organization and the client or sector in question.

The interaction of an NMHS with its users must be a two-way process and involve a focus from both parties to learn more about the business of the other; it takes time and consistent communication. The NMHS staff need to know and understand the business of the client to be able to tailor the available weather information most effectively. The client needs to understand not just the potential afforded by meteorological guidance but also the limitations of such guidance. Deep interaction between NMHSs and their clients should lead to a high level of user satisfaction. During this time, an NMHS should constantly monitor, formally or informally, the level of this satisfaction. It is only then that the question of user value should be approached.

Understandably, a commercial enterprise may not be willing to reveal to a service provider (in this case, an NMHS), or to the public, the detailed financial information which would allow the full value provided through meteorological services to be identified. It is imperative that any communication of SEB study results deriving from such specific clients or sectors should be fully cleared with the users in question before being released to the public or employed in any other communication context.

9.3 UNDERSTANDING AND INTERPRETING SOCIOECONOMIC BENEFIT STUDY RESULTS

9.3.1 Policy aspects

Any consideration of the results of an SEB study should be prioritized in the context of the definition of the organization's role and mission. This definition may have been determined through one of a number of processes:

– There may be a meteorological law that stipulates the role and responsibilities of the NMHS (Rogers and Tsirkunov, 2013);

– There may be a governmental or ministerial order or a similar formal decision that defines these roles and responsibilities;

– In the absence of these there will be established practice which can be augmented by reference to authoritative documentation, such as the WMO guidance on the role and operation of NMHSs (WMO, 2013).

While a definition of the role and responsibilities of an NMHS will not normally delineate the expected economic benefits explicitly, the anticipated societal benefits will usually be articulated in this definition, or may be inferred from it. This definition can provide a benchmark against which the results of an SEB can be measured. Emphasis on how the NMHS is meeting its public duty commitments needs to be a key aspect of any campaign to communicate the outcomes of an SEB study.

Many NMHSs follow policies based on the commercialization of weather data. In some cases, these policies are established by central government as part of a cost recovery programme, whereby users of publicly funded information contribute to the costs of collecting that information. However, an SEB study may allow a more rounded, holistic view to be taken of the value of weather data, whereby the total value to a national economy of well-delivered meteorological and hydrological products and services can be set against the cost of providing those services. In the commercialized model, the total value of meteorological data is established by what the market will pay for that information, which is often only a fraction of the total cost of data acquisition and collection. A model which can estimate the entirety of the economic contribution made through NMHS products and services, including some estimation of the value of archived information for future use, provides a more realistic measure of the value of those entities.

9.3.2 **Economic aspects**

Climate services have recently come to the forefront due to the establishment of GFCS by WMO. This initiative is partly a response to the increasing threat to lives and livelihoods posed by climate change, but the concept of climate services is not. Climate services involve the provision of meteorological and related information on climate timescales (months, years, decades and centuries). These data are typically highly statistical in nature, providing information on the mean and extreme values of specified weather parameters, or on the statistical likelihood of certain thresholds (for example, low temperatures, or rainfall accumulations) being reached or exceeded.

Going beyond economic valuations must likely include narratives of experience; this will strengthen the expert analysis by distilling the information in an understandable form. While economic benefits can be quantified in numerical form that will be important when communicating the outcomes of an SEB study, there are other, broader, societal benefits which are more difficult to quantify, but which are nonetheless real and substantial. Among these are the “convenience benefits”, which accrue when people schedule their daily or weekly activities to take advantage of good weather and avoid inclement conditions. It may be difficult to aggregate these benefits across society in any meaningful way, although some suggested approaches are discussed in Chapter 6 and featured in case studies in Appendix E. Nevertheless, such benefits can be communicated effectively through these narratives and stories that flow from the experiences of real people. The more the narratives can relate to a greater number of people the better, as it will lead to a greater appreciation of the value of good meteorological advice and guidance. Narratives have often been supported by expert commentary from psychologists and similar, and framed with quantitative analysis of the overall benefits from met/hydro services.

Routine forecast services provided to members of the public and to specific agencies or commercial entities are core functions of NMHSs. It is through these services and the surrounding interactions with users that an NMHS can establish and build a reputation for reliability, credibility and service quality. It is therefore important that a study team includes these routine services in some manner and equally important that the communication of the outcomes relating to these services be given significant emphasis.

These routine services are the strongest connection an NMHS has with its user base, and form the fundamental underpinning of the strength of the NMHS brand. The derived benefits will frequently be more societal than purely economic, but as outlined in Chapter 6 these benefits can be quantified, albeit not always in a fully economic sense.

Ideally, the communication of, and discussion around, SEB study outcomes will be related to some established baseline for comparison purposes, such as past studies in the country or similar studies in other countries, sectors or regions. However, this will rarely result in directly comparable studies and the interpretation and understanding will need to take full account of key differences.

At the other end of the weather spectrum are the severe weather and hydrological events, which are now more often referred to as high-impact weather. Warnings of high-impact weather are the most basic task of any NMHS and contribute directly to the mission of all governments to ensure the safety and security of its citizens.

While substantial benefits are provided by NMHSs through routine meteorological and hydrological services, especially significant societal benefits will likely arise in the context of periods of severe or high-impact weather. Such foreknowledge can facilitate some measure of control among members of the public faced with severe weather events, as opposed to the feeling of powerlessness when the impacts of severe weather or flooding arrive without adequate advance warning.

Statistics available in the *Atlas of Mortality and Economic Losses From Weather, Climate and Water Extremes (1970–2012)* (WMO, 2014) indicate a significant fall-off in the number of lives lost to weather hazards during recent decades. These figures suggest that the NMHS community has been successful in promulgating warnings that allow people to be moved away from approaching danger. However, the trend of economic losses due to weather-driven disasters has been increasing rather than decreasing over time. It is much more difficult to move economic resources (for example, property) away from the path of an approaching hazard, or to protect them effectively. Thus the amelioration of economic losses from high-impact weather due to weather warnings will probably be greatest in saving lives or preventing injury. There will usually be some measurable benefit from the removal of mobile economic assets from the path of a hazard (motor vehicles or livestock, for example, or the moving of electrical goods and soft furnishings to higher floors in a property when flooding threatens).

The communication of economic benefits deriving from warnings of high-impact weather will thus be best served through a mix of numerical economic benefits and narratives which relate to actual experiences. The broader societal benefits, as noted above, relate to the improved psychological outcomes among those who have experienced weather disasters but who have had some control in the mitigation of risk due to forewarning, and can also be cited. The very large sums typically expended on infrastructure, and guided by long-term planning, provide a basis for describing and communicating the benefits that can be derived from climate services. As an analogy, planning is akin to mapping the future and the costs of climate services are part of the necessary cost in drawing that map.

9.4 SOCIOECONOMIC BENEFITS STUDY RESULTS TRANSLATED INTO AN AUDIENCE MESSAGE

An SEB study can be a rich source of information for the management team of an NMHS. This information can guide decisions, strategies and actions on a number of levels. This section examines in turn a number of means to best utilize the results of an SEB study when discussing with external audiences.

Public and private advocacy

Elaborating the case for resources: All NMHSs rely on core funding from government, whether this is provided directly or by means of service-level agreements or similar, which relate to the core public tasks of the organization. In addition, many NMHSs derive funding from other government agencies or bodies in exchange for the provision of defined services. In all cases, the NMHS which can plausibly demonstrate that it provides good value for money (whether societal or economic in character) is in a better position to argue for retention of, or an increase in, its existing resources.

Advocacy to the public: Every NMHS must develop a strong degree of credibility and trust with the public. Primarily, this is necessary to ensure that the public takes proper account of forecasts and warnings and takes appropriate actions. Unless actions are taken, the potential benefits of met/hydro services will go unrealized. There is a virtuous circle or feedback loop here; increasing the confidence of the public in the services provided through an NMHS will increase the uptake of services and the translation of guidance into actions and decisions. The positive outcomes will increase the confidence of the public still further and lead to yet higher uptake of services and improved outcomes at the end of the value chain. No matter where an NMHS stands in the confidence of the public it can engage in improving this confidence and, hopefully, commence this positive feedback process.

To achieve this, part of the message that an NMHS needs to communicate to the public is that it has used public resources wisely and efficiently, and that it represents a net contributor to the economic and societal well-being of the nation. An NMHS with a positive public profile will be more likely to gain positive response to resource requests.

Advocacy to key users: While direct advocacy by an organization on its own behalf is valuable, third-party advocacy by other agencies and organizations is infinitely more so. Typically, NMHSs provide services to organizations in both the public and private sector, including energy utilities, water and sanitation companies, roads and transport agencies, environment agencies, radiological protection institutes, and the like, as well as to private companies engaged in many spheres of economic life. If these organizations can become advocates for the greater investment of resources in the NMHS, their leaders' views will then carry significant weight. While an SEB study may well focus on some of these organizations or sectors in particular, the demonstration of positive economic and/or societal benefit deriving from such a study will be of interest to all such organizations and will help to raise the profile and the prestige of the NMHS in question.

Advocacy to the aviation community: The case of aviation deserves special mention. Most NMHSs provide services to aviation in accordance with the "Chicago Convention" of the International Civil Aviation Organization (ICAO) (ICAO, 2014) and recover their costs, or a portion thereof, through the imposition of en-route and landing charges on airline operators. Increasingly these charges are set by regulators who have a brief to minimize the charges levied while maintaining adequate safety of air travel through air navigation support services. When presenting a case to the regulator for the proper allocation of resources to support aviation meteorology, an SEB study is an important tool. Increasingly, such tools will be needed to counter the trend of discounted pricing within the aviation industry.

9.5 INTERNAL AND EXTERNAL INTERPRETATION OF THE SOCIOECONOMIC BENEFIT STUDY

9.5.1 Internal audience

Operational meteorology is a multilayered enterprise and, within an NMS, one can expect to find a range of perspectives and interpretations of SEB study results. The collective wisdom in any organization can be substantial, if it is properly assimilated.

The senior managers of the NMHS will likely be instrumental in commissioning the SEB study, and they will need to use the outcomes effectively to argue for adequate resources for the sustainable development of the organization. They will need to pick a number of clear, consistent messages from the study outcomes and emphasize these in discussion with officials from the parent department, officials from the finance ministry, politicians, and the like, as well as making notes with staff concerning relevant narratives for later use.

It will be important to consider and decide in advance who will be the key spokesperson of the NMHS in promoting the study through the media. This might be the director or some other senior manager, but it must be a person who is comfortable in dealing with journalists, who is effective at making presentations to groups, and who can confidently deliver on-air interviews. This person must be given time to become thoroughly familiar with the study and its results, and be provided with resources (graphics artists, web specialists, and the like) to enable effective presentation across the wide range of communication platforms.

Where an organization is distributed geographically, it will be especially important to engage the regional managers and regional staff in the process of interpreting and communicating the results of the SEB study. The methods of circulating information will vary greatly depending on the size of the NMHS, but could include presentations to staff, team meetings, newsletters, intranet, and the like. It will be vital for senior and regional managers to gather together in seminars to learn of, and discuss, the SEB results. The regional managers should then organize meetings at regional and local level to keep all staff fully informed.

Front line staff will have an important role in the communication process – this is especially true of forecasters, climatologists, and applications developers who, through their daily work, have direct contact with many of the users of the NMHS. Their contacts and relationships with users may prove an invaluable resource when seeking to identify and collect "stories" or narratives of individual experiences that will add colour and depth to the statistical results of the SEB study.

For those NMHSs which are large enough to have their own internal capability in the areas of media liaison and public relations, these staff will also be a key resource in this regard. Indeed, it should be the public relations staff who have a responsibility for designing the overall communication strategy around the SEB study and results. They should be consulted at an early stage in the planning of the study, and can support the efforts throughout implementation.

9.5.2 **External audiences**

Governmental bodies, and especially finance or public service ministries, will be a key target for effective communication of SEB study outcomes, which should be disseminated in varying methods depending on the target audience. Sending a paper or electronic copy of the report does not constitute adequate communication, although this of course is necessary to provide detail and material for reference. A more proactive approach will be required. The finance people will need to see the numbers, but these can be given greater impact through well-chosen graphics used to illustrate key findings. Ideally, there should be presentations to relevant officials in a seminar-type format, in which the key messages are presented, the detail is readily available, and the questions and concerns of the officials can be answered and teased out in discussion afterwards.

As noted earlier, public service users of meteorological services can be very effective advocates for NMHSs within government structures. Many public service users (emergency management community, military, energy utilities, and so on) will have annual meetings, conferences or other regular events. Especially at a regional or local level, these are tremendous opportunities for an NMHS to address key user groups, to tell them about advances in meteorology and help them identify the tangible benefits that quality meteorological services can generate.

As with public sector users, private sector users are often best addressed within their own social and communication structures, through conferences and seminars. To impact a private sector audience, it will be advisable to prepare illustrations of actual and potential economic benefits deriving from met/hydro services, and to make every effort to demonstrate the economic and societal contribution of an NMHS. The private sector often views public sector bodies in general as inefficient.

User communities in the aviation sector pose a particular challenge because of the unique nature of that business, where safety is paramount and economics is fundamental. Aviation has become much more complex since the days when the provision of the significant weather chart, the aviation routine weather report, the terminal aerodrome forecast, and the significant meteorological information constituted adequate service. Economic aircraft routing is a key concern, while the working of a busy airport poses a myriad of meteorological challenges. If the SEB study has specifically addressed the aviation sector, then there will be considerable material to communicate to this constituency. If not, then the information may not be of great relevance, but may still help inform where improved meteorological services can offer economic benefit.

Many NMHSs will have existing media partners in the public or private sectors with which they work to disseminate weather forecasts and warnings. An SEB study which illustrates societal and/or economic benefit to the general public (as opposed to specific sectors) represents a good news story for these media partners and an NMHS should encourage these partners to advertise the positive outcomes of the study. The co-benefits of the story will help strengthen and deepen the working and institutional relationship between the two organizations.

When the SEB study has been completed, the media liaison staff who work within the NMHS itself should initiate a media campaign to communicate the outcomes, which should be focused on societal and economic benefits generated by the NMHS. Some of this may be soft in nature, such as informal meetings with journalists to outline the results and consider news angles. Alternatively, there might be a more formal presentation of the results and outcomes through a press conference, with associated press packs provided that will help journalists to prepare and illustrate their stories. Information is best disseminated when drip-fed over a longer period of time.

Marketing and sales staff will play an important role by demonstrating to existing clients the range of positive outcomes which can flow from good use of weather information, and in illustrating to potential clients the value of taking a professional service from their NMHS. They will need to be selective in using the study outcomes, matching the individual statistics and stories with the business needs of their client contacts. More information about engaging external audiences is provided in section 9.7.

The elements of a communication strategy are discussed below, but the vital point is that it should deliver clear, coherent and consistent information about the SEB study and its outcomes to a wide range of audiences – from key decisionmakers in funding agencies through staff members and users to the general public.

9.6 AUDIENCE DIVERSIFICATION AND VARYING DISTRIBUTION CHANNELS

Any SEB study must be carefully planned, starting with the initial concept and following on to refining the aims and objectives, selection of the study team, implementation of the study itself, analysis of the findings, and publication of the results. It might be tempting to think of the publication of results as being the end of the exercise, but it is, in many ways, only a beginning if the study is to be more than a purely academic exercise. Indeed, the communication of SEB study results should not be thought of as a one-off activity. The occurrence of a high-impact meteorological or hydrological event, among other opportunities, will offer new occasions on which SEB results can be presented in a manner that generates further focus and attention.

News media: When approaching the communication of technical information to and through the news media, there is a need to consider carefully the style of the media and the likely time that will be allocated to covering the story. At one end of the scale will be the tabloid media or popular press and their broadcast equivalent, the "sound bites", required for short, snappy news bulletins aired on radio stations. These media will need simple headline facts, such as "Hydro/met service delivers X dollars of benefit for every dollar of public money spent". For these media, this sort of story will not be a highlight of their output; the best that can be hoped for in terms of coverage is a few short paragraphs.

At the other end of the scale will be the analytical articles such as will be found in the financial or editorial pages of the press and trade and professional magazines and journals. The broadcasting equivalent might be a long (five to ten minute) interview-based item on a current-affairs radio programme (or, less frequently, a television programme).

While the statistics will be important, it will be desirable to augment and illustrate them with narratives or stories about specific examples of benefits. The narratives will more likely make it to print or onto the airwaves if supplementary information is provided such as background briefing material, fact sheets, a potential headline of the story, some narratives of good examples of benefits (if these are available) and the contact details of the NMHS person who can provide further information or be interviewed on the topic.

The media gets many "story ideas" proposed to it, often by professional public relations firms acting on behalf of clients, and stories from NMHSs will need to compete for attention if they are to be selected.

Television/Internet: These are primarily visual media, and as such the primary "driver" of a story will be the quality of the graphical treatment. For television, a narrative or story illustrating positive examples of benefit experienced by individuals, businesses or user communities will also be of value. A television report on the results of an SEB study might contain four distinct elements:

– A headline giving the key findings of the study;

– An interview with a user who has a good story to tell;

– Graphics showing the benefits – perhaps by sector – in a visual manner;

– An interview with an NMHS representative who can comment on and contextualize the study (and make the case for increased investment).

Almost all NMHSs host their own websites, which by their nature will usually attract a significant audience seeking weather information and forecasts. Links to the SEB study and results can be placed on the main page, but need to be positioned in a promotional capacity, attracting users to click through to the pages featuring the study results. That page should be largely graphical, with the minimum of explanatory text; the more detailed information can be placed in subsidiary pages where those with particular interest can access and peruse it.

Electronic/social media/blogs: In the very crowded environment of social media, stories typically command a very short attention span and have to compete with a vast array of other content. Here, the strategy might be to place a few simple headline stories on networks such as Twitter with links back to the pages of the NMHS website or an online social media source, which carry the full detail of the study as described above. Social media has a role in being a "signpost" to the more detailed treatment of the story elsewhere. Interest in the story can be elevated by using well-known personalities, who regularly blog or tweet, to carry the story or make reference to it, with appropriate links back to the source material. Creating a lot of interest in a story on social media is also a means to generate interest in the story within the conventional media, who source many of their stories on social media and will need to cover stories that trend strongly in this market.

9.7 TARGET AUDIENCES

Funding agencies: While all of the communication strategies and plans are important, those aimed at funding agencies and the like are perhaps most important of all, in that they can leverage significant benefit for the NMHS. The communication to funding agencies does not exist in a vacuum, however; the more broadly based communication through the mainstream media will affect and inform the attitudes and decisions of individuals within funding agencies. However, decisions to allocate funds will need to be supported by specific, targeted information. This can be communicated graphically, but will need to be backed up by detail concerning the SEB study's funding, methodologies and findings.

If the findings are to influence funding decisions they will need to be specific about the sectoral benefits, and possibly inform where funding might best be applied. If there are inferences that can reasonably be made that support increased investment in, for instance, the ground observation network, weather radar, or forecaster provision and training, then these should be highlighted. If supported by the outcomes of the SEB study, a detailed assessment of what investments need to be made will significantly improve the chances of leveraging increased funding as it demonstrates an analytical approach by NMHS management.

Users: The publication of an SEB study for the user community of an NMHS is an opportunity to broaden and deepen the communication between service suppliers and their clients. Initially, this might be by means of a newsletter-type publication, and significant users will expect to be directed towards a more detailed assessment of the study. Therefore, opportunities should be created for the user community to meet with both the team who worked on the study and relevant NMHS personnel in a seminar or workshop setting, where users have the opportunity to ask questions and to probe interests and concerns. These occasions may also lead to increased business opportunities for the NMHS, as users gain a greater awareness of the range of benefits which may be afforded by more targeted use of weather information in their businesses.

Academic users/reviewers: This is a very specific community who may be interested in an SEB study in terms of both methods and results, and as references for guiding future work. In general, this community will be served through the traditional means of published papers and academic lectures. In a country where studies of meteorological services have not previously been carried out – and there are many – the publication of such a study represents an opportunity to engage economists and public policy experts who may not have considered NMHSs as a topic of interest (Perrels et al., 2013). In this manner, a study can catalyse further work, perhaps looking in more detail at different user sectors, or at the benefits of state investment in NMHSs vis-à-vis other public sector service providers. While NMHSs typically have a high public profile, their value isn’t necessarily conveyed as a similar high priority for funding. As a result, it may be beneficial to encourage and sustain interest in met/hydro services amongst those in the academic community who are often key influencers of politicians and other senior decisionmakers in government.

As well as promoting the results of an SEB study, subsequent seminars and lectures for the academic community will need to focus on the methodologies employed and the resources consumed in preparing the study, as these details will assist those academics who might choose to engage in further studies, either by replicating the methodology in a different context or attempting to verify the findings using complementary methodologies. When presenting studies and results to academia, it will be important also to communicate clearly that appropriate academic rigour was brought to the exercise and to the analysis.

Press release/media interview: It is important for an NMHS to realize that while the media are largely a means of mass communication to a large cohort of listeners and viewers, these journalists can also be used to speak directly to policymakers, who are usually avid consumers of the mass media and take a keen interest in the topics that appear. Every press release, for example, may lead to a newspaper article that is read by a minister or a senior decisionmaker. Recognizing that every news story has a “shelf life” and that interest will fade in time (a week is a long time for a story to survive in the media) the communication strategy should be to maximize media coverage over a short period, ideally aligned with key decisionmaking timetables in funding agencies or departments.

Recycling lessons learned into the education of younger meteorologists: The education of meteorologists in general, and forecasters in particular, is normally focused exclusively on the physical sciences and rarely touches on user needs and requirements. The availability of an SEB study offers the opportunity to build this element into meteorological education; both to confirm to students the value of their chosen career and to help them better identify opportunities for the application of meteorological science to societal needs. Indeed, it may inspire students to develop new and innovative weather services that better match meteorological information to user needs.

A summary of the possible points of interaction with a range of stakeholders is provided in Table 9.1.

Table 9.1. Socioeconomic benefit study audiences and opportunities for engagement

Audience	*Opportunities*	*Engagement options*
Public authorities	Public authorities are influential advocates for improved meteorological infrastructure	– Finance ministry – Numbers, graphs, visuals. Emphasize economic benefit
Regulator	Regulators review the NMHS service provisions, especially aviation	– Aviation industry – Annual meetings or specially convened seminars
Service users	Service users and taxpayers expect efficiency, so publicize realized benefits and potential benefits	– Business leaders – Media, conferences, and professional clubs
Funding authorities	Public fund investment decisionmakers are interested in service efficiency. An SEB study can help balance pressures to excessively commercialize weather data and services; it provides information on the overall economic benefits to society	– Politicians – Respond to voters, and politics is local. Run local campaigns in tandem – Science funding agencies – Scientific quality and evidence of economic benefit crucial. Formal presentations
Media partners	As existing users of weather services and existing channels of communication to end users, they are likely to be interested in the “good news story” which the publication of an SEB study would represent	– Opinion shapers – Journalists, etc., should be approached for one-on-one meetings; background materials/press packets recommended
Emergency managers	Emergency managers have a strong interest in the resilience of weather services generally and NMHSs in particular. Their voice carries considerable weight with decisionmakers – especially investment in meteorological infrastructure	– Emergency management users, stakeholders – One-on-one meetings, conferences. Publication of articles in trade journals
Civil society	Communication with civil society will likely be through the mass media and specific strategies for maximizing publicity	– General public – Address through the media with local NMHS staff or presentations to town council meetings, etc.

9.8 ANALYSING THE OVERALL SUCCESS OF A SOCIOECONOMIC BENEFIT STUDY COMMUNICATION STRATEGY

Not all the elements in a communication strategy will work equally well, and some measure is needed by which an NMHS can assess what is working and what is not. Of course, the ultimate test will be whether sustainable funding is achieved, but this may take years to evolve and analyse. In the shorter term, some more accessible measures are required.

A good place to start is by defining at the outset a list of metrics that the SEB study communication strategy manager will track (that is, activity, reach, engagement and impact). These can be direct measures, such as minutes of radio airtime or column inches in the printed press. There is a wealth of statistics available through website analytics, downloads, re-tweets, and the like. Numbers of presentations made to conferences and professional groups can be counted, and the direct audience estimated, as well as focus group and survey-based qualitative and quantitative information tracked and analysed (Public Library of Science, 2014). By doing this, the NMHS will have access to data for reporting back via information graphics and assessments. These may include, for example, trends throughout a campaign, or number of audience members reached for specific sectors of the external audience (for example, regional emergency management personnel). As part of the overall communication strategy of an NMHS, these results should be included in presentations, especially to public and funding authorities, regulators and service users. With access to analytical information about how met/hydro services are directly benefiting its wide array of users, an NMHS will be well-placed to discuss and promote its services to local, regional or countrywide audiences in varying sectors.

9.9 CONCLUSIONS

This chapter has outlined the critical role that good communication can play in the successful use of SEB studies in advocacy, in building and maintaining public support, and in strengthening the NMHS brand. It has looked at the different audience segments, both external and internal, that an NMHS might wish to reach and has also reviewed the optimum manner of presentation appropriate to a variety of communication media. Identification of key target audiences and tailoring the communication strategy accordingly will greatly assist the usefulness and impact of an SEB assessment.

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CHAPTER 10. LOOKING FORWARD

Chapter 1. Introduction
Chapter 2. Met/hydro services
Chapter 3. Purpose of SEB studies
Chapter 4. Designing SEB studies
Chapter 5. Economic essentials
Chapter 6. Benefits
Chapter 7. Costs
Chapter 8. BCA
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Chapter 10. Looking forward

Met/hydro services enhance economic development and will no doubt play a crucial role in how we adapt to changes the future brings. Those changes may well be substantial. A recent report (Global Commission on the Economy and Climate, 2014) reminds us that over the next 15 years global production (defined as GDP) will grow by more than half, a billion more people will come to live in cities, and rapid technological advance will continue to change businesses and lives. In addition, climate change is already having serious economic consequences, especially in more exposed areas of the world. The SEB analysis described in this publication can help identify priority needs for investments to ensure reliable met/hydro services.

The Madrid Conference of 2007 (see Chapter 1), a substantial milestone of global collaboration for improving practice, inspired a burst of interest in SEB studies of met/hydro services, for example the work undertaken in Europe under the WMO Regional Association VI (summarized in Perrels et al., 2013*a*). Since then and at least partially motivated by the Madrid Conference, new levels of collaboration between WMO and development partners, particularly the World Bank Group, are facilitating not only better and more knowledge exchange, but also increased investment in modernizing met/hydro services. It is hoped that this publication will further drive an intensification of these efforts.

This publication endeavours to raise awareness, increase understanding and provide practical guidance for evaluating, demonstrating and enhancing the benefits of met/hydro services. While it attempts to capture the currently available wealth of experience and expertise across different countries, sectors and disciplines, it is not the end point for developing global knowledge on SEB analysis of met/hydro services. Rather it is another substantial milestone.

10.1 GUIDING INCREASED BENEFIT DELIVERY BY NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES

10.1.1 Supporting sustainable development through better-informed services

Met/hydro services play a key role in building more resilient societies and should be recognized as such. However, beyond the obvious appeal for advocating with financial decisionmakers, politicians and the public, the core value of SEB analysis of met/hydro services lies in the process rather than the final numerical results. Application and utilization of such analysis should be treated as a continuous process that leads not only to improvement of the effectiveness of NMHSs, but of performance in conducting and exploiting SEB analysis methodologies themselves. These processes are sources of valuable information for improving the effectiveness of services in all phases of the value chain and prioritizing focal areas of service innovation (Perrels et al., 2013*b*).

Public financing is increasingly under pressure and will likely continue to be for the foreseeable future (International Monetary Fund, 2014), raising the need for well-designed, targeted and communicated SEB studies. The economic context in which they operate should be understood by NMHSs, and they should regularly review how they use their limited resources to improve cost efficiency while meeting priority user demands.

Particularly in middle- and low-income countries, NMHSs would benefit from routine inclusion in national development, poverty reduction and climate adaptation plans. If national accounting systems and macroeconomic equilibrium models consider potential, realized and avoided impacts of weather and climate, government budgets and financial plans will likely include provisions for providing and enhancing met/hydro services. This foresight is, however, currently not usually the case; for example, national accounting does not adequately measure disaster impacts (United Nations Office for Disaster Risk Reduction, 2013) or natural capital assets (Wealth Accounting and the Valuation of Ecosystem Services, 2014); the optimal management of both, however, require met/hydro services. A changing climate makes consideration of anticipated benefits essential for the future.

Better SEB studies will therefore not only send a strong message of the need for adequate resourcing for the delivery of met/hydro services, but will also contribute to guaranteeing the sustainability of such services as part of longer-term development. While the World Bank Group is convinced that modernizing NMHSs in developing countries is a high-value investment requiring sufficient scope to be transformative, it also emphasizes that government commitment to sustained financing of operations and maintenance of basic met/hydro services is needed.

10.1.2 **Decisionmaking needs good data**

Data and information availability, in addition to resource availability, will always be a limiting factor for selecting the type and framing the detail of an SEB study. To build confidence with stakeholders in processes and results, three important approaches should be employed:

(a) Recognize limitations from the beginning;

(b) Transparently justify and document assumptions used to offset data shortcomings;

(c) Corroborate results through application of multiple methods.

For SEB analysis, NMHSs should approach the collection and management of the required data in a similar fashion to met/hydro data. Long-term commitment and investments are needed to ensure reliable and regular acquisition of socioeconomic information through a mix of approaches. Systems are needed for data quality management and consistency, and a transparent and open approach (for example, through a willingness to share) helps ensure reliability through external review and use, ultimately building confidence in both the input information and resultant studies.

Therefore, NMHSs need to be proactive in assembling the data for SEB studies, which may entail a change of mindset and explicit commitments of resources (see Chapter 4). It cannot be expected that an NMHS would hold all necessary data, so closer collaboration will be needed with relevant partners/agencies such as ministries of finance and national statistical offices.

10.1.3 **Increasing value with better access to services**

It is clear that if met/hydro products are not being used, they have no value. The value chain used in this publication indicates that value is only realized once information is collected, processed, delivered and a decision or action is taken based on the information. It follows that the more met/hydro products are used, the more value they will deliver. Efforts to increase use should therefore be pursued.

In 1995, WMO and its Members recognized that to better enable provision of services to help protect life, property and well-being, certain meteorological data should be freely exchanged at the international level (WMO, 1995). This was followed by similar considerations regarding hydrological data four years later (WMO, 1999). Characterizing basic meteorological data and services as public goods, resulting in a liberal approach towards data policy with free-of-charge provision of infrastructure data and products, is very likely to generate greater SEBs (Weiss, 2002). As consumption under open-data policies is non-rival, the marginal cost of supplying information to additional users is close or equal to zero, and the costs of exclusion from use (that is, controlling proliferation of charged data) are too high, if not impracticable (Rogers and Tsirkunov, 2013).

Despite delivering clear contributions to social welfare and positive public and private externalities,[25] the concept that using public financing to provide free met/hydro data and basic services increases economic value is not always immediately apparent to governments. However, experience shows that an open-data policy, meaning information is both technically accessible and legally licensed to permit commercial and non-commercial use and reuse without restrictions (World Bank, 2014), tends to lead to a dramatic increase in the use of the data. In 2006, the Norwegian Meteorological Institute decided to stop charging for weather and climate data to facilitate a broader use of its data and products. In addition to adopting open-data and open-access policies, in 2007 it partnered with the Norwegian National Broadcaster to

[25] Also called "external benefits" or "external economy", this refers to positive effects on a third party who/that did not make the decision of applying an open-data approach; for example sectoral and business opportunities through data refinement and reuse for user-specific products.

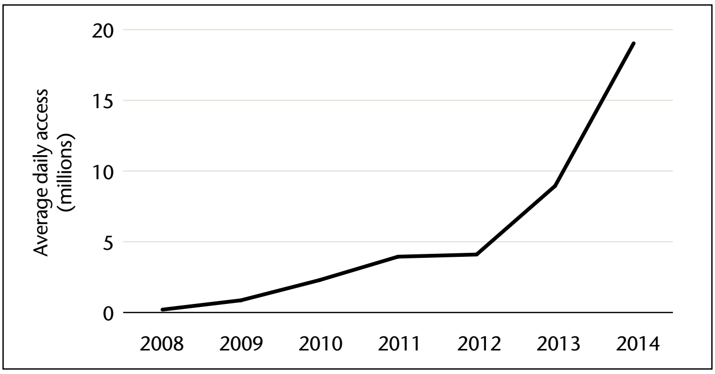

Figure 10.1. Growth in usage of the Norwegian Meteorological Institute's web services following adoption of open-data (2006) and open-access (2007) approaches

Source: Adapted from Figure 6 of Lyng et al. (2014)

foster commercial free and easier domestic and international access to its data and products, for both use and reuse, through the Internet. This policy has not only led to exponential increases in the use of the Norwegian Meteorological Institute's data and products (see Figure 10.1), but has contributed to the institute having the best public reputation of all Norwegian governmental institutions for nine years running (based on official annual polls), as well as high staff morale (Lyng et al., 2014).

Modern technology enables increased access to met/hydro products and services. It is important that NMHSs rapidly embrace evolving innovations to ensure continued and growing product use, as FMI has done to adapt to domestic tripling of smartphone ownership from 2011 to 2014, and a quadrupling of tablet ownership from 2012 to 2014, as shown in Figure 10.2 (Harjanne and Ervasti, 2014).

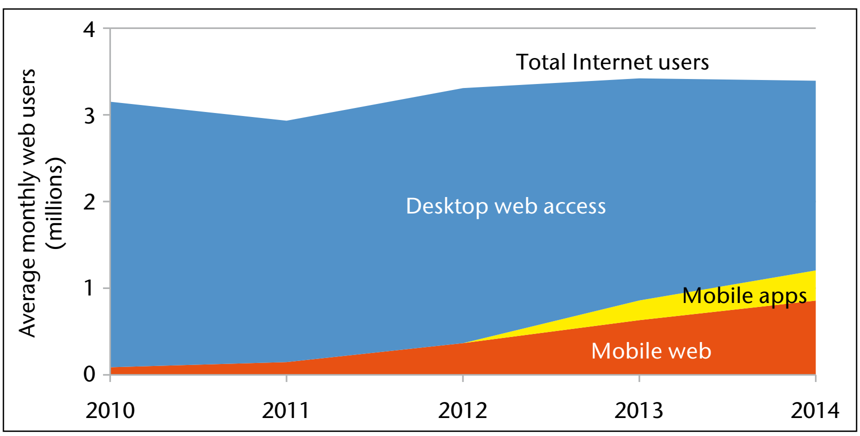

Figure 10.2. Growth in mobile and mobile application users of the Finnish Meteorological Institute's web products, 2010–2014

Source: Adapted from Figure 2 of Harjanne and Ervasti (2014)

10.1.4 Increasing value with better utilization of services

Just because met/hydro products and services are being accessed and used more does not necessarily mean they are being fully or better exploited. If information is misunderstood or misinterpreted, it could even lead to poor decisionmaking, resulting in negative value. The third World Climate Conference highlighted that capacity-building to disseminate, communicate, understand and utilize met/hydro services is as important as the need to further develop met/hydro services themselves, reflected as a key element of the Global Framework for Climate Services (World Climate Conference-3, 2009).

Assumptions of perfect decisionmaking based on all the information available are generally not realistic. For example, if a perfect agrometeorological forecast is provided for the growing season, it is unlikely that farmers will cultivate the optimal crops at the optimal times (Stewart, 1997; Letson et al., 2001). By jointly exploring shortcomings both in met/hydro products and the decisions they inform, NMHSs teams and their partners can optimize investments and therefore benefits realized through shared roles.

The higher the quality of met/hydro services, the more value they can deliver. In a mutually reinforcing modernization strategy, SEB studies will help inform the design and implementation of investments to improve services, leading to increased recognition, use and therefore value of services. Scientific and technological advances should be operationalized for maximum benefit. For example, probabilistic forecasts enable better decisionmaking than deterministic forecasts in the case of early warning by allowing false alarm rates to be set to levels acceptable to stakeholders, as opposed to strict threshold-driven targeting (Pappenberger et al., 2014). Efforts such as the WMO World Weather Research Programme's High Impact Weather Project (HIWeather), which aims to increase resilience by improving impact forecasts and enhancing their communication and utility in social, economic and environmental applications, should be pursued to increase met/hydro service benefits at local, national, regional and global levels.

National Meteorological and Hydrological Services rely on efficient data and information exchange from global to local levels, within the overall framework of WMO WWW. Global models provide input for regional models which, in turn, provide guidance for national/local forecasting. Such cascading approaches ensure that all NMHSs have access to the latest technology and methodologies, without burdening most NMHSs with the high costs of maintaining and operating global and regional numerical modelling systems. Currently, the viability of such global services depends on the voluntary contribution of the advanced service providers. The structure is under increasing stress from budget constraints, especially in the major traditional provider countries. To support these systems and improve the weather and met/hydro services available to the developing world, it would be worth exploring public financing models for global goods, utilizing a number of approaches described in this publication.

10.2 ENHANCING THE QUALITY AND UTILIZATION OF SOCIOECONOMIC BENEFIT ANALYSIS

Increasingly, NMHSs need to confront new realities in their operational contexts, and not just those related to public financing. Specifically, rapid changes and innovations in information technology; globalization of societal, economic and technological systems; and the changing climate are some of the key processes facing met/hydro service providers. These present both risks and opportunities, and economics as a discipline can help NMHSs navigate changes in an optimal manner. Risk management should be a powerful instrument for development, not only by building resilience, but also by taking advantage of opportunities for improvement (World Bank, 2013).

Every country, no matter what the level of development or capacity of the NMHS, can benefit from strengthening its application and utilization of SEB assessments of met/hydro services. The continuum of approaches outlined in this publication provides opportunities to employ methods across a range of resource and expertise availability. The capacity for SEB analysis exists in all countries, either within or outside their NMHSs. The sourcing and leveraging of this capacity must depend on the scope of the decision to be informed.

10.2.1 Linking communities

Met/hydro SEB assessment requires an interdisciplinary approach that brings together a number of different expert groups and stakeholders. The strengthening of linkages between the met/hydro and socioeconomic technical communities is of particular importance, as are joint approaches to communicating results externally.

Associated with the partners and efforts engaged in the development of this publication, it is planned to establish a website to ease accessibility to it, but more importantly to provide a platform for the exchange of ideas, experiences and new studies.

The Global Framework for Climate Services – with its primary focus on better access and use of climate information by users, encouragement of global, free and open exchange of climate-relevant data as international public goods, and basis in partnership – provides a broader platform within which to promote the use of SEB studies to improve met/hydro services. Spin-offs from GFCS, such as the Climate Services Partnership (http://www.climate-services.org/) have already engaged key members of the extended community to better link efforts (Pappenberger et al., 2014).

10.2.2 Monitoring and evaluation

Analysis of SEBs should form an integral component of the monitoring and evaluation systems of NMHSs. Existing systems may need to be adapted to better capture the relevant baselines and the user decisions being made utilizing met/hydro products and services. Monitoring must, therefore, include outcomes and results, not just outputs

Box 10.1: Using crowdsourcing to monitor use and satisfaction in the United Kingdom

The United Kingdom Met Office currently uses social media networks such as Facebook and Twitter, as well as the organization's website, to monitor the effectiveness of, and to improve, weather and climate services. This monitoring technique enables the Met Office to better understand how their forecasts are perceived and allows engagement with the public in real time. Social media reports are also used to assess the impacts of the weather and these are added to evidence collected to assess warnings. The Met Office regularly reviews monitoring and evaluation systems to ensure they are taking advantage of the latest technology, combined with more traditional methods (radio, television and print) to ensure a holistic approach to understanding the needs of the public, emergency responders and private sector.

Source: Pinder (2014)

such as the number of forecasts made or warnings sent. In most cases, this last phase of the value chain is outside the direct responsibility of the NMHS, lying primarily with the users. Monitoring and evaluation partnerships are thus needed.

New technologies to monitor and assess uptake, use, satisfaction and ultimately the benefits of data from met/hydro products and services should be employed – for example crowdsourcing (see Box 10.1), big data, cloud computing, and the like. The further along the value chain that data can be captured (referring again to outcomes and results), the better the SEB analysis will be informed.

