# Primer on Economics
# for
# National Meteorological and Hydrological Services

Jeffrey K. Lazo [1]
Robert S. Raucher [2]
Thomas J. Teisberg [3]
Carolyn J. Wagner [2]
Rodney F. Weiher [4]

**Sponsored by**
The U.S. Contribution to the World Meteorological Organization
Voluntary Cooperation Program
Managed by the National Weather Service (NWS) International Activities Office
and
National Center for Atmospheric Research (NCAR), Societal Impacts Program

**August 6, 2009**

*Note:* This document will be updated, revised, and augmented as new information becomes available. If you have any questions, inputs, or thoughts about how to improve its content and information, please send comments to Jeff Lazo at lazo@ucar.edu (fax 303.497.8401) or mail to Jeff Lazo, NCAR, Box 3000, Boulder, CO 80307.

[1] Corresponding author. NCAR – Box 3000, Boulder, CO 80307. lazo@ucar.edu
[2] Stratus Consulting, Boulder, CO
[3] Consulting economist, Charlottesville, VA
[4] Chief Economist, Program Planning and Integration, NOAA, Silver Spring, MD.

# Primer on Economics for National Meteorological and Hydrological Services

Jeffrey K. Lazo
Robert S. Raucher
Thomas J. Teisberg
Carolyn J. Wagner
Rodney F. Weiher

August 6, 2009

## Summary

This primer on economic theory, methods, and applications is primarily for members of the weather community. It is intended to increase their understanding of economic methods and their applicability in evaluating both the impacts of national meteorological and hydrological services (NMHS) and the associated benefits and costs of those services. To this end, the document (1) explains the concept and practice of an economic benefit-cost analysis (BCA); (2) discusses why conducting such economic analyses is important and useful; (3) offers guidance on how to conduct BCAs and document and communicate the inputs and outputs of such analyses; and (4) presents illustrations of economic analysis for NMHS projects in the form of case studies.

## Acknowledgments

We wish to thank the U.S. National Weather Service (NWS) International Activities Office (IAO) for supporting this work