The tools, assumptions, and processes of SEB analysis can always be improved. Ex-post SEB studies on met/hydro services are therefore needed to improve future performance. This could involve, among other activities, continuous monitoring, collection of data to revisit methodologies, integration with non-economic methods (for example, other social sciences), and identification of new benefits, all under a continuous process.

10.3 GOALS FOR THE FUTURE

As national implementation of the 2014 WMO Strategy for Service Delivery is pursued, SEB analysis will become increasingly important to inform planning and investment in NMHSs with the ultimate goal of improving services. Concurrently, a number of global processes and agreements will likely help raise the profile and urgency of strengthening met/hydro services, including the post-2015 framework for disaster risk reduction, the post-2015 sustainable development goals, the New Universal Climate Agreement in 2015 (under the auspices of the United Nations Framework Convention on Climate Change) and continued development and implementation of GFCS. Considering this growing interest and demand, the agencies and authors involved in this publication envision a number of developments over the next few years.

To achieve the strengthening of these services, the community of practitioners working in the field should expand and diversify, facilitated by interactive web platforms and resources. This network should include experts from a number of disciplines including met/hydro services, economics, social sciences, public administration and more, and ranging across professional responsibilities from managers to technical specialists, and researchers to civil society representatives. It is hoped that professional societies, for example those focusing on issues such as meteorology and environmental economics, will actively engage and move the effort forward.

The methodologies described in this publication, potentially added to and improved upon through interactive knowledge-sharing, will be applied in as many countries as possible. This effort will generate more experiences and case studies, eventually providing a knowledge base covering all relevant sectors and contexts. The existing case studies should also be revisited to assess the application and performance of approaches, informing refinements of methodologies and assumptions.

To achieve these goals, the pool of people across disciplines available to provide technical support and training should be widened. Relevant managers and staff will benefit from the integration of the training of SEB analysis methodologies within WMO, NMHSs and partners. It would be particularly valuable if the WMO Regional Training Centres were to introduce basic modules in meteorological economics across a range of their professional and technical training courses. To further support national capacity, twinning arrangements for lower capacity NMHSs to benefit from the expertise of higher capacity NMHSs could also be facilitated.

To support longer-term utilization and refinement of SEB analysis for met/hydro services, it is hoped that the academic world better takes up the topic to maximize the exposure and interest of the next generation of met/hydro professionals. This publication, for example, could be translated into a teaching resource. Students of economics, public management, meteorology, hydrology and many more disciplines could benefit from, but also contribute to, inclusion of the topic in academic curricula.

None of the above will be possible without dedicated financial resources, and such resources can only be made available if the SEB agenda is considered a priority by the involved parties. Both NMHSs and their governing ministries will need to allocate budgets, as will development partners in their programmes and projects. As the age old expression goes, "one has to spend money to make money"; this wisdom also applies to utilizing SEB assessment to improve cost efficiency of met/hydro services. With the case studies reviewed in this publication indicating that met/hydro services deliver benefits relative to costs of ratios ranging from 2 to 1 to 36 to 1, clearly there are great benefits in assessing and understanding how to optimize the value of met/hydro services. It is therefore worth investing in a better understanding of how to invest!

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APPENDIX A. GLOSSARY OF TECHNICAL TERMS

Note: In certain instances, the authors have summarized or edited glossary definitions as needed for contextualization.

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects. "Incremental adaptation" refers to adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale. "Transformational adaptation" refers to adaptation that changes the fundamental attributes of a system in response to climate and its effects (Intergovernmental Panel on Climate Change (IPCC), 2014).

Adaptation benefits: The avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures (IPCC, 2007).

Agrometeorology: The study of the interaction between meteorological and hydrological factors, on the one hand, and agriculture in the widest sense, including horticulture, animal husbandry and forestry, on the other (WMO, 1992). Agrometeorology is a sub-field of meteorology and includes agroclimatology.

Atmosphere: Gaseous envelope which surrounds the Earth (WMO, 1992).

Avoided cost method: A valuation method that assesses actual or imputed costs for preventing environmental deterioration by alternative production and consumption processes, or by the reduction of or abstention from economic activities (OECD, 2008); for example, measuring the benefits of reduced air pollution by assessing the cost of installing indoor air purifiers.

Basic services: Those services provided by National Meteorological and Hydrological Services in discharging their governments' sovereign responsibility to protect the life and property of their citizens, to contribute to their general welfare and the quality of their environment and to meet their international obligations under the Convention of the World Meteorological Organization and other relevant international agreements (WMO, 1990).

Benchmarking: A process in which a business evaluates its own operations (often specific procedures) by detailed comparison with those of another business (especially a competitor), in order to establish best practices and improve performance; the examination and emulation of other organizations' strengths (*Oxford English Dictionary*).

Benefit: A quantified gain of an action (Tietenberg and Lewis, 2009; from benefit–cost analysis).

Benefit–cost analysis: The quantification of the total social costs and social benefits of a policy or a project, usually in money terms. The costs and benefits concerned include not only direct pecuniary costs and benefits, but also externalities, meaning external effects not traded in markets. These include external costs, for example, pollution, noise and disturbance to wildlife, and external benefits such as reductions in travelling time or traffic accidents. Benefit–cost analysis is often used to compare alternative proposals. If the total social benefits of an activity exceed total social costs, this can justify subsidizing projects that are not privately profitable. If the total social costs exceed total social benefits, this can justify preventing projects even when these would be privately profitable (Black et al., 2012; from cost–benefit analysis).

Benefit transfer: Transferring benefit estimates developed in one context to another context as a substitute for developing entirely new estimates (Tietenberg and Lewis, 2009).

Climate: Synthesis of weather conditions in a given area, characterized by long-term statistics (mean values, variances, probabilities of extreme values, and the like) of the meteorological elements in that area (WMO, 1992).

Climate change: Climate change refers to a change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014).

Climate data: Historical and real-time climate observations, along with direct model outputs covering historical and future periods. Information about how these observations and model outputs were generated (metadata) should accompany all climate data (WMO, 2014*a*).

Climate information: Climate data, climate products and/or climate knowledge (WMO, 2014*a*).

Climate prediction: A climate prediction or climate forecast is the result of an attempt to produce (starting from a particular state of the climate system) an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or long-term timescales. Because the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature (IPCC, 2014).

Climate projection: A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative-forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized (IPCC, 2014).

Climate product: A derived synthesis of climate data. A product combines climate data with climate knowledge to add value (WMO, 2014*a*).

Climate scenario: A plausible and often simplified representation of the future climate, based on an internally consistent list of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate changes, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate (IPCC, 2014).

Climate services: The provision of climate information in a way that assists decisionmaking by individuals or organizations. A service requires appropriate engagement along with an effective access mechanism and must respond to user needs (WMO, 2014a). *Note:* This publication uses the term met/hydro services as opposed to climate services, except when the term climate services is germane to the topic under discussion, for example, in relation to GFCS and CSP.

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, and the like) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2014). See also climate change.

Climatology: Study of the mean physical state of the atmosphere together with its statistical variations in both space and time as reflected in the weather behaviour over a period of many years (WMO, 1992). Climatology is a subfield of meteorology.

Conjoint analysis: A survey-based technique that derives WTP by having respondents choose between alternate states of the world where each state of the world has a specified set of attributes and a price (Tietenberg and Lewis, 2009).

Consumer surplus: The excess of the benefit a consumer gains from purchase of a good or service over the amount paid for the good or service (Black et al., 2012).

Contingent ranking: A valuation technique that asks respondents to rank alternative situations involving different levels of environmental amenity (or risk). These rankings can then be used to establish trade-offs between more of the environmental amenity (or risk) and less (or more) of other goods that can be expressed in monetary terms (Tietenberg and Lewis, 2009).

Contingent valuation: A survey method used to ascertain WTP for services or environmental amenities (Tietenberg and Lewis, 2009).

Cost: The value of the inputs needed to produce any good or service, measured in some units or numeraire, generally money (Black et al., 2012).

Cost-effectiveness: The achievement of results in the most economical way. This approach assesses efficiency by checking whether resources are being used to produce any given results at the lowest possible cost. Cost-effectiveness is most relevant as a concept of efficiency in cases such as the provision of defence, education, health care, policing or environmental protection, where it is sometimes difficult to measure the monetary value of the results achieved (Black et al., 2012).

Customer (of meteorological or hydrological services): The person or organization which pays for products and services and agrees on the specifications for delivery through a customer–supplier agreement or service-level agreement. The customer may or may not be the user (WMO, 2014*b*).

Customer satisfaction survey: A survey designed to measure how products and services supplied by a company (or met/hydro service provider) meet or surpass customer expectation (American Marketing Association, 2014; from "customer satisfaction").

Demand: The desire and ability to acquire a good or service, or the quantity of a good or service that economic agents are willing to buy at a given price (Black et al., 2012).

Discounting: Placing a lower value on future receipts than on the present receipt of an equal sum. The fundamental reason for discounting the future is impatience: immediate consumption is preferred to delayed consumption (Black et al., 2012; from "discounting the future").

Discount rate: The interest rate at which future benefits or costs are discounted to find their present value (Black et al., 2012). See also discounting.

Double counting: An error that occurs when a total is obtained by summing gross amounts instead of net amounts. For example, finding the total product of an economy by adding up the gross sales of each enterprise, without subtracting purchases of inputs from other enterprises, involves double counting. As firms buy large amounts of fuel, materials, and services from one another, simply adding gross outputs results in double, or multiple, counting of output. Double counting is avoided by subtracting purchased inputs from gross output to get value added for each enterprise. The national product is total value added (Black et al., 2012).

Economic efficiency: A general term that expresses the notion that all available resources are allocated optimally. Economic efficiency in this sense is purely descriptive, and does not provide a precise definition or test. Pareto efficiency is a formalization of the concept of economic efficiency that provides a method of testing for efficiency (Black et al., 2012).

Economies of scale: The factors which make it possible for larger organizations or countries to produce goods or services more cheaply than smaller ones. Economies of scale that are internal to firms are due to indivisibilities and the division of labour. Economies of scale that are external to firms, but operate at the national level, arise from similar causes; there is scope for more specialist services in a larger economy than in a small one (Black et al., 2012).

Economies of scope: The benefits arising from engaging in related activities. These are similar to economies of scale, but whereas with economics of scale cost savings arise from carrying out more of the same activity, with economics of scope cost savings arise from engaging in related activities (Black et al., 2012).

Efficiency: Obtaining the maximum output for given inputs. Efficiency in consumption means allocating goods or services between consumers so that it would not be possible by any reallocation to make some people better off without making anybody else worse off. Efficiency in production means allocating the available resources between industries so that it would not be possible to produce more of some goods or services without producing less of any other (Black et al., 2012).

Ex ante: Literally translated from Latin: from before. The term describes activities (for example, actions, decisions, formation of expectations) that are undertaken before the state of nature is revealed. For instance, an ex-ante SEB study involves the analysis of potential benefits of a new or improved met/hydro service before it is actually available to user communities. Ex ante is contrasted with ex post, meaning as viewed after the event (Black et al., 2012).

Ex post: Literally translated from Latin: from after. The value of a variable, or of a decision made, as it appears after the outcome of randomness has been realized, that is, what actually occurred. Ex post is contrasted with ex ante, which means looking at things before the event (Black et al., 2012).

Expenditures: Spending, by consumers, investors or the government. Consumer expenditure is restricted to purchasing real goods and services; acquiring assets of making transfers to others by individuals does not count as expenditure. Government expenditure is treated differently; some government expenditure is on real goods and services, but government interest payments and transfer payments to individuals, such as pensions, are counted as government expenditure, and government spending is not clearly divided between current and capital account items, possibly because these are hard to distinguish. National expenditure is what a country spends (Black et al., 2012).

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2014).

External cost: A cost arising from any activity which does not accrue to the person or organization carrying out the activity. Negative externalities (external costs) cause damage to other people or the environment, for example by radiation, river or air pollution, or noise, which does not have to be paid for by those carrying out the activity (Black et al., 2012; from "externality"). See also externality.

Externality: A cost or benefit arising from any activity which does not accrue to the person or organization carrying out the activity. Negative externalities (external costs) cause damage to other people or the environment, for example by radiation, river or air pollution, or noise, which does not have to be paid for by those carrying out the activity. Positive externalities (external benefits) are effects of an activity which are pleasant or profitable for other people who cannot be charged for them, for example fertilization of fruit trees by bees, or the public's enjoyment of views of private buildings or gardens (Black et al., 2012).

Forecast: A statement of expected meteorological (or hydrological) conditions for a specific period and for a specific area or portion of air space (WMO, 1992).

Global Framework for Climate Services: A global partnership of United Nations and international agencies (led by WMO), governments, regional organizations and stakeholders, established by unanimous decision at the third World Climate Conference held in 2009 that seeks to enhance the production and application of climate services worldwide (WMO, 2014*a*).

Hazard: The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (IPCC, 2014).

Hedonic pricing: The method of pricing a good for estimating the value of the individual characteristics that form the good. For example, a house would be seen as comprised of a number of rooms, a garden, and a location. The values of the characteristics are summed to derive a price for a good (Black et al., 2012).

Hindcast: A retrospective forecast issued by a model based on information available at a prior time (Planque et al., 2003, p. 213).

Hydrology: Science that deals with the waters above and below the land surfaces of the Earth, their occurrence, circulation and distribution, both in time and space, their biological, chemical and physical properties, and their interactions with their environment including their relation to living beings (WMO, 2012*a*). Hydrology is often subdivided into "scientific" and "operational" hydrology.

Hydrological cycle: Succession of stages through which water passes from the atmosphere to the Earth and returns to the atmosphere: evaporation from the land, sea or inland water, condensation to form clouds, precipitation, interception, infiltration, percolation, runoff, accumulation in the soil or in bodies of water, and re-evaporation (WMO, 2012*a*).

Hydrological services: The provision of information and advice on the past, present and future state of rivers, groundwater and other inland waters, including but not limited to streamflow, river and lake levels, and water quality (this publication).

Hydrometeorology: Study of the atmospheric and land phases of the hydrological cycle, with emphasis on the interrelationships involved (WMO, 2012*a*).

Joint costs: Costs which are shared by two or more products. It may be possible for a firm to measure the marginal cost of each product separately, but joint costs make it impossible to measure the average cost of each product (Black et al., 2012).

Loss: The result of a business operation where expenditures exceed receipts. Business losses may arise internally, through failure to produce enough of anything the market will buy to cover production expenses, or externally, through failure of others to pay bills due, or to repay debts. (Black et al., 2012).

Macroeconomics: The macro aspects of economics, concerning the determination of aggregate quantities in the economy. Macroeconomics considers what determines total employment and production, consumption, investment in raising productive capacity, and how much a country imports and exports. It also asks what causes booms and slumps in the short run, and what determines the long-term growth rate of the economy, the general level of prices, and the rate of inflation. Macroeconomics considers how these matters can and should be influenced by government through monetary and fiscal policies (Black et al., 2012).

Marginal benefit: The additional benefit from an increase in an activity. This is the addition to total benefit resulting from a unit increase if it varies discretely, or the addition to total benefit per unit of the increase, if it varies continuously. Marginal private benefit is marginal benefit accruing to the person or firm deciding on the scale of the activity, excluding any external benefits; marginal social benefit includes external benefits as well as private benefits accruing to the decisiontaker (Black et al., 2012).

Marginal cost: The additional cost from an increase in an activity. This is the addition to total cost resulting from a unit increase in output if it varies discretely, or the addition to total cost per unit of the increase, if it varies continuously. Marginal cost may be short run, when only some inputs can be changed, or long run, when all inputs can be adjusted. Marginal private cost is marginal cost falling on the person or firm deciding on the scale of the activity, excluding any external costs; marginal social cost includes external costs as well as private cost falling on the decisionmaker (Black et al., 2012).

Meteorology: The science of the atmosphere dealing in particular with its structure and composition, interactions with the oceans and land, movements (including weather-forming processes), weather forecasting, climate variability and climate change (WMO, 1996).

Meteorological services: The provision of information and advice on the past, present and future state of the atmosphere including information on temperature, rainfall, wind, cloudiness, air quality and other atmospheric variables and on the occurrence and impacts of significant weather and climate phenomena such as storms, floods, droughts, heatwaves and cold waves (this publication).

Met/hydro services: The provision of weather, climate, and hydrological information and products. See also climate services.

Microeconomics: The micro aspects of economics, concerning the decisionmaking of individuals. Microeconomics analyses the choices of consumers (who can be individuals or households) and firms in a variety of market situations. Its aim is to explore how choices should be made, and to provide an explanation of the choices that are made. Microeconomics also considers economics composed of individual decisionmakers, and studies the existence and properties of economic equilibrium. The effect of government choices upon consumers and firms is also analysed, with the aim of understanding economic policy (Black et al., 2012).

Monte Carlo method: A method of investigating the behaviour of economic models which are too complicated for analytical solutions to be possible. A system is started off at a large number of initial positions chosen at random, and followed through a numerical simulation to see how it evolves. Monte Carlo methods can be used to check whether a system has an equilibrium, and whether this is stable for any starting point, or some limited region of possible starting points (Black et al., 2012).

National Hydrological Service: An organization with national responsibility for river, lake and other hydrological observation, data management, research, modelling and streamflow forecasting and warning responsibilities (WMO, 1992, 2000, 2001, 2012*b*). The functions of the NHS are similar to those of the National Meteorological Service but focused mainly on the surface phase of the hydrological cycle; NHSs are often located with water supply or river management ministries.

National Meteorological and Hydrological Service: Refers to an NMS or NHS, or an organization which combines the functions of both (WMO, 1992, 2000, 2012*b*). The plural, NMHSs, refers to multiple organizations (NMHS, NMS, and NHS).

National Meteorological Service: An organization established and operated primarily at public expense to carry out those national meteorological and related functions which governments accept as a responsibility of the state in support of the safety, security and general welfare of their citizens and in fulfilment of their international obligations under the Convention of the World Meteorological Organization (WMO, 1992, 2000, 2012*b*; Zillman, 1999). The primary functions of an NMS are usually identified as observation, data archival, research, service provision and international cooperation.

Net benefits: The excess of benefits over costs resulting from some allocation (Tietenberg and Lewis, 2009).

Net present value: The present value of a security or an investment project, found by discounting all present and future receipts and outgoings at an appropriate rate of discount (see discount rate). If the NPV calculated is positive, it is worthwhile investing in a project (Black et al., 2012).

Non-excludability: A property of a good or service that exists when no individual or group can be excluded from enjoying the benefits that good or service may confer, whether they contribute to its provision or not (Tietenberg and Lewis, 2009).

Non-market goods and services: Goods and services not distributed through markets (Black et al., 2012, from "non-marketed economic activities"), for example, clean air and water, scenic vistas and beach visits.

Non-market valuation: The economic valuation of goods and services not distributed through markets (Black et al., 2012; from "non-marketed economic activities"). Methods can be based on either revealed-preference or stated-preference methods, and assessed either directly or indirectly.

Non-rivalry: A property of a good or service that exists when consumption by one consumer does not reduce the quantity available for consumption by any other (Black et al., 2012; from "public good").

Nowcast: A description of current weather and a short-period (one to two hours) forecast (WMO, 1992).

Numerical weather prediction: The forecasting of the behaviour of atmospheric disturbances by the numerical solution of the governing fundamental equations of hydrodynamics, subject to observed initial conditions. Electronic computers and sophisticated computational models are required (Geer, 1996).

Oceanography: The science of the ocean, including its composition, circulation and behaviour, and the observation, description and forecasting of characteristic ocean phenomena on various time and space scales. It is often subdivided into physical, chemical and biological oceanography (Holland and Pugh, 2010).

Operational hydrology: (a) Measurements of basic hydrological elements from networks of meteorological and hydrological stations: collection, transmission processing, storage, retrieval and publication of basic hydrological data;

(b) hydrological forecasting; (c) development and improvement of relevant methods, procedures and techniques in those areas of activity (WMO, 1996).

Opportunity cost: The cost of something in terms of an opportunity forgone. Opportunity cost is given by the benefits that could have been obtained by choosing the best alternative opportunity. For example, for a farmer the opportunity cost of growing wheat is given by what they would have earned if they had grown barley, assuming barley is the best alternative (Black et al., 2012).

Pareto efficiency: A form of efficiency for an economic allocation. An allocation is Pareto efficient if there is no feasible reallocation that can raise the welfare of one economic agent without lowering the welfare of any other economic agent. The concept of Pareto efficiency can be applied to any economic allocation whether it emerges from trade, bargaining, strategic interaction, or government imposition (Black et al., 2012).

Prediction: The act of making a forecast of a future occurrence, such as a weather event, or the forecast itself (Geer, 1996). In established meteorological usage, "prediction" is essentially interchangeable with "forecast", although some preferred usages exist for some timescales.

Present value: The value today of a future payment, or stream of payments, discounted at some appropriate compound interest – or discount – rate (Downes and Goodman, 2010). See also discount rate.

Price elasticity: The ratio of a proportional change in quantity supplied or demanded to a proportional change in price. The price elasticity of supply is $E_s = (p/q)(dq/dp)$, where p is price and q is quantity. The price elasticity of demand is often defined as $E_d = -(p/q)(dq/dp)$ so that it is positive, but the minus sign is not universally used (Black et al., 2012).

Producer surplus: The excess of total sales revenue going to producers over the area under the supply curve for a good. If the supply curve is perfectly elastic there is no producer surplus, but if the supply curve is upward-sloping, those productive resources which would have stayed in the industry at a lower price earn quasi-rents (Black et al., 2012).

Public good: A good that no consumer can be excluded from using if it is supplied and for which consumption by one consumer does not reduce the quantity available for consumption by any other. The first property is referred to as non-excludability, whereas the latter is termed non-rivalry. As a consequence of these properties, public goods cause market failure (Black et al., 2012).

Public weather services: Those basic weather and related services provided, usually by the NMS, for the benefit of the public (WMO, 1999).

Ramsey pricing: A pricing policy that maximizes economic welfare subject to firms achieving given profit targets. If all firms produce with constant returns to scale and must break even, then Ramsey pricing reduces to marginal cost pricing. If firms have increasing returns to scale and must break even then the markups of the Ramsey prices over marginal cost are inversely related to the elasticity of demand. Ramsey pricing has been investigated in the context of public sector monopoly and regulated private sector natural monopoly (Black et al. 2012).

Resilience: The capacity of a social-ecological system to cope with a hazardous event or disturbance, responding or reorganizing in ways that maintain its essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (IPCC, 2014).

Revealed-preference methods: Methods for valuating non-market goods and services based on actual observable choices and from which actual resource values can be directly inferred. These methods can be direct (such as market prices or simulated markets) or indirect (such as travel costs and hedonic pricing) (Tietenberg and Lewis, 2009, p. 39).

Risk: The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the consequences if the events occur. Risk results from the interaction of vulnerability, exposure, and hazard (IPCC, 2014).

Scarcity: The property of being in excess demand at a zero price. This means that in equilibrium the price of a scarce good or factor must be positive (Black et al., 2012). Scarce goods or services are limited in availability.

Sensitivity analysis: The study of how the uncertainty in the output of a model (such as a BCA) can be apportioned to different sources of uncertainty in the model input (Saltelli, 2002).

Social benefit: The total benefit from any activity. This includes benefits accruing directly to the person or firm conducting the activity, as well as external benefits outside the price system accruing to other people or firms (Black et al., 2012).

Social cost: The total cost of any activity. This includes private costs which fall directly on the person or firm conducting the activity, as well as external costs outside the price system which fall on other people or firms (Black et al., 2012).

Social welfare: The well-being of society. This can be measured by a social welfare function (Black et al., 2012).

Social welfare function: (a) The level of welfare in an economy or society expressed as a function of economic variables. Social welfare is expressed as a function of the aggregate consumption levels of goods. Alternatively, an individualistic social welfare function is a function of individual utility levels. (b) A process for aggregating individual preferences into social preferences (Black et al., 2012).

Special weather services: Those services beyond the basic service aimed at meeting the needs of specific users and user groups, and which may include provision of specialized data and publications, their interpretation, distribution and dissemination (WMO, 1990).

Stated-preference methods: Methods for valuating non-market goods and services in which respondents are directly asked about their WTP for a good or service, such as the preservation of a species. These methods can be direct (such as contingent valuation surveys) or indirect (such as contingent ranking or conjoint analysis) (Tietenberg and Lewis, 2009, p. 39).

Supply: The amount of a good or service offered for sale. The supply function relates supply to the factors which determine its level. These include the price of the good, the prices of factor services and intermediate products employed in producing it, the number of firms engaged in producing it, and their levels of capital equipment (Black et al., 2012).

Trade-off: The requirement that some of one good or one objective has to be given up to obtain more of another. The need to trade off goods or objectives against one another is a sign of economic efficiency; if it is possible to get more of one good without accepting less of another, or to achieve one objective without sacrificing another, the economy is not Pareto efficient (Black et al., 2012).

Transaction costs: The costs incurred in undertaking an economic exchange. Practical examples of transaction costs include the commission paid to a stockbroker for completing a share deal, and the booking fee charged when purchasing concert tickets. The costs of travel and time to complete an exchange are also examples of transaction costs. The existence of transaction costs has been proposed as the explanation for many of the economic institutions that are observed. For example, it has been argued that production occurs in firms rather than through contracting via the market because this minimizes transaction costs. Transactions costs have also been used to explain why the market does not solve externality problems (Black et al., 2012).

Travel cost method: A pricing method that seeks to estimate a money value on the basis of the amount that people actually pay (in money and time) to gain access to beautiful sites, wilderness and so on, or to avoid various forms of damage and degradation. The costs incurred by visitors to a site are used to determine a demand curve for the recreational value they place upon that site. This can be the basis for estimates of the value of the site, and hence of the significance in monetary terms of benefit or damage to or loss of availability of the site (OECD, 2008).

Triple bottom line: Using ecological and social criteria for measuring organizational success, in addition to financial performance (Allen and Lieberman, 2010, p. 82).

Uncertainty: A consciousness of limited knowledge about present facts or future events. There is a formal distinction between risk and uncertainty: risk applies when probabilities can be assigned to the likely occurrence of future outcomes; uncertainty applies when probabilities cannot be assigned (Black et al., 2012).

User (of meteorological or hydrological services): The individual, organization or intermediary who receives the product and services and bases his or her decisions on them. For the delivery of public weather services, members of the public will ideally have their needs considered by an organization or representative body, although in reality this is often done in an ad-hoc manner based on different information-gathering methods such as surveys or focus groups, involving little direct contact with individual members of the public (WMO, 2014*b*).

Value added: The amount by which the value of information, services or goods is increased at each stage of its production (*Oxford English Dictionary*).

Value chain: The process or activities by which value is added to information, services or goods, from production to final use or consumption (Stevenson and Waite, 2011).

Value of information: The value of the outcome of action taken with the information less its value without the information (West and Courtney, 1993, p. 230).

Verification: A process for determining the accuracy of a weather or climate forecast (or prediction) by comparing the predicted weather with the actual observed weather or climate for the forecast period (Glickman, 2000).

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014).

Weather: State of the atmosphere at a particular time, as defined by the various meteorological elements (WMO, 1992).

Weather forecast: A statement of expected meteorological conditions for a specific time period and for a specific area (Geer, 1996). A weather forecast usually specifies the various meteorological elements and phenomenon on a day-by-day basis out to the predictability limit of a few weeks.

Weather service: The provision of weather forecasts and warnings about hazardous conditions, and the collection, quality control, verification, archiving and dissemination of meteorological data and products (WMO, 1992).

Whole-of-service assessment: A comprehensive assessment of all of the services provided by a given entity, as opposed to an assessment of one or more specific services (this publication).

Willingness to pay: The maximum amount that an economic agent is willing to pay to acquire a specific good or service. The WTP is private information but may be obtained using revealed-preference methods or stated-preference methods (Black et al., 2012).

World Weather Watch: The coordinated international system for the collection, analysis and distribution of weather information under the auspices of WMO (Geer, 1996).

World Meteorological Organization: A specialized agency of the United Nations established for the meteorological and related purposes set down in Article 2 of the 1950 Convention of the World Meteorological Organization as subsequently amended (WMO, 2012*b*; Geer, 1996). Through a 1975 amendment, it was given United Nations system responsibility for operational hydrology. Its membership consists of national governments who carry out its responsibilities through a World Meteorological Congress and a number of other subsidiary constituent bodies, including an elected Executive Council.

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APPENDIX B. METEOROLOGICAL, HYDROLOGICAL AND RELATED SERVICES

B.1 INTRODUCTION

Meteorological, hydrological and related services involve the provision of information and advice on weather, climate, river, lake, ocean and other environmental conditions as a basis for decisionmaking to increase the benefits and reduce the costs of environmental impacts on human activities and of human impacts on the environment.

The basic concept of met/hydro service provision and application for societal benefit is shown schematically in Figure B.1 (and explained in more detail in Chapter 2).

In the absence of the services, the various meteorological and related influences and phenomena (left-hand box of Figure B.1) impact on the weather-, climate- and water-sensitive socioeconomic sectors and activities (top horizontal arrow) to produce a range of favourable and adverse outcomes. With a service provision system in place (lower part of Figure B.1), the information provided on past, present and expected future meteorological, hydrological and related conditions enables better-informed decisions and resulting actions (for example, disaster preparedness

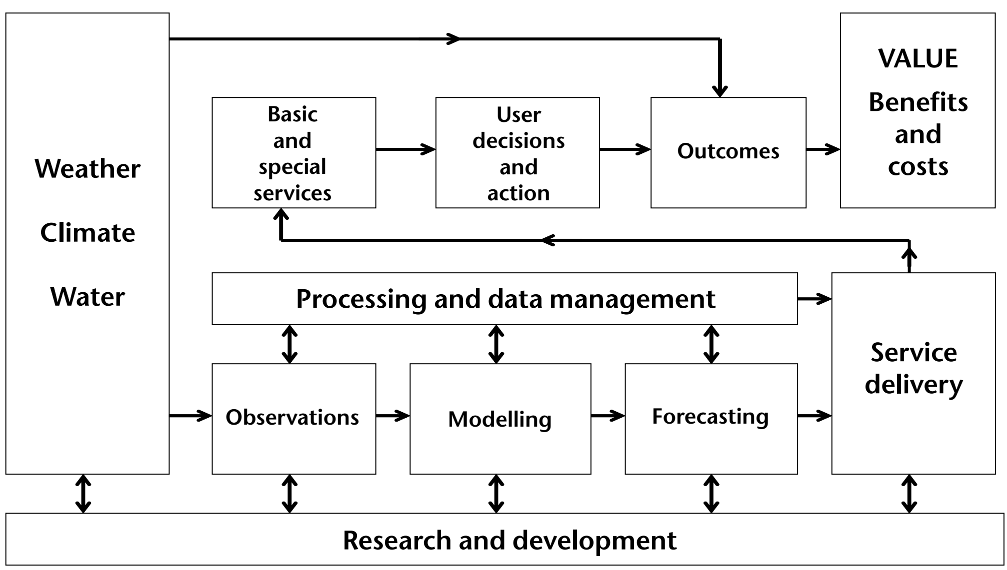

Figure B.1. The production and delivery of met/hydro and related services (lower part of diagram) and the value chain (upper part of diagram) through which these services deliver economic value (benefits minus costs) to user communities (see Chapter 2)

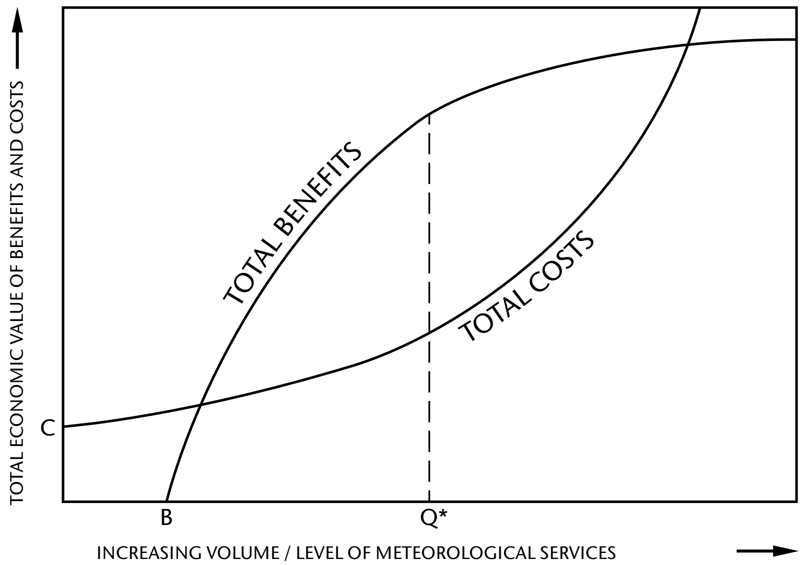

Figure B.2. Total value of the costs and benefits of meteorological and related service provision as a function of the volume and level (including quality) of service provided (WMO, 2009*a*). The greatest excess of benefits over costs is achieved for the level of service (Q*) for which the slopes of the total cost and benefit curves are the same, that is, at the point of intersection of the marginal cost and benefit curves (see Chapter 5)

and well-timed crop fertilizer distribution and planting), which lead to reduced costs and greater rewards and hence net individual (private) and societal (public) benefits from the use of the services. When the additional benefits achieved from the use of the services exceed the costs of their provision, net value is added and society is better off.

One of the characteristic features of meteorological (and to a more limited extent, hydrological) service provision is the need for a substantial underpinning observational and data-processing infrastructure (the “Observations”, “Modelling” and “Processing and data management” boxes in Figure B.1) as a prerequisite for the production of scientifically sound information, forecast and advisory services. Thus, substantial funds (C in Figure B.2) must be invested in infrastructure to achieve even a minimal level of service, with additional funding enabling a higher level of service up to some limit where essentially no further improvement is achievable, making the cost curve for service production concave upwards as shown schematically by the “Total costs” line in Figure B.2. On the other hand, the quality of the service has to reach some threshold level (B) which will win the confidence of potential users before it begins to deliver benefits – with the benefits then increasing as the level of service is enhanced until no further value can be added by the service and the benefits curve plateaus as shown by the “Total benefits” line in Figure B.2.

Historically, the perceived importance of weather information, especially warnings of imminent dangerous weather, to safety of life and property was so great that it was seen as self-evident that all citizens should be provided with a basic level of meteorological services. And, because essentially the same observational, data management and modelling infrastructure and service provision arrangements needed for warning purposes could also meet the needs of most other potential users, the responsibility for service provision to all sectors of the community was historically accepted by governments through establishment and operation of NMSs. In recent times, as emphasis has increased on achieving the most economically efficient provision of all categories of public services, governments and service-providing organizations have focused on optimizing national arrangements for the provision of essential public services and on minimizing and most appropriately allocating, their costs (Alford and O'Flynn, 2012). This has raised challenging issues of funding and charging, especially for services that go beyond governments' basic public interest responsibilities to their national communities.

B.2 METEOROLOGY, HYDROLOGY AND OCEANOGRAPHY

Meteorology is the science of the atmosphere, dealing in particular with its structure and composition, interactions with the oceans and land, movements (including weather-forming processes), weather forecasting, climate variability and climate change (WMO, 1996). Meteorology includes, by definition, both weather and climate (Met Office, 1972).

Hydrology is the science that deals with the waters above and below the land surfaces of the Earth, their occurrence, circulation and distribution, both in time and in space, their biological, chemical and physical properties, their reaction with their environment, including the relation to living beings (WMO, 1992). Hydrology is often subdivided into scientific and operational hydrology. Scientific hydrology is concerned with understanding all stages of the hydrological cycle. Operational hydrology (WMO, 1996) comprises:

- Measurements of basic hydrological elements from networks of meteorological and hydrological stations;

- Hydrological forecasting;

- Development and implementation of related methods, approaches and techniques in those areas of activity.

Oceanography is the science of the ocean, including its composition, circulation and behaviour and the observation, description and forecasting of characteristic ocean phenomena on various time- and space scales. It is often subdivided into physical, chemical and biological oceanography (Holland and Pugh, 2010).

In identifying an appropriate framework for maximizing the benefits of meteorological, hydrological and oceanographic services, it is important to understand the nature and impact of weather, climate, river, lake, ocean and related environmental conditions on society, and the significance of the various links in the end-to-end service production, delivery and application chain shown schematically in the lower part of Figure B.1.

B.3 WEATHER, CLIMATE AND WATER

Weather is the state of the atmosphere at a particular time as defined by the various meteorological elements (WMO, 1992). It is described in terms of the temperature and other meteorological variables on timescales of minutes, hours, days and weeks and the location and movement of weather-producing synoptic systems such as the highs, lows, troughs and fronts that appear on the familiar television and newspaper weather maps.

Climate is a synthesis of weather conditions in a given area, characterized by long-term statistics (mean values, variances, probabilities of extreme values, and the like) of the meteorological elements in that area (WMO, 1992). It is essentially a statistical description of weather and its variability over longer time periods, usually months, seasons, years, decades and centuries. It is described in terms of local values and spatial patterns of the averages and extremes of the weather.

Water appears in various forms (liquid, solid, vapour). Atmospheric water is an integral part of most weather and climate phenomena, while surface water interacts with land surfaces and biospheres. The succession of stages through which water passes from the atmosphere to the Earth and returns to the atmosphere – evaporation from the land or sea or inland water, condensation to form clouds, precipitation, interception, infiltration, percolation, runoff, accumulation in the soil or in bodies of water, and re-evaporation – is known as the hydrological cycle (WMO and UNESCO, 2012).

The weather- and climate-forming processes of the atmosphere and the ocean are globally interconnected and closely coupled. Because of its greater density and heat content, the ocean is characterized by phenomena on generally longer timescales than those of the atmosphere. However, because they are both governed by the same physical laws that enable certain aspects of their future state and behaviour to be determined from their past and present states, their evolution over time can be simulated numerically with powerful computers to produce forecasts or predictions of future weather and climate. It is useful, in describing meteorological and related services, including forecast services, to categorize the phenomena of weather and climate according to their characteristic space and timescales, as shown schematically in Figure B.3.

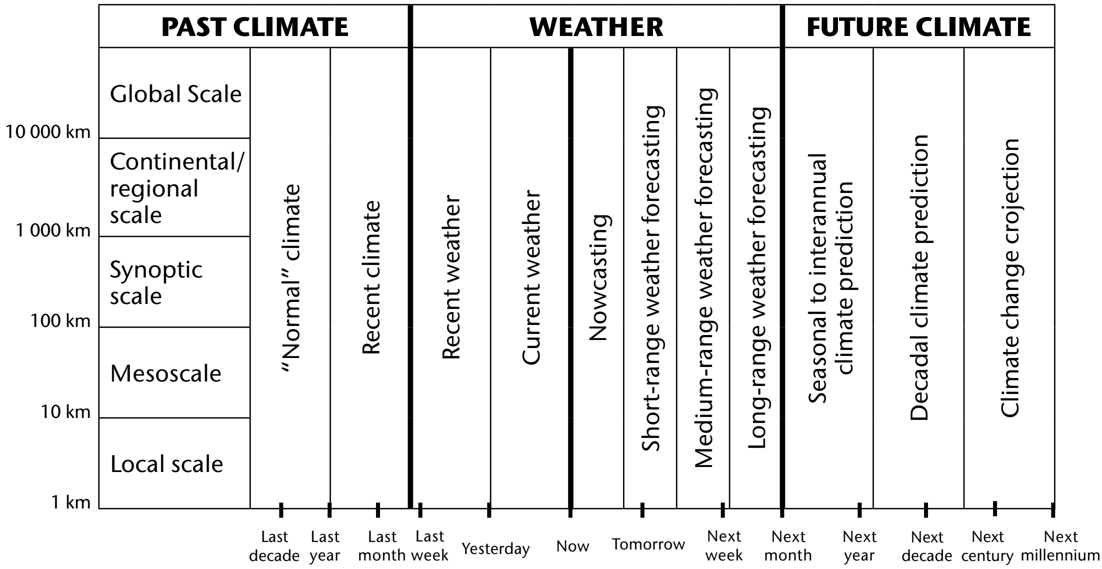

Figure B.3. Characteristic space scales of weather phenomena (left-hand scale) and the approximate timescale terminology for weather and climate description and prediction (lower scale)

B.4 WEATHER-, CLIMATE- AND WATER-SENSITIVE ACTIVITIES, SECTORS AND COUNTRIES

Virtually every person and every country and almost all human activities are directly or indirectly influenced by weather and climate. Also, many people are – from time to time – seriously impacted by floods, ocean waves, storm surges and other hydrological and oceanographic phenomena. The impacts extend over countries, regions, economic sectors, social classes and age groups.

The sectors of society that are most sensitive to weather and climate include agriculture, aviation, construction, emergency management, energy, health, natural resource management, shipping and tourism (WMO, 1996).

Different types of weather and climate phenomena have varying impacts in different parts of the world. Developing countries, in general, are more sensitive to weather and climate than the economically stronger developed countries where infrastructure planning and engineering have done much to reduce vulnerability albeit, often, with more and far more costly assets at stake. Thus, developing countries reliant on rain-fed agriculture are especially vulnerable to drought, while hurricanes remain an ever-present threat to safety of life and property in many tropical countries, especially those with extensive coastal tourism infrastructure (WMO, 2007*a*).

B.5 IMPACTS OF WEATHER, CLIMATE AND WATER

Weather and climate have shaped the history of civilizations and nations through the ages (Durschmied, 2000). Their extremes impact widely across society (Burroughs, 1997). There are many different metrics used for quantifying the impacts of weather, climate and related environmental conditions and phenomena on the different sectors of society and on national communities and economies as a whole. Two of the most important are:

- Numbers of people adversely affected and lives lost as a result of dangerous meteorological and hydrological phenomena;

- Economic costs of the damage from extreme weather, climate and hydrological events and the economic benefits (for example, to farming or the tourism industry) from spells of "good" weather.

There are also many different approaches to categorizing and aggregating these impacts, both positive and negative, by phenomenon, impact sector, country and so on. Even without specific factoring in of natural disasters, United States economic activity (as GDP) varies by up to plus or minus 1.7% due to weather variability, resulting in impacts as large as US$ 485 billion of the US$ 14.4 trillion 2008 GDP (Lazo, 2011). A 1990s study suggested that the strongest single indicator of the state of the Australian economy, apart from the global economy, was the meteorological Southern Oscillation Index (McTaggart and Hall, 1993).

Worldwide, it is estimated that, in 2011, about 206 million people were victims of natural disasters with an economic cost of US$ 366 billion (Rogers and Tsirkonov, 2013) with the largest part of this due to disasters of meteorological and hydrological origin.

B.6 ORIGIN OF MET/HYDRO SERVICES

Meteorological service provision (see also section C.2) has a very long history stretching back, in one sense, for thousands of years (WMO, 1990; Halford, 2004). The origin of scientifically based services dates from the second half of the nineteenth century when, for example:

- Maury (1855) provided climatological wind and current maps for the oceans from ships' logs as a service to marine navigation;

- Fitzroy (see Gribbin and Gribbin, 2003) initiated storm warnings for ships at sea and began issuing public weather forecasts for parts of England;

- Abbe (see Cox, 2002) used the new real-time data collection powers of the electric telegraph to prepare and distribute daily weather forecasts for several cities across the United States.

Soon, many countries began establishing NMSs to prepare weather bulletins and maps for public information, with their data collection and exchange arrangements coordinated internationally through the International Meteorological Organization (IMO), established in 1873, via its regular "Conferences of Directors of Meteorological Services" (Daniel, 1973).

Meteorological service provision expanded rapidly to almost every country during the first half of the twentieth century, especially in support of agriculture and shipping and to meet the burgeoning needs for both current and forecast information for the safety and economy of civil aviation. Under the broad guidance of IMO, all major nations and their colonies established observation networks, data collection arrangements (initially by both telegraph and mail) and climatological and forecasting offices serving shipping and aviation. In most countries, they also issued public weather forecasts through newspapers and radio. The community demand for both current weather information and forecasts became insatiable (see for example, Fleming, 1996; Cox, 2002).

The concept of hydrological services has a shorter history than that of meteorological services in most parts of the world, albeit that measurements and records of lake and river levels also go back thousands of years, and streamflow and other hydrological monitoring became an integral part of river management with the establishment of the major river commissions in Europe in the nineteenth century. It was only following the International Hydrological Decade of 1964–1974 and decision by governments to vest international responsibility for operational hydrology in WMO in 1975 that the concept of hydrological information as a service, analogous to a meteorological service, became widely adopted in most of the rest of the world.

B.7 NATURE AND SCOPE OF MET/HYDRO SERVICES

Meteorological services range widely in nature and include almost every type of information, advice or investigation on past, present and future weather and climate and their impacts on society (Zillman, 1999). They often also include provision of information on river, lake and ocean conditions and thus are sometimes regarded as including both hydrological and oceanographic services. They are usually, though somewhat artificially, subdivided into weather services and climate services (or met/hydro services).

Weather services involve the provision of information and advice on recent, present and expected weather conditions on timescales from a few hours (nowcasting) out to a few weeks (medium-range weather forecasting). Weather forecasts or predictions aim to describe the meteorological conditions at an individual location or over an area or region at any point in time out to the limits of predictability of individual synoptic weather systems. Weather warnings are aimed at alerting potentially affected communities to severe or dangerous conditions and of the actions needed to reduce their adverse impact.

Met/hydro services involve the provision of climate information in a way that assists decisionmaking by individuals or organizations. A climate service requires appropriate engagement along with an effective access mechanism, and must respond to user needs. Met/hydro services include the provision of historical climate data and information, analysis of current climate conditions and outlooks, predictions, projections and scenarios of future climate on timescales from months to millennia.

With the establishment of WMO in 1950 (Daniel, 1973), the initiation of WMO WWW in 1963 (Rasmussen, 2003) and the major advances in atmospheric predictability through the GARP in the 1970s and 1980s (WMO, 1990), the useful application of weather and met/hydro services became widespread across the community. In 1991, WMO initiated its Public Weather Services Programme (WMO, 2007*b*) to assist all countries to enhance the public availability and usefulness of daily weather information, whether provided by NMSs or through private sector, academic or media service providers. The establishment of the World Climate Applications (and Services) Programme as part of the World Climate Programme initiated in 1979 (Boldirev, 1991) greatly expanded the nature and scope of met/hydro services in many countries. The concept of met/hydro services was greatly broadened through the work of IPCC, established in 1988 (Bolin, 2007). The focus on met/hydro services was further enhanced through the Climate Agenda (WMO, 1993), the World Climate Conference-3 in 2009 (WMO, 2009*b*) and establishment of the GFCS (WMO, 2014*a*).

Hydrological services overlap significantly with meteorological services and cover similar timescales but focus primarily on the surface component of the hydrological cycle, especially streamflow and river height prediction. They include water resource monitoring and assessment, and the important category of flash (short-term) and riverine (long-term) flood warning. Warnings for flooding, especially flash-flood warnings, are usually regarded as both meteorological and hydrological services.

B.8 ECONOMIC CHARACTERISTICS OF MET/HYDRO SERVICES

The policy, funding and charging arrangements for provision of met/hydro services and the mechanisms through which they deliver benefits to society are significantly influenced by the overall economic and policy framework within which they are provided (WMO, 2002). This is especially so according to the extent of their economic properties of rivalry and excludability (Freebairn and Zillman, 2002*a*).

Most meteorological services have historically been regarded as public goods (Samuelson, 1954; Harris, 1995; Stiglitz, 2000; Gunasekera, 2004) characterized by the twin properties of:

– Non-rivalry: One person's consumption of the service does not reduce the amount or value available to others;

– Non-excludability: The service having been made available to one user, it is impossible or very costly to exclude others from its use.

However, some economists regard the non-rivalrous criterion as the most important in the characterization of public goods such as meteorological services.

Public goods have a number of other economic characteristics (Bailey, 1995) that influence the way they are provided and consumed by society:

– Because they are collectively owned and no property rights can be invested in them, markets fail to exist for their provision;

– The decision on whether they should be provided, and at what level, must be taken by government;

– The cost of their provision must be (primarily) met by taxation;

– The beneficiaries are the whole of society and the total benefit to society is the larger the more widely they are consumed.

Some public meteorological services, especially warning services, have the additional characteristic of "merit goods" (Bailey, 1995), that is, goods with consumption that is proactively fostered by governments in the public interest.

It should be noted, however, that there is also a substantial range of meteorological and related services that are by nature of private (that is, rival, excludable) or mixed goods (Gunasekera, 2004). Most user-specific special services are, at least to some degree, rival and excludable and are most efficiently provided through market processes. This can be achieved either through private sector service providers or through commercial arms of NMSs. And, in some circumstances in some countries, some of the revenue from commercial services may be used to offset the cost of provision of the public service.

At the international level, many meteorological services may be further categorized as "global public goods" (Kaul et al., 1999), that is, goods with consumption that benefits many countries, a broad spectrum of the global population and future as well as present generations. To some extent, the WMO system of international cooperation in meteorology is itself a global public good (Gunasekera and Zillman, 2004).

While some hydrological services such as flood warnings and river and lake level regimes possess essentially the same public-good character as public meteorological services, others, such as real-time information on streamflow, dam level, soil moisture and water quality have historically been more linked with water resource management and commercial water supply, and have been regarded as more of the nature of private or mixed goods. In some parts of Europe, river-flow data have been exchanged for a long time but, at the global level, hydrology lacks the strong tradition of free and unrestricted data exchange that underpins global meteorology, with many countries reluctant to release river flow information beyond national borders. In this sense, hydrological information has more of the rival and excludable properties of private goods.

B.9 PROVIDERS OF METEOROLOGICAL AND RELATED SERVICES

The provision of meteorological services in every country relies on the existence of some form of end-to-end NMS system (lower part of Figure B.1) consisting of four basic components:

- A national observation network;
- A research and development effort (although this may be very small or non-existent in some developing countries);
- Data management and modelling/forecasting/archival capabilities;
- A service delivery system.

These components are supported by arrangements for international cooperation in data collection and service provision (WMO, 2009*a*).

In the broadest sense, each of these must be regarded as essential links in an integrated national service provision chain (for example, the observation network provides an essential service to both research and modelling), but the main focus is usually on the final step in the process through which historical and current data and model outputs are transformed into information products suited to user needs, including both the general public and the many specialized user communities.

The major participants in the NMS system (in recent United States terminology (National Research Council, 2003) the "weather, water and climate enterprise") are (Zillman, 2014):

- The government agency, the NMS, usually publicly funded, responsible for the operation of the national meteorological infrastructure and for provision of (at least) the basic service to the community;
- The academic (university) research community which usually plays a key role in advancing the scientific basis for service provision and trains many of the professional staff who move into service provision;
- The mass media that, in most countries, work in close partnership with the NMS in delivering essential services to the public;
- Private sector and other providers, including commercial providers of value-adding tailored services and special in-house service providers in many of the major user sectors and organizations (for example, energy companies and airlines).

Many NMSs also carry national responsibility for a range of hydrological, oceanographic and other environmental services. Those that have formal national responsibility for provision of hydrological as well as meteorological services are often referred to as National Hydrometeorological Services, albeit with the same WMO acronym (NMS) as those with responsibility only for meteorology. In other countries, the major responsibility for hydrological service provision resides with separate NHSs, often located in water supply ministries. Some countries also operate separate National Oceanographic Services. Both NHSs and National Oceanographic Services operate on a broadly similar end-to-end basis as NMSs, albeit without the strong public service delivery mechanisms that characterize well-established NMSs.

B.10 **USERS OF MET/HYDRO SERVICES**

The users of met/hydro services embrace virtually every individual, organization and community sector whose activities are sensitive to the impacts of weather, climate and water. The user community is normally regarded as consisting of the general public, as the users of basic services, and all the various economic and social sectors and organizations as the users of what are often referred to as special services. In the case of tailored (special) services provided on a commercial basis, it is now usual, in many countries, to refer to the users of the services as clients or customers.

B.11 **NATIONAL METEOROLOGICAL SERVICES**

A country's NMS is an essential component of its basic infrastructure (WMO, 1999*a*; Zillman, 1999). Although their detailed responsibilities vary from country to country, most NMSs are responsible for:

– Operation of the national meteorological (and in some cases, also hydrological and oceanographic) observation network, including both surface and upper air observations needed for weather forecasting and for the climatological record;

– Assembling and maintaining the national climate data archive, including processing and quality control of all available observations, and their storage and safeguarding in standard and appropriately accessible formats;

– Advancing knowledge of their countries' weather and climate through research and investigation, in the overall national interest, as well as to improve their weather and met/hydro services;

– Providing a wide range of weather, climate and related (often including hydrological, oceanographic, ionospheric and other environmental) services to their national communities, both widely through the mass media and through specialized delivery arrangements tailored for major user sectors or organizations;

– Meeting their countries' obligations for international data collection and exchange under the Convention of the World Meteorological Organization, including, usually, leadership of national involvement in the various constituent bodies and programmes of WMO (and, in the case of those with oceanographic service responsibilities, in the Intergovernmental Oceanographic Commission of UNESCO).

The ultimate goals of NMSs also vary between countries, but in most they focus particularly on (WMO, 2007*a*):

– Protection of life and property;

– Safeguarding the environment;

– Contributing to sustainable development;

– Promoting long-term observation and collection of meteorological, hydrological and related environmental data;

– Promotion of endogenous capacity-building;

– Meeting international commitments;

– Contributing to international cooperation.

Historically, most NMSs, whether in advanced or developing countries, were organized fairly simply into observation, telecommunications, research, climate and forecasting branches or departments. In recent decades, however, particularly since many NMSs have adopted more business-oriented approaches to their missions, a wide range of operating models has come into use (Rogers and Tsirkunov, 2013).

Zillman (1999) provides a general overview of the role and operation of NMSs and Zillman (2003) summarizes the state of NMSs around the world in the early twenty-first century. WMO (2013) provides a detailed listing of contemporary NMS functions and services.

B.12 NATIONAL HYDROLOGICAL SERVICES

In many countries, the primary responsibility for river, lake and other hydrological observation, data management, research, modelling and streamflow forecasting and warning resides with organizationally separate NHSs, which are often located with environmental, natural resource management, water supply or emergency services ministries.

The basic functions of NHSs are essentially similar to those of NMSs but focused on the surface phase of the hydrological cycle, including precipitation, runoff, river flow, storage (in soil and lakes) and loss to the atmosphere through evaporation and evapotranspiration. The main NHS products and services include information on historical and current rainfall and evaporation, river height and discharge and lake and dam levels, as well as forecasts of river flow (including low flows) and warnings of flash and riverine flooding. Many NHSs also have responsibility for monitoring of underground water resources.

The role and operation of NHSs are discussed in a range of WMO and other publications over recent decades with an excellent overview available (see WMO, 2001).

B.13 INTERNATIONAL COORDINATION OF MET/HYDRO SERVICES

The essential standardization and coordination of meteorological observation, data collection and service provision were carried out from 1873 to 1950 by the non-governmental IMO, especially through its regular international “Conferences of Directors of Meteorological Services” and its subsidiary system of expert technical commissions. Since 1950, the primary mechanism for international cooperation and coordination in meteorology has been provided by the intergovernmental WMO. The responsibility for international cooperation in hydrological data collection and exchange, which had resided historically with the river basin commissions, was added to the WMO Convention in 1975, with UNESCO assuming responsibility for international cooperation in scientific hydrology.

The purposes of WMO under its convention now include (WMO, 2012):

– To facilitate worldwide cooperation in the establishment of networks of stations and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;

– To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;

– To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;

– To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;

– To promote activities in operational hydrology and to further close cooperation between meteorological and hydrological services.

Most of the international technical coordination of meteorological and hydrological services is carried out through the specialized intergovernmental technical commissions of WMO, in particular:

- The Commission for Basic Systems that, in addition to its role in guiding the operation of the common underpinning infrastructure, carries primary international responsibility for the WMO Public Weather Services Programme;

- The Commission for Agricultural Meteorology, which coordinates weather and met/hydro services for agriculture;

- The Commission for Aeronautical Meteorology, which works in conjunction with ICAO to coordinate the provision of meteorological services for civil aviation;

- The WMO–Intergovernmental Oceanographic Commission Joint Technical Commission on Oceanography and Marine Meteorology, which provides essential international coordination of meteorological and oceanographic services for shipping and other offshore activities;

- The Commission for Climatology, which coordinates the provision of met/hydro services;

- The Commission for Hydrology, which provides essential international coordination of all aspects of operational hydrology including the provision of hydrological services.

Within the WMO Secretariat, essential international coordination activities are organized through a series of application and service programmes such as the Public Weather Services Programme, the Agricultural Meteorology Programme and the Aviation Meteorology Programme. Following World Climate Conference-3 in 2009, WMO and its partner international organizations agreed to enhance the provision of met/hydro services through the GFCS (WMO, 2009*b*; 2014*a*).

The viability of service provision within every country is heavily dependent on national access to essential meteorological and related data and products from neighbouring countries and from around the world. Following resolution of the major data exchange controversies of the 1990s (Bautista Perez, 1996), the basic policy and practice regarding international data exchange in support of various categories of service is set down in Resolution 40 of the 1995 WMO Congress (for meteorology) and Resolution 25 of the 1999 Congress (for hydrology).

B.14 LEVEL AND QUALITY OF SERVICE

Inevitably, the level and quality of meteorological and hydrological services vary considerably from country to country depending, among other things, on:

- Coverage and performance of the national observing networks and data management systems;

- Access to data (especially satellite data) and products from other countries;

– Sophistication and skill of prediction models and the effectiveness of the cascading forecasting process through which the products of global and regional centres are employed by NMSs in local forecasting operations;

– Training and expertise of forecasting and other service staff;

– Effectiveness of provider–user interaction and service delivery arrangements.

Most countries' NMSs maintain extensive performance monitoring of the various links in the service provision chain, including especially the accuracy and skill of their various forecast products (Murphy, 1993, 1997). In its *Guidelines on Performance Assessment of Public Weather Services* (WMO, 2000), WMO elaborates the important distinction between forecast accuracy, precision, skill and reliability, and outlines an overall framework for forecast verification and performance assessment from both provider and user perspectives.

There is now an active research community and an extensive literature on forecast verification (see, for example, Ebert et al., 2013) aimed at better quantifying various key aspects of NMS performance and, in particular, at providing objective assessment of the contribution of various stages of the service provision chain and various new approaches and technologies, to forecast improvement. It has been shown, for example, that, in the southern hemisphere, satellite data extend the time range of skilful numerical weather prediction by a factor of four (Le Marshall et al., 2013).

Such performance measures, coupled with studies of forecast impact in the various user communities, represent an essential foundation for national initiatives on investment in NMS modernization.

B.15 SERVICE DELIVERY

In order to deliver value to their user communities, met/hydro services require efficient and effective service delivery systems. In recent years, the WMO Public Weather Services Programme has led the development of a comprehensive service delivery strategy and implementation plan (WMO, 2014*b*) which is described in Chapter 2.

B.16 APPLICATION OF MET/HYDRO SERVICES IN DECISIONMAKING

The applications of meteorological services range widely across all weather- and climate-sensitive sectors of society – from the simple, almost subconscious response of individuals and households to the daily weather forecast, through the largely invisible incorporation of detailed terminal and en-route winds and weather conditions in aviation operations (affecting important safety, economic and regulatory decisions such as the carriage of "holding" fuel), to sophisticated modelling of meteorological influences on such long-term economic decisions as water-supply design or crop-yield planning and forecasting. Useful summaries of the range of applications of traditional weather services are included in the various programme documents of WMO, including the report of the Madrid Conference (WMO, 2009*a*). The proceedings of the first, second and third World Climate Conferences (WMO, 1979, 1991 and 2009*b*) provide a good overview of the applications of met/hydro services and the GFCS Implementation Plan (WMO, 2014*a*) outlines some of the new opportunities emerging from improvements in climate prediction and IPCC assessments of human-induced climate change.

The traditional users of hydrological services were located primarily in agricultural, energy, navigation and water-supply sectors, with a long history of use of precipitation and streamflow information in dam design, irrigation scheduling, and the like. Increasingly in recent decades, the broader community applications of hydrological services, in both qualitative and quantitative decision models, have advanced in line with the underpinning technologies (especially satellite observation) and the increasing challenges of reliable water supply for growing populations in both developing and developed countries.

Many different factors influence the effectiveness of the application of met/hydro services in decisionmaking and the ultimate benefits that flow to individual users and society as a whole from their use. In addition to the inherent quality of the services and effectiveness of their delivery, these include:

– The strength of the weather/climate/water sensitivity of the socioeconomic activities or sectors concerned;

– The confidence of the users in the quality and usefulness of the services;

– The sophistication of the decision models employed.

The confidence of users and potential users in the skill and reliability of forecast information is especially important. Experience suggests that forecasts need to reach a reasonably high threshold of skill and reliability (see Figure B.2) before users will institutionalize them in economically significant decisionmaking (and be prepared to forgive occasional forecast errors). Indicators of provider confidence in forecast reliability in individual circumstances can be useful in building up user trust and confidence to this end.

B.17 FUNDING, PRICING AND CHARGING FOR SERVICES

Historically, meteorological service provision, including provision of the essential observational and data-processing infrastructure, was seen as a fundamental responsibility of governments funded by taxpayers through government appropriations in the interests of the community at large.

The established meteorological concept of government-funded NMSs freely exchanging their data internationally to help each other to deliver maximum benefits to their national communities was firmly in place half a century before the economic concept of public goods (Samuelson, 1954) became institutionalized in national treasuries and budget processes. The IMO/WMO model of voluntary cooperation emerged especially from the dependence of NMSs on observations from shipping, not just to provide maritime forecasts and warnings for the safety of life at sea but also to provide the best possible forecast services for their own national territories.

With the advent and rapid growth of civil aviation, however, the requirements for meteorological services expanded so rapidly that the concept of funding at least the aviation-specific services and, in some cases, the observational and forecasting infrastructure needed to support them, through air navigation charges emerged. In many former colonies and developing countries where only primitive NMSs had existed in the pre-aviation era, various aviation industry-based funding arrangements were put in place, with the capacity of the NMSs to provide public weather services essentially subsidized from aviation user charges. Over time, a range of incremental and other user charging models have been put in place through ICAO–WMO mechanisms (for example, ICAO, 1997; WMO, 1999*b*).

Two major developments placed the traditional government and/or aviation industry funding of NMSs under pressure in the 1980s and early 1990s. The first was the substantially increased costs of the national and international meteorological infrastructure (especially satellites) that resulted from the WWW and GARP initiatives (WMO, 1990). The second was the move, in some parts of the world, to commercialize or privatize many types of "public" services that had traditionally been provided by government. This precipitated a period of considerable turmoil in WMO, with difficult negotiations on issues of data exchange, commercialization and alternative service delivery (Bautista Perez, 1996; WMO, 1999*a*). The relationship between NMSs and the national and international private sector also came under stress, with different approaches and policies adopted in different countries (WMO, 1996). Freebairn and Zillman (2002*b*) and Gunasekera (2004) provide an analysis of some of the economic and policy considerations involved in meteorological service funding, pricing and charging. Rogers and Tsirkunov (2013) provide a useful survey of the funding and operating models that have evolved over the past decade, including those where NMS operations depend on a combination of government funding and user charging.

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APPENDIX C. A SHORT HISTORY OF STUDIES OF SOCIOECONOMIC BENEFITS OF METEOROLOGICAL AND HYDROLOGICAL SERVICES

C.1 INTRODUCTION

There is an extensive literature on the social, economic and environmental benefits from the application of meteorological services over the past 60 years (for example, Bijvoet and Bleeker, 1951; Thompson and Brier, 1952; Gibbs, 1964; Maunder, 1970; Taylor, 1972; Price-Budgen; 1990; Katz and Murphy, 1997; WMO, 2007*a*). Increasingly during the past 50 years, the convergence of expertise from the separate, but in some ways similar, disciplines of economics and meteorology, including through the work of some who have excelled in both fields (see, for example, Arrow, 2008), has led to a more quantitative approach to valuation and emergence of a significant field of meteorological economics (WMO, 2002; Gunasekera, 2004; Katz and Lazo, 2011).

The World Meteorological Organization became substantially involved in studies of the economic benefits of meteorology in conjunction with the increased financial investment in observational infrastructure associated with the establishment of WWW in the 1960s (WMO, 1966). This inspired a range of economic benefit studies at the national level (WMO, 1968) and triggered academic interest in more refined methodologies for establishing the economic value of meteorological information (Freebairn, 1979). The World Meteorological Organization continued to foster economic studies in conjunction with its work on more effective application of the expanded range and increased quality of meteorological and hydrological services through the 1980s and 1990s (WMO, 1990*a*, 1994) and, in particular, through the 2007 Madrid Conference and Action Plan (WMO, 2009*a*).

The World Bank has maintained a general interest in the role of met/hydro services in natural disaster reduction and other development goals over the years, albeit mostly as a minor component of much larger infrastructure projects in developing countries. It was only with the initiation of a major World Bank project on modernizing the Russian Hydrometeorological Service (Roshydromet) in the early 2000s (Tsirkunov et al., 2006) that the Bank became substantially involved in specific projects focused on strengthening the role and operation of NMHSs. This led to an extensive series of projects aimed at demonstrating the benefits from improved met/hydro services in the former Union of Soviet Socialist Republics (WMO, 2007*b*), with subsequent extension to Africa and other developing regions and preparation of a comprehensive World Bank guidance document (Rogers and Tsirkunov, 2013).

C.2 ORIGINAL MOTIVATION FOR PROVISION OF METEOROLOGICAL SERVICES

Meteorology has, from the beginning, been an intensely applications-oriented field of science, with investment in data collection infrastructure and research strongly influenced by the need to deliver useful information for societal benefit. The origins of international cooperation in meteorology (see also section B.6) in the mid-nineteenth century resulted from the perceived benefits from using increased knowledge of climatological wind and current patterns over the oceans to enhance the efficiency and safety of marine navigation (Maury, 1855). The first systematic attempts at scientifically based weather prediction were inspired by the need to provide forewarning of dangerous storms to ships at sea (Cox, 2002). The initial establishment, in the late 1800s and early 1900s, of the predecessors of many of the present-day NMSs was inspired by widespread belief in the benefits that would flow to society from better information on the weather (for example, Day, 2007; Walker, 2012). Community faith in the value of reliable meteorological services was well summarized in the parliamentary debate on the establishment of the Australian Bureau of Meteorology as a federal agency in 1906 (McColl, 1906):

> In our present complex civilization … the discovery and formulation of laws governing the weather are of first importance. To obtain an accurate meteorological service throughout Australia, the government would be justified in incurring almost any expenditure. To all sections of the community the matter is one of great importance – to those interested in commerce, transportation, navigation, agriculture and trade of all descriptions. In short, it concerns everybody whose living and comfort depend upon the seasons and upon the weather.

With the birth of civil aviation and the extreme weather sensitivity of aircraft in the first half of the twentieth century, the need for reliable meteorological information increased rapidly and its benefits, in terms of the safety, efficiency and economy of air operations, were widely seen as self-evident and very large (Cartwright and Sprinkle, 1996). Few governments or citizens queried the essentiality of expenditure on the observational networks needed to provide reliable aviation weather services. The global need for international cooperation in meteorological service provision and the rationale for conversion of the non-governmental IMO, that had existed since 1873, into the intergovernmental WMO were taken as given and widely supported by governments (Daniel, 1973).

From time to time, however, the reliability, usefulness and value of meteorological service provision was called into question, often from the scientific perspective when it was argued that the level of scientific understanding was not yet sufficient to support the level of services provided or demanded. Scientific peer pressure forced the cessation of Admiral Fitzroy's highly valued public forecasts and storm warnings in the 1860s (Walker, 2012). Sir Napier Shaw, in 1939 (Shaw, 1939), bemoaned that "The stress of service has hampered the progress of science", and Professor Joe Smagorinsky resisted global climate models being pressed into "premature servitude" (Tucker, 1997). Most NMSs have found themselves severely criticized, from time to time, for major forecast errors and for unreliable and "useless" services; but, throughout most of the world over the past century, the importance of having an effectively operating NMS and the benefits to the community from the services it provides have been widely accepted by citizens in all walks of life and by national governments of both developed and developing countries (WMO, 2003).

C.3 EARLY WORK ON THE ECONOMICS OF METEOROLOGICAL INFORMATION AND SERVICES

The first significant publications on the economic value of meteorological information – originating from both the meteorological and economics communities – appeared in the early 1950s (for example, Bijvoet and Bleeker, 1951; Thompson and Brier, 1952). The interest in meteorological economics grew rapidly during the 1960s and 1970s on the basis of both academic/research studies (for example, Thompson, 1962; Glahn, 1964; McQuigg and Thompson, 1966; Maunder, 1970; Doll, 1971; Anderson, 1973; Murphy, 1977; Freebairn, 1979) and a number of service-, application-, industry- and country-focused studies (for example, Borgman, 1960; Bollay Associates, 1962; Lave, 1963; Gibbs, 1964; Mason, 1966).

C.4 ECONOMIC STUDIES IN SUPPORT OF WORLD WEATHER WATCH

In the late 1950s, the international meteorological community began to contemplate the potential of earth-observing satellites, digital computers and advances in understanding of atmospheric processes to bring dramatic improvements in the quality and usefulness of meteorological services throughout the world (WMO, 1990*b*). In September 1961, United States President John F. Kennedy urged the United Nations General Assembly to establish a cooperative global system of weather and climate monitoring and prediction, which was soon to emerge, following the 1963 fourth World Meteorological Congress (WMO, 1963), as WMO WWW. The 1967 Congress approved an ambitious Plan and Implementation Programme for WWW that over the following decades was to become widely accepted as the core programme of WMO and the foundation for dramatically improved weather service provision in every country (Rasmussen, 2003; Zillman, 2013).

Before the WWW era of satellites and powerful computers, the costs of meteorological service provision were relatively modest and the perceived benefits so great that it was not seen as especially important to undertake formal economic assessment of the benefits and costs of the various components of the infrastructure needed for service provision. However, with international planning proceeding for weather satellites, large computer-equipped modelling centres and the various other costly observing and information systems envisaged for WWW, it was judged appropriate, as an integral part of WWW planning, to build on the limited sectoral and national studies already undertaken to provide more rigorous economic assessment of the overall benefits of WWW implementation and the benefits potentially available to individual countries through participation in WWW. The World Meteorological Organization issued three significant WWW planning reports on economic issues over the period 1966–1968 as follows:

– No. 4 – A review of earlier economic studies of weather and climate information and an overall assessment of the economic and other value of WWW (WMO, 1966);

- No. 17 – An 11-page set of guidelines produced by an ad-hoc group of economists and meteorologists on methodologies for assessing the economic value of an NMS (WMO, 1967);

- No. 27 – A summary of economic benefit studies of NMSs of Australia, France, Germany, the Russian Federation, the United Kingdom and the United States, along with a general assessment of the applicability of BCA in meteorology and a review of potential economic benefits from improved meteorological services in developing countries (WMO, 1968).

The national assessments summarized in WWW Planning Report No. 27 were presented to the 1968 session of the WMO Executive Committee with the European Commission concluding, inter alia, that “Assessing what additional benefits will result from improvements associated with the World Weather Watch … is a fascinating field of study which can best be treated by a team of meteorologists and economists” (Thompson and Ashford, 1968).

C.5 THE 1970s AND EARLY 1980s

Following the initial economic studies associated with the establishment of WWW, the major focus of international meteorology through the 1970s and early 1980s turned to the challenges of WWW implementation and conduct of the 1979 Global Weather Experiment (Zillman, 1977) as a basis for more accurate and longer-range weather prediction. While most NMSs and a substantial number of individual experts (for example, Maunder, 1977) continued to work on economic aspects of service development and application, the primary emphasis in the 1970s and early 1980s was on the scientific and technological aspects of service improvement rather than on the societal benefits of the improved services.

A few NMS staff, however, found themselves under increased pressure from governments to provide economic justification for the public expenditure needed to support their expanded services and, in collaboration with the relevant professional societies and communities, initiated a series of conferences on the economic benefits of meteorological services (for example, Australian Bureau of Meteorology, 1979; Hickman, 1979). This entrained a new generation of economists into the issues of meteorological service provision and fostered support in WMO for more systematic long-term planning of national and international investment in the infrastructure for service provision (WMO, 1982).

At the same time, the WMO assumption of responsibility for operational hydrology within the United Nations system in 1975 began to strengthen the links, already in place in some countries, between meteorological and hydrological service provision, and opened up the scope for increased alignment between NMSs and NHSs at the national level in those countries where they operated as separate organizations. While this brought out some of the historically different approaches to funding and charging for meteorological and hydrological services, it also provided the foundation for the more integrated approach to delivery of the benefits from weather, climate and hydrological service provision that developed during the 1980s.

C.6 THE WORLD METEOROLOGICAL ORGANIZATION CONFERENCES OF 1987, 1990 AND 1994

Three important developments of the early 1980s generated a heightened awareness in WMO circles of the importance of better explaining and more rigorously demonstrating the potential social and economic benefits from the investments in NMHSs necessary to deliver the improved and expanded services (WMO, 1983):

– Recognition of the major opportunities for improved service provision opened up by the dramatic scientific and technological progress of the 1970s;

– Greatly expanded capabilities for use of met/hydro products and services for improved decisionmaking in weather- and climate-sensitive sectors;

– The severe downward pressure developing on the budgets of NMHSs of both developed and developing countries.

As an integral part of its long-term planning system introduced in the early 1980s, aimed at delivering the benefits of the scientific progress of the previous decade and bridging the gap between the NMHSs of the developing and developed countries (Zillman, 1984), WMO organized three major international conferences focused on SEBs of improved services:

– **Symposium on Education and Training with Emphasis on the Optimal Use of Meteorological Information and Products by all Potential Users**, at Shinfield Park, United Kingdom, 13–18 July 1987. The symposium was attended by more than 150 participants from 72 countries with some 42 papers focused particularly on applications and benefits in the area of water resources, environment, agricultural production and urban and regional development (Price-Budgen, 1990). The participants identified 10 key issues involved in enhancing the benefits from improved services;

– **Technical Conference on Economic and Social Benefits of Meteorological and Hydrological Services**, in Geneva, 26–30 March 1990 (WMO, 1990*a*). The conference was attended by 125 participants from 67 countries with some 61 papers presented under five major topics focused especially on evaluation methodologies, user requirements and the role of NMHSs in economic and social development. The outcome of the conference was directed particularly at informing the 1991 World Meteorological Congress approval of the WMO Third Long-term Plan, including the establishment of the proposed new WMO Public Weather Services Programme (WMO, 2007*c*);

– **Conference on the Economic Benefits of Meteorological and Hydrological Services**, in Geneva, 19–23 September 1994 (WMO, 1994). The conference was held in collaboration with several other United Nations system organizations and was attended by more than 250 participants from 127 countries. Its objective was to review methodologies and assess SEBs of NMHSs. The benefits were estimated to be five to ten times the investments made by NMHSs. The conference recommended that economic benefit analysis should be further developed and refined to underpin continued and increased government funding of NMHSs, and to stimulate revenue, as appropriate, from the private sector.

The outcome of the WMO conferences played a significant part in influencing WMO policies and strategy through the 1990s, especially in shaping the international handling of the difficult commercialization and data exchange debates of the period (for example, Bautista Perez, 1996; Zillman, 1999).

C.7 CLIMATE INFORMATION AND SERVICES

Studies of the economic benefits of climatological services date from the 1970s (for example, WMO, 1975*a*). However, the establishment of the World Climate Programme in 1979, with one of its four main focuses on enhancing the application of climate information and services, led to greatly increased awareness of the benefits potentially available from informed use of climate information. A major effort commenced on the demonstration and delivery of the benefits available from the effective use of climate information, especially through provision of enhanced access to historical climate records in developing countries through the highly successful CLICOM programme (Boldirev, 1991; Bruce, 1991).

The 1990 Second World Climate Conference decision to establish the comprehensive GCOS was based heavily on the recognition of the enormous potential benefits from improved climate data in all countries that had emerged from the WMO "Economic Benefits" conference earlier in that year, together with the findings of the 1990 First Assessment Report of the IPCC. The GCOS Joint Scientific and Technical Committee established an expert working group on SEBs, which provided initial estimates of the likely benefits of providing an effective GCOS at between US$ 5 billion and US$ 10 billion per annum (GCOS, 1995).

Work on the economic value of climate information and services continued under the leadership of the WMO Commission for Climatology and the World Climate Applications and Services Programme, with a major review of studies to that date published in 1996 (WMO, 1996). The economic value of climate forecasts featured strongly again at the 1997 International Conference on the World Climate Research Programme (WMO, 1997) and in the successive sessions of the Interagency Committee on the Climate Agenda, especially in the context of the growing international focus on the economics of human-induced climate change (for example, Cline, 1992).

C.8 WORLD METEOROLOGICAL ORGANIZATION ECONOMIC FRAMEWORK

By the end of the 1990s, with WMO focused strongly on efforts to better define and strengthen the role of NMSs at the national level (Zillman, 1999), attention turned to establishment of a more comprehensive and rigorous overall economic framework for the provision of meteorological services. Following a number of national studies and consideration by a WMO Executive Council Advisory Group on the Role and Operation of NMHSs over the period 1999–2001, WMO convened an Expert Meeting on the Economic Framework for Meteorology in Geneva, 25–27 March 2002. The overall framework document (WMO, 2002), subsequently endorsed by the WMO Executive Council, elaborated a range of economic concepts bearing on meteorological service provision and outlined the essential elements of such a framework under four broad headings:

- The mechanisms for evaluating the costs and benefits of meteorological services;
- The economic characterization of meteorological service provision;
- Competition policy issues that affect the provision of meteorological services;
- Issues related to international exchange of meteorological information.

C.9 MADRID CONFERENCE AND ACTION PLAN

Following the adoption of the WMO Economic Framework, the 2003 fourteenth World Meteorological Congress agreed on the need for a high-level conference on the benefits of weather, climate and water services. The Government of Spain subsequently agreed to host such a conference in Madrid in 2007.

Preparatory regional workshops focused especially on economic case studies were held in Brazil, Croatia, Kenya, Kuwait, Mali, the Philippines and the United Republic of Tanzania over the period November 2005 to February 2007, and the International Conference on Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services (the Madrid Conference) was held in Madrid on 19–22 March 2007 under the patronage of Her Majesty Queen Sofia of Spain. The conference was attended by some 450 participants from 115 countries who reviewed evaluation methodologies and case studies of the benefits of weather-, climate- and water-related information and services in six major socioeconomic sectors including:

- Agriculture, water resources and the natural environment;
- Human health;
- Tourism and human welfare;

- Energy, transport and communications;
- Urban settlement and sustainable development;
- Economics and financial services.

The Madrid Conference was supported by a substantial publication (*Elements for Life* (WMO, 2007*a*)) containing sectoral and other case studies (Rogers et al., 2007) including several papers (for example, WMO, 2007*d*) on evaluation methodologies. In its final session, the conference participants agreed on a Madrid Conference Statement and Action Plan (WMO, 2007*e*, 2009*a*) that summarized the essential conclusions on the current state of knowledge on the SEBs of met/hydro services and proposed a five-year strategy for further enhancing and evaluating those benefits.

The overall objective of the agreed 15-point Action Plan, which was subsequently endorsed by the 2007 World Meteorological Congress, was to achieve, within five years, a major enhancement of the value to society of weather, climate and water information and services in response to the critical challenges represented by rapid urbanization, economic globalization, environmental degradation, natural hazards and the threats from climate change. Action 11 focused specifically on valuation methodologies in the following terms:

- Encourage the NMHSs and the social science research community to develop knowledge and methodologies for quantifying the benefits of the services provided by NMHSs within the various socioeconomic sectors, in particular:
  - Develop new economic assessment techniques including especially techniques of economic assessments for developing and least developed countries;
  - Develop WMO guidelines on operational use of economic assessment techniques;
  - Train national staff on the use and practical application of economic assessment of the benefits of services provided by NMHSs;
  - Present results of economic assessments to governments and donors or international financial institutions with the goal of modernizing the infrastructure of NMHSs and strengthening their service delivery capacity.

C.10 WORLD METEOROLOGICAL ORGANIZATION TASK FORCE, FORUM AND POST-MADRID ACTIVITIES

In the lead-up to, and follow-up from, the Madrid Conference, the main focus on economic valuation in WMO resided with the Public Weather Services Programme and its Task Force on Socioeconomic Applications of Public Weather Services, later broadened to Task Force on Socio-Applications of Meteorological and Hydrological Services, and subsequently retitled WMO Forum: Social and Economic Applications and Benefits of Weather, Climate and Water Services.

The WMO Task Force provided much of the initial input to planning for the Madrid Conference and guidance to the WMO Secretariat on follow-up work on the Madrid Action Plan as adopted by the 2007 congress. This included a significant emphasis on economic benefit issues in post-Madrid public weather service workshops for developing countries (for example, Zillman, 2007) and the initiation of a series of economic valuation studies in individual WMO regions – especially in Europe under the guidance of a Regional Association VI Task Team on Social-Economic Benefits (Perrels et al., 2013).

In conjunction with the increased emphasis on economic valuation of meteorological services in the lead up to the Madrid Conference, the WMO Hydrology and Water Resources Programme initiated preparation of a comprehensive document *Guidelines on Valuation of Hydrological Services* (WMO, 2007*f*), which included a comprehensive bibliography on the economic value of hydrological services and a useful overview of methodologies for use by NHSs.

Several other WMO programmes including, especially, the World Weather Research Programme and the WMO–Intergovernmental Oceanographic Commission–International Council for Science World Climate Research Programme are now also placing considerable emphasis on assessment and demonstration of the societal benefits of weather and climate research.

C.11 **WORLD BANK STUDIES OF ECONOMIC BENEFITS**

The World Bank was first faced with the need to develop a methodology for an express assessment of economic efficiency of an NMS in 2003 while preparing the National Hydrometeorological Modernization Project in the Russian Federation (WMO, 2008; Hancock and Tsirkunov, 2013). In light of the Roshydromet experience, the World Bank initially worked with a number of NMHSs in Eastern Europe and Asia on the development and application of new and simplified approaches for assessing the current economic benefits from existing NMHSs and, especially, for estimating the additional economic benefits potentially available from their upgrading and modernization (WMO, 2007*b*). The Bank approach relied heavily on bench-marking with two stages: determining the benefits; and correcting them according to country-specific characteristics.

Following the close collaboration between the World Bank and WMO in the organization of the Madrid Conference and its immediate follow-up, and in the light of further World Bank studies (for example, Hallegatte, 2012) and modernization projects in the context of natural disaster reduction and climate change, most of the earlier experience was brought together for internal World Bank guidance purposes in the publication *Weather and Climate Resilience – Effective Preparedness through National*

Meteorological and Hydrological Services (Rogers and Tsirkunov, 2013). While this latter publication goes well beyond the issues of benefit assessment to provide a comprehensive view of the potential role of modernized NMHSs (cf. Appendix B), it also provides a useful overview of the World Bank's approach to economic aspects of the organization and operation of NMHSs.

C.12 GLOBAL FRAMEWORK FOR CLIMATE SERVICES AND CLIMATE SERVICES PARTNERSHIP ACTIVITIES

The 2009 World Climate Conference-3 decided to establish a new GFCS to strengthen the production, availability, delivery and application of science-based climate prediction and services (WMO, 2009*b*). The conference and the follow-up high-level task force (WMO, 2011) placed special emphasis on enhancement of the sectoral and national benefits from more effective application of met/hydro services in all of the many climate-sensitive sectors of society. In addition to its emphasis on the various other pillars of the framework, especially the need for an effectively operating GCOS (Houghton et al., 2012), the GFCS Implementation Plan (WMO, 2014) approved by the October 2012 Extraordinary World Meteorological Congress focused particularly on issues of service delivery and application in enhancing the societal benefits from climate information.

One particularly significant implementation mechanism for the GFCS is the CSP, which originated from the (first) International Conference on Climate Services held in New York in October 2011. The Climate Services Partnership established a Working Group on Economic Valuation of Climate Services, with one of its first tasks being a comprehensive assessment of recent published literature on the economic value of met/hydro services (Clements et al., 2013).

C.13 RECENT STUDIES

Following the Madrid Conference and partly stimulated by it, a number of NMHSs and individual researchers initiated a range of new economic benefit studies using established methodologies. These include:

- A comprehensive study of the economic benefits of weather and marine services in India (National Council of Applied Economic Research, 2010);

- A study of the economic benefit of meteorology in the Swiss road transport sector (Frei et al., 2012);

- A study of the value of historical climate knowledge and Southern Oscillation Index-based seasonal climate forecasting on cropping in south-east Australia (Wang et al., 2008).

C.14 VALUATION METHODOLOGIES

While determination and demonstration of the benefits of met/hydro services are, in one sense, just a small subset of the wide range of approaches to determining the economic value of information (Stiglitz et al., 2000), the meteorological economics literature of the past 60 years summarized above includes a number of important attempts to frame the various general valuation approaches in a form for specific application to met/hydro services and especially to the operation of NMHSs.

Some of the more significant contributions have included the following:

- World Weather Watch Planning Report No. 17 (1967) that provided simple guidelines in a form for ready application by NMSs;

- The WMO publication (WMO, 1975*b*) that sought to provide more explicit guidance for use by NMS staff;

- An analysis by Freebairn (1979) that addressed some of the methodological challenges of valuation within a broader economic framework;

- The WMO Conferences in 1990 and 1994, the proceedings of which include a substantial number of papers outlining new and more refined approaches to economic valuation of met/hydro services;

- The report by Chapman (1992) that elaborated a methodology for assessing the marginal benefits of modernization of the United States NWS;

- The work of Anaman et al. (1995, 1998) that further developed the various available methodologies and demonstrated their application to a range of services provided by the Australian Bureau of Meteorology;

- The publication edited by Katz and Murphy (1997) that provided the first comprehensive treatise on methods for assessment of the economic value of weather and climate forecasts;

- Three papers (Zillman and Freebairn, 2001: Freebairn and Zillman, 2002*a*, 2002*b*) that attempted to provide an overall economic framework for funding and charging for meteorological services and a summary of available methodologies for valuation of benefits;

- A monograph by Gunasekera (2004) elaborating and demonstrating the application of available methodologies via a series of case study summaries from around the world;

- The WMO guidelines document on valuation of hydrological services (WMO, 2007*f*);

– The 2009 *Primer on Economics for National Meteorological and Hydrological Services* (Lazo et al., 2009) aimed at providing a simple overview for non-economist staff of NMHSs on the methodologies for BCA for met/hydro services.

While these and the many other publications on valuation theory and methodology present a useful overview of progress over the past 60 years, they do not provide the integrated conceptual approach and practical guidance, which is the primary objective of this publication.

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APPENDIX D. COMPLEMENTARY ROLES FOR OTHER SOCIAL SCIENCE APPLICATIONS IN SOCIOECONOMIC BENEFIT STUDIES

D.1 INTRODUCTION: MORE THAN JUST ECONOMICS

For the purposes of this appendix, the focus is on those social sciences, not including economics, that aim to describe, understand, or explain the human condition in relation to its natural and social environment – it explicitly includes the social, behavioural, and decision sciences. From an epistemological point of view, social sciences are diverse, characterized by a wide breadth of disciplines, paradigms, methodologies, national traditions and underlying political and social philosophies (International Social Science Council, 2010). In other words, there isn't one social science – there are many – with great variation found even within individual disciplines (for example, see the American Economic Association's *Journal of Economic Literature* classification system for a breakdown of subfields within economics).

Although much of this report is focused on the techniques and applications of economics to benefit assessment, a number of other social science disciplines and professions offer salient contributions to the overall evaluation of met/hydro services. In some cases, for instance in developing robust survey designs, the practices are already embodied within economic benefit assessment. In others, social scientific approaches, methods, techniques and findings serve to complement the economic studies and assist with contextualizing, extrapolating, qualifying and interpreting results and their relevance for policy and decisionmaking. Thus, in these latter cases, a better overall understanding of value results is achieved when other social sciences are included in the overall SEB analysis.

The following social science fields are most commonly found to report applications relevant for weather, climate and water: anthropology, applied health studies, communication studies, economics, valuation research, human and hazards geography, political science, psychology and sociology. Several recently published example studies outside the field of economics are noted in Table D.1 for illustration. Fundamentally, such research attempts to explain or evaluate critical assumptions about the nature of human behaviour, in relation to weather, climate or water, and decisionmaking, both generally and in the face of uncertainty. Researchers focused on weather applications tend to draw from the instrumental (that is, problem-solving) and, to a lesser extent, interpretive orientations in social science, rather than from the critical perspective. As ethical issues continue to emerge, for instance regarding the availability of potentially life-saving forecast information services to vulnerable populations in developing nations, critical contributions from social science and humanities fields such as philosophy and history may become more numerous and important in the future.

Applications of social science methods, for instance in the form of satisfaction surveys or focus groups with important users, have traditionally been used by NMHSs to demonstrate their worth or influence and to provide evidence to justify budget allocations and investments that are continually being challenged and tested for alternative beneficial uses. Historically, social science input and applications have been

Table D.1. Recent examples of peer-reviewed weather-related social science studies

Field/discipline	*Title/reference*	*Contribution relevant to SEB analysis*
Anthropology	Making use of hidden data: Towards a database of weather predictors (Pennesi, 2012)	Explores the challenge and benefits of uncovering and documenting unique local and cultural terms used to predict weather
Applied health studies	An evaluation of the progress in reducing heat-related human mortality in major U.S. cities (Kalkstein et al., 2011)	Developed and applied a method to indirectly assess the impact of early warning systems and associated services to cope with excessive heat events in 40 large United States cities
Decision sciences	Factors affecting the value of environmental predictions to the energy sector (Davison et al., 2012)	Defined, explained and applied a series of simple decision experiments based on expert/stakeholder knowledge to estimate the potential impact of weather-related information
Hazards geography	Social vulnerability and hurricane impact modelling (Burton, 2010)	A social vulnerability index was developed and combined with physical hazard indicators to explore the relationships between social vulnerability and hurricane damage
Inter-disciplinary	Exploring variations in people's sources, uses, and perceptions of weather forecasts (Demuth et al., 2011)	Applied factor and regression analysis to data from a nationwide survey of the United States public to understand patterns in people's sources, uses and perceptions of everyday weather forecasts and relationships with personal characteristics and experiences using forecasts
Psychology	Reducing probabilistic weather forecasts to the worst-case scenario: Anchoring effects (Joslyn et al., 2011)	Explored anchoring and correction biases within the context of numeric weather forecast information and uncertainty

sought rather irregularly, often in response to political or public pressure in the wake of a major weather event. More often, however, this knowledge of value and impact is now viewed as an intrinsic and continuous part of service planning and operations in larger service agencies and as essential tools to develop new clientele in the private meteorological sector. Encouraged by WMO and the World Bank, NMHSs seem to generally accept that a better understanding of the use and value of providing meteorological, hydrometeorological and climatological information could be fundamental input to measuring and improving services or making critical decisions with respect to the application of new technologies and changes to existing monitoring networks, observation strategies, communications, computer infrastructure, human resource management and priorities for research and development.

There remains, however, a need to produce and gain experience from more in-depth and robust social science applications, especially in developing and non-Western countries, and to analyse and develop better practices. Towards this end, Appendix D will illustrate and recommend a few uses of social science methods in two critical yet overlapping application areas pertinent to NMHSs and SEB evaluation: (a) identifying and understanding user problems, needs and perceptions; (b) evaluating products and services.

D.2 IDENTIFYING AND UNDERSTANDING USER PROBLEMS, NEEDS AND PERCEPTIONS

D.2.1 An informed inventory of products, services and intra-organization perceptions

Understanding the audience (users, clientele, market, customers, stakeholders), its problems, needs and perceptions, and use of existing products and services, is an essential activity for modern NMHSs and one in which social science methods play an important role. A seemingly mundane first step in this process, but one that is important before commencing the evaluation of the products and services delivered, is to identify what an NMHS or other producer provides and the rationale for doing so. Such an exercise could be geared to support a whole-of-service assessment (that is, the entire NMHS) or it might be confined to a sector, subset or package of services (for example, surface transportation) depending on the nature of the larger SEB study. With the possible exception of the few NMHSs that operate largely on a cost-recovery or profit model, for example those of the United Kingdom or New Zealand, most agencies cannot easily point to a comprehensive document that summarizes the character and intent of their services and the clients, stakeholders and citizens who utilize them.

This inward-looking exercise should go beyond a simple shopping list of variables or elements (for example, temperature forecasts) and include reflective commentary on the following aspects of particular products and services: information/message content, attributes related to precision and quality, frequency, duration, format, means of distribution/dissemination, production and dissemination process, support services assisting with interpretation, competing/complementing products from other sources, target audience, intended/expected use and historical evolution of the product/service.

Such an annotated inventory may assist the economic analysis of an SEB assessment, for example in articulating and framing the weather information product in a CV survey instrument. The most important aspects though are the perceptions of the developers/producers concerning their target audience, the intended or expected use of the information and resulting outcomes. Differences in perceptions between those developing a product/service and those of the intended user audience may point to significant sources of untapped or poorly developed value (that is, disconnections between services and needs). The final element of the inventory – historic evolution – captures the development timeline for the product or service. Sorting through the primary drivers of service changes (including cessation of a product/service), which often are motivated by technological advances but also user demand, political, institutional and financial factors, may assist in the value assessment, especially when interpreting sensitivities to external factors (sensitivity scenarios) or clarifying recall bias among survey respondents or interviewees.

Much of the basic information required to complete an inventory may be obtained by canvassing general NMHS dissemination platforms (largely Internet based) and through reviews of existing and historical NMHS operational, planning and annual reporting documents. The information can be verified using qualitative interviews and focus groups with participants selected (most likely in a non-random fashion) from those engaged in the production and delivery of information and services. Intraorganization perceptions and beliefs about the intended and expected uses of information would also be solicited through this process. Interview questions could be complemented with an individual or group exercise to define value chains (or influence diagrams and logic models) specific to the targeted service. An online survey to obtain the same information might be warranted if it was important to verify the representativeness of the expressed opinions across an entire NMHS organization. All elements would need to be scoped to the geographic, social and organizational dimensions of the service and NMHS under examination.

D.2.2 **Understanding actual use and information needs**

A subsequent step involves moving from what was, and currently is, provided to how such products and services are actually being used, by whom and for what purpose. Bounded by the scope of the SEB assessment, an initial list of users can be compiled from those identified by NMHS participants in the previous inventory exercise. To supplement the initial user set, it may be possible to draw upon several other sources of information within the domain of an NMHS (or neighbouring NHMSs, WMO, and the like). Such sources could include: client databases; contract and service agreements; product/service requests, inquiries, feedback forms and data/product download records; completed internal needs/use surveys, assessments and stakeholder workshops. Invariably, the list will be composed of entrants from the following categories:

- Private enterprise, non-governmental organizations and public sector institutions that provide, communicate and tailor weather and related risk or impact information, advice and services to their clients/constituents/audiences in support of decisionmaking;

– Businesses, organizations and government agencies with experience in, and responsibility for, managing weather-related risks and opportunities;

– Various segments of the general public engaging in weather-sensitive activities.

Needs are likely to extend to other weather- or climate-sensitive actors not yet currently served by a particular NMHS. Identifying such users may require incorporation of other information, as may be obtained through a content analysis of weather-related media reports (to screen for those sectors, organizations, communities and populations that are affected by an event) or a systematic review of the peer-reviewed literature. For example, a state-level study by Lazo et al. (2011) revealed high degrees of weather sensitivity in the real estate, insurance and finance sectors of the United States economy relative to those sectors traditionally thought of as being significantly affected by variable weather conditions (for example, agriculture and transport). The broader weather and climate-related impact literature, for example in hazards and applied meteorology, contains studies reporting on a wide range of additional sensitivities that may also define or indicate potential underserved users and needs.

The final compilation of users serves as the sampling frame for exploration of decision problems, preferences, perceptions and needs. Different types of social science methods may be employed at this stage, but they generally break down into two categories: (a) direct solicitation of the opinions and perceptions of representative users or experts (stated preferences/intentions); (b) analysis of actual behaviour and decisionmaking (revealed preferences/intentions). Budget, time and available expertise permitting, it is best to use a mix of techniques from both categories to test and corroborate findings.

Direct solicitation of opinion is typically conducted through self-administered, telephone, or computer-aided survey questionnaires, or through face-to-face interviews. Several example surveys and some general guidance are posted on the WMO website. Closed (that is, the respondent chooses from the options provided) or open (the respondent freely responds or “thinks aloud”) questioning can be used in both questionnaire and interview formats. Closed questions are best used when one is interested in testing hypotheses about relationships between variables and making statistical inferences about the sampled populations (for example, do all emergency managers making evacuation-order decisions have similar risk tolerances for particular weather-related hazards?). Open-format questions and interviews are preferred for exploratory research that aims to generate new ideas and often offer richer insight into a topic (that is, through dialogue about real situations and examples). It often makes sense to conduct a limited number of open format interviews and, through coding of results, use the findings to develop a structured survey with closed questions.

While noting the need to tailor applications to specific NMHSs, and the inherent difficulty in prescribing a ubiquitous instrument and approach, there are some general elements that should be addressed. As in most surveys, collecting information about sociodemographic characteristics, education levels, practical experience, risk-taking, or other basic psychological profiles help to situate respondents relative to the larger population. As noted by Weaver et al. (2014) for emergency managers there can be a rather large degree of variation across individuals for certain characteristics, which in turn may significantly influence the generalizability of responses.

In terms of content, survey and interview questions should be designed and tested to elicit input regarding the types of problems and opportunities confronting the unit of analysis – be it a business, organization, community, household or individual – and the various weather and non-weather factors that influence decisions and behaviours. The instrument should reveal the temporal, social, organizational and spatial scales and context of decisionmaking and extract formal decision thresholds (including attendant certainty or confidence levels), informal rules (such as rules of thumb, instinct, cues, and the like) and important information attributes from respondents. Furthermore, there should be some appreciation of the extent to which respondents rely upon cognitive/rationale or emotive/affective processes when making decisions. In addition to decision processes, questions should be aimed at identifying outcomes of importance to the user, noting that these might extend beyond the more obvious, and measurable, things such as "injury avoidance" or "dollars of damage or profit", to more qualitative things embodied in feelings (for example, sense of accomplishment, safety, assurance or flexibility). Finally, the survey or interview can include questions to solicit input regarding the benefits of realizing outcomes as well as the costs and implications of failing to achieve them – aspects that have been alluded to in Chapters 4–7.

The previous elements create a composite picture of the relative role and importance of weather and weather information within the decisionmaking context of the respondent – making it possible to derive needs either indirectly from the interview or questionnaire responses or directly through a final set of questions focused on stated information needs. The stated requirements may be combined with a series of focus groups, meetings, workshops or symposia to develop a general set of needs or to establish priorities at a higher order or scale. A very successful example of this type of activity is documented in *Weather Information for Surface Transportation: National Needs Assessment Report*, developed in the United States (Office of the Federal Coordinator for Meteorological Services and Supporting Research, 2002).

Even the most carefully designed stated-preference survey cannot entirely avoid the potential mismatch between what people say they do and what they actually do. Fortunately, a range of techniques have been developed in social science to analyse actual behaviour, some based upon original data collection and others based on secondary or existing data. Field research and analysis of existing data are discussed below, while other techniques, including experimentation, are introduced later on in the appendix as part of the evaluation discussion.

Field research, pioneered in anthropology and sociology disciplines, aims to immerse the researcher in the real-world environment of particular sets or classes of decisionmakers, for example emergency managers, in order to observe, interact with and learn from them. A qualitative approach, it enables researchers to gain a very detailed and personal account of the actors' decisionmaking processes, interactions with others and how they make sense of the world. Observations in the form of notes, audio or video recordings and maps or diagrams are typically collected over a period of time that is much longer than the traditional interview (that is, days, weeks or months).

Patterns, explanations and theory are developed inductively and iteratively through the course of the research in contrast to the deductive, hypothesis-testing designs adopted in many quantitative social science studies.

Not surprisingly, field research, as well as the interviewing methods already discussed, place the researcher in a position to potentially influence what a respondent or observant says or does. “Unobtrusive approaches” (also called “non-reactive”) are available to address such concerns, though the trade-off is often a lack of complete control over the collection and structure of the data. Content analysis is a technique used to decipher meaning from various forms of communication, for example newspaper articles. How often a term, phrase or reference to a behaviour, product, issue, and the like, is used and with what intent (for example, associated with a particular quality or meaning – such as good, bad, successful or failed) become the data subject to analysis. Any form of communication could be used, including radio or television weather reports, text-based weather forecasts or warnings, press releases and reports from weather-sensitive organizations, and even electronic records such as e-mail exchanges. One of the greatest potential sources of data for content analysis research is publicly available records of social media exchanges. Because such sources are not designed specifically for the intended research, it is crucial to ensure that the terms and phrases chosen to indicate a particular important variable or meaning are valid and applied consistently in the analysis.

Existing data originally collected for another purpose is sometimes available for use in estimating the occurrence of certain behaviours of interest and assessing the validity or extent of perceived impacts. The extent to which people say they are sensitive to, or engage in actions given information about, a weather-related hazard or opportunity can be examined and verified. For example, traffic and modal-share data can indicate trip cancellation, route-altering and speed adjustment behaviour among motorists and evacuation participation levels; Internet and telecommunications data can suggest risk information-seeking patterns associated with storms; retail purchasing information can point to behaviours associated with preparedness (for example, generators or plywood in advance of a hurricane; dwelling location choice and style in consideration of flooding potential); and hospitalization or other medical care data can be used to estimate the impact of certain weather-related conditions on health and level of response (that is, people seeking care). As this type of data are usually available only at an aggregate level (a large region, population or long time period) the scalability of inferences to individual behaviour is always subject to some assumptions. Nevertheless, it makes a useful complement to stated-preference studies and is often utilized to estimate or generalize exposure levels in economic studies.

D.3 EVALUATION OF MET/HYDRO PRODUCTS OR SERVICES

Another area of application where social scientific methods may assist NMHSs is in the development and evaluation of existing or planned products and services. Evaluation research has a long-standing tradition in social science and is the subject of several academic journals (for example, the *American Journal of Evaluation* and *Evaluation and*

Program Planning). The intent, of course, is to assess the merits of a particular programme or activity and NMHSs have been quite active in recent years in collecting and analysing such information to help them quantify, qualify and otherwise articulate their worth to funders and users. As noted in Table D.2, a variety of performance indicators have been used or cited in NMHS annual corporate reports and, above all, internal studies.

Table D.2. A range of indicators and associated example measures and methods used to evaluate meteorological warnings issued by NMHSs

NMHS performance indicator	*Example measures*	*Example methods*
Warning is accurate (location, timing, severity)	– Traditional numerical verification (for example, probability of detection, false alarm ratio) – Likert rating scale (for example, 1–5) or percentage of time correct/accurate	– Statistical analysis of warning forecasts relative to observations – Survey to assess public or user-specific opinion
Warning is disseminated	– Counts of warnings issued to public/users over a period of time	– Summation of warnings by region, time period, channel – Descriptive or relative statistics over longer period of time (multi-year trend in annual counts)
Warning reaches intended audience (that is, penetration)	– Percentage of population receiving warnings – Unique website “hits” – Post-event interviews	– Survey to assess public or user-specific opinion – Analysis of Internet statistics
Warning meaning is understood as intended (factual content)	– Percentage of correct interpretations (that is, intended by NMHS) by public/users – Post-event interviews	– Survey to assess public or user-specific opinion
Warning consequences and suggested actions are understood	– Percentage of correct interpretations (that is, intended by NMHS) by public/users	– Survey to assess public or user-specific opinion
Behavioural intent	– Percentage of people intending to take action in response to the warning	– Survey to assess public or user-specific opinion
Satisfaction with warnings	– Likert rating scale (for example, 1–5) of degree of time satisfied – Percentage of time satisfied	– Survey to assess public or user-specific opinion

The indicators, measures and methods in Table D.2 are limited in terms of assessing the influence of a product or service on the actual use of weather information in decisionmaking and associated outcomes. Experimental social research, whether based on observations from "natural" experiments (for example, comparing those affected or unaffected by a particular weather disaster) or simulated/laboratory settings, offers an alternative structured approach to quantify such variables. Often the biggest concern with the former is how best to control for factors that may offer alternative explanations for the findings, while generalizability to the "real world" can be problematic for the controlled, laboratory experiment (for example, raising questions about external validity).

The classical experimental design involves conducting pre- and post-intervention tests on randomly assigned control and treatment groups. Its intent is to isolate the effect of the intervention, thus making the identification of causal relationships between independent and dependent variables more likely – for instance between hurricane warning advice and evacuation participation. Not surprisingly, it generally isn't possible, desirable or ethical to intentionally deny a population the best available warning information or service in advance of a particular weather condition. Thus quasi-experimental designs, where some aspects of the classical design are relaxed (for example, no control group used but one group repeatedly measured several times before and after the product/service is in place), are more likely to be utilized. For example, Joslyn et al. (2011) assessed the relative merits of different approaches to characterizing uncertainty in weather forecasts (probability of precipitation) using a survey delivered to a convenience sample of undergraduate psychology students.

Implicit in many measures and experiments is a sense of what should be evaluated. From an academic perspective, this is usually made explicit and involves formal testing of a hypothesis or element of theory. For an NMHS, however, the use of experiments is more pragmatic – did or will a particular service or product perform well? Thus, one sees many contracted studies, internal reports, and the like, that focus on a particular output or outcome measurement (for example, 65% of the public are very satisfied with our 1–2-day forecasts) with minimal attention to the interpretation of the result, important processes and the testing of alternative explanations that might yield valuable information for designing and assessing services. In other words, there is a need to expose and understand the theories of behavioural change implicit in the evaluation.

Fortunately, the evaluation literature offers a holistic approach to make these theories explicit and, in doing so, guide an evaluation. A "theory-driven evaluation" moves the exercise from documenting evidence of impact, through causal description and ultimately to causal explanation of why and how this particular intervention changes outcomes given available resources and antecedent conditions. Also called "theory-based evaluation" and "programme theory", the approach has been used extensively and effectively in medical and health promotion applications over the past three decades (Weiss 1997; Coryn et al., 2011). While weather-related applications seem to be absent in the peer-reviewed literature, some in the weather community have noted elements of the approach, typically in the form of "logic modelling". A logic model is a tool used to articulate the linkages among sets of components within a programme, including: inputs; activities; outputs; and short-term, intermediate and longer-term outcomes (MacLaughlin and Jordan, 1999). A partial NMHS-related example, focused exclusively upon activities and outcome sets, was developed by Gordon and Shaykewich (WMO, 2000) and is provided in Figure D.1.

The theory of change in the example figure is not specified in much detail, as its original use was chiefly illustrative. Nevertheless, one can infer a type of "knowledge-attitudes-action" model of change in the diagram. The various activities in the operational outcomes somehow lead to a chain of intermediate outcomes whereby an increase in the awareness of information (that is, a future weather condition/state and its implications) among users affects their decisions and behaviours such that impacts are reduced (ultimate outcomes). It is these processes and inter-linkages that become the additional focuses of the evaluation – quantitative, qualitative or mixed methods and supporting data would then be selected and collected to test the presence, validity and strength of any supposed relationships. Ideally, the evaluation of a particular change in services is conducted as part of the initial design (that is, screened against the underlying theory to assess potential effectiveness) and then monitored over time through its entire lifecycle. Underachievement may be a function of a failure

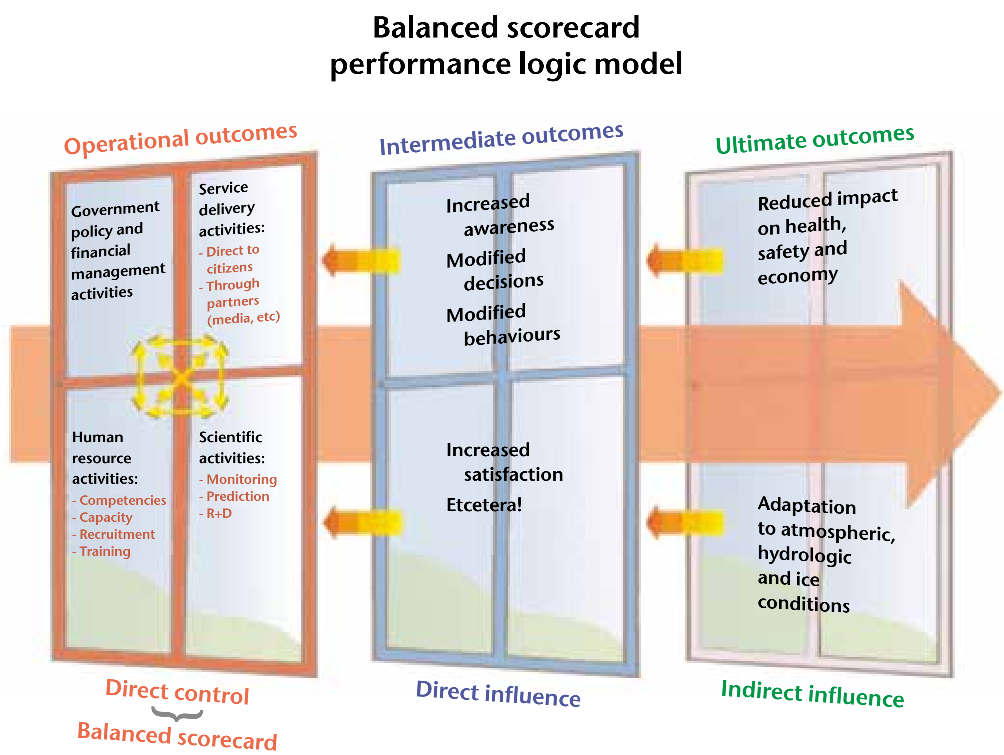

Figure D.1. Generic logic model of NMHS performance

Source: WMO (2000)

in programme implementation, of the contextual or situational inappropriateness of the theory, or a failure of the theory itself.

A more robust theory of change might draw upon aspects of behavioural models in psychology and social psychology, for example social cognitive theory (Bandura, 1991) and the theory of planned behaviour (Azjen, 1991). It might also be developed inductively through empirical observation of cases, or through consultation and interaction with users (Patton, 2008). Many of the social science contributions to understanding suggested in previous sections will assist in the development of logic models and explicit characterization of theories of change or action, and ultimately through to effective applications and services that achieve outcomes.

D.4 FINDING EXPERTISE AND BUILDING CAPACITY TO CONDUCT SOCIAL SCIENTIFIC RESEARCH AND APPLICATIONS

The previous two sections propose new or expanded kinds of activities and methods to identify and explore user needs and to evaluate weather, water and climate services. For an already fiscally lean or extended NMHS, this likely means reallocating resources, finding extra efficiencies, or developing creative partnerships to sustain a social scientific programme. Even if resources are made available, the task of finding and retaining access to suitable expertise may be a challenge. Larger NMHSs or those associated with or mandated to manage other government functions (for example, pertaining to water, environment, natural resources, or transportation) might employ or have access to social science and policy analysis expertise. Most organizations, and certainly smaller services, must rely upon academic institutions or the private sector consulting industry for support. In some cases it may be possible to examine existing relationships with national universities where an NMHS already has an established agreement or partnership, for example in training atmospheric scientists, hydrologists or forecasters. Most large institutions will have programmes in psychology, sociology, anthropology, geography, business/marketing/communications, economics and health-related disciplines where expertise can be sought. Where endogenous capacity and expertise are limited, it is hoped that WMO and its Members, the World Bank and non-profit enterprises such as CSP will continue to help coordinate, if not conduct, regional training sessions and establish demonstration projects to move from classroom to applications and eventually to enhance internal capabilities.

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APPENDIX E. CASE STUDIES

E.1 SUMMARY OF CASE STUDY ECONOMIC ASSESSMENTS

Part E.1 of this appendix provides an overview of the economic assessments that are included as nine case study examples in this publication and that follow in Parts E.2–E.10. In the following sections of E.1, background is provided on our rationale for selecting these examples, together with a high-level summary of each assessment. Additional information for each study appears in the detailed case study descriptions.

Background and overview

Our case study examples represent a diverse set of studies that the NMHSs and other organizations have developed to assess the economic benefits of met/hydro services. In selecting these examples, we have aimed to include sound economic studies that have been conducted in various parts of the world, with an emphasis on developing countries. We have also attempted to obtain diversity among key study parameters, including:

- Study objectives, for example, to obtain additional funding and justify existing services;
- Types of met/hydro services examined, for example, whole-of-service studies and studies examining specialized services;
- Types of benefits and costs analysed, for example, avoided asset losses, increased profits and lives saved;
- Valuation methods, for example, contingent valuation and decision models;
- Level of aggregation, for example, sector analysis and household-level analysis.

Because relatively few NMHSs have conducted studies of the economic benefits of met/hydro services, it was not always possible to meet our initial criteria for case study selection. For example, several of the studies were conducted in developed countries, and we have included one study that academic researchers initiated, rather than an NMHS or other relevant organization (for example, international donor organizations such as the World Bank). However, the nine studies described in Appendix E all contain valuable information that can help NMHSs conduct or manage economic assessments to examine the value of met/hydro services, based on their own objectives and available resources.

The following sections provide short summaries of each case study example; more detailed case study descriptions comprise the remainder of this appendix (parts E.2–E.10). The detailed descriptions of each economic study provide background on the reason that the study was conducted, describe the study methods and results, discuss study limitations and offer suggestions for how the study could be tailored to individual NMHS circumstances. In developing most of the case study descriptions, we were able to interview and receive input from a primary author of the study.

E.1.1 Case study 1: Evaluating the economic efficiency of NMHS modernization in Europe and Central Asia using sector-specific and benchmarking approaches

In 2003, the World Bank and Roshydromet, the NMHS of the Russian Federation, developed a sector-specific approach, described below, to evaluate the benefits and costs of modernizing Roshydromet's services and products. The success of this project encouraged the World Bank to launch similar economic studies in countries in Europe and Central Asia, where many NMHSs are in decline because of underfunding.[26] The purpose of these studies was to identify the key economic benefits from large-scale modernization of NMHS services in the region, and to enable national decisionmakers to understand how to allocate resources to NMHSs to ensure functioning at a level suited to national needs. The studies were commissioned in close cooperation with the NMHSs under review, and were developed based primarily on inputs from NMHS and sectoral experts. This case study summary discusses these European and Central Asian World Bank studies in aggregate.

Methods

The Roshydromet study used a "sector-specific" approach to evaluate the economic benefits of modernizing Roshydromet services for weather-dependent sectors of the economy. This approach relies on in-country data and interviews with sectoral experts to estimate the current direct weather-related losses (losses caused by direct destruction, breakdown or damage to any types of property and tangible assets) for each sector, and the potential reduction in these losses that large-scale modernization would achieve. In nine of the subsequent Europe and Central Asia country evaluations,[27] the World Bank applied the sector-specific approach to estimate the benefits of improved met/hydro services. For these countries, the World Bank also looked at the reduction in indirect weather-related losses (losses that a business entity or economic sector suffers because of decreased revenues or additional expenditures on production cycles) associated with modernization. The incremental reduction in direct and indirect weather-related losses compared to the costs of modernization represents the economic efficiency of met/hydro improvements, as defined by the World Bank.

In all the European and Central Asian countries studied the World Bank also used a simplified benchmarking approach as an alternative method for evaluating the economic efficiency of investments in met/hydro services. The benchmarking approach allows NMHSs to evaluate the economic benefits of their services in

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[26] Studies took place in Albania, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Serbia, Tajikistan, Turkmenistan and Ukraine.

[27] Sufficient information was not available for Kazakhstan and Turkmenistan to use this method.

Table E.1. Summary of case study examples of economic benefit assessments

Case study	*Objectives*	*Sectors/beneficiaries analysed*
1. Economic efficiency of NMHS modernization in Europe and Central Asia (World Bank, 2008)	– Identify economic benefits of large-scale NMHS modernization – Enable national decisionmakers to understand the necessary level of funding for NMHS services	Weather-dependent sectors of the economy (not specified)
2. Benefits of Ethiopia's LEAP drought early warning and response system (Law, 2012)	– Better understand the role of met/hydro services in disaster risk reduction – Demonstrate benefits and costs of preventive versus reactive humanitarian assistance – Inform strategic-level investment decisionmaking	National-level assessment of households affected by drought Providers of humanitarian food assistance (Government, humanitarian agencies, donors)
3. Success of the NWS Heat Watch/Warning System in Philadelphia (Ebi et al., 2004)	– Demonstrate effectiveness of heat warning systems – Provide data for other locations considering such systems	Households/elderly residents
4. Benefits and costs of improving met/hydro services to reduce disaster losses in developing countries (Hallegatte, 2012)	– Demonstrate the benefits of improving early warning systems in developing countries to developed country standards	National-level benefits and weather-sensitive sectors
5. Potential value of general circulation model (GCM)-based seasonal rainfall forecasts for crop management (Hansen et al., 2009)	– Understand the potential value of seasonal forecasts in a context characterized by high-risk smallholder agriculture and relatively high predictability – Understand the potential use and value of seasonal forecasts downscaled from a GCM	Individual farmers
6. Value of met/hydro information in Switzerland for the aviation transport sector (von Grünigen et al., 2014)	– Estimate benefits of TAFs for Switzerland's domestic airlines – Evaluate how hydro/met services could be improved to maximize social and economic gains	Swiss domestic airlines
7. Avoided costs of FMI met/hydro services across economic sectors (Leviäkangas and Hautala, 2009)	Determine the value of FMI existing met/hydro services per euro of investment	Transportation, construction and facilities management, logistics, energy and agriculture sectors
8. Household WTP for improved met/hydro services (Lazo and Croneborg, forthcoming)	– Estimate costs and benefits of improving met/hydro services for households – Help obtain funding for met/hydro improvements that would reduce damages from future extreme weather event	Households
9. Socioeconomic evaluation of improving met/hydro services for Bhutan (Pilli-Sihvola et al., 2014)	– Evaluate stakeholder needs for improved services – Qualitatively assess benefits of improved services for different economic sectors – Estimate costs and monetary benefits (where feasible) of future met/hydro services	

[a] As defined by the World Bank, economic efficiency represents the benefit of improving met/hydro services (in this case, the additional reduction in weather-related losses that would result from improvements) divided by the cost of the improvements.

Geographic location	Methods	Results
11 countries in Europe and Central Asia	Sector-specific and benchmarking approaches to estimate avoided weather-related losses	Economic efficiency of modernization could range from 199% to 1 440% over 7 years, a depending on method and country
Ethiopia	BCA to quantify avoided livelihood losses for households and decreased assistance costs associated with LEAP	– Very early LEAP-activated early response: US$ 2.8 million NPV benefits over 20 years, compared to conventional humanitarian emergency drought response – Delayed LEAP-activated early response: US$ 2.3 billion NPV benefits over 20 years, compared to conventional response
Philadelphia, Pennsylvania	Regression analysis to determine lives saved by NWS system; application of the EPA VSL estimate	– Heat warning system saved 2.58 lives per day when the NWS issued a formal heat warning – Value of the programme estimated to be US$ 468 million over three-year period
All developing countries	Benefit-transfer approach to quantify avoided asset losses, lives saved and total value added in weather sensitive sectors	– US$ 300 million to US$ 2 billion per year in avoided asset losses – 20 000 lives saved per year, valued between US$ 700 million and US$ 3.5 billion – US$ 3 billion to US$ 30 billion per year in additional economic benefits – Annual BCR between 4 to 1 and 36 to 1
Two semi-arid regions in Kenya	Used crop modelling and prescriptive decision model to evaluate how changes in maize crop management in response to met/hydro information increase gross margins	– Value of perfect information represented 24%–69% of gross margin – Thus, farmers could potentially increase their average income substantially with the use of seasonal forecasts
Zurich and Geneva airports	Applied simple decision model to analyse how TAFs can reduce fuel and flight deviation costs for airlines	– Use of TAFs at Zurich airport generates about SwF 14 million per year – When Geneva airport is included, total economic benefits amount to between SwF 13 million and SwF 21 million per year
Finland	Applied decision framework to quantify avoided costs and productivity gains associated with use of FMI services; used impact models and expert elicitation	– Annual benefits of FMI services for selected sectors amount to between € 262 million and € 285 million (2006) – Annual BCR between 5 to 1 and 10 to 1 – Perfect information could increase benefits by 65%–100%
Mozambique	CV, benefit transfer, expert elicitation	– Average estimated WTP for improved weather information is Mtn 2.9 per year per individual (about US$ 0.09)
Bhutan	Cardinal rating method, benefit transfer, expert elicitation	– Qualitative evaluation found significant benefits for most sectors for services based on historical climate data – Forecasting services most significant for agriculture – NPV BCR of improved services in Bhutan is about 3.1

situations where there is inadequate or insufficient data for conducting sector-specific assessments. This method relies on readily available data from other countries (in this case from developed countries, the Russian Federation and China) on the level of annual direct economic losses caused by unfavourable weather events (expressed as a share of GDP), as well as the level of annual losses that could be prevented with modernization. This information is adjusted for the study country using expert opinion about three basic country characteristics: the weather dependence of the economy, meteorological vulnerability and the current status of met/hydro service provision. The simplified benchmarking approach only considers direct damages caused by weather impacts.

Conclusions

The initial Roshydromet study found that improvements in forecasting and large-scale modernization of met/hydro services would reduce weather-related economic losses by 8.5%. In addition, total returns on investment in the modernization project were estimated to range from 400% to 800% over seven years. As a result of this valuation, support for the modernization effort reportedly increased from US$ 80 million to approximately US$ 133 million.

The economic estimates for Europe and Central Asia also found that improvements in forecasting could result in significant economic benefits. Depending on the method and country, the World Bank estimated that the economic efficiency of met/hydro service improvements could range from 199% to 1 440% over seven years.

The World Bank has concluded that both the sector-specific and benchmarking approaches provide order-of-magnitude valuations of the likely benefits of NMHS improvements. However, these approaches are both limited in that they rely heavily on expert opinion. Thus, the results of the analysis are subject to potential biases and knowledge limitations of the experts involved in the study. In addition, a limited amount of data are available to support expert findings, and neither approach assesses the value of met/hydro information for households. Benchmarking is further constrained by the fact that it does not take into account indirect weather-related losses, as well as by the limited amount of data used to establish its parameters.

E.1.2 **Case study 2: Using benefit–cost analysis to evaluate the socioeconomic benefits of Ethiopia's national drought early-warning and response system**

In 2012, the World Food Programme (WFP), with the support of the United Kingdom Department for International Development and the Netherlands Directorate-General for International Cooperation, conducted a study to evaluate the benefits and costs of Ethiopia's LEAP system. Livelihoods, Early Assessment and Protection is an integrated drought early warning action system developed in 2008 by the Government of Ethiopia, with the support of WFP and the World Bank. It was designed to scale up Ethiopia's existing national food and cash safety net in case of drought by triggering an established contingent fund. This type of integrated system, which combines early warning with contingent financing and social safety nets, allows the Government of Ethiopia and its humanitarian partners to respond much faster to a drought. It enables the provision of food assistance before households have been negatively affected by drought – which is often not the case with the conventional humanitarian relief system. Early response has the potential to reduce humanitarian relief costs and prevent households from engaging in destructive drought risk-coping strategies. The study, conducted by Anna Law with the support of WFP, was intended to quantify the economic benefits of early drought response in Ethiopia, and specifically evaluate the cost-effectiveness of the LEAP system.

Methods

Law used a forward-looking BCA to evaluate costs and benefits of the LEAP system over the next 20-years. Law compared three scenarios to draw her conclusions about the costs and benefits associated with the LEAP system: a conventional emergency response (that is, a baseline scenario without LEAP, in which response is triggered eight months after the first early warning of an impending drought), an ideal LEAP-activated early response (two months after the early warning), and a delayed LEAP-activated response (five months after the early warning). The benefits of a LEAP-triggered early response were calculated in terms of avoided livelihood losses for households, including losses related to stunting, reduced adult food and non-food consumption, and the "distress sale" of productive assets. Law also examined benefits in terms of decreased assistance costs for those who provide food aid: the Government, humanitarian agencies, and donors. For the two LEAP scenarios, Law included the cost of setting up and maintaining the LEAP system.

In the absence of quantitative data on how beneficiary numbers increase over time from early to late response, Law assumed that beneficiary numbers would remain constant in all three scenarios. In reality, it is likely that the number of people in need of assistance increases with time as a crisis escalates – probably in a non-linear fashion. However, Law assumed that the benefits of acting early do not result from lower beneficiary numbers, but rather from (a) lower cost of assistance per beneficiary, and (b) lower livelihood losses per beneficiary. Several additional assumptions are described in the complete case study. The study did not quantify and monetize certain benefits, such as number of lives saved, avoided livestock losses and other indirect benefits.

Conclusions

This study concluded that both LEAP scenarios provided economic benefits that greatly outweighed the costs. Law estimated that the ideal LEAP-activated response and the delayed LEAP-activated response would generate US$ 2.8 billion and US$ 2.3 billion, respectively, in NPV benefits (compared to the conventional response scenario), over a 20-year period. Most of these benefits are because of avoided livelihood losses, although there were also benefits associated with lower assistance costs. Benefits could be higher if the number of people requiring assistance is reduced by early response, and if drought frequency and/or magnitude increase under climate change.

E.1.3 Case study 3: Quantifying the success of the United States National Weather Service's heat watch/warning system in Philadelphia in terms of lives saved

This study, conducted by Ebi et al. (2004), quantified the potential benefits of NWS extreme heat warning notices for the Philadelphia, Pennsylvania area in terms of the number of lives saved. The research reflects both a desire to demonstrate the usefulness of such systems, and to provide specific evidence concerning Philadelphia's approach as a potential benchmark for other locations considering such systems. The Electric Power Research Institute and NOAA funded the study.

Methods

The authors used regression analysis to evaluate the relationship between weather conditions, heatwave warning announcements and daily summertime mortalities for people aged 65 and older, who are particularly vulnerable to heat mortality, for the years 1995 to 1998. The study looked at two types of "heatwave days": (a) days when NWS issued a formal heat warning, and (b) days when NWS did not issue a heat warning but Philadelphia's Hot Weather-Health Watch/Warning System (PWWS) indicated that weather conditions posed a risk to human health. For each of these heatwave days, the authors compared daily mortality data for the warning day and the following three days. Including these subsequent days, the total number of days evaluated was 45 with NWS formal heat warnings and 210 with PWWS-indicated risks. The authors used the regression analysis to determine the number of additional deaths that would have occurred on the 45 days that NWS issued a warning if the warning had not been called, such as on the 210 days with PWWS-indicated risks.

To monetize the estimated number of lives saved by the NWS-issued warning, as determined by the regression analysis, the authors used the EPA VSL estimate, approximately US$ 6 million at that time, as a starting point. Based on a limited review of studies of the sensitivity of the VSL to age, the authors concluded that a value of US$ 4 million was appropriate because of the study population's tendency to be elderly. However, making "age-based adjustments" to the VSL is not generally appropriate. Attempts to monetize potential future or observed changes in mortality risk or outcomes need to be carefully considered and guided by local conditions and available data.

Conclusions

Ebi et al. concluded that there were approximately 2.58 fewer excess deaths per day on each of the 45 days when the NWS issued a formal heat warning.[28] Multiplying

[28] However, the regression analysis was not statistically significant at the commonly used 5% level, and therefore the authors could not rule out the possibility that the warnings do not save lives.

the extrapolated number of lives saved by the author's adjusted VSL of US$ 4 million provided an estimate of the programme's value as US$ 468 million over the three-year study period.

The study drew notable attention because of the magnitude of the estimated benefits. However, the study evaluated a period when the city and its residents may have been especially responsive to heat warnings. Specifically, the 1995 to 1998 study period evaluated actions following the 1991 and 1993 heatwaves in Philadelphia, as well as the extreme heat mortality and nationwide coverage of the 1995 heatwaves in Chicago. However, some researchers, for example Sheridan (2007), have found that heat warnings do not cause at-risk individuals to modify their behaviour and more frequent warnings might desensitize the public to risks.

E.1.4 Case study 4: Applying benefit transfer to evaluate the benefits and costs of improving met/hydro services to reduce disaster losses in developing countries

World Bank economist Stephane Hallegatte conducted this study in 2012 as part of a larger effort to demonstrate the national-level benefits of improving met/hydro information and early warning systems in developing countries. This research serves as an example of how existing data, estimates from the literature and expert knowledge can be applied to estimate the value of met/hydro services in other contexts.

Methods

Hallegatte (2012) employed a benefit-transfer approach to develop estimates of the benefits and costs of improving met/hydro information and early warning systems in developing countries to meet developed-country standards. Benefit-transfer approaches use existing data from other studies and attempt to apply their findings to a study case with limited or no available data. For this study, the author used readily available data and existing studies to first estimate the benefits from early warning systems in Europe in terms of avoided asset losses, number of lives saved and economic gains for weather-sensitive sectors of the economy. Hallegatte applied the findings of this evaluation to estimate the potential benefits of providing these services in developing countries.

To transfer avoided asset loss data to the developing world, Hallegatte used existing data to estimate that early warning systems in developed countries result in avoided asset losses that amount to between 0.003% and 0.17% of GDP. He applied this information to developing countries by grouping them into four categories, ranging from those with no basic met/hydro services to those with met/hydro services and early warning systems comparable to those in Europe. The author assumed that countries with the least amount of services would benefit the most from improvements, while countries with the greatest amount of services would not require improvements.

Hallegatte also made assumptions about the number of people's lives that improved early warning systems could save, based on rates of weather-related deaths in Europe, and reductions in weather-related deaths associated with an early warning system in Bangladesh. He applied a dollar value to the number of lives saved based on guidelines from the Copenhagen Consensus.

In addition to the benefits of early warning systems, Hallegatte estimated the economic benefits that improved met/hydro services could provide to developing countries in the form of useful services for industries, businesses, households and individuals when no weather-related emergencies occur. For example, weather forecasts are used to plan in the agricultural sector, anticipate electricity demand, optimize air traffic and ship routes, plan road salting and achieve many other purposes in various sectors. To estimate additional economic gains (that is, value added) associated with improved met/hydro services, Hallegatte first determined that in Europe, weather forecasts have led to value-added gains of between 0.1% and 1.0% in weather-sensitive sectors, amounting to between 0.025% and 0.25% of GDP. Hallegatte applied these estimates to developing countries, again taking into account the existing level of met/hydro services based on the four categories of developing countries described above.

Conclusions

The study estimated that the potential benefits from upgrading the met/hydro information production and early warning capacity in all developing countries to developed-country standards would include:

– US$ 300 million to US$ 2 billion per year of avoided asset losses caused by natural disasters;

– An average of 20 000 people's lives saved per year, valued at between US$ 700 million and US$ 3.5 billion per year using the Copenhagen Consensus guidelines;

– US$ 3 billion to US$ 30 billion per year of additional economic benefits.

Based on this analysis, the total benefits to developing countries would be between US$ 4 billion and US$ 36 billion per year. This can be compared to costs of around US$ 1 billion per year, for a BCR of between 4 and 36, with the majority of these benefits attributed to economic gains resulting from the availability and use of improved met/hydro information.

Hallegatte conducted this analysis at a global scale, using simple assumptions that provide orders of magnitude rather than project-level estimates. This study also did not account for the increase in people's lives saved or the avoided asset losses that would likely occur with population and economic growth. However, this research provides rough estimates of the value of met/hydro services – estimates that could be used to help developing countries make an initial case for increasing investment in early warning systems and other met/hydro services.

E.1.5 Case study 5: Using crop models and decision analysis to assess the potential value of general circulation model-based seasonal rainfall forecasts for crop management in Kenya

This study used crop growth and decision models to assess the potential value of seasonal rainfall forecasts, based on downscaled GCM data, for maize farmers located in two areas of semi-arid Kenya. A team of academic experts led by the International Research Institute for Climate and Society at Columbia University conducted this research to gain a better understanding of (a) the potential value of feasible seasonal forecasts in a context characterized by high-risk smallholder agriculture and relatively high predictability, and (b) the potential use and value of seasonal forecasts downscaled from a GCM (Hansen et al, 2009).

Methods

The researchers compared the expected outcome of optimal decisions made in response to seasonal rainfall forecasts to optimal decisions made based on historical climate information, which assumes average conditions. They assumed that the value of the forecast was a function of (a) management variables that maximize expected gross revenues, (b) the cost of production associated with the management strategies, and (c) climate and environmental variables.

The authors evaluated two management variables (that is, decisions) that farmers in the study region could alter to maximize gross margins in response to seasonal forecasts: stand density and nitrogen fertilizer application rate. First, they used a crop model to determine the combination of stand density and fertilizer application rate that would result in the highest average gross margin under different climate conditions. They determined gross margins using agricultural enterprise budgets, which they developed based on local cost data for production inputs and market price data for maize.

Next, the authors developed seasonal hindcasts, simulating what the seasonal forecast would have been in each year of a 34-year simulation period (1968–2002). The authors developed these hindcasts for two different GCM-based forecast types. To assess the value of the forecasts, the authors used the crop model to determine the gross margins realized each year of the simulation period, based on (a) the optimal management strategies selected for the forecast, and (b) the actual observed weather. The authors compared the gross margins for the different forecast scenarios to those that would have been realized using a climatological approach. The authors also estimated gross margins for a scenario in which the farmer had perfect knowledge of daily weather conditions. For each scenario, they evaluated optimal management strategies and gross margins with and without labour costs as a factor of production.

Conclusions

The results indicated that farmers could increase their average income from maize substantially if they could perfectly anticipate weather for the upcoming growing season. The estimated value of perfect information represented 24%–69% of gross margin, depending on location and whether or not labour costs were considered. These results suggested that farmers would increase their average income from maize substantially if they could perfectly anticipate weather for the upcoming growing season. As expected, the estimated value of seasonal predictions from the observed GCM-based forecasts was lower than the value of perfect information. However, the results indicated that the more skilful forecast has the potential to increase average gross margins by 10% to 24% (when labour costs are included), depending on location.

Although these types of studies can be resource intensive and require outside expertise, they can serve as important tools in helping NMHSs and in-country partners (for example, agricultural extension agencies and food security organizations) to identify management strategies that could result in the greatest benefits for farmers under different forecast scenarios. The results of the studies could also be used by NMHSs to encourage farmers to use seasonal forecasts and adopt alternative strategies when warranted.

This study is limited in that it focuses on the effect of only two management strategies, thereby ignoring many other determinants of forecast value. A more realistic and robust picture of the potential value of seasonal forecasts to farmers could be obtained from a farm-level analysis that includes additional management options, and represents the difference in farm types in the study region.

E.1.6 Case study 6: Using decision models to assess the value of met/hydro information in Switzerland for the aviation transport sector

In 2009, MeteoSwiss commissioned a pilot study to develop rough valuations of the economic benefits of met/hydro services for Swiss households and the agriculture and energy sectors. The pilot study found that benefits from met/hydro services were in the order of hundreds of millions of Swiss francs, with a probable BCR of 5 to 1. Based on the findings of this analysis, MeteoSwiss agreed that more detailed, sector-level analyses would be necessary to gain a better understanding of the value of met/hydro services within the Swiss context and to evaluate how met/hydro services could be improved to maximize social and economic gains. Towards that end, MeteoSwiss commissioned two additional studies, focusing on the economic value of met/hydro services for the road and aviation transport sectors. The present case study focuses on the aviation study, which looked at the benefits to domestic airlines of using TAFs to determine weather conditions at their destination airport.

Methods

The authors of this study developed a decision model to analyse how the use of TAFs can reduce fuel and flight deviation costs for airlines. If adverse weather conditions are expected at the destination airport, the airlines can carry additional fuel reserve to be able to extend the flight time. If an airline decides to carry extra fuel and the actual conditions at the destination are not adverse for landing, the airline will have incurred unnecessary additional costs. However, if aeroplanes do not have enough fuel to extend a flight until it is safe to land, the flight crew must land at a different airport and face additional costs such as passenger compensation, transfer costs, landing fees, fuel and reputation costs, among others. The authors compared the costs that airlines incur with and without the use of TAFs by determining the frequency with which forecast conditions accurately predicted the actual weather conditions, and the frequency with which the airlines decide to correctly or unnecessarily carry extra fuel. The analysis relied on TAF verification data from April 2008 through March 2010.

Conclusions

The study found that the use of TAFs at Zurich Airport generates significant economic benefits for domestic airlines, amounting to between SwF 11 million and SwF 17 million per year. When extrapolated to Geneva Airport, the study suggests that the total economic benefits for Switzerland's domestic airlines amount to between SwF 13 million and SwF 21 million (US$ 14 million–US$ 22 million) per year. However, this estimate does not account for the different economic and aeronautical conditions at Geneva Airport, and the estimates depend greatly on the price of fuel. Additionally, the authors did not report the costs associated with installing and using the TAFs. However, the costs of TAFs are expected to be relatively minimal.

The decision model employed for this study is relatively simple, and could potentially be completed in-house with the adequate expertise and resources. In the authors' view, one main lesson from their work can be useful for similar studies: companies know quite well where and why they use meteorological information; however, they often cannot easily quantify the benefits related to that use. Thus, NMHSs should not rely on surveys or interviews to learn about the monetary benefits of meteorological information. Instead, they should conduct explorative interviews to understand the decisionmaking process within the companies. Then, based on that knowledge, the agencies should build, validate and use a decisionmaking model to evaluate the monetary benefits.

E.1.7 Case study 7: Evaluating the avoided costs of the Finnish Meteorological Institute's met/hydro services across economic sectors

In 2007, the Technical Research Centre of Finland (VTT) conducted a valuation of the benefits of FMI met/hydro services. This study focused on the benefits of met/hydro services for various sectors and user groups to determine the value that FMI met/hydro services generate per euro of investment. Specifically, the study developed initial, order-of-magnitude estimates of the benefits of FMI met/hydro services for transportation, construction and facilities management, logistics, energy and agricultural sectors. Although many other sectors are also likely to benefit from the use of met/hydro services, the authors excluded them from their analysis because of limitations of available data or difficulties in expressing benefits in monetary terms. The Finnish Meteorological Institute has continued to develop more in-depth assessments since the completion of this initial study.

Methods

For each sector, the authors identified decisions or behaviour that can be altered in response to met/hydro information. Next, they identified and quantified the effects of these changes and, where feasible, attached unit prices to estimate economic benefits in terms of avoided costs and productivity gains. For example, in the transportation sector, information on adverse weather and poor road conditions might cause drivers to stay home or avoid affected areas. This would reduce the number and severity of accidents, and the associated costs of personal injuries and material damages. Likewise, seasonal forecasts for agriculture can increase value added through increased crop production.

The authors applied this framework to compare the benefits of the then-current level of FMI services and services that delivered “perfect information”. The authors introduced the concept of perfect information so that FMI would have a reference point for the maximum benefits that could be achieved through the dissemination of met/hydro information.

The authors used data and interviews to determine the current level of use of met/hydro services, how individuals and organizations change their decisions in response to this information, and how this benefits the decisionmaker, or others. When possible, the authors used available data, statistics and models to quantify the effects associated with using the met/hydro services in each sector. They relied on literature, interviews, market price data and other available information to assign monetary values to the quantified effects.

Conclusions

The study estimated that the annual benefits of FMI services for the selected sectors amounted to between € 262 million and € 285 million (price level and exchange rate of 2006 euros). Using the annual FMI budget as the “cost” of providing met/hydro information, the annual BCR for these services is between 5 to 1 and 10 to 1. If FMI were able to provide perfect information, the benefits could increase by 65% to 100%.

A somewhat surprising result of the study was that warnings about slipperiness for pedestrians and cyclists appeared to be the single most beneficial service. According to the VTT study, the reduction in medical costs, lost working hours, avoided lifelong injuries and even lives saved amounted to an estimated € 113 million per year at the level of services provided at the time. Even though the warning service is in all likelihood quite beneficial, the estimate is really uncertain and quite – if not surprisingly – high.

The valuation framework that the authors used for this study provides a straightforward process that NMHSs can use to assess the benefits of met/hydro services within the context of the met/hydro services value chain. However, to complete the study, the authors had to make a number of assumptions regarding the use and effects of met/hydro services across sectors. The reliability of estimates such as these depends largely on the availability of impact models and relevant data, as well as the knowledge and understanding of the use and value of met/hydro services by the experts who contributed to the study.

Despite these limitations, NMHSs can use this type of analysis to justify their budgets and to explore the value chain for met/hydro services in different sectors. Such an effort could lead to more detailed valuations of specific services, serving as an important feedback tool in the development process.

E.1.8 Case study 8: Estimating household willingness to pay for improved met/hydro services in Mozambique

Mozambique has experienced major flooding in recent years, resulting in numerous deaths, displacement of populations and destruction of infrastructure. The World Bank and other organizations are supporting enhancements of the water sector to reduce damages from future extreme weather events, including improvements to met/hydro data services.

This project (Lazo and Croneborg, forthcoming) evaluated the costs and benefits of improving met/hydro services for households in Mozambique. It used a combination of three approaches: (a) a benefit-transfer approach, (b) an expert elicitation related to specific economic sectors, and (c) a stated-preference survey of the general public. The present case study primarily focuses on the stated-preference survey.

Methods

The stated-preference public benefits assessment consisted of a multipart survey using a CV method (also known as “stated value”). The authors used an in-person survey of more than 500 individuals to understand how much people in a relevant (that is, non-random) population would be willing to pay for improved met/hydro services. The authors used two versions of the CV method survey question; each respondent was randomly assigned only one version. One version described a programme of intermediate improvements in services and another described a programme of maximal improvements. The respondents were asked about the maximum amount they would be willing to pay for the improved programme, ranging from nothing to Mtn 9 000. The survey also asked questions about the respondents’ socioeconomic status, their knowledge about and sources of weather information and their motivations for their value statement.

A significant concern in undertaking non-market valuation studies in developing countries is that many individuals have no monetary income and thus asking WTP in monetary terms may not yield meaningful results. The authors constrained the results by asking questions about the incomes of respondents. Respondents may also reject a scenario if they do not understand or believe some aspect of the scenario. The authors attempted to address this concern by asking questions about individuals' motivations for their value statement.

Conclusions

The CV-method study indicated a mean annual WTP of about US$ 0.09 per individual for improved weather forecast information. Analysis of responses indicated reasonable factors influencing WTP. For example, the authors found that urban, more highly educated and higher income respondents were willing to pay more for improved forecast information than rural, less educated and lower income respondents. They also found that individuals revealing some form of scenario rejection stated a lower WTP that would cause a downward bias in benefit estimates if not accounted for. Finally, individuals who wanted to make sure future generations had improved weather information (that is, had a bequest motivation) stated a higher WTP. Implementation of this study faced many challenges, including difficulty in sampling a representative cross section of the public, potential language barriers and income limitations to WTP.

Aggregation of results across the Mozambican population using a 3% rate of discount over a 50-year benefit lifespan would suggest a total present value of benefits of over US$ 50 million – significantly more than the project fixed costs of about US$ 21 million. This indicates that improved met/hydro services in Mozambique could provide significant societal benefits, dependent in part on ongoing support of operations and maintenance following any initial largely fixed cost investment.

In addition to the economic information, the survey provided a range of essential information on respondents' experience with weather, water and climate, as well as their sources, uses, preferences and values for met/hydro information. Little or no information existed on public use of met/hydro products and services prior to this survey. Results of the study will therefore serve as a baseline for responsible agencies in assessing the usefulness of and needs for met/hydro information, as they work to improve their capabilities.

E.1.9 **Case study 9: Evaluating the benefits and costs of improved weather and climate services in Bhutan**

Bhutan is subject to significant weather variability and extreme weather and hydrological events, the frequency and severity of which are expected to increase under climate change. In light of these factors, the Bhutanese Department of Hydro-Met Services (DHMS) and FMI initiated a study to investigate how DHMS can strengthen weather, climate, and hydrological services in Bhutan. As part of this investigation, FMI completed an SEB study to (a) evaluate stakeholder needs for improved met/hydro services, (b) qualitatively assess the potential benefits of improved services for different economic sectors, and (c) estimate the costs and monetary benefits (where feasible), of future met/hydro services (Pilli-Sihvola et al, 2014).

Methods

The authors evaluated the benefits and costs of climate services, weather forecast services, and early warning systems for 15 economic sectors. The scope of the study was to evaluate the benefits of an overall upgrade of met/hydro services in Bhutan at a broad level, rather than to assess any particular investment in great detail.

For each sector, the authors evaluated how potential services could affect operations and investments, avoid or reduce weather- and climate-related damages, and/or be used to better exploit opportunities (for example, through optimal sizing and location of hydro, wind and solar power units, or optimized crop choice). Information sources used included existing climatic and economic data (where available), estimates from the literature, interviews, and two workshops.

Where feasible, the authors quantified potential benefits by applying changes in damage probability or estimating increased productivity associated with the use of met/hydro information and services. The benefit valutations were largely determined using benefit transfer and information from in-person interviews. For each service and sector, benefits were also evaluated qualitatively through the filtering steps of the weather service chain approach (Nurmi et al., 2013).

In addition to benefits, the authors evaluated the costs associated with improving met/hydro services to the envisaged level. The study assumed a gradual build-up of services, with space for learning and stepwise upgrading to more sophisticated systems. Maintenance and staffing requirements were also taken into account.

Conclusions

Given the varied quality of available information, the authors qualitatively assessed potential benefits based on a cardinal rating method, indicating one to five plus (+) signs, depending on the estimated significance of the benefit. This assessment shows significant benefits associated with basic climate services (based on historical climate data) in most sectors, while forecast services (for example, seasonal forecasts) are the most significant for agriculture.

The report also presents an overall evaluation of the (quantifiable) benefits and costs for the period 2015–2030. Overall, the authors estimate that the NPV BCR of providing improved services in Bhutan is about 3.1. This includes the relatively high capital costs of DHMS modernization.

Data and budget limitations consideration

The authors were not able to conduct a full quantitative BCA due to data and budget limitations for this study. A more in-depth analysis would have required substantial data from the different economic sectors, as well as sectorial and macroeconomic modelling capabilities. However, the "quick scan" of costs and benefits of improved services has provided a good starting point for future service improvements. Specifically, the authors report that the SEB study effectively demonstrated the need for service development and related investments in up-to-date observation, data-processing and forecasting capacity. It has also helped to set priorities within DHMS and raise awareness among potential end users.

E.1.10 **Summary and conclusions**

The case studies highlighted in this publication clearly demonstrate that met/hydro services can provide significant benefits for individual users, industries and national and global economies. These studies help to make the case for increased investments in met/hydro services, including specialized services (for example, TAFs for aviation, seasonal forecasts for agriculture), large-scale early warning systems, weather forecasts and entire NMHS information systems. Because the studies were conducted with different assumptions and evaluated different types of services, it is not possible to directly compare study results or to draw conclusions regarding a general return on investment associated with met/hydro services.

Several of the case study examples rely largely on expert opinion and/or existing data from other countries to assess the benefits of met/hydro services across economic sectors. Examples include the World Bank's sector-specific and benchmarking studies, the VTT study of the benefits of existing FMI services, and Hallegatte's evaluation of the benefits of improving early warning systems and met/hydro information in developing countries to meet developed country standards. The advantage of these studies is that they do not require a large amount of data or modelling expertise, and they are relatively inexpensive to conduct. With a basic understanding of the relevant economic concepts, most NMHS agencies can conduct these types of studies in-house. However, it is important to recognize that these studies can generally only provide order-of-magnitude evaluations of the benefits of met/hydro services, which limits their usefulness for specific applications. For example, these studies should not be used to assess the trade-offs between different types of met/hydro services for budget prioritization purposes, or to determine how to improve met/hydro services to maximize their value. However, they can serve as a useful tool to help NMHS agencies justify their funding, obtain additional funding or assess which services they may want to evaluate in greater detail.

In contrast, many of the case study examples employ robust economic methods, including decision models, CV and regression analysis to evaluate specific services. Such studies include Law's analysis of Ethiopia's LEAP drought response system, the MeteoSwiss valuation of the benefits of TAFs for Swiss domestic airlines, the Ebi et al. study of the benefits of the NWS heat watch/warning system for Philadelphia, the use by Hansen et al. of crop models to estimate the benefits of GCM-based seasonal rainfall forecasts for farmers in Kenya, and the study by Lazo and Croneborg of household WTP for specific met/hydro services in Mozambique. The complexity and data requirements of these studies vary considerably, and in most cases these types of analyses will require NMHS agencies to retain an outside expert. However, the methods can substantially reduce the uncertainty of study estimates, and can be used to better evaluate the benefits of met/hydro services in relation to the met/hydro services value chain.

As pointed out by von Grünigen et al. (2014), NMHSs should not rely solely on one method to evaluate the benefits of meteorological information. Ideally, they should conduct explorative interviews and review existing data to understand the met/hydro decisionmaking process. Based on that knowledge, NMHSs can use decisionmaking models or other methods to evaluate monetary benefits. The level and type of analysis conducted will ultimately depend on the objectives of the NMHS, as well as the resources available for the study.

To date, there have not been many studies initiated by NMHSs or similar organizations to evaluate the benefits of met/hydro services. However, many academic researchers have addressed this topic, particularly in relation to agriculture. Many of these studies are referenced throughout the main guidance document. They are also described in more detail in a literature review completed for USAID in 2012 (http://www.climate-services.org/sites/default/files/CCRD-Climate-Services-Value-Report_FINAL.pdf). Similar to the case study examples, NMHSs can review these studies to identify options for conducting their own SEB valuations.

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E.2 CASE STUDY 1: EVALUATING THE ECONOMIC EFFICIENCY OF NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES MODERNIZATION IN EUROPE AND CENTRAL ASIA

E.2.1 Background

While preparing for the Russian Federation's National Hydrometeorological Modernization Project in 2003, the World Bank and Roshydromet recognized the need to evaluate the economic benefits of improving national met/hydro services to help make the case for large-scale NMHS modernization. With limited time and resources, the agencies used a sector-specific approach (described below) to evaluate the economic efficiency of improving Roshydromet's services and products. A joint World Bank–Roshydromet working group developed this approach, in coordination with NOAA economists and experts from WMO. The study found that improvements in forecasting would reduce weather-related economic losses by 8.5%. In addition, total returns on investment in the modernization project were estimated to range from 400% to 800% over seven years. The Russian Government and WMO noted that support for the project increased from US$ 80 million to approximately US$ 133 million as a result of the valuation.

The success of this project encouraged the World Bank to launch similar economic studies in Europe and Central Asia, where many NMHSs are in decline because of underfunding. Accordingly, the World Bank, jointly with a number of NMHSs in the Europe and Central Asia region, is developing and piloting methods to evaluate the benefits associated with existing weather and climate services, as well as the benefits that modernization might achieve. The purpose of these studies is to identify the key economic benefits from enhanced services of the NMHSs of Europe and Central Asia and to enable national decisionmakers to understand how to scale appropriately the allocation of resources to NMHSs to ensure functioning at a level suited to national needs. The studies have been commissioned in close cooperation with the NMHSs under review and developed based primarily on inputs from NMHSs and sectoral experts (World Bank, 2008).

E.2.2 Methods

To date, the World Bank has conducted economic studies in 11 European and Central Asian countries (see Table E.2). As described below, these studies applied three economic methods to evaluate the economic benefits of met/hydro services:

– Sector-specific assessments, based on the Russian case study, to estimate weather-related losses for weather-dependent industries and sectors of the economy, with and without improved met/hydro services. The World Bank implemented sector-specific assessments in all of the participating countries in Europe and Central Asia;

– Simplified benchmarking approach (described below) where data were inadequate or insufficient to carry out sector-specific assessments. The World Bank conducted benchmarking studies in nine of the European and Central Asian countries;

– Contingent valuation studies to assess economic benefits for households based on stated WTP. The World Bank conducted CV valuation studies in two of the countries.

Case study 1 focuses on the sector-specific and benchmarking approaches because case study 8 (Mozambique) describes CV in detail. Although there are limitations to the use of sector-specific and benchmarking methods (for example, the World Bank has acknowledged deficiencies in the use of benchmarking for detailed assessment, see Tsirkunov et al., 2007), the World Bank finds this method useful for providing order-of-magnitude valuations that help NMHSs justify increasing public funds to support their services.

Sector-specific method

The sector-specific method evaluates the economic benefits that would accrue in weather-dependent sectors from the modernization of an NMHS. In the European and Central Asian countries the World Bank used available country data and surveyed national experts from NMHSs and weather-dependent sectors to evaluate current sectoral losses from weather events, and determine the potential reduction in losses that modernization would achieve. The World Bank also used the surveys to determine the costs associated with actions taken by organizations and entities to prevent weather-related losses, both with and without modernization. The results of the studies compare the benefits of modernization, expressed as the additional prevented losses from hazardous events and unfavourable weather, with the costs associated with modernizing the NMHS and implementing preventive measures. This comparison (that is, the incremental reduction in weather-related losses compared to the costs of modernization) represents the economic efficiency of met/hydro improvements, as defined by the World Bank.

For the Europe and Central Asia studies, the World Bank expanded upon the methodology it employed in the Roshydromet study by evaluating both the direct and indirect economic losses that would occur as a result of unfavourable weather events, with and without modernization. In the context of this study, the World Bank defined direct economic losses as those that are caused by direct destruction, breakdown or damage to any types of property and tangible assets. Indirect economic losses include those that a business entity or economic sector suffers because of decreased revenues or additional expenditures on production cycles.

Box E.1 shows the basic steps that the World Bank employed in evaluating the preventable losses associated with NMHS modernization.

Box E.1. Evaluating the benefits of NMHS modernization in Europe and Central Asia using the sector-specific approach (Smetanina et al., 2006*a*, 2006*b*)

First, the World Bank used existing data and surveys of NMHSs and sectoral experts to determine:

(a) Sectors of the economy that suffer significant economic losses from hazardous events and unfavourable weather (i);

(b) The share of potentially preventable losses at the current quality of met/hydro services (R_i). Determined using expert assessments for the most weather-dependent sectors of the economy;

(c) The share of potentially preventable losses that could be avoided with modernization (S_i); estimated for the selected sectors of the economy, and possibly varying from 0% (that is, the modernization will not reduce potentially preventable losses) to 100% (the modernization will allow for the avoidance of all potentially preventable losses);

(d) Mean level of losses from hazards and unfavourable weather at the current forecast quality level (V); evaluated on the basis of official data and independent assessments of direct losses available at the time of the study and on the basis of expert assessments of indirect losses;

(e) Mean annual expenditures (C); required to take preventive and protective actions against met/hydro hazards and unfavourable weather events;

(f) The largest possible changes (relative changes) in the level of expenditures on actions required to prevent the effect of met/hydro hazards and unfavourable weather events that would result from the improved accuracy and lead time of met/hydro information (Δi); determined using expert assessments for the selected sectors of the economy.

Using the above basic components, the World Bank derived the following formula for evaluating the economic efficiency (viability) (E) of the expected modernization:

$$E = \{(V \cdot \Sigma R_i S_i - C_i \Sigma \Delta_{1i})/n\}/PC$$

Where PC equals the estimated costs (expenditures) required for the modernization of an NMHS; and n represents the number of economic sectors surveyed.

The World Bank noted that special attention should be given to estimating S_i because it relates directly to the expected modernization and the improvement of forecast quality and lead time. Therefore, the expert survey should contain a clear, quantitative definition of the improvements expected after the modernization effort.

Benchmarking method

Similar to the sector-specific approach, benchmarking assesses the losses caused by earlier events and estimates the reduction in losses that could be achieved with improved services. However, the benchmarking method provides a way to address limited sector-level data and expertise on weather-related losses in the European and Central Asian countries. This method relies on expert opinion and readily available data to assess the vulnerability of the country's overall economy to weather-related events and obtain results about direct damages caused by weather impacts (that is, unlike the sector-specific approach, benchmarking does not take into account indirect losses).

Benchmarking is carried out in two stages:

(a) Determining benchmarks – Using data and estimates from other countries and expert judgment, the authors define and adjust the following two benchmarks for each country:

   (i) The level of annual direct economic losses caused by met/hydro hazards and unfavourable weather events, expressed as a share of GDP;

   (ii) The level of annual prevented losses, with and without modernization, expressed as a percentage of the total level of losses;

(b) Correcting benchmarks – In this stage, data are adjusted to benchmarks according to country-specific estimates of weather and climate conditions, structure of the economy and other factors.

For the European and Central Asian countries, the authors determined the level of annual direct losses and annual prevented losses based on findings from studies conducted in several countries.[29] These studies showed that the mean annual level of direct losses from met/hydro hazards and unfavourable events varies between 0.1% and 1.1% of GDP.[30] The studies also showed that the share of prevented losses may vary from 20% to 60% of total weather and climate-related losses.

To evaluate these basic parameters for a specific country, the authors made adjustments to the average values based on three basic country characteristics: the weather dependence of the economy, meteorological vulnerability and the current status of met/hydro service provision. The authors evaluated these factors, and the extent to which they influence the benchmarks, based on quantitative data and expert assessments.

In the second stage of the benchmarking process, the authors further adjusted the benchmarks based on rapid assessments of national climate, agency capacity, national economic structure and other factors. The adjusted benchmarks are used to assess the marginal efficiency of met/hydro services, with and without modernization. Results are reported as the absolute value of the expected reduction in total losses resulting from modernization divided by the cost of the NMHS modernization improvements.

E.2.3 **Results**

All assessments indicate that improving met/hydro services and information can result in significant economic benefits. The World Bank applied the benchmarking method in all countries. In countries with sufficient information, the Bank also applied the

[29] The values used are based on studies that assessed the economic efficiency of met/hydro information in developed countries and in China and the Russian Federation.

[30] These figures represent the mean annual level of losses for a fairly long period of observations. Losses for some specific year in some specific country may be well beyond the range given.

sector-specific approach. Table E.2 presents the economic efficiency estimates determined using the benchmarking and the sector-specific approaches.

Economic efficiency compares the estimates of prevented losses to the NMHS funding level. For example, economic efficiency in Kyrgyzstan ranges from 244% to 318%, meaning that every dollar spent on the NMHS could yield US$ 2.4 to US$ 3.2 in revenues as a result of avoided damages. Information and data were too limited to apply the sector-specific method in Kazakhstan and Turkmenistan.

E.2.4 Communication of results and outcomes

From these assessments, many further projects and efforts followed, which attempted to achieve the same benefits that were highlighted in these studies. Some countries used the results of the studies to independently finance the investment, instead of using World Bank funding. In addition, the heads of the respective NMHSs have emphasized the importance of these studies in enhancing dialogue with national planners.

Table E.2. Comparative results of the Europe and Central Asia economic assessments, economic efficiency estimates for the benchmarking and sector-specific approaches (percentage efficiency over seven years)

Country	*Economic efficiency estimate – benchmarking*	*Economic efficiency estimate – sector-specific assessment*
Albania	210	320–680
Armenia	440	1 070
Azerbaijan	430	1 440
Belarus	530	480–550
Georgia	260	1 050
Kazakhstan	540	N/A
Kyrgyzstan	244	318
Serbia	880	690
Tajikistan	199	357
Turkmenistan	413	N/A
Ukraine	310	410–1 080

Note: The World Bank did not conduct sector-specific assessments in Kazakhstan or Turkmenistan because sufficient data were not available in these countries.

These studies were also communicated within the sector unit of the World Bank that has an interest in weather and with the Europe and Central Asia region. World Bank representatives have presented the results of the studies at a WMO conference on economic benefits.

E.2.5 **Challenges and limitations**

Sector-specific assessments

The World Bank developed the sector-specific approach to help NMHSs provide understandable results to decisionmakers with limited time and resources. Another stated benefit of this approach is that input from economic experts can contribute to the design of a modernization project and establish connections between providers and users of weather information, which can lay the groundwork for private–public partnerships.

However, the sector-specific method is severely limited in that it relies primarily on expert opinion to determine the current level of weather-related losses for a given sector, the additional reduction in weather-related losses that modernization would achieve and the costs associated with mitigation options. Thus, the results of the analysis are subject to the potential biases and knowledge limitations of the experts involved in the study. In addition, there is a limited amount of data available to support expert findings and the inability of this method to estimate economic benefits to households.

Another challenge relates to the fact that the agricultural sector is a significant beneficiary of improved climate services and weather forecasting. However, farmers are dispersed, which makes it difficult to obtain information about met/hydro services, such as those services they need, those they already use and the quality of these services.

Benchmarking

Benchmarking is less expensive than most other methods because it does not require any detailed analytical studies or surveys. However, similar to the sector-specific method, the accuracy of benchmarking estimates is subject to expert opinions and potential biases. Additional restrictions result from the fact that this method is intended to evaluate direct economic losses and does not take into account indirect losses associated with loss of life and lost profit of economic entities.

Benchmarking is further constrained by the limited amount of data used to establish its parameters. For example, a single value to characterize the country’s meteorological vulnerability will not capture all of the complexities of the real situation. Similar to the sector-specific approach, the benchmarking method does not assess the value of meteorological information for households.

Despite these limitations, the World Bank maintains that this approach is useful in developing order-of-magnitude estimates of the likely benefits of NMHS improvements, based on global averages.

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E.3 CASE STUDY 2: USING BENEFIT–COST ANALYSIS TO EVALUATE THE EFFECTIVENESS OF A DROUGHT EARLY WARNING AND RESPONSE SYSTEM IN ETHIOPIA

E.3.1 Background/introduction

Ethiopia's LEAP system is an integrated drought early-warning/early-action system that predicts crop yield reductions. The LEAP system has three primary components, including early warning, contingency planning and contingency financing. The World Bank administers a US$ 160 million relief fund, and the LEAP system's drought index triggers the disbursement of these funds once a drought reaches a certain level. This is opposed to traditional drought relief, which is implemented after drought losses have occurred. The three components of LEAP support the scale-up of a social safety net, which LEAP uses to assist people in times of drought.

Evidence suggests that early response leads to lower relief costs for governments and donor agencies, and can result in avoided livelihood losses for households (Law, 2012). For governments and donor agencies, the cost of providing early assistance is lower than during the emergency phase, when expensive food packages and support to rebuild lost assets are needed. In addition, by the time response arrives under the traditional drought relief framework, households have usually resorted to destructive risk-coping strategies that can have significant long-term detrimental health and economic impacts. Early provision of food or cash can prevent households from having to engage in such coping strategies, by allowing them to maintain consumption levels without having to sell productive assets (Law, 2012).

Despite the widely acknowledged benefits of early response, governments and donor agencies continue to rely on traditional drought relief strategies. One key explanation for the continued dominance of reactive aid is the lack of quantitative evidence on the cost-effectiveness of early response (Owens et al, 2003; Choo, 2009; International Federation of Red Cross and Red Crescent Societies , 2009; and as cited in Law, 2012).

In 2012, the United Kingdom Department for International Development and the Netherlands Directorate-General for International Cooperation funded a study to evaluate the benefits and costs of LEAP. The primary motivations for this research included: (a) to gain a better understanding of the role of climate services in disaster risk reduction, (b) to "inform strategic-level investment decisionmaking within governments and donor/humanitarian agencies" (Law, 2012, p. 21), and (c) to demonstrate whether quantitative evidence on the cost-effectiveness of early response justifies preventive humanitarian aid rather than reactive humanitarian aid. The specific objectives were to:

– Quantify the economic benefits of early drought response to humanitarian agencies, governments and beneficiaries – the total population in need of assistance – in Ethiopia;

– Evaluate the cost-effectiveness of the LEAP integrated early-response model;

– Create a model for evaluating the costs and benefits of early-response systems used for drought-induced food crises.

This study is important because it represents, in part, an attempt to quantify the downstream effects associated with severe drought, including long-term livelihood losses. Anna Law, a doctoral candidate from the University of Oxford, conducted this research.[31]

E.3.2 **Methods used**

The author used a BCA approach to provide a more holistic valuation of Ethiopia's LEAP system by monetizing its associated costs and benefits at a national scale over a 20-year period.[32] It had originally been planned to conduct the BCA at a regional scale, but Law was unable to do so because of a shortage of regional econometric studies on livelihood losses associated with drought. Law used Microsoft Excel to conduct all of the analyses presented in her dissertation.

Law used three scenarios to draw her conclusions about the costs and benefits associated with the LEAP system: a conventional emergency response (baseline scenario without LEAP), an ideal LEAP-activated early response, and a delayed LEAP-activated response. The benefits of LEAP were calculated in terms of avoided livelihood losses for households and decreased assistance costs relative to the baseline scenario. The two benefit categories were quantified separately because each provided a benefit to a different group of people: avoided livelihood losses benefits beneficiaries, while lower assistance costs benefits governments, humanitarian agencies and donors.

To calculate costs for each scenario, Law quantified (a) the average per-capita cost of emergency assistance, which includes the cost of food and non-food assistance, and (b) the cost of long-term livelihood losses, which includes losses related to stunting, to reduced adult food and non-food consumption, and to the "distress sale" of productive assets. For the two LEAP scenarios, the costs of installing and maintaining the LEAP system were also included. Table E.3 summarizes the key assumptions and calculations that were used to calculate the costs of the different scenarios, including key assumptions.

To calculate the total aid costs and livelihood losses over time, the author conducted a hazard analysis to determine the frequency of severe droughts and an exposure analysis to determine the number of beneficiaries affected by a severe drought event.

Defining what constitutes a medium, severe or catastrophic drought is extremely subjective, and depends in part on whether drought is defined in terms of an

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31 Law's dissertation does not represent the views of the United Nations WFP, the Government of Ethiopia or any other entity associated with LEAP.

32 Law used the BCA to (a) provide an input to decisionmaking and not as a decision rule, and (b) place a relative value rather than an absolute one on projects.

Table E.3. Cost calculations for the conventional and the Livelihoods, Early Assessment and Protection scenarios (in 2012 US$)

Type of costs	*Assumptions*	*Calculation*	*Monetized cost*
Conventional emergency response			
Cost of assistance	Calculated based on the average per-capita cost of emergency assistance in terms of (a) costs of food assistance; and (b) non-food assistance, such as water and sanitation, agriculture, health and nutrition	Cost of food assistance: Used US$ 77, which is the WFP per-capita cost of food aid delivery in Ethiopia Cost of non-food assistance: Added 30% to the cost of food assistance	US$ 100 per beneficiary
Cost of long-term livelihood losses	Conducted vulnerability assessment to determine (a) lifetime earnings lost by stunted children, and (b) lower household income growth in years following a drought Calculated for low-income, agrarian Ethiopian households	Lifetime earnings lost by stunted children: Calculated the expected present value of lifetime earnings without a drought and applied a 14% reduction (based on approach by Alderman et al. (2006)) to estimate earnings with drought Lower household income growth: Calculated the expected present value of household income over the next 20 years without a drought and applied a 16% reduction (based on approach by Clarke and Vargas Hill (2012)) to estimate household income with drought	Lifetime earnings lost by stunted children: US$ 10 per capita Lower household income growth: US$ 216 per capita Total: US$ 226 per capita
LEAP early-response and delayed-response scenarios			
Cost of the LEAP system	The cost of installation and maintenance over the next 20 years	Calculated based on personal communications (A. Kumar, WFP/DRMFSS;[a] N. Balzer and R. Choularton, WFP, 2012)	US$ 567 790
Cost of assistance	Calculated based on the average national cost of cash and food assistance		US$ 34 per beneficiary
Cost of long-term livelihood losses	For lifetime earnings by stunted children: the average household will start reducing consumption three months after harvest For household income growth: the average household will reduce consumption of and sell livestock three months and five to eight months after harvest (for ideal and delayed LEAP scenarios, respectively) Limitation: not enough data on the timing of when people switch to different drought-coping strategies	Calculated relative to the baseline emergency response scenario in terms of livelihood losses avoided under each early-response scenario Adapted estimates from Clarke and Vargas Hill (2012) regarding the timing of drought coping strategies	Lower lifetime earnings by stunted children: Ideal LEAP – 10% Delayed LEAP – 30% Lower household income growth: Ideal LEAP – 10% Delayed LEAP – 30%

Notes:
All United States dollar values reported in 2012 values.
[a] Disaster Risk Management and Food Security Sector of the Ministry of Agriculture and Rural Development.

agrometeorological anomaly or in terms of human impact. Because this study focuses on the effects of drought on people, Law defined a severe drought as one that leads to important livelihood losses, even if it is not considered very severe or unusual by agrometeorological standards. Severe drought was defined as a drought on a similar scale to those that occurred in Ethiopia in 2008, 2009 and 2011; the author assumed that such a drought occurs every five years, based on estimates from the literature (Hess et al., 2006; World Bank, 2006; Cabot Venton et al., 2012).

Law calculated the number of beneficiaries for all three scenarios using the Humanitarian Requirements Documents for the recent severe droughts in Ethiopia, based on the average number of emergency food beneficiaries identified in the documents for the three droughts: 4.6 million beneficiaries in 2008, 6.2 million in 2009 and 4.6 million in 2011 (Ethiopia, 2008, 2009, 2011) – an average of 5.1 million beneficiaries per drought.

In the absence of quantitative data, it was assumed the number of beneficiaries remained constant in all three scenarios. In reality, the number of people in need of assistance increases with time as a crisis escalates, and this increase is likely non-linear, with numbers increasing exponentially once people cross a certain survival threshold. However, this analysis assumed that the benefits of acting early do not result from lower beneficiary numbers, but rather from (a) lower cost of assistance per beneficiary, and (b) lower livelihood losses per beneficiary. When calculating the cost of response over 20 years, beneficiary numbers were assumed to increase by 1% per year, to account for population growth and an increase in population vulnerability.

Data requirements/collection efforts

The author conducted three literature reviews to understand (a) the nature of humanitarian response to drought-induced emergencies; (b) how the LEAP system works and its associated costs and benefits; (c) the economic impacts of drought on households. The author used existing data rather than conducting a primary study because of time and budget constraints.

Uncertainty

Law dealt with uncertainty in the data and her assumptions by conducting sensitivity analyses on key inputs, including: drought frequency, discount rate, initial number of beneficiaries, annual changes in population exposure, livelihood losses avoided under early response, and per-capita cost of assistance under the emergency scenario.

E.3.3 Resources required, including cost and expertise

The entire study – data collection, elaboration of methodology, analysis and write up – took three months. The author received a grant from the United Kingdom Department for International Development and the Netherlands Directorate-General for International Cooperation, through the Climate and Development Knowledge Network, as well as an internship stipend from WFP. The grant and internship stipend covered the author's living expenses during the period of the study, and in total amounted to approximately US$ 2 500. The only other cost was a two-day trip for two people to Ethiopia to present the findings, which cost in the range of US$ 3 000.

The author received help from WFP staff in Rome and Ethiopia to conduct interviews and discuss the analysis methodology and also received feedback from personnel in the Ethiopian Government's Ministry of Agriculture.

E.3.4 **Findings/results**

Table E.4 provides a summary of the results for the three scenarios included in the study.

The author came to three main conclusions:

– The economic benefits of early response are high: Even in the delayed LEAP-activated scenario, relative to the conventional emergency response, the benefits outweigh the costs. This is true even when sensitivity analyses were used to test different input assumptions that would lead to a more conservative estimate of benefits. Most of these benefits are due to avoided livelihood losses, although the benefits of lower assistance costs are also significant;

– Drought early warning systems are among the most cost-effective disaster risk reduction investments for food security: The author finds that this is mostly due to the fact that the benefits come primarily from avoided livelihood losses rather than avoided crop losses;

Table E.4. Summary of costs and benefits under baseline assumptions, over 20 years (US$ billions)

	Emergency	*Ideal LEAP*	*Delayed LEAP*
Assistance costs	1.039	0.353	0.353
Livelihood losses	2.350	0.235	0.705
Cost of LEAP	–	0.001	0.001
Total costs	**3.389**	**0.589**	**1.059**
Net assistance benefits (once cost of LEAP is subtracted)	–	0.686	0.686
Net livelihood benefits	–	2.115	1.645
Total net benefits (NPV)	–	**2.800**	**2.330**

Note: Totals may not sum due to rounding.

- Benefits over time will be larger than portrayed in the study if drought frequency and/or magnitude increase under climate change. However, there is still great uncertainty regarding how climate change will affect drought in Ethiopia (World Bank, 2010, as cited in Law, 2012; IPCC, 2012). According to the sensitivity analyses, drought frequency has the second largest impact on the results; discount rate has the largest impact.

E.3.5 Communication of results and outcome of the analysis

The results of the BCA were not published, but the preliminary findings were presented to the Ethiopian Government in Addis Ababa. The author received a lot of positive feedback and many questions about what she did not quantify, such as avoided livestock losses and other indirect benefits. Indirect benefits that were not used in the analysis due to data limitations include "improved national meteorological infrastructure, enhanced inter-ministerial collaboration, potential for use of agrometeorological information and LEAP indices for other services (such as community or household-level index insurance schemes), and capacity-building (training of government staff in data analysis and use of the LEAP software)". These discussions helped highlight potential improvements for the LEAP system and commonly overlooked benefits.

E.3.6 Lessons learned/challenges

The key lessons learned and challenges associated with this project are listed below:

- Evaluating non-monetary benefits for disaster risk reduction: Law did not quantify and monetize the number of avoided lives lost under each scenario because of the limited availability of mortality data associated with droughts. In addition, she stated that monetizing the number of avoided lives lost raised ethical questions about placing a value on human lives (however, as described in the main guidance and in other case studies, economists often apply VSL estimates in BCAs);

- Selecting an appropriate discount rate: The results of the BCA are highly sensitive to discount rate. Law used a sensitivity analysis to look at a high (15%), medium (10%) and low (0%) discount rate, and a 10% discount rate for the main analysis;

- Predicting future risk patterns with limited meteorological records and uncertainty about the effects of climate change on drought frequency and magnitude in Ethiopia: To overcome this inherent uncertainty, the author used a sensitivity analysis assuming a higher and lower drought frequency. She found that drought frequency had the second largest impact on study results; the selected discount rate had the largest impact;

- Gaining access to and obtaining the right data: In many instances the author was unable to perform the analysis she wanted to due to lack of available data;

– Predicting changes in population exposure: Law used sensitivity analysis assuming various increases in population exposure.

Despite these challenges, the author maintains that the BCA framework is a useful strategic decisionmaking tool that can help governments and donor agencies choose between alternative investment scenarios for disaster risk reduction. Thus, the analysis compares differences in the reliability of returns between projects. Sensitivity analysis was used to highlight investments that consistently generate positive returns, while flagging those where returns are vulnerable to critical analysis assumptions, such as the discount rate or drought hazard frequency.

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E.4 CASE STUDY 3: QUANTIFYING THE SUCCESS OF THE NATIONAL WEATHER SERVICE'S LIFE-SAVING HEAT WATCH/WARNING SYSTEM IN PHILADELPHIA

E.4.1 Background and introduction

Although cities around the world continue to develop and implement extreme heat watch/warning systems, only an extremely limited number of peer-reviewed studies attempt to quantify the effectiveness of these systems. One frequently referenced example of such a study is the Ebi et al. (2004) review of potential avoided deaths attributable to the extreme heat warning notices that NWS issues for the Philadelphia, Pennsylvania, area.

Ebi et al. were motivated to examine whether the benefits of PWWS could be quantified in terms of the number of lives saved by the system's warnings and associated community response actions. The research reflects both a desire to demonstrate the usefulness of such systems and to provide specific evidence concerning Philadelphia's approach as a potential benchmark for other locations considering such systems. Funding for the authors' research came from the Electric Power Research Institute and NOAA.

The following sections outline the methods the authors used for their analysis and its key findings. Following this, the study results are considered more generally in terms of their relevance for NMHSs.

E.4.2 Methods used

To determine whether the warnings resulted in fewer mortalities associated with extreme heat events, Ebi et al. used regression analysis to evaluate the relationship between daily summertime mortalities for people aged 65 and older, weather conditions and heatwave warning announcements for Philadelphia for the years 1995 to 1998. A brief summary of the critical study elements and conclusions follows.

Study days

The study design relied on a relatively unique circumstance to define two types of "heatwave days" that occurred in Philadelphia during the study period: days on which NWS actually issued a heat warning, and days on which PWWS (see section E.1.3.1) indicated that weather conditions posed a risk to human health.

Philadelphia developed PWWS following a series of devastating heatwaves in the early 1990s, including one from 6 to 14 July 1993, when the medical examiner's office determined that 118 deaths were attributable to heat. At that time, formal findings of such a large mortality impact attributable to extreme heat were unheard of. In response, the city funded development of PWWS to identify and provide warning of conditions likely to elevate mortality. During the study period, staff in the local NWS office were responsible for issuing heatwave warnings. To guide their decisions, staff used NWS forecast information, as well as information that PWWS produced.

Philadelphia's Hot Weather-Health Watch/Warning System evaluates NWS forecasts to identify conditions (that is, air masses) that had previously produced elevated daily mortalities compared to seasonal averages. For the period under study, when forecasters identified such conditions, PWWS then recommended issuing a heat warning. However, NWS forecasters did not completely rely on PWWS recommendations and were often conservative in issuing advisories and warnings.

Thus, the first set of days in the study consisted of those summertime days when PWWS recommended issuing a warning. This produced a pool of 210 potential heatwave days, including the recommended warning day and the three days following the recommended warning day. The authors included the three days following the recommended warning day because heat-induced health effects can last for several days, and conditions often remain critical in the days following an extreme heat event, even if they do not warrant a heat watch/warning.

The second set of study days included days when the NWS staff issued a heatwave warning based on actual and forecast heat index values, which reflect the combined effect of heat and humidity. Heat warnings were issued by NWS for 21 days during the study period. Thus, the second set of heatwave days included 45 total days, when the three days following the actual warning day were included.

Mortality data

The mortality outcome that the authors considered was the estimate of excess daily mortality among people aged 65 and older during the summer season. Excess mortality is the measure of how the reported deaths in a population, here people aged 65 and older, vary from a longer-term average for the time period. Ebi et al. created a time series database of daily excess mortality among people aged 65 and older in Philadelphia for both sets of heatwave days.

The authors obtained the daily mortality data for the Philadelphia metropolitan statistical area from the National Center for Health Statistics. They chose to limit the analysis to people aged 65 and older because older people are more vulnerable to excessive heat; therefore, they reasoned that the statistical evidence regarding the effectiveness of the warning system would be strongest for this age group.

Regression analysis

In their regression analysis, the authors used daily excess mortality values for people aged 65 and older as the dependent variable, so the coefficients on the explanatory variables reflect the effects of each variable on this daily mortality measure. After considering a number of potential explanatory variables, the authors reported values for a regression with variables that were significantly associated with excess mortality. The resulting regression included a constant and the following explanatory variables: time of season, for which values reflected a sequential count of the days in the summer season; a warning indicator variable, which reflected whether the data represented a day (or one of the three days following) on which the NWS warning was actually issued.

The authors completed their analysis with the multiple linear regression function in Microsoft Excel.

Value of a statistical life

To monetize the estimated number of lives saved by the NWS-issued warning (as determined by the regression analysis), the authors used the EPA VSL estimate, approximately US$ 6 million at that time, as a starting point. Based on a limited review of studies of the sensitivity of the VSL estimate to age, the authors concluded that a value of US$ 4 million was appropriate because of the older study population. We discuss some issues with this approach in greater detail in section E.4.7.

E.4.3 **Results**

The results of the regression analysis indicated there was a reduction of 2.58 excess deaths in the 65-and-older population each day that NWS issued a heat warning, or within the three following days. Extrapolating over the 45 days in the study period when an NWS-issued warning occurred, the authors suggest the warnings may have saved a total of 117 people in this age group over the three-year study period (that is, 45 warning days or successive days x 2.58 people saved per day).

However, as the authors noted in their paper, these quantitative results came with a caveat that the warning coefficient has a t-test statistic value of 1.43 and a p value of 0.08 (significant at the 92% level) and the regression equation explained only 4% of the observed variation in the data (that is, an R-squared value of 0.04). This result means that at the commonly used 5% level of statistical significance used to evaluate the effect of a variable, the authors could not reject the hypothesis that the warnings do not save lives. The authors considered the low p-value for the warning days coefficient and discussed a second interpretation – a 92% chance that the system operation contributed to saving at least one person’s life. This created a frame of reference for the programme’s benefits, resulting in a large range from one person saved to 117 people saved.

Multiplication of the extrapolated number of lives saved by the author’s adjusted VSL of US$ 4 million provided an estimate of the programme’s value over the three-year study period as US$ 468 million.

E.4.4 Communication of results and outcomes

As mentioned above, reviews of the potential effectiveness of heat health watch/warning systems in other peer-reviewed articles and agency documents widely cite the Ebi et al. paper. The authors' results appear in presentations in a wide range of professional conferences, such as the annual American Meteorological Society meetings. However, whether or how the results of the study assisted in adjusting subsequent heat advisories or components of PWWS is unclear.

E.4.5 Challenges and lessons learned

The Ebi et al. study revealed a subtle challenge with respect to identifying extreme heat days. Specifically, the difference in the number of days PWWS recommended issuing heat warnings compared to the number of days where NWS actually issued a warning reveals how alternative criteria can produce vastly different determinations of health risk associated with specific meteorological conditions. While this discrepancy was crucial for producing the data the authors evaluated, it raises additional questions. For example, would the potential benefits have increased if the public clearly understood that the recommendations were linked to a past association with elevated mortality? Or would the potential benefits have diminished if residents began to interpret more frequent warnings as reflecting "typical," rather than "extreme" conditions?

E.4.6 Resources and expertise required

As reported in Lazo et al. (2009), completing the analysis to produce the study took Ebi et al. approximately 340 hours and approximately US$ 45 000. The analysis also required the services of, in this case, an economist with the expertise to complete the regression analysis.

However, the crucial element for this study was having access to the underlying daily mortality, weather and heat warning data. As Lazo et al. noted in their review, this data had already been assembled because one of the Ebi et al. co-authors, Kalkstein, was a principal developer of PWWS. In particular, the effort and resources associated with categorizing days in terms of their corresponding air mass category for PWWS was not reflected in the reported financial resources required to generate this research. In sum, such studies entail a labour-intensive process that requires access to, and the ability to evaluate, a wide range of meteorological data.

E.4.7 Recommendations for tailoring methods to NMHS circumstances

The Ebi et al. study draws notable attention because of the aforementioned quantitative results. Considering how others could or should replicate the study is important, as is whether other conclusions from the study are worth noting. This section addresses these considerations.

Replicating the Ebi et al. study

Replicating the Ebi et al. study exactly would be difficult. The main difficulty is that the study evaluated the relatively unique situation where two different systems were in place for the issuing of heat warnings. In most cases, an area would develop and operate a single system.

Determining the resources that others would need to complete a similar study is also complicated because the authors had obtained a much larger funding commitment to support the work of developing the excess mortality and air-mass relationships that underlie PWWS and that presumably informed the NWS criteria.

Looking to NMHSs elsewhere, others could execute the work to develop heat-warning criteria with varying ranges of complexity and cost. In general, such work would require participation of health officials with access to daily mortality data for a targeted area and weather officials with access to historical meteorological data. A less resource-intensive effort could consider evidence that mortality increases when specific meteorological criteria, consistent with extreme heat, occur. A more resource-intensive effort would be to conduct a full mapping of historical days into air mass categories and then evaluate the relationship for elevated mortality based on the air-mass-specific results mirroring the general process used to develop PWWS.

Considering the Ebi et al. results for NMHSs

One issue of particular note is the authors' use of the US$ 4 million value per estimated life saved, which the authors applied to produce a monetized estimate of the benefits of the programme. They chose the value to reflect the age of the study population and potential mortality displacement. The article correctly noted that the literature available at the time reported mixed results with respect to the support for age-based adjustments to the VSL estimate; however, the selected value of US$ 4 million was nonetheless a choice the authors made, instead of an empirically supported adjustment. Finally, we note that attempts to monetize potential future or observed changes in mortality risk or outcomes need to be carefully considered and guided by local conditions and available data. In future studies, authors would need to carefully evaluate using the current VSL estimates available from EPA; using the US$ 4 million value per estimated life saved that Ebi et al. used would be problematic given the lack of empirical support for the value.

An interesting consideration for this study is that although it quantifies the effects of the heat warning announcement, this announcement in turn triggers a series of actions that the city implements in response to anticipated conditions. In short, attributing the estimated benefits to the announcement would be short-sighted and we would lose sight of the city's efforts to identify and evaluate at-risk individuals and provide protective services and actions that contribute to saving people's lives. Other research, for example that by Sheridan (2007), found that when individuals in an at-risk group were aware of heat warnings, they did not modify their behaviour to reduce their risks.

In addition, the Ebi et al. study evaluated a period when the city and its residents may have been especially responsive to heat warnings. Specifically, the 1995 to 1998 study period evaluated actions following the 1991 and 1993 heatwaves in Philadelphia, as well as the extreme heat mortality and nationwide coverage of the 1995 heatwaves in Chicago. On the other hand, some posit that the public could show a reduced response to heat warnings, over time, if members of the public begin to lose sensitivity to the real risk. We have noted the discrepancy reported in the study between the number of days that PWWS recommended warnings compared with the days where the NWS actually issued warnings. Had warnings been issued on all of the days that PWWS recommended, the public might have questioned whether a truly significant event was occurring; the level of public response may have then trailed off over time.

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E.5 CASE STUDY 4: APPLYING BENEFIT TRANSFER TO EVALUATE THE BENEFITS AND COSTS OF IMPROVING MET/HYDRO SERVICES TO REDUCE DISASTER LOSSES IN DEVELOPING COUNTRIES

E.5.1 Introduction and background

Many developing countries lack the resources or relevant expertise to conduct quantitative assessments of the value of the met/hydro services they provide. The World Bank's 2012 study, *A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation* (Hallegatte, 2012) addresses this issue by applying a low-cost benefit-transfer methodology to estimate the benefits and costs of improving met/hydro information and early warning systems in developing countries.

Case study 4 provides an overview of the methods and results of this study, which was funded by the Office of the Chief Economist at the World Bank. Led by World Bank economist Stephane Hallegatte, this research is part of a larger effort by the World Bank to demonstrate the national-level benefits of improved met/hydro services and to contribute to development policy discussions around the world.

This case study has been included because it serves as an example of how existing data, estimates from the literature and expert knowledge can be applied to estimate the value of met/hydro services in other contexts. However, as we discuss below, the study provides large ranges for the potential benefits of early warning systems and other met/hydro services. Because the study did not rely on a direct analysis of benefits in developing countries, these results should be interpreted as initial, order-of-magnitude estimates that help indicate the potential value of met/hydro service improvements. Local and context-specific analyses will need to be incorporated by NMHSs wishing to apply this approach before real investments are made.

E.5.2 Methods used

Hallegatte employed a benefit-transfer approach to develop estimates of the benefits and costs of improving met/hydro information and early warning systems in developing countries to meet developed-country standards. Specifically, the author:

- Estimated the benefits from early warning systems in Europe in terms of avoided asset losses and people's lives saved, based on existing literature and data for Europe;

- Applied the findings of this valuation to estimate the potential benefits of providing similar services in developing countries;

- Estimated other economic benefits that could accrue from using the met/hydro information required for early warning systems in weather-sensitive sectors, including agriculture, energy, construction, transportation, health, tourism, among others. The author derived these benefits for Europe and applied them to developing countries;

- Estimated the costs associated with improving met/hydro information and early warning capacity in developing countries to developed country standards;
- Developed a range of BCRs for met/hydro services and early warning systems in developing countries.

Benefits from early warning and preparation measures in Europe

As a first step to this analysis, Hallegatte relied on existing data to estimate the benefits of early warning systems in Europe in terms of avoided asset losses and the number of people's lives saved.

Avoided asset losses

Hallegatte evaluated avoided asset losses associated with early warnings based on a review of literature related to emergency preparedness and response to floods and storms in Europe, as well as his own knowledge and experience. Based on this approach, Hallegatte estimates that the use of early warning systems in Europe avoids between € 460 million and € 2.7 billion in lost assets per year. This represents between 0.003% and 0.017% of European GDP. Table E.5 shows the assumptions and sources that the author used to calculate these estimates.

Table E.5. Calculations and assumptions used to estimate avoided asset losses provided by early warning systems in Europe

	Floods	*Storms*
Average annual cost to Europe (€)	€ 4.0 billion (Barredo, 2009)	€ 2.6 billion per year (Swiss Re, 2006)
% of events forecasted	50% to 75% (author's estimate)	100% (author's estimate)
% reduction in losses because of early warnings	10% (author's estimate) to 50% (Carsell et al., 2004)	10% to 50% per year (assumed to be the same as floods)
Total annual loss reduction	€ 200 million to € 1.5 billion	€ 260 million to € 1.2 billion
Total benefit	€ 460 million to € 2.7 billion per year	

Lives saved

Weather-related threats to human safety in Europe include floods, heatwaves, winter storms, cold spells and avalanches. Hallegatte reviewed existing data and literature to determine the average number of people who have died in Europe as a result of each of these events and the frequency with which these events occur. He then made an assumption about the number of people who would have died if no early warnings had been in place. The author does not report the exact method used to determine this estimate, but notes that he took into account the effectiveness, use and response to early warnings for different sectors of the economy (for example, maritime and air transport, outdoor activities, and government emergency preparations).

Based on this assessment, Hallegatte estimates that early warning systems in Europe save at least 200 people's lives per year. The author maintains that this is an extremely conservative estimate, based on lower-bound estimates from the literature, and that met/hydro services more likely save upwards of 800 lives per year.

Application of benefit estimates for Europe to the potential benefits of providing similar services in developing countries

Some of the potential benefits from early warning systems already occur in the developing world. Thus, to transfer findings on the benefits for Europe to developing countries, the author determined (a) how much of these benefits are already captured, and (b) how much it would cost to capture the full benefit potential. To answer these questions, Hallegatte identified four groups of developing countries based on the following assumptions:

– Group 1 (low-income countries) includes countries with no basic met/hydro services, where benefits are likely to be close to zero. Hallegatte assumed that 10% of the benefits achieved in Europe are already realized in these countries because of existing regional or global services;

– Group 2 (lower middle-income countries) includes countries where basic met/hydro services exist but are not fully operational. Hallegatte assumed these countries realize 20% of the benefits achieved in Europe;

– Group 3 (upper middle-income countries) includes countries with well-functioning met/hydro services but with gaps in the chain from data production to early warning systems. Hallegatte assumed that 50% of the European benefits are achieved in these countries;

– Group 4 (high-income countries) includes countries where met/hydro services and early warning systems are comparable to European ones. Hallegatte assumed 100% of the European benefits are achieved in these countries.

Avoided asset losses

To estimate asset losses avoided as a result of improved early warning systems in developing countries, Hallegatte assumed that the magnitude of potential avoided losses depends on the level of existing services for each country group, as defined above. For example, for developing countries in group 1 (low income), where Hallegatte assumed that the countries currently achieve only 10% of the benefits achieved in Europe, he calculated the lower-bound estimates for avoided asset losses from improved services as follows:

– Potential total benefits of the European level of services = GDP (US$ 413 000 million) x 0.003% (lower-bound estimate for avoided asset losses as a percentage of GDP) = US$ 12 million;

– Estimated benefits from existing level of services = US$ 12 million x 10% = US$ 1 million;

– Additional potential benefits from improved services = low estimate of potential benefits (US$ 12 million) – low estimate of benefits provide by current services (US$ 1 million) = US$ 11 million.

Table E.6 summarizes this analysis by country group. Hallegatte's results show that developed countries could avoid losses of about US$ 300 million to US$ 2 billion per year as a result of implementing early warning systems.

Table E.6. Estimated benefits from avoided asset losses because of implementation of early warning systems (US$ millions)

Developing country income group	*GDP*	*Potential total (European-like) benefits*		*Assumed ratio of current vs. potential benefits*	*Existing benefits*		*Potential benefits from improved services*	
		Lower bound (0.003% of GDP)	*Upper bound (0.017% of GDP*		*Lower bound*	*Upper bound*	*Lower bound*	*Upper bound*
Group 1: Low income	413 000	12	69	10%	1	7	11	62
Group 2: Lower-middle income	4 300 000	122	714	20%	24	143	97	572
Group 3: Upper-middle income	15 300 000	433	2 542	50%	217	1 271	217	1 271
Group 4: High income	43 000 000	1 217	7 145	100%	1 217	7 145	–	–
Total	63 013 000	1 748	10 470		1 459	8 565	324	1 904

Note: Totals may not sum because of rounding.
Source: Hallegatte (2012)

Lives saved

To estimate the number of lives that would be saved with improved early warning systems, Hallegatte first investigated the number of weather-related deaths that occur annually in Europe and developing countries. Based on data from the International Disaster Database developed by the Centre for Research on the Epidemiology of Disasters, weather-related extreme events killed an average of 43 000 people per year in developing countries between 1970 and 2011. The total population in developing countries in 2011 was approximately 5.7 billion; thus, the annual death probability associated with weather-related events was approximately 7.5 per million inhabitants. In developed countries, the death toll was 2 500 persons per year. With a total population in developed countries of approximately 1.1 billion, the annual death probability was approximately 2.2 per million inhabitants.

Hallegatte acknowledges that differences in housing and infrastructure quality, disaster protection and climate contribute to the much higher death probability rate in developing countries. However, he attributes much of the difference in death probability rates to the availability and effective use of early warning systems in Europe. We are unable to independently confirm whether access to early warning information explains the difference in risk or whether other factors also contribute. Citing the reduction in deaths resulting from the use of an early warning system in Bangladesh during Hurricane *Sidr* (as compared to previous hurricanes in the region, when no such system was in place), Hallegatte assumed that improving early warning and evacuation systems in developing countries to a level available in Europe would make the death probability decrease from 7.5 per million to 4 per million – a 46% reduction. This means that early warning systems would reduce human deaths associated with extreme events from 43 000 to 23 000 per year – saving 20 000 lives per year.

To assign a value to these estimates, Hallegatte applied the Copenhagen Consensus guidelines on the value of a human life (ranging from US$ 1 000 to US$ 5 000 per "disability-adjusted life year").[33] He assumed that each death from weather-related events was equivalent to 30 lost years to estimate that the annual value of avoided deaths would be US$ 600 million (assuming US$ 1 000 per life) to US$ 3 billion (assuming US$ 5 000 per life).

Note that this represents a lower-bound estimate, as most researchers have applied much higher estimates for the value of human life. For example, a report on the transportation sector in France estimated € 1 million per life (République Francaise, 2005). Viscusi and Aldy conducted a comprehensive review and evaluation of studies conducted throughout the world on the estimated VSL. They found VSL estimates for United States labour market studies to be in the range US$ 4 million to US$ 9 million. In developing countries, VSL estimates ranged from US$ 750 000 in the Republic of Korea to US$ 4.1 million in India (Viscusi and Aldy, 2003). For more information on VSL estimates, see Chapter 7 (benefits).

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[33] The disability-adjusted life year measures one lost year of a "healthy" life.

Economic benefits from met/hydro information (excluding benefits from early warning systems)

Improving met/hydro services will not only allow for better early warning systems; these services can also produce economic benefits in the form of useful services for industries, businesses, households and individuals when no weather-related emergencies occur. For example, weather forecasts are used to plan in the agricultural sector (for example, to decide when to plant or apply fertilizer), anticipate electricity demand, optimize air traffic and ship routes, plan road salting and achieve many other purposes in various sectors.

Based on existing literature, Hallegatte estimated that weather forecasts led to value-added gains of between 0.1% and 1.0% in weather-sensitive sectors, amounting to between 0.025% and 0.25% of GDP. Hallegatte considered this to be a lower-bound estimate because evidence from the literature suggests much higher values are possible. For example, a World Bank study of met/hydro services in south-eastern Europe found the economic benefits from met/hydro services ranged from 0.09% in Croatia to 0.35% in the Republic of Moldova. In addition, Hallegatte's estimate did not include values for households.

Based on the 0.025%–0.25% estimate, the value of weather forecast information in Europe was between € 3.4 billion and € 34 billion per year. Table E.7 shows how Hallegatte generalized these estimates to developing countries. As shown in the table, he estimated that the economic benefits associated with met/hydro information used during normal conditions could vary from US$ 3 billion to US$ 30 billion per year.

Table E.7. Potential economic benefits from improved met/hydro services, excluding benefits from early warning systems (US$ millions)

Developing country income group	*GDP*	*Potential benefits (European-like)*		*Assumed ratio of current vs. potential benefits*	*Estimate of existing benefits*		*Estimate of benefits from improved services*	
		Lower bound (0.025% of GDP)	*Upper bound (0.25% of GDP)*		*Lower bound*	*Upper bound*	*Lower bound*	*Upper bound*
Group 1: Low income	413 000	103	1 033	10%	10	103	93	929
Group 2: Lower-middle income	4 300 000	1 075	10 750	20%	215	2 150	860	8 600
Group 3: Upper-middle income	15 300 000	3 825	38 250	50%	1 913	19 125	1 913	19 125
Group 4: High income	43 000 000	10 750	107 500	100%	10 750	107 500	–	–
Total	63 013 000	15 753	157 533		12 888	128 878	2 865	28 654

Note: Totals may not sum because of rounding.
Source: Hallegatte (2012)

Estimated costs of upgrading met/hydro information production and early warning capacity

Improving met/hydro services and early warning systems in developing countries would entail costs associated with developing local observation systems; increasing local forecast capacity, capacity to interpret forecasts and capacity to translate them into warnings; developing communication tools to distribute and disseminate information, data and warnings; increasing institutional capacity; and ensuring that users make decisions based on the information available.

Hallegatte points out that it will not be necessary for developing countries to develop the most expensive components of early warning systems and met/hydro information (for example, Earth observation satellites and global weather forecasts) because the international met/hydro community has already built these systems.

Based on information available for several developed countries, Hallegatte estimated the cost, including maintenance and operational costs, of providing appropriate early warning systems in developing countries to be approximately US$ 50 million per country over a five-year period.[34] This would be equal to about US$ 2 billion over five years for all developing countries, for an annual cost of US$ 800 million per year for all developing countries. He further estimated that the cost to invest in NMHS capacity-building and development of skills would be about US$ 200 million per year. Thus, the total cost of providing services across all developing countries would be approximately US$ 1 billion per year.

E.5.3 Findings/results

The study estimated that in Europe met/hydro information and early warning systems save several hundred people's lives per year, avoid between € 460 million and € 2.7 billion of disaster asset losses per year and produce between € 3.4 billion and € 34 billion in additional benefits per year through the optimization of economic production in weather-sensitive sectors. The potential benefits from upgrading the met/hydro information production and early warning capacity in all developing countries to developed-country standards would include:

– US$ 300 million to US$ 2 billion per year of avoided asset losses caused by natural disasters;

– An average of 20 000 people's lives saved per year, valued at between US$ 700 million and US$ 3.5 billion per year using the Copenhagen Consensus guidelines;

– US$ 3 billion to US$ 30 billion per year of additional economic benefits.

[34] The author acknowledges that costs will vary considerably by country depending on local scientific capacity, including the existence of university and research programmes, local infrastructure and transportation capacity, the size of the country, how information is communicated, people's level of trust in the local forecast producers, and other factors.

Based on this analysis, the total benefits to developing countries would be between US$ 4 billion and US$ 36 billion per year. This can be compared to costs of around US$ 1 billion per year, giving a BCR of between 4 and 36.

E.5.4 Outcomes and recommendations for tailoring methods to NMHS circumstances

Hallegatte's analysis identified a large potential for investments by developing countries in met/hydro services and early warning and evacuation systems to reduce human and economic losses from natural disasters. The research also estimated the value of other SEBs that could accrue from met/hydro services during times when the weather is not severe.

When reviewing this study, we noted some considerations for reflection:

- The author's assumptions were not always based on existing data or analyses. For example, the author applied a 46% reduction in lives lost during weather-related events to estimate the number of lives that would be saved by improving early warning systems in developing countries. This number seems arbitrary, but does provide a benchmark with which to evaluate potential benefits. This number could be higher or lower, depending on the frequency and type of events that developing countries experience;

- Some of the methods the author employed were inconsistent. For example, the author used country groups to assess avoided asset losses; however, he does not apply this approach to estimate the costs associated with met/hydro improvements;

- The study methodology did not seem to consider the difference between the type, frequency and severity of extreme events in Europe and developing countries. However, the author did acknowledge the importance of these factors;

- As the author noted, this study did not account for the increase in people's lives saved or the avoided asset losses that would likely occur with population and economic growth.

Despite these concerns, this research provides rough valuations of met/hydro services – valuations that could be used to help developing countries make an initial case for increasing investment in early warning systems and other met/hydro services. Hallegatte conducted this analysis at a global scale, using simple assumptions that provide orders of magnitude rather than project-scale valuations. Because of these simplified assumptions, we would suggest that NMHSs interested in applying this approach first incorporate local and context-specific analyses before making real investments. For example, the World Bank used Hallegatte's findings in a loan appraisal for a met/hydro project in Nepal. World Bank personnel employed a benefit-transfer approach to evaluate the benefits of avoided asset losses plus economic benefits by applying Hallegatte's methodology, making adjustments for observed weather-related mortality and sector sizes in the country. They then compared these benefits to project costs. The World Bank's analysis required approximately two days to complete. The World Bank has also applied Hallegatte's methodology in BCA studies in Ethiopia, Nigeria and Yemen.

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E.6 CASE STUDY 5: USING CROP MODELS AND DECISION ANALYSIS TO ASSESS THE POTENTIAL VALUE OF GLOBAL CIRCULATION MODEL-BASED SEASONAL RAINFALL FORECASTS FOR CROP MANAGEMENT IN KENYA

E.6.1 Introduction and background

Many studies have paired crop growth models with economic decision models to assess the value of forecast information at the farm level. These studies have generally shown that advance information in the form of seasonal climate forecasts has the potential to improve on-farm management, leading to at least modest and sometimes substantial increases in expected farm profits.

This case study describes academic research that used crop growth and decision models to assess the potential value of downscaled GCM-based seasonal rainfall forecasts for farmers located in two areas of semi-arid Kenya. Specifically, the authors evaluated how maize planting and fertilizer management decisions made in response to seasonal forecasts can result in increased farm revenues compared to a no-forecast scenario in which farmers rely on historical climate information.

The study considered two locations in Kenya's semi-arid Eastern Province: the National Dryland Farming Research Centre at Katumani, in the Machakos District; and Makindu, in the Makuene District. Maize production in this region strongly depends on rainfall that occurs during the October through December "short rains" season. Maize production is risky in this semi-arid environment partly because of its sensitivity to year-to-year variability in the amount and timing of rainfall (Hansen et al., 2009). Thus, farmers could potentially realize substantial gains with the use of improved forecast information.

A team led by the International Research Institute for Climate and Society at Columbia University conducted this research to gain a better understanding of (a) the potential value of feasible seasonal forecasts in a context characterized by high-risk smallholder agriculture and relatively high predictability, and (b) the potential use and value of seasonal forecasts downscaled from a GCM.[35]

E.6.2 Methods used

This section provides an overview of the basic methodology the authors used. The study itself contains a much more comprehensive description of these different methodology components, as well as the methods used to develop the GCM forecast scenarios.

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[35] Hansen et al. (2009) includes detailed information on the downscaled GCM data.

Decision framework

To derive benefit estimates, the authors compared the expected outcome of optimal decisions made in response to seasonal rainfall forecasts to the expected outcome of optimal decisions made based on previous climate information (the climatological distribution, in this case), such that the value of the rainfall forecast system, V_f, is equal to:

$$\underbrace{n^{-1}\sum_{i=1}^{n}\left(P_T y(\mathbf{x}^* \mid F_i;\theta_i,\mathbf{e}_T) - c_{\mathrm{x}^*\mid F_i}\right)}_{\text{Expected outcome with use of seasonal forecasts}} - \underbrace{n^{-1}\sum_{i=1}^{n}\left(P_T y(\mathbf{x}^* \mid \Theta;\theta_i,\mathbf{e}_T) - c_{\mathrm{x}^*\mid\Theta}\right)}_{\text{Expected outcome based on historical climate information}}$$

Where:

- $P =$ crop price
- $y =$ crop yield
- $\mathbf{x}^* =$ vector of crop management strategies that maximize expected return
- $C_{\mathrm{x}^*} =$ cost of production associated with management strategies x^*
- $F_i =$ the seasonal rainfall forecast in year i
- $\Theta =$ the climatological distribution
- $\theta_i =$ observed weather in year i
- $T =$ the current year
- $n =$ the number of historic years sampled
- $\mathrm{e}_T =$ the current value of other environmental variables, limited in this case to initial soil moisture and nitrogen conditions (representative of soil fertility)

Thus, the value of the forecast is a function of (a) management variables that maximize expected gross revenues, (b) the cost of production associated with the management strategies, and (c) climate and environmental variables. For each year of weather data, crop yield was determined as a function of observed weather and management optimized for either the forecast or the climatological distribution. Within this framework, farmers derive value because forecasts are closer to the weather that actually occurs (when averaged among all years) than the climatological distribution. Thus, forecast-based management strategies are more optimal for actual weather.

Crop simulation and profit-maximizing management strategies

As a first step, the authors used the APSIMv4.2 crop model to simulate maize yield response to weather inputs and management strategies, including varying levels of stand density and nitrogen fertilizer application rate.[36] The model required the following inputs:

[36] Yield predictions from this model have been verified through several field experiments conducted in Kenya and other countries of sub-Saharan Africa.

- Daily weather data (minimum and maximum temperatures, precipitation and solar irradiance);
- Dates of planting;
- Local soil properties;
- Soil water content at the beginning of the season;
- Cultivar characteristics;
- Stand/plant density;
- Nitrogen fertilizer inputs.

The authors used observed daily weather data over 34 years (1968 to 2002) from stations located within the Katumani and Makindu study areas. They determined planting dates for each year of the simulation based on the first time that at least 25 millimetres of rain fell on two consecutive days within the fall planting window (October 15 to November 15). If this did not occur, the authors assumed planting took place on November 15. Local soil properties, initial soil water content and cultivar characteristics were held constant across the simulation years.

To identify optimal management, the authors considered four different stand densities and 11 fertilizer application rates. They then selected the combination of stand density and fertilizer application that resulted in the highest average gross margin under different climate conditions. The authors determined gross margins using agricultural enterprise budgets, which they developed based on local cost data for production inputs and market price data for maize.

Forecast scenarios

Next, the authors developed seasonal hindcasts, simulating what the forecast would have been for each year of the 34-year simulation period. The authors developed hindcasts for two different GCM-based forecast types that incorporated a common set of global sea-surface temperature (SST) boundary conditions:

- Observed SST seasonal forecast – a 24-member ensemble of GCM simulations driven by "observed" monthly global SSTs. This is not a true forecast prediction because it incorporates information that would not have been available until after the forecast date. The authors developed this hindcast to simulate the skill level of forecasts that are available today;
- Persisted SST seasonal forecast – a 12-member ensemble of GCM "predictions" derived by adding SST anomalies observed in August to long-term average global SSTs during the October through February forecast period.

The persisted SST forecast was used to represent the simplest possible SST forecast system and served as a lower limit in terms of GCM forecast skill for the study region. The observed SST forecast was used to represent the upper limit of operational predictability from a given GCM-based seasonal forecast system.

To assess the value of these forecasts, the authors used APSIM and crop enterprise budgets to determine the gross margins realized each year of the simulation period, based on (a) the optimal management strategies selected for the forecast, and (b) the actual observed weather. The authors compared the gross margins for the different forecast scenarios to those that would have been realized using a climatological approach. The authors also evaluated gross margins for a scenario in which the farmer had perfect knowledge of daily weather conditions. For each scenario, they evaluated optimal management strategies and gross margins with and without labour costs as a factor of production. Labour costs were estimated based on a 1989–1997 field experiment conducted at a local research station. The authors assumed that labour required for sowing is proportional to stand density associated with the different forecasts.

E.6.3 **Results and key findings**

The results of the APSIM analysis indicated that optimal fertilizer rate and stand density varied considerably in response to rainfall variability. In wet years, gross margins were best at a higher fertilizer rate and higher stand densities; in dry years, the authors found that the optimal fertilizer rate and stand density were much lower. This positive interaction between rainfall and optimum input levels suggests that farmers should adjust fertilizer and stand density jointly to exploit the greatest value from seasonal rainfall forecast information.

Table E.8 summarizes the estimated value of three forecast information scenarios: perfect knowledge of daily weather, GCM simulations run with observed SSTs, and

Table E.8. Predicted value of seasonal rainfall forecasts

	Value (K Sh per hectare per year)		*% of gross margin*	
	Katumani	*Makindu*	*Katumani*	*Makindu*
Including labour cost				
Perfect information	9 333	6 851	68.7	43.6
GCM, observed SSTs	3 277	1 383	24.1	8.8
GCM, persisted SSTs	-794	-1 289	-5.8	-8.2
No labour cost				
Perfect information	11 657	7 268	44.2	23.6
GCM, observed SSTs	4 295	734	16.3	2.4
GCM, persisted SSTs	31	-1 066	0.1	-3.5

Note: At the time of this study, K Sh 1 was equivalent to US$ 0.01319 and € 0.00997.

GCM forecasts run with persisted SSTs. As shown, the estimated value of perfect information represented 24%–69% of gross margin, depending on location and whether or not labour costs were considered. These results suggest that farmers would increase their average income from maize substantially if they could perfectly anticipate weather for the upcoming growing season.

As expected, the estimated value of seasonal predictions from the observed SST forecast was lower than the value of perfect information. However, the use of this forecast increased average gross margins by 24% at Katumani and by close to 10% at Makindu. At both sites, omitting the labour expenditure from the enterprise budget increased the average optimum planting density and fertilizer application in response to the observed SST forecast. This increased the yield enough to offset the increased cost of seed and fertilizer, and therefore increased the forecast value on an absolute basis at Katumani, but not at Makindu. The authors reported that forecasts based on the persisted SST forecast showed negative or near-zero value largely because they did not show significant positive prediction skill. However, the authors maintain that the persisted SST forecast likely under-represents the skill of seasonal rainfall forecasts currently available for the study region (see Hansen et al., 2009).

E.6.4 Outcomes and recommendations for tailoring methods to NMHS circumstances

As noted above, several studies have examined the potential value of seasonal forecasts for on-farm management using crop growth models and profit maximization principles. These studies range in complexity, but generally require significant expertise related to local agricultural production, crop growth and economic optimization models. Many NMHSs do not have this expertise in-house and may need to hire an outside consultant to perform this type of analysis.

Although these types of studies can be time and resource intensive, they can serve as important tools in helping NMHSs and in-country partners (for example, agricultural extension agencies and food security organizations) to identify management strategies that could result in the greatest benefits for farmers under different forecast scenarios. The results of such studies could be used by NMHSs to encourage farmers to use seasonal forecasts and adopt alternative strategies when warranted.

As Hansen et al. noted, a primary limitation of their study is that it focuses on the effect of only two management strategies, thereby ignoring many other determinants of forecast value. For example, the authors report that farmers who participated in two-day training workshops at each of the project locations in 2004 collectively identified a wide range of potential management responses related to: timing and method of land preparation, crop and cultivar selection, planting strategy, weeding, soil fertility management, pest management, area cultivated, terrace maintenance, labour procurement and allocation, fencing and cover for livestock, forage management, and grain and fodder storage. However, the available options differ substantially among farms, and particularly between commercial farms and smallholder farms; the latter tend to be more diversified and much more resource constrained. A more realistic and robust picture of the potential value of seasonal forecasts to farmers could be obtained from a farm-level analysis that represents the heterogeneity of farm types and includes additional management options.

As detailed in the main guidance chapters of this publication, studies that use decision analysis to assess the value of met/hydro services for an individual decisionmaker do not take into account the potential price effects associated with the widespread use of seasonal forecasts. For example, a single agricultural decisionmaker who begins using seasonal forecasts would have little impact on supply or demand within the local region. However, widespread adoption of seasonal forecasts may cause changes in total supply, which would have an impact on price in a competitive market. Price changes would impact both consumers and producers as the market settles at a new equilibrium.

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E.7 CASE STUDY 6: ASSESSING THE VALUE OF MET/HYDRO INFORMATION IN SWITZERLAND FOR THE AVIATION TRANSPORT SECTOR

E.7.1 Background

In 2009, MeteoSwiss commissioned a pilot study to evaluate the benefits of met/hydro services in Switzerland for different sectors of the economy. This study (Frei, 2010) was part of a larger goal to understand how weather-sensitive sectors use met/hydro services to make decisions, and to identify improvements in these services that would result in additional social and economic benefits. The objective of the pilot study was to provide initial, order-of-magnitude benefit valuations because at the time it was undertaken, very little was known about the value of met/hydro services in Switzerland.

The author of the 2010 study used a benefit-transfer approach to develop rough valuations of the economic benefits of met/hydro services for Swiss households and the agriculture and energy sectors. Results indicated that the benefits from met/hydro services (excluding long-term climate services) in Switzerland amount to hundreds of millions of Swiss francs, with a probable BCR of 5 to 1. This estimate does not include benefits for key economic sectors that were not evaluated as part of the study, such as insurance, telecommunications, tourism, transport and logistics.

Based on the findings of this analysis, MeteoSwiss agreed that more detailed, sector-level analyses were necessary to gain a better understanding of the value of met/hydro services within the Swiss context and to indicate how met/hydro services could be improved to maximize social and economic gains. Towards that end, Frei and colleagues Stefan von Grünigen and Saskia Willemse conducted two additional studies, focusing on the economic value of met/hydro services for the road and aviation transport sectors (Frei et al., 2014, and von Grünigen et al., 2014, respectively).

Case study 6 focuses on the aviation transport study (von Grünigen et al., 2014), which applies a simple decision model to analyse the economic benefits of using TAFs for Switzerland's domestic airlines at Zurich airport.

E.7.2 Methods used

Von Grünigen et al. used a decision model to evaluate the benefits of TAFs in terms of avoided costs for Switzerland's domestic airlines at Zurich airport. The following describes the decision model and data that the authors used to quantify this benefit.

Decision framework

In weather-sensitive sectors, met/hydro information serves as an important input into decisionmaking and production processes. Thus, the use of met/hydro forecasts results in better-informed decisions relative to a scenario in which decisionmakers do not use forecast information or rely only on climate data. This generally leads to increased economic gains through lower production costs and/or improvements in the quality or quantity of output. We can therefore evaluate the economic benefits of met/hydro services by comparing the outcomes that occur when decisionmakers use met/hydro services to the outcomes that occur when they do not.

Applying this theory to the aviation sector in Switzerland, von Grünigen et al. developed a decisionmaking model to analyse how the use of TAFs can reduce fuel and flight deviation costs for airlines. The model assumes that an airline's decision to carry additional fuel on a particular flight is based on forecast weather conditions. If adverse weather conditions are expected at the destination airport, pilots and flight dispatchers carry an additional fuel reserve to better deal with weather-related flight time extensions. Without this additional fuel reserve, there is an increased risk that a flight will have to deviate and land at an alternative airport. Flight deviations lead to additional passenger compensation, transfer, landing fee, fuel and reputation costs, among others. Thus, additional fuel serves as insurance against the risk of costs from avoidable deviations. The price of this insurance is equal to the price of the fuel burned to carry the additional fuel. In other words, airlines face a trade-off between the insurance fee (that is, the cost of carrying additional fuel) and the downside risk (that is, the cost of deviation).

Decision model

Whether or not an aeroplane can land at its destination airport depends on (a) actual weather conditions at the destination, and (b) the decision to carry extra fuel.

For this study, the authors considered two different weather conditions: "good" and "adverse". The decision model assumes that if the weather is good, landing is always possible. During adverse weather conditions, landing is possible with probability p if extra fuel was carried and with probability q without the extra fuel. Hence, a deviation to another airport occurs with probability $1 - p$ if extra fuel was carried and with probability $1 - q$ without extra fuel. Figure E.1 provides an illustration of this decision process.

The authors modelled the decision process under two scenarios: one in which airlines use TAFs to make decisions and one in which they do not. They then compared the expected costs associated with each scenario, as described below, to obtain the economic benefits of TAFs.

For the airlines, cost components include the cost of deviation (D) if the flight cannot land and the cost of insurance (I) if the airline carries additional fuel. To obtain expected costs associated with the use of TAFs, the authors defined a specific cost variable for each combination of forecast and actual weather, as shown in Table E.9.

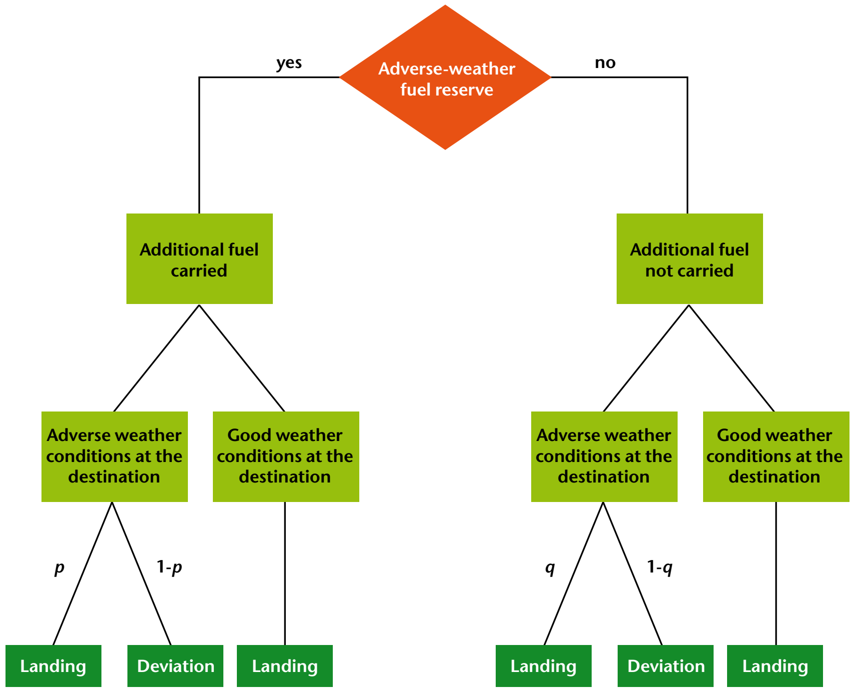

Figure E.1. Decision paths implemented in the model

Source: Von Grünigen et al. (2014)

For example, $C2$ represents the costs that airlines incur when adverse weather conditions are forecast but the actual weather is good; $C2$ is equal to insurance costs I since in this case the airline would have decided to carry additional fuel based on the adverse forecast and it would not incur deviation costs. Costs $C1$ and L are calculated based on insurance costs I, deviation costs D, and probabilities p and q (see Figure E.2), as follows:

$$C1 = C2 + [(1 - p) \times D]$$

Thus, the costs that airlines incur when adverse conditions are forecast and adverse conditions actually occur ($C1$) are equal to the cost of carrying additional fuel ($C2$), plus the probability of deviation when additional fuel is carried ($1 - p$) multiplied by the cost of deviation (D).

Table E.9. Costs incurred for different combinations of forecast and actual weather

		Forecast weather conditions	
		Adverse	*Good*
Actual weather conditions	Adverse	$C1$	L
	Good	$C2$	0

Source: Von Grünigen et al. (2014)

Table E.10. Relative frequency of forecast and actual weather conditions

		Forecast weather conditions		
		Adverse	*Good*	*No forecast*
Actual weather conditions	Adverse	*F11*	*F21*	*F01*
	Good	*F12*	*F22*	*F02*

The costs that airlines incur when good conditions are forecast but adverse conditions actually occur (L) are equal to the probability of deviation when additional fuel is not carried ($1 - q$) multiplied by the cost of deviation (D):

$$L = [(1 - q) \times D]$$

To calculate costs that airlines incur with the use of TAFs, the authors had to determine the frequency with which forecast conditions accurately predicted the actual weather conditions. For the no-forecast scenario, the authors had to determine the percentage of time that the actual weather was considered "adverse" and the percentage of time that it was considered "good". These frequencies are represented in Table E.10.

The expected costs associated with the use of TAF forecasts (EC_T) are then calculated by the cross-multiplication of Tables E.9 and E.10, as follows:

$$EC_T = F11C1 + F12C2 + F21L$$

In most cases, airlines have to carry enough fuel to reach one alternative destination airport (for example, Basel or Geneva when flying to Zurich) in case of an emergency. When TAFs are not used, regulations require airlines to carry enough additional fuel to reach two alternative airports instead of one. This additional cost (A) is considered in the calculation of the expected costs associated with not using TAFs ($EC_N T$), as follows:

$$EC_{NT} = F01C1 + F02C2 + A$$

Based on these calculations, the authors were able to calculate the economic value (EV) of the TAFs, as follows:

$$EV = EC_{NT} - EC_T$$

Data

To estimate EV, the authors input economic, aeronautical and meteorological data into the model described above. They obtained economic and aeronautical data from two different domestic airlines, a network carrier and a point-to-point carrier, and Zurich airport. Meteorological data were provided by MeteoSwiss.

The airlines provided estimates of aeroplane-based cost components, fuel prices and the probabilities p and q, while Zurich airport provided detailed information about flight plans and landing frequencies. Based on this information, the authors classified flights into categories by flight duration. For each category, the authors defined a typical aeroplane and assigned costs accordingly.

The authors used TAF verification data for the period April 2008 to March 2010. This verification is based on the comparison of the forecast and the actual meteorological parameters of visibility, cloud base, wind speed and direction, as well as the present weather. The authors used visibility to determine the two weather situations needed for the model. They defined weather conditions as “good” when visibility was greater than or equal to 5 000 metres, and “adverse” when visibility was less than 5 000 metres. The authors used visibility as their leading parameter because various weather conditions affect visibility, and the forecast quality for visibility is worse than for other parameters, which prevents the overestimation of the economic benefits connected with the use of TAFs. Additionally, there are clear rules concerning visibility and airport operations (time between landings, closure of runways, and the like), whereas the same cannot be said for the other available parameters. Based on the verification of the TAF forecasts between April 2008 and March 2010, the authors calculated the relative frequencies of the forecast and actual weather conditions.

E.7.3 **Key findings and results**

This paper demonstrates that the use of TAFs at Zurich airport generates significant economic benefits for domestic airlines. Results of the analysis indicate that the economic benefits of TAFs amount to between SwF 73 and SwF 1 780 (US$ 78–US$ 1 906)[37] per landing, depending on the duration of the flight. In 2009, there were roughly 110 000 landings registered at Zurich airport, of which 60% were generated by domestic airlines. Together, the two airlines included in this study generated more than 95% of all the landings by domestic airlines. Thus, the authors estimated the overall economic benefits of TAFs to Switzerland’s domestic airlines at Zurich airport by adding the benefits of the landings by the two airlines and extrapolating average benefits per landing to the other 5% of landings. Based on this methodology, the authors evaluated the total economic benefits of TAFs at approximately SwF 14 million (US$ 15 million) per year. The authors did not report the costs associated with installing and using TAFs.

These results are based on costs estimated by the airlines involved in the study. To take into account the uncertainty in these calculations, the authors evaluated total benefits based on benefit-maximizing and benefit-minimizing estimates provided by the airlines (see von Grünigen et al. (2014) for more information on these scenarios). These calculations yield a range of values for the economic benefits to domestic airlines at Zurich airport of between SwF 11 million and SwF 17 million (US$ 12 million–US$ 18 million) per year.

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[37] Exchange rate used in the report.

The authors extrapolated these results to Geneva airport based on the average benefit per flight to estimate the total economic benefits of TAFs to Switzerland's domestic airlines at the two main airports. This analysis indicates that total economic benefits of TAFs amount to between SwF 13 million and SwF 21 million (US$ 14 million–US$ 22 million) per year. However, this valuation does not account for the different economic and aeronautical conditions at Geneva airport. In addition, all results are very sensitive to changing fuel prices, as the authors found fuel to be the most important cost factor within the context of this study.

E.7.4 Tailoring the study to NMHS circumstances

This study was performed by a consultant, in coordination with MeteoSwiss, over a period of about nine months. The cost of the study amounted to approximately SwF 91 000 (US$ 100 000). This included interviews with airline representatives to help develop the decision model and provide important inputs. The decision model employed is relatively simple, and could potentially be completed in-house with the adequate expertise and resources.

In the authors' view, one main lesson from their work can be useful for similar studies: companies know quite well where and why they use meteorological information; however, they often cannot easily quantify the benefits related to that use. Thus, NMHSs should not rely on surveys or interviews to learn about the monetary benefits of meteorological information. Instead, they should conduct explorative interviews to understand the decisionmaking process within the companies. Then, based on that knowledge, the agencies should build, validate and use a decisionmaking model to evaluate the monetary benefits.

Interviews with airline managers and flight dispatchers conducted as part of a broader study (Bade et al., 2011) on the economic benefits of meteorological services in the Swiss transport sector confirmed this observation. According to von Grünigen et al., the interviews showed that meteorological information is very important for the safety and profitability of the aviation industry. However, in most cases, interviewees could not separate the contribution of meteorological information to safety and profitability from other contributions (for example, organizational measures).

In the current context, the use of a decisionmaking model to analyse the economic benefits of TAFs enabled the authors to draw, ceteris paribus (that is, all else equal), conclusions concerning the influence of TAFs on the profitability of airlines. This simple model provides (at minimum) order-of-magnitude estimates for the economic benefits that can be expected from the use of met/hydro services.

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E.8 CASE STUDY 7: EVALUATING THE AVOIDED COSTS OF THE FINNISH METEOROLOGICAL INSTITUTE'S MET/HYDRO SERVICES

Case study 7 highlights an economic assessment prepared by VTT to evaluate the benefits of the met/hydro services of FMI (published as part of Hautala and Leviäkangas (2007) and Leviäkangas and Hautala (2009)).

E.8.1 Background

The Finnish Meteorological Institute was one of the first NMHSs in Europe to conduct an economic valuation of its services. The institute initiated this effort in 2006, even ahead of the Madrid Action Plan, as well as impending service model changes associated with the European Union's INSPIRE directive. The institute's goal for this study was to determine the value that met/hydro services generate per euro of FMI budget.

At the time that FMI initiated its analysis, VTT was in the midst of developing EVASERVE (www.EVASERVE.fi), a set of evaluation tools designed to support the development and implementation of different types of information services in Finland. The Technical Research Centre launched EVASERVE in 2006 because it believed that information services had not penetrated the market to the extent possible with modern information and communication technologies.

Leveraging resources from both agencies, FMI and VTT worked together to integrate the economic assessment of FMI services into the EVASERVE project – FMI reported that partnering with VTT helped ensure a reasonable degree of independence for the assessment, thereby raising the credibility of the results. Staff members from VTT, Raine Hautala and Pekka Leviäkangas, served as the lead analysts and lead authors for the assessment.

Following the EVASERVE framework, the authors focused on developing monetized benefit valuations for various sectors and user groups. Specifically, the economic assessment evaluated the impacts and benefits of FMI met/hydro services for transportation, construction and facilities management, logistics, energy, and agricultural production. For most sectors, the authors' assessment provides initial, order-of-magnitude estimates. The Finnish Meteorological Institute continues to develop more in-depth benefit assessments to help evaluate specific weather service products. For example, for road transport and rail services additional valuations have been made (Nurmi et al., 2012; Nurmi et al., 2013).

The study was conducted in 2006 and 2007 and lasted approximately 12 months. Besides the two above-mentioned senior researchers, nine other VTT researchers contributed. The Finnish Meteorological Institute steering group had eight members, mainly senior managers, including the Director-General of FMI at that time. Fifty-two persons were interviewed, of whom five experts of FMI. Two FMI experts contributed to the main VTT report. The overall work effort for FMI amounted to approximately 2.5 person months. Several FMI experts indicated that in the year after completion of the study some working days were also used for dissemination activities, for example, visiting sister organizations abroad. The work effort of VTT was embedded in the EVASERVE programme and therefore the specific effort for the evaluation of the services of FMI is hard to obtain in retrospect, but was probably between 15 and 20 person months. It should be realized that the socioeconomic impact evaluation (as it was called) of the FMI services at the time was the first of its kind for VTT. The programme EVASERVE was mainly funded by the Finnish Funding Agency for Innovation, although other stakeholders, such as FMI, did contribute with moderate amounts.

E.8.2 Methods

This section describes the general methods that the authors used to assess the benefits of FMI services, including an overview of the assessment framework, input data and valuation methods.

Assessment framework

The authors applied a general framework to evaluate the benefits of met/hydro services within each sector (Figure E.2). First, they identified "impact mechanisms" associated with different met/hydro services. Impact mechanisms represent decisions or behaviour that can be altered in response to met/hydro information. For example, in the road transportation sector, drivers may decide to stay at home or avoid specific areas in response to information on adverse weather and road conditions. In this case, driver behaviour is the impact mechanism.

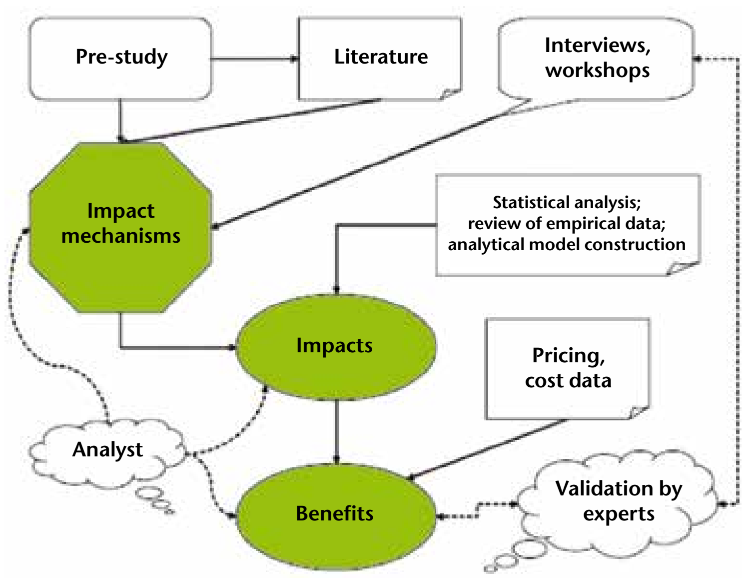

Figure E.2. Valuation process, repeated for each sector

Source: Leviäkangas and Hautala (2009)

Second, the authors identified and quantified the actual impacts (often referred to as outcomes) resulting from changes in the identified decisions or behaviour. Following the example above, changes in driver behaviour in response to relevant weather information would likely reduce the number and severity of accidents on the roadway. This reduction would represent the impact of the weather information.

Finally, when feasible, the authors attached unit prices to the identified impacts to obtain benefit estimates in terms of avoided costs. For the road transportation example, the authors evaluated benefits based on the avoided costs associated with the reduction in the number and severity of car accidents.

The authors then applied this framework to evaluate the impacts and benefits of (a) current FMI services, and (b) services that deliver perfect information.

To assess the value of current services, the authors used data and interviews to determine the current level of use of met/hydro services, how individuals and organizations change their decisions in response to this information, and how this benefits the decisionmaker, or others. The authors then evaluated FMI services under a perfect information scenario, where they assumed perfect forecast accuracy and that all potential users of met/hydro information had access to it, used it and adjusted their behaviour and decisions accordingly. The authors used the concept of perfect information so that FMI would have a reference point for the maximum benefits that could be achieved through the dissemination of met/hydro information.

As noted above, the authors evaluated the impacts and benefits of FMI met/hydro services only for Finland’s transportation, construction and facilities management, logistics, energy and agricultural sectors. However, many other economic sectors are likely also to benefit greatly from the FMI services. The authors excluded these sectors from the analysis because of lack of available data or difficulties in expressing benefits in monetary terms. In addition, VTT did not have the expertise or resources to conduct an exhaustive analysis. The authors assumed that the sectors included in the analysis represented the greatest beneficiaries of FMI services. However, this study is only a partial analysis of the total benefits of FMI services.

Input data and valuation methods

To determine the impacts and benefits of FMI services for each sector, the authors started with an extensive review of existing literature on the economic valuation of met/hydro services. With the exception of the agricultural sector, for which they relied on data from a previous study, the authors also conducted interviews with sector experts and FMI representatives.

When possible, the authors used available data, statistics and models to quantify the impacts associated with the use of met/hydro services in each sector. They relied on literature, interviews, market price data and other available information to assign monetary values to the quantified impacts. Box E.2 provides a brief description of the pricing regimes used in this valuation.

Box E.2: Unit costs used to obtain benefit valuations

Accident costs: To obtain benefit valuations in terms of avoided accident costs, the authors used official accident unit costs published by the Finnish Road Administration. These estimates include costs associated with personal injuries (including hospital and health-care costs and loss of production), loss of well-being and human suffering (based on Nordic studies of WTP) and material damages. The Finnish Road Administration and the Ministry of Transport and Communications update these unit costs on an annual basis. With the exception of material damages, the authors applied the same costs to the number of avoided accidents resulting from the use of met/hydro services whether in the road, rail, water or aviation transportation sectors.

Time costs: Met/hydro information can also reduce travel and transport time. To monetize this benefit, the authors applied standard values for time, as established by the Ministry of Transport and Communications for use in Finnish transport investment calculations. These values are based on (a) average salaries of transport operator personnel (for example, bus drivers, truck drivers, train engineers) and business travellers, as determined based on national labour statistics; and (b) time values for commuters and leisure travellers, based on WTP studies carried out in Nordic countries.

Cost savings in operations and other benefits: To evaluate operational cost savings associated with the use of met/hydro information, the authors primarily relied on interviews and the confidential statistics that interviewees provided. The authors conducted a total of 60 in-depth interviews with managers and experts from various fields. They used the cost information obtained in these interviews to evaluate costs for the whole of Finland. When the uncertainties of upscaling were too high, the authors did not use monetary estimates.

Information was provided by FMI on the costs of producing selected services. In addition, because FMI shares the Finnish meteorological information market with one other major met/hydro service provider, Foreca Ltd., the authors had to estimate the percentage of total benefits generated solely by FMI services. The authors determined this percentage based on the estimated market share of the two providers. Using information from interviews, customer data and the judgment of VTT experts, the authors estimated FMI's total market share to be approximately 70%. Thus, they assumed that FMI services generate 70% of the total benefits that result from the use of met/hydro services in Finland.

Because the authors used different methods and varying levels of analysis to evaluate impacts and benefits for different sectors, they consider some estimates to be more reliable than others. For example, to evaluate benefits for the road transportation sector, the authors used an existing impact model that applied standard methods and data. The authors and interviewees also had a comprehensive understanding of the use and benefits of met/hydro services in the transportation sector. The authors therefore considered the estimates for the sector to be fairly reliable. On the other hand, although the value of met/hydro information was explicitly recognized by railway managers, little data and few existing studies supported the benefit valuations for the rail transportation sector. Similarly, there were very little data on the use and value of met/hydro services in the logistics and supply-chain operations sector. The authors therefore analysed benefits for these sectors based on interviews and subjective scaling of impacts to the national level and considered the reliability of these valuations to be relatively weak.

Table E.11. Evaluated benefits of the Finnish Meteorological Institute's current services and the additional value of perfect information

Sector	*Impact*
Road transportation	Reduction in accidents, more efficient infrastructure maintenance
Pedestrians and cyclists	Reduction in slipping accidents, more efficient maintenance
Waterways and marine transportation	Reduction in accidents and environmental damage, more efficient operations, reduction in fuel consumption
Aviation	Reduction in accidents and emissions, more efficient operations, time savings for travellers
Rail transportation	Higher accuracy of train timetables, passenger and freight time savings
Logistics, supply chain	Higher predictability of deliveries, reduction in storage costs and risks
Construction, facilities management	Mould and mildew damage prevention, more-efficient maintenance
Energy production and distribution	Improved production capacity and availability predictions, reduced damage, prevention of production and distribution interruptions
Agriculture	Crop protection, pest control and damage reduction, improved harvest timing
Total	

Source: Leviäkangas and Hautala (2009)

E.8.3 **Results and key findings**

As shown in Table E.11, the authors evaluated the annual benefits of current FMI services for the selected sectors at between € 262 million and € 285 million (2006 euros) per year (between US$ 359 million and US$ 390 million).[38] The annual budget of FMI is between € 50 million and € 60 million (US$ 68.5 million to US$ 82.2 million). Thus, the annual BCR for existing services is at least 5 to 1, and potentially up to 10

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[38] Based on an average 2007 exchange rate of US$ 1.37 to € 1.

	Value of current FMI services (€ millions)	*Value of additional benefits with perfect information (€ millions)*
	Accidents: 9–18 Maintenance: 2	Accidents: 9–18 Maintenance: not calculated
	Slipping accidents: 113	Slipping accidents: 122–203
	Maintenance: not calculated Accidents: 14–28 Efforts to combat oil spills: 10 Rescue operations fuel savings: 1	Not calculated
	Accidents: 46 Fuel savings: 4 Airport maintenance: 3 Environmental damage: 1	4 total
	Time savings: 0.3	Time savings: 0.2
	Not calculated	5 total
	Construction: 10 Facilities management: 5	Construction: 10 Facilities management: 5
	Prevention of interruptions: 2 Production predictions: 3 Peat production: 5	Prevention of interruptions: 3–8 Production predictions: 5–15
	Increased crops: 12 Crop damage: 12 More efficient cultivation: 8 Other benefits: 2	3–15 total
	262–285	166–283

to 1. In the case of perfect information, the benefits of FMI services would increase by 65% to 100%.

For the road transportation sector, the authors evaluated the avoided costs associated with accident reduction to be from € 9 million to € 18 million per year and that perfect information would double these benefits. Furthermore, met/hydro services would generate another € 2 million in annual benefits in terms of avoided road maintenance costs. In the aviation, and waterways and marine transportation sectors, accident reduction benefits amounted to approximately € 14 million to € 46 million per year in avoided costs. The authors evaluated the total benefits of current met/hydro services at approximately € 34 million per year for agriculture. This figure included both avoided damage costs and improved productivity.

A somewhat surprising result of the study was that warnings about slipperiness for pedestrians and cyclists appear to be the single most beneficial service. The reduction in medical costs, lost working hours, avoided lifelong injuries and even lives saved was evaluated at € 113 million per year at the current level of services. A population accessing perfect information would avoid another € 120 million per year. These figures are somewhat uncertain because of attribution issues and the varying valuation basis of the avoided cost elements. However, even if the benefits for this sector were halved, the amount would still be significant. Furthermore, the result would still signal that the costs avoided for non-motorized transport modes are more significant than for motorized ones.

E.8.4 **Finnish Meteorological Institute outcomes**

According to FMI, the VTT valuation illustrated the potential to capture additional benefits by also improving the later stages of the value chain associated with FMI services. Following the study, FMI intensified its engagement with the media and various user groups, conducting surveys at intervals of two to three years. This engagement has resulted in a steady flow of improvements and innovations in weather and climate services, both in the public and commercial domains. In addition, FMI has also developed new services for the public sector (for example, emergency services) in cooperation with other public agencies and ministries.

Finally, after this study was completed, FMI also established a research group to assess the societal impacts of climate change and climate adaptation, as well as economic valuation of weather and climate services. Economists from this group have assessed SEBs of selected services for some sectors. Efforts have also been increased by FMI to develop a large database with joint observations of impacts and weather or climate conditions by time period and area. Such databases enable more thorough economic valuations of impacts and impact reduction attributable to weather services. More recently, the group is elaborating on the notion that assessment of the effectiveness of improved weather services can also apply to climate change adaptation studies (Perrels et al., 2013; Pilli-Sihvola et al., forthcoming). Studies by this group reaffirm the significance of monitoring and improving all stages of the value chain (Nurmi et al., 2013).

E.8.5 **Tailoring analysis to NMHS circumstances**

The study we have summarized has provided order-of-magnitude valuations for the benefits of met/hydro services in terms of avoided costs for Finland’s transportation, construction management, facilities management, energy and agriculture sectors. The assessment framework provided a straightforward process that NMHSs can use to evaluate the benefits of met/hydro services within the context of the met/hydro services value chain.

To complete the study, the authors made a number of assumptions regarding the use and impacts of met/hydro services across sectors. The reliability of valuations such as these depends largely on the availability of impact models and relevant data, as well as the knowledge and understanding of the use and value of met/hydro services by the experts that contributed to the study.

Furthermore, this study excluded several economic sectors that would likely benefit greatly from the services of FMI because of lack of available data, expertise and resources. The authors assumed that the sectors included in the analysis represent the greatest beneficiaries of FMI services. However, the study primarily focused on transportation subsectors.

In addition, although the study accounted for priced weather services in particular sectors (that is, the authors subtracted these costs from the benefit estimates to obtain net benefits), it did not consider media costs associated with information acquisition and processing. The BCR for met/hydro services would be slightly lower if these costs were taken into account.

The authors also did not account for price effects associated with increased efficiency in relevant sectors. Finally, since the applied valuation methods involved both actual costs and WTP estimates, readers should consider some of the study's aggregate sums with caution and avoid making direct comparisons with GDP or the total public budget.

Despite these limitations, NMHSs can use this type of analysis to justify their budgets and to begin to understand the value chain for met/hydro services in different sectors. Such an effort can lead to more detailed valuations of specific services, serving as an important feedback tool in the development process.

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E.9 CASE STUDY 8: ECONOMIC BENEFITS OF IMPROVED MET/HYDRO SERVICES IN MOZAMBIQUE

This case study[39] highlights an economic analysis that was conducted as part of the Strategic Programme for Climate Resilience project for Mozambique to better understand the costs and benefits of improving met/hydro services in the country. This analysis included a three-pronged approach to benefit valuation: (a) a benefit-transfer approach, (b) an expert elicitation related to specific economic sectors, and (c) a stated-preference survey of the general public. This case study focuses primarily on the stated-preference survey of the general public.

E.9.1 Background

In recent years, Mozambique has been hit by several major flooding events. In 2000, 2001, 2007 and 2013, extreme weather and water events collectively resulted in over 1 200 deaths, displacement of 1.5 million people and destruction of US$ 1.5 billion in physical infrastructure. Most recently, extreme flooding hit Mozambique in the lower stretches of the Limpopo, Incomati and Zambezi river basins in January and February of 2013. Over 170 000 people were evacuated, 113 lives were lost, and 89 000 hectares of crops were destroyed. The spread of malaria and schistosomiasis increased with the rising, stagnant waters. The economic costs of the physical damages were estimated to be in the order of US$ 403 million.

The mandate for water and weather observation and forecasting is delegated to several agencies across two government ministries in Mozambique. In the Ministry of Public Works and Housing (Ministério das Obras Públicas e Habitação), the National Directorate of Water (Direcção Nacional de Águas) and the five Regional Water Authorities (Administrações Regionais de Águas) are responsible for hydrology. The Ministry for Transport and Communication (Ministério dos Transportes e Comunicações) delegates responsibility for meteorology to the National Institute for Meteorology (INAM – Instituto Nacional de Meteorologia).

Since the mid-1990s, the World Bank and other international partners have actively supported the water sector in Mozambique. Building on a programme of water sector support, the World Bank developed a Country Water Resources Assistance Strategy for Mozambique in 2009. This programme committed the Bank to identify financial resources for enhancing met/hydro data for the core operation of water resources planning, infrastructure development and transboundary cooperation with neighbouring countries.

The Country Water Resources Assistance Strategy for Mozambique spurred a number of activities and investments related to improving met/hydro services in the country. In 2011, Mozambique initiated a National Water Resources Development Programme,

[39] Development of this case study benefited significantly from materials provided by Louise Croneborg, one of the World Bank task team leads for this work. Any remaining errors are solely the responsibility of Jeff Lazo who was lead on the economic analysis. For more information on this study please see Lazo and Croneborg (forthcoming).

with the support of the World Bank's International Development Association, that included a dedicated project for strengthening the country's met/hydro services. That same year, the World Bank's Climate Investment Fund created a Strategic Programme for Climate Resilience for Mozambique, which established a pilot investment for met/hydro services. Following approval of the Strategic Programme for Climate Resilience, Mozambique's Council of Ministers endorsed a National Strategy for Climate Change in which they specified the need to strengthen the work of INAM, the Direcção Nacional de Águas and the Administrações Regionais de Águas as a key national priority. In 2013, the World Bank approved additional funding for the National Strategy for Climate Change for a dedicated project to improve met/hydro services within the country. This project is also financed by parallel financing from the Nordic Development Fund.

The objective of the economic analysis, which was funded by the World Bank, was to evaluate and quantify the assumption that improved met/hydro services will increase productivity in economic sectors, and to enhance resilience to water and weather-related hazards. The analysis evaluated met/hydro services in economic terms in order to improve dialogue and decisionmaking on policy, planning and budget allocation (as well as inform project design and implementation). Equally important, the analysis was intended to enable the responsible government agencies to evaluate their interventions, optimize the use of current resources and guide future research and investments.

E.9.2 **Methods**

The public benefits valuation comprised a multipart, in-person survey to (a) assess preferences for met/hydro services among Mozambican households, and (b) estimate household WTP for various services. To assess WTP, the survey included a CV-method question. The following sections describe the methods that Lazo used to develop and implement the survey, and also some of the key issues associated with the CV-method approach.

E.9.2.1 ***Survey methods – Development, sampling and implementation***

The survey was developed based on prior work using the CV approach primarily in the United States and a limited number of developing countries. Prior CV-method surveys implemented in other contexts in developing countries were also consulted specifically to address issues of income limitations, which can impact a respondent's stated WTP. A number of surveys on other topics implemented in Mozambique were also used to base questions specific to Mozambique. For the stated-choice portion of the survey, a set of weather forecast improvement attributes were defined and quantified based on a set of focus groups with INAM employees and through a stakeholders workshop held in Maputo. Once the survey was developed and translated into Portuguese a small number of in-person preliminary tests were conducted to identify potential survey issues. Based on these preliminary tests, the survey was revised prior to final implementation.

As the survey was conducted in person it was not possible to undertake a random sample national survey. Instead, the authors selected a limited number of sites for implementation, attempting to achieve a cross-section of the population based on a range of country characteristics: urban to be compared to rural areas; southern to be compared to central and northern areas; different weather and climate regimes. Some provinces were not sampled at all due to the sparse population, difficulty in getting to locations and (at the time of implementation) potential violence and political conflicts in certain areas. Future work should target some of these less accessible areas as they are also less likely to have access to weather, water and climate information.

The survey was conducted from 11 June to 18 June 2013. Data were collected either onto hard copy written survey instruments by the interviewer or using personal digital assistants data capture. In some areas a local public official accompanied the interviewer and assisted in translation if needed. The survey company did not record the number of contacts made in order to achieve the target sample size, and therefore response rates could not be computed. While interviewers did record interview start times, the company did not record completion time or time to complete. Verbal reports indicated that interviews lasted 30 minutes or more in general.

E.9.2.2 ***Contingent valuation method***

Given the public-good nature of weather forecasts, the economic value of most weather forecasting services is not directly observed in the market. It is therefore difficult to determine the economic value of changes to the services provide, although this is exactly what is required to undertake a BCA.

In stated-preference method studies such as the one described here, value is estimated using surveys in which a representative sample of the relevant population expresses a stated preference that can be directly or indirectly used to determine WTP for a good or service. The value obtained for the good or service is contingent on the nature of the constructed market described in the survey scenario. Stated-preference methods include the CV method and stated-choice methods, both of which were used in the study. Case study 8 focuses on the CV method aspect of the study. Use of a CV method refers to the hypothetical transaction framework in which subjects are directly asked to give information about their values for specific goods or services. Contingent valuation is often defined to include direct open-ended questions such as "How much would you be willing to pay for … ?".

Relative to information a respondent may already have about a commodity, CV studies need to define the commodity to be valued, including characteristics such as the timing of provision, certainty of provision and availability of substitutes and complements. For weather forecasts, it is likely that individuals already have considerable experience with and a reasonable understanding of such information. This reduces the cognitive burden of defining and explaining the commodity compared to other commodities (such as the effects of airborne acid deposition on cultural monuments).

Respondents must also be informed about the framework of the transaction, including the method and timing of payment, and they should be aware of their budget constraints. The context in which the hypothetical payment decision would take place is clearly defined to encourage respondents to answer based on their actual preferences, so individuals are able to identify their own best interests, and to minimize strategic behaviour. When these conditions are met, it is more likely that individuals' stated preferences will be consistent with economic measures of welfare change.

Several potential biases or confounding aspects of CV-method studies are generally addressed in survey design, implementation and analysis. Three that we discuss in this case study are (a) income constraints; (b) scenario rejection, and (c) altruistic motivations. Examining such potential biases or confounding issues helps the researcher have a better understanding of the true value of the commodity of interest – in this case the value of improved weather information.

E.9.2.3 ***Income constraints***

A significant concern in undertaking non-market valuation studies in developing countries is that many individuals have no monetary income, and thus asking WTP in monetary terms may not yield meaningful results regarding the value to a respondent. We attempted to address this issue by identifying respondents with a monetary constraint and factoring that into the analysis of responses. Of the respondents interviewed, 32.1% (185 of 576) indicated that they had no monetary income (another 4.7% refused to answer this question). Rather than imputing a wage based on value of labour or developing a wealth measure, we developed a variable "money constrained", where a zero means there is no difficulty in getting money and 12 means it is impossible for the individual to get money for these approaches. We feel this scale thus represents a measure of the individual's access to monetary activities, whether due to restricted income or by inability to access monetary transactions. Values on the scale ranged from no constraint (2.78% of respondents) to extreme constraint (6.60% of respondents).

E.9.2.4 ***Scenario rejection***

Potential scenario rejection has been a longstanding issue in the CV literature. If the individual does not understand or believe some aspect of the hypothetical scenario, she/he may not state a true value for the commodity. In general, it is suspected that individuals will state a zero WTP if they reject the scenario. It is also possible that individuals will understate their true value if they feel uncertain about the commodity or the likelihood of its provision. Some researchers suggest that a high number of zero bids in an open-ended or payment-card CV survey is evidence of potential scenario rejection. Because scenario rejection most likely cannot be eliminated from survey instruments, the most productive approach to dealing with scenario rejection is to identify potential scenario rejectors through debriefing questions or by examining responses to questions that would indicate that the individual does in fact have a positive value for the commodity.

In an effort to identify and account for potential scenario rejection, we include debriefing questions exploring individuals' motivations for their value statement. A factor analysis of these statements is used to generate a "rejection score" that is then included in regression analysis as an explanatory variable. Individuals with a high rejection score are expected to understate their true value or to state a zero value for the commodity. Not accounting for this potential bias could lead to significant underestimates of true WTP.

E.9.2.5 *Altruistic and bequest values*

A third issue we considered is whether individuals' motivation for stating their WTP for forecast improvements could be the value they place on their own use or the value potentially to others (altruistic values), or even to future generations (bequest values). Such values have been shown to play a significant role in the value of non-market environmental commodities (for example, clean air or species preservation) but we had no reason a priori to think such aspects would play a significant role for the value of weather information, which we feel is primarily for individual use.

E.9.2.6 *Payment card*

The survey was implemented using a payment-card approach where individuals are presented the hypothetical scenario and then asked to circle the number on the card indicating their maximum WTP for the programme (see Figure E.3). Two versions of the survey were implemented (respondents only saw one of the two versions). One version had a programme of intermediate improvements on all attributes and the second version had maximal improvements on all attributes. The payment card was then followed by debriefing questions regarding potential scenario rejection and potential altruistic or bequest motivations.

E.9.3 **Results**

At the time of writing we have not completed a comparison of sample sociodemographics to population sociodemographics but this should be undertaken to assess the ability to generalize to the population. The study found:

- A little less than half of respondents indicated they were single (48%); 45% are married or in a marital union and the remainder (7%) divorced or widowed;

- The average length of residence within 50 kilometres or current location is 14.5 years (median was 13 years);

- Only 9.9% of the respondents indicated being employed full-time; another 23.8% indicated part-time employment and 22.2% were unemployed; 13.9% were self-employed or business owners (this is not exclusive of full- or part-time employment);

Version: 1

WILLINGNESS TO PAY FOR IMPROVEMENT PROGRAMME

Rather than comparing programmes, we now want you to consider a single programme to improve weather forecasts as indicate by Programme I below.

	Current Accuracy of Forecasts	Programme Q
Cyclone warnings and advisories lead time	Current lead time 2 days	**Increase lead time to 3 days**
All other warnings and advisories lead time	Current lead time one day	**Increase lead time to 2 days**
Geographic detail	Three sections of country (south, central, north)	**Province level (10+Maputo City)**
Time period covered	Currently for entire day	**Information broken down between night and day**
Accuracy of high and low temperature forecasts	One day generally accurate ±2°C	**Extend to 2 days with same accuracy as current 1 day**
Accuracy of rainfall information	Correct 75% of the time	**Being correct 80% of the time**
Maritime information	Correct 70% of the time	**Being correct 80% of the time**
Reliability of seasonal forecasts	Reliable 65% of the time	**Being reliable 70% of the time**
Accuracy of flooding and water levels	Correct 70% of the time	**Being correct 80% of the time**

CVM1 **What is the maximum amount you would be willing to pay each year for this single programme to improve weather forecasts? Please circle the number below indicating the maximum annual amount your household would be willing to pay for this programme.**

MT 0 (I would pay nothing)	MT 15	MT 30	MT 60	MT 120
MT 240	MT 480	MT 720	MT 1,440	MT 2,160
MT 3,240	MT 5,400	MT 9,000 or more	Other (enter amount) ___________	

Note: MT = Mozambique meticais.

Figure E.3. Contingent valuation question and payment cards used in the study

– A little less than 19% were students, 24.3% were retired and 0.5% considered themselves homemakers.

A survey code book was developed that shows for each question the frequency of responses, mean, median, standard deviation, number of responses and number of missing responses. Initial visual examination of this information allows the researcher to develop a good "feeling" for the data as well as to check for any coding errors and assess the potential impact of missing data. This type of data quality assurance/quality control should be conducted with all survey data prior to analysis.

E.9.3.1 ***Data adjustments, missing values and fitted income estimation***

As is common practice in survey data analysis we selectively replaced a limited number of missing responses with either the mean or median values so that these observations were not lost in subsequent multivariable analysis. A set of dummy and recoded variables were created from questions with multiple categorical responses for purposes of subsequent data analysis. Specifically, these included dummy variables for each respondent to indicate: (a) whether they lived in an urban or rural area; (b) whether they lived in the south part of Mozambique or north-central areas; (c) if they were employed (full or part-time) or not; or (d) if they had any type of monetary income. Additional variables were adjusted for analysis including a question asking whether individuals had experienced any impact from weather or a weather event over the prior 10 years; their level of money constraint; education in years; and how long they had lived in the area where they currently lived. Additional sociodemographic information included gender, age, household size and income. As a significant portion of respondents did not report income levels (18.8% indicated "Don't know" and 17.9% refused the information) we used a linear regression analysis to generate fitted values of income for all individuals.

E.9.3.2 ***Results from "non-economic" portions of the public survey***

An important and valuable aspect of the survey work was the information collected on respondents' sources, understanding of, preferences for, and uses of weather, water and climate information. These data were collected in part to develop the context for the valuation portions of the survey as well as to generate useful data for the NMHS on the public's hydrometeorological information process. This portion of the survey elicited information on respondents':

– Experience with weather impacts;

– Concern with future weather events;

– Awareness of weather impacts and information;

– Source of weather information.

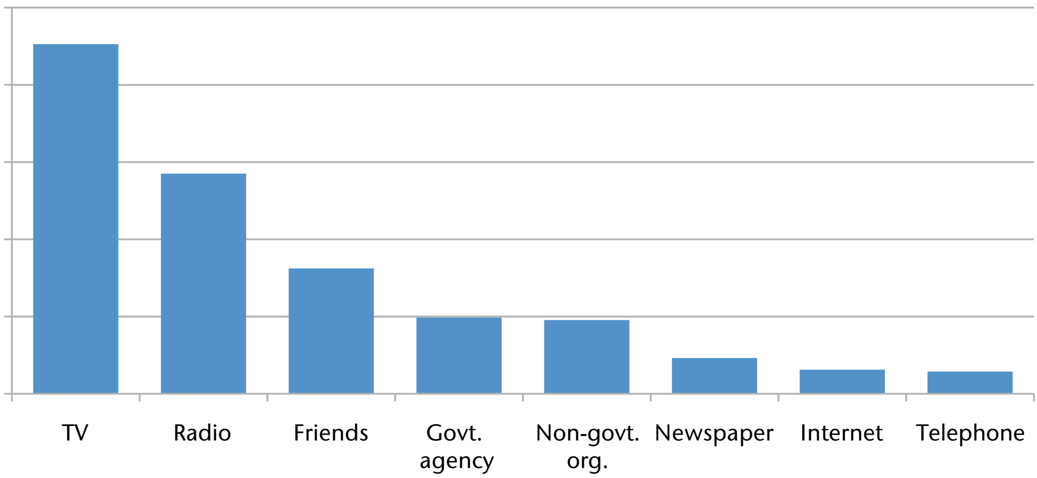

Figure E.4. Annual frequency of exposure to weather information sources (n = 576)

We cannot present results from this aspect of the work in detail, but provide an example of the type of information and analysis related to two questions from this "non-economic" portion of the survey – specifically questions on respondents' sources of weather information. We first provided a definition of what weather forecasts are, including information on water and climate conditions, to clarify the use of terminology throughout the remainder of the survey. Specifically we indicated that "Weather forecasts are predictions about future weather, water or climate conditions". Only 72 respondents (12.5%) overall indicated that they did not have access to weather forecasts through any means (such as television, radio, newspapers or friends). As may be expected, a statistically significantly higher portion did not have access in rural areas (17.5% in rural areas and 5.4% in urban areas).

We then asked what respondents' sources were for weather information and the frequency with which they used a number of potential communication channels (see Lazo et al. (2009) for results from a similar question asked in the United States). The question was phrased ("How often do you get, see or use weather forecasts from the sources listed below?") to determine all exposure to forecasts and not just how often they actively seek information. Response options ranged from "Never/rarely" to "Two or more times a day" for each of eight possible information channels. The responses were recoded into "times per year" using lower bound values so as to not overstate frequencies. For instance, "Two or more times a day" was recoded to 730 times per year.

Figure E.4 shows the average annual frequency by source (as recoded from verbal items indicating frequency). The average total frequency across all sources was slightly over 600 per year with a median of 365 (or once a day). This strongly suggests that weather information does play a role in day-to-day decisionmaking for average Mozambicans.

An analysis of differences between rural and urban areas showed that respondents in the rural areas accessed weather information approximately 60% more often than those in the urban areas in Mozambique (almost 770 times a year in the rural areas versus 480 in urban Mozambique). Those in rural areas were significantly more likely to access weather information by television, newspaper, telephone and Internet. We also examined differences in sources by respondents in the two "zones" (south and north-central Mozambique), finding that respondents in the south accessed weather information about 50% more often than those in the upper areas in Mozambique (almost 700 times a year in the south versus 463 in the rest of Mozambique). Those in the southern region were significantly more likely to access weather information by television, and via government and non-government agencies, whereas those in the north-central region were significantly less likely to access weather information by newspaper. Finally, a factor analysis on source frequency generated three factors: (a) "frequent sources" such as radio and television; (b) non-government organizations and government agencies; and (c) "infrequent sources" such as Internet, newspaper and telephone.

Table E.12. Attributes and levels for two versions of the contingent valuation-method question

	Current accuracy of forecasts	*Version 1*	*Version 2*
Cyclone warnings and advisories lead times	Current lead time 2 days	Increase lead time to 3 days	Increase lead time to 5 days
All other warnings and advisories lead times	Current lead time 1 day	Increase lead time to 2 days	Increase lead time to 4 days
Geographic detail	Three sections of country (south, central, north)	Province level (10 + Maputo City)	District level (128 districts)
Time period covered	Currently for entire day	Information broken down between night and day	Information broken into 3-hour increments
Accuracy of high- and low-temperature forecasts	1 day generally, accurate ±2°C	Extend to 2 days with same accuracy as current 1 day	Extend to 5 days with same accuracy as current 1 day
Accuracy of rainfall information	Correct 75% of the time	Being correct 80% of the time	Being correct 90% of the time
Maritime information	Correct 70% of the time	Being correct 80% of the time	Being correct 90% of the time
Reliability of seasonal forecasts	Reliable 65% of the time	Being reliable 70% of the time	Being reliable 80% of the time
Accuracy of flooding and water levels	Correct 70% of the time	Being correct 80% of the time	Being correct 90% of the time

Table E.13. Frequency of willingness-to-pay responses for two versions of the payment card (a single response that was entered as an open-ended verbal response was replaced with the median value of 30 meticais (MT))

What is the maximum amount you would be willing to pay each year for this single programme to improve weather forecasts? Please circle the number below indicating the maximum annual amount your household would be willing to pay for this programme.															
Version	MT 0	MT 15	MT 30	MT 60	MT 120	MT 240	MT 480	MT 720	MT 1 440	MT 2 160	MT 3 240	MT 5 400	MT 9 000	Other	n
V1	52	56	33	50	36	19	3	0	0	3	0	0	2	14	268
	19.4%	20.9%	12.3%	18.7%	13.4%	7.1%	1.1%	0.0%	0.0%	1.1%	0.0%	0.0%	0.7%	5.2%	
V2	63	73	41	37	39	22	4	2	0	0	1	0	0	26	308
	20.5%	23.7%	13.3%	12.0%	12.7%	7.1%	1.3%	0.6%	0.0%	0.0%	0.3%	0.0%	0.0%	8.4%	

E.9.3.3 ***Results from the payment card contingent valuation question***

As noted before we implemented a payment-card CV method using two versions of the survey with different levels of the attributes for programme improvements. Figure E.3 shows the payment-card question for version 1 of the survey. Table E.12 shows the attributes and levels from the two versions of the survey. Table E.13 shows the frequency distribution of WTP responses for the two versions of the survey as well as the total number of respondents who saw each version of the survey.

A regression was run on the stated WTP from the payment card to explore issues of monetary constraints, scenario rejection, and altruistic and bequest values. Table E.14 reports these results. In addition the regression examines other factors influencing stated WTP such as sociodemographic characteristics of the respondents and perceptions, uses and sources of weather information. Standardized regression coefficients are reported that are based on independent variables normalized so that their standard deviation is one. The reported coefficients thus indicate the relative influence of the different explanatory variables on the independent variable. The $Pr > |t|$ column reports the significance level of the parameter estimates. Values below 0.10 (or 10%) suggest that the parameters are significantly related to the stated WTP and thus have an influence on individuals' values for the improvements in weather forecasts. Variance inflation factors are also reported to examine potential colinearity between the independent variables. As all the variance inflation factors are less than three we conclude that colinearity is not a problem in this regression.

Urban, more highly educated, and higher-income respondents, those with positive motivations for improved forecasts (as measured by the variable CVM1_Valid_Positive), those with greater use values (as measured by the variable CVM2_Benefit_Me), and

Table E.14. Regression on payment card stated WTP (n = 576; adjusted R-square = 0.108)

Variable	*Standardized estimate*	*Pr > |t|*	*Variance inflation factor*
Intercept	0.00	0.75	0.00
Urban_Rural_Dummy	0.11	0.02	1.34
Zone_South_Dummy_Vbl	-0.01	0.80	1.44
Sociodemographics			
Age	-0.04	0.35	1.04
Education_Continuous	0.13	0.01	1.38
Gender_Male_Dummy_Vbl	0.00	0.95	1.06
Income_Continuous_Final	0.12	0.01	1.35
Monetary_Constraint	-0.01	0.85	1.30
Employed_Dummy	-0.03	0.52	1.12
Married_Dummy_Vbl	0.00	0.94	1.12
HH_Size	0.00	0.90	1.06
Length_of_residency	0.01	0.88	1.11
Forecast satisfaction and uses			
PartB_Q18_satis_fcst	0.03	0.46	1.13
PartB_Q10_freq_imm_area	0.00	0.94	1.26
Use_Total_Freq	0.05	0.29	1.47
Sources of forecast information – factor scores			
Sources_Factor1_Agencies	-0.09	0.03	1.19
Sources_Factor2_Infrequent_Sourc	0.02	0.72	1.19
Sources_Factor3_Frequent_Sources	-0.01	0.87	1.38
Concern about weather impacts – factor scores			
Wx_Concern_Factor1_Lower_Concern	-0.02	0.70	1.23
Wx_Concern_Factor1_Higher_Concer	0.07	0.14	1.25
Scenario rejection and response motivations			
CVM1_Rejection	-0.11	0.01	1.12
CVM1_Valid_Positive	0.07	0.10	1.17
CVM1_Factor3	0.02	0.71	1.90
Altruistic and bequest values			
CVM2_Benefit_Me	0.11	0.09	2.68
CVM2_Benefit_Family	-0.06	0.38	3.05
CVM2_Benefit_Future_Gen	0.11	0.06	2.28

those with greater bequest values (as measured by the variable CVM2_Benefit_Future_Gen) were willing to pay more for improved forecast information (as indicated by the positive and significant parameter estimates).

As expected, those who didn't reveal their true WTP due to some form of scenario rejections (as measured by CVM1_Rejection) stated a lower WTP. Not accounting for this potential bias would understate the public's true WTP for weather forecast improvements.

Interestingly, those who more frequently accessed forecasts provided by public agencies such as INAM or the Direcção Nacional de Águas (as measured by Sources_Factor1_Agencies) were willing to pay less for improved forecasts than others. This is a counter-intuitive result that should be investigated in further depth in future studies.

Using results from the regression analysis we estimated "fitted values" for each individual for the forecast improvement scenario they evaluated. Table E.15 shows summary statistics on these fitted values for the two levels of improvement. The mean and median values for the programmes are very similar (or even a little less for the programme with the larger improvements) which raises questions of "scope" with respect to results from this analysis. A "scope test" would normally require a larger value for the larger forecast improvement. Future analysis will evaluate potential scope issues in further depth.

E.9.4 **Communication of results and outcomes**

Preliminary results have been broadly presented in several professional venues including the American Meteorological Society meetings, the World Weather Open Science Conference, and the 2014 Weather Economics Association International meeting. At the time of writing the researchers are in the process of completing the analysis and reporting on this survey. A completion report will be submitted to the World Bank and made available to the relevant agencies in Mozambique. A project report will also be available on the University Corporation for Atmospheric Research open-access library system (https://opensky.library.ucar.edu/). The information, including the survey instrument, code books and report will be available to any interested parties for adaptation of the survey instrument and implementation and analysis methods to other contexts (for example, in other countries). Following further analysis, results will also be submitted to peer-reviewed publications for broader dissemination.

E.9.5 **Challenges and limitations**

Implementation of this study faced many challenges and limitations typically associated with less developed countries. Due to the low level of Internet use and limited phone or mail access, as well as time and resource constraints, the survey was implemented using a non-random sample. While the researchers feel the final sample was reasonably diverse and reached some vulnerable populations, it likely cannot be

Table E.15. Summary statistics on predicted maximum willingness to pay by version

Survey version	*No. observations*	*Mean*	*Std. dev.*	*Median*
CVM version 1	268	2.97	1.26	2.86
CVM version 2	308	2.87	1.27	2.84

generalized to the entire Mozambican population. Regardless of this limitation, the total value for improved forecasts that could be attributed to the sampled population is still likely to be significantly more than the World Bank programme cost and thus would satisfy basic benefit–cost criteria for programme valuation.

Another challenge in implementing the survey was the number of primary languages spoken in Mozambique. While Portuguese is the official language, a significant portion of the population speaks one of 43 or more other languages. It was not feasible to implement the survey in all potential languages and thus some populations may have been excluded due to language barriers.

With a significant portion of the Mozambican population being subsistence farmers in rural areas, the research also likely underrepresents that portion of the population in this analysis. Technically, from a strict benefit–cost perspective, subsistence farmers will have very low or non-existent WTP due to their severe or total income constraints. From a broader societal perspective, it is very important to represent their sources, uses, preferences and needs for weather, water and climate information. More work could focus on reaching these potentially more vulnerable populations in order to meet societal goals that transcend the standard benefit–cost economic framework.

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E.10 CASE STUDY 9: SOCIOECONOMIC EVALUATION OF IMPROVING MET/HYDRO SERVICES FOR BHUTAN

This summary[40] depicts the main features of the subproject Socio-Economic Study on Improved Hydro-Meteorological Services in the Kingdom of Bhutan, which was part of a project entitled Strengthening Hydro-Meteorological Services for Bhutan, funded by the Ministry for Foreign Affairs of Finland. The SEB study was carried out in 2013. The final approved report was published in February 2014 (Pilli-Sihvola et al., 2014).

The SEB study served three purposes:

(a) To provide a qualitative overview of the potential benefits of improved met/hydro services to Bhutan's economic sectors;

(b) To provide feedback to the Bhutanese Department of Hydro-Met Services (DHMS) on the needs of their current and potential future stakeholders and services;

(c) 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.

The study covers the effects of climate, weather forecast and early warning services. The study is forward looking, meaning that the assessed services are not yet provided, or at least not provided in the way envisaged in the socioeconomic study. Therefore, it provides an estimate of the net SEBs generated once the observation, data-processing and forecasting systems are installed and operating, and the consequent new services are fully available.

Bhutan is expected to be subjected to very significant climate change effects, which necessitates the development of adequate climate services that can in turn serve adaptation planning in various sectors. In addition to climate change, Bhutan is subject to the variability of current weather and to extreme weather and hydrological events. Furthermore, the most important economic sectors, namely electricity generation with renewable energy resources (hydro, solar and wind), agriculture and forestry, and tourism are highly sensitive to weather and climatic conditions. Due to the combination of the objectives to be served, some service improvements will start to produce benefits soon after establishment (for example, in case of early warning services), whereas others will build up over time (notably climate services, which depend on long observation series).

E.10.1 Overall approach and methods used

The evaluation was carried out over four types of met/hydro services and the benefits were assessed for 15 sectors/categories. The broad scope was intended to assess the macroeconomic sensibility of an overall upgrade of the met/hydro services in Bhutan

[40] Summary made by Adriaan Perrels and Karoliina Pilli-Sihvola (both of FMI).

and not intended to assess particular investments in great detail. As a consequence, many parts of the study have the character of a so-called "quick scan". For pragmatic reasons, such as limitations on availability and quality of data, various methods have been used in parallel.

A key distinction in the study is how the deployment of the evaluated services is expected to develop, since the deployment largely steers how generated SEBs develop over time. This feature also illustrates how the purpose of a study steers the structuring of the analysis – not unlike the industrial design adage "form follows function".

Based on the eleventh five year plan of DHMS, four service categories were identified for socioeconomic evaluation:

(a) Compilation and distribution of information on past weather and hydrological conditions – that is, basic services based on historical data, notably observations;

(b) Provision of information on the current state of rivers (water level), flood information and atmospheric conditions – that is, hydrological and meteorological monitoring services;

(c) Provision of forecasts, notably general forecasts for the community at large and specialized forecasts for a range of users – three-days-ahead weather forecasts, seasonal precipitation forecasts and flood forecasts;

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

The socioeconomic effects were evaluated for renewable energy, agriculture, construction of buildings and infrastructure, disaster management, road transport and road maintenance, public health and civil aviation sectors. For each sector, the study assesses how the four envisaged services could affect operations (services in points (b), (c) and (d)) and investments (point (a)). Benefits are generated both by avoiding damage (to crops, infrastructure, and the like) and by better exploiting opportunities (for example, optimal sizing and location of hydro, wind and solar power units, and optimized crop choice). Potential benefit estimates are based upon simple cost–loss analysis (for example, applying changes in damage probability owing to the use of forecasting information) or by estimating changes in productivity associated with forecast use (for example, changes in average annual energy production due to optimized sizing and location choice based on climatic and current observation data). For each service and sector, the benefits have been further qualitatively assessed through the filtering steps of the weather service chain approach (Nurmi et al., 2013) emphasizing the need to give attention to the rest of the value chain, beyond information generation.

Information sources comprised: (a) statistics (climatic, economic sectors), (b) interviews (adding in-depth sector information) and (c) two workshops (for initial indications of the significance of the envisaged services and impacts and feedback for initial results). The benefit estimates are often based on benefit transfer (results or modelling parameters taken from other studies). In some cases, lower and higher estimates are produced, for example, in relation to the expected growth of a sector (such as hydropower production). Because an explicit formalized accounting for uncertainties is often difficult due to scarcity of data, a general principle of caution is applied, meaning that conservative figures are used for representing changes in service quality and uptake of services by users.

The benefit assessments do account for economic and/or population growth developments in various sectors, but indirect and induced economic (that is, macroeconomic) effects are not taken into account. For example, higher productivity in various sectors is assumed not to affect product prices in these sectors. It is also assumed that only DHMS will provide the considered services in Bhutan, which in this case is a fair assumption.

Next to an estimate of generated benefits, the costs required to improve the level of services were considered. Included are:

(a) The installation and maintenance of a lightning location system;

(b) A ceilometer for Paro international airport;

(c) Upper air sounding – acquisition and maintenance;

(d) Data management capacity (including staffing);

(e) Observation station maintenance and calibration;

(f) Staffing and equipment for expanding the forecasting services.

The various investments considered, including extra staffing needed, were planned to be implemented in the first few years of the considered evaluation periods.

For items in points (a), (d), (e) and (f), a gradual build-up is assumed in the study, with space for learning and stepwise upgrading to more sophisticated systems (such as in case of a lightning location system) and sufficient attention for maintenance and adequate staffing.

E.10.2 **Results**

With regard to the benefits of current observations, only the aviation sector appeared to be a significant user of such data. Other user groups may become interested if observation data, of appropriate resolution and in relevant areas, become available. Considering the investment and development orientation of the study, the quantification efforts concentrated on the other three service categories, these being large-scale hydro, tourism and road transportation. Table E.16 shows the benefits of historical met/hydro information and Table E.17 the benefits of forecast services. Furthermore, given the varied quality of the available information, the results are in the first place presented by means of a cardinal rating method, indicating one to five plus (+) signs, depending on the estimated significance of the benefit. The preliminary results presented in this way were discussed with stakeholders and other experts in a workshop in Bhutan. For some of the sectors more precise monetized effects are indicated.

Table E.16. Benefits of historical met/hydro information (basic climate services)

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) per plant +++++
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 approximately US$ 1.4 million (starting 2020) ++++
Disaster risk reduction	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 +++
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 ++++

Table E.17. Benefits of forecast services

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 (approximately € 771 445) ++	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, heatwaves and cold waves ++	Prepare for outbreaks, inform the public ++
Road transportation	Prepare for road blocks and mobilize the workforce earlier, inform the public ++	Improved planning and preparedness +
Natural resource use	Optimize operations in the stone quarries and forests ++	Optimize operations in the stone quarries and forests ++

E.10.3 **Benefits of early warning services**

The high uncertainties regarding benefits of early warning services made numerical assessment at this stage less meaningful. Furthermore, the evolving effectiveness and specificity of the forecast services will affect the value generation capacity of the warning services. Also, efforts further down the value chain, aimed at actually reaching users with timely and understandable messages, are essential for significant benefit generation. It is, however, obvious that the benefits potential is very large as soon as various parts of the value chain have sufficiently improved in quality. Benefit–cost ratios easily surpass 10 under such conditions (Perrels et al., 2013).

The report also presents an overall assessment of the development of (quantifiable) benefits and costs for the period 2015–2030. A summary is shown in Figure E.5. The benefit–cost ratio based on the NPV of these monetized flows (see section 8.3.1) is approximately 3.1 when considering the high initial costs of modernizing DHMS. Excluding the initial costs increases the NPV BCR 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.

The preliminary results of the assessment were presented to the stakeholders of DHMS at the second workshop held in Thimphu in January 2014. The final report has been shared with all government ministries in Bhutan to inform other sectors of the value of met/hydro services in the country. However, it is challenging to estimate the long-term value of the study as it usually takes a long time for the benefits to accrue.

The SEB study has functioned as an effective underpinning for the need for service development and related investments in up-to-date observation, data-processing and forecasting capacity. It has also helped priority-setting and awareness-raising among potential end users due to the two stakeholder workshops and particularly due to the extensive stakeholder interviews organized during the study.

Producing a full-blown BCA would require substantial data from different sectors, which were not available for the study, and sectorial and macroeconomic modelling efforts, which were not possible due to the limitations of the study. Indeed, for a relatively young met/hydro service, a quick scan of the costs and benefits of improved

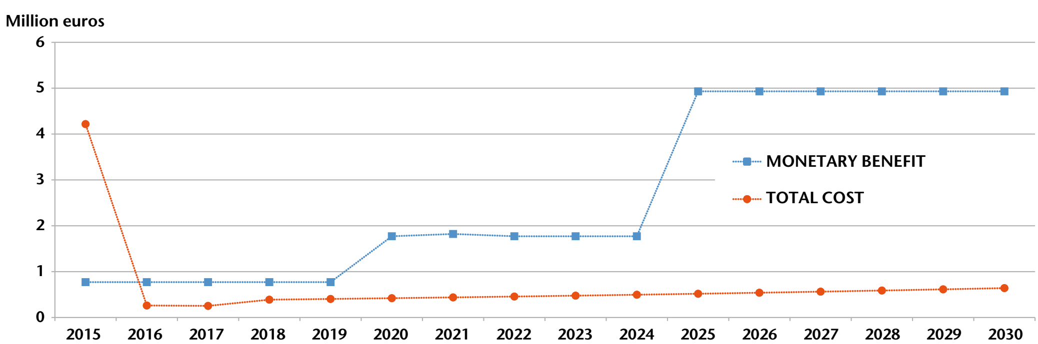

Figure E.5. Annual quantifiable direct benefits and costs of improved weather, hydrological and climate services in Bhutan

Source: Pilli-Sihvola et al. (2014)

services, such as undertaken in this study, provides a good starting point for future service improvements and the development of interactions with potential stakeholder and user groups. The workshops and interviews in Bhutan were highly successful, as they increased the visibility of the NHMS among key future stakeholders.

The study includes two recommendations regarding SEB studies:

(a) DHMS should regularly involve stakeholders in the service development process and also develop systematic interaction with stakeholders to ensure regular feedback on service quality and indications for future service development;

(b) DHMS is advised to conduct a follow-up economic valuation in 2020, to learn, inter alia, to what extent outcomes deviate from projections and why.

It is planned by DHMS to update and expand this study in order to sustain government and partner support in advancing the service system to provide greater relevance and utility for Bhutanese society.

The socioeconomic benefits associated with met/hydro services are highly context and location dependent. Therefore, if the study is done by an external, foreign consultant, the researcher(s) need to obtain a good understanding of the societal, economic and cultural context of the country as they determine how information is used and where it creates value. However, the benefits of a foreign consultant arise from the better objectivity of the results of the study. Therefore, each study needs to be designed for the context. In developing countries, where the data on economic societal and performance factors are often scarce, producing a thorough qualitative analysis can also serve the purpose of demonstrating the benefits to society. A well-done qualitative analysis is often better than a poor, highly uncertain quantitative analysis. Therefore, the context and location often determines the method used to conduct the SEB study as well. The described SEB study in Bhutan was mostly an interview-based qualitative study as there was data scarcity and uncertainty regarding the future development of the society; for instance in the agricultural sector. However, for policymakers, quantitative monetary results are usually of more value. Therefore, studies should strive to include elements of both.

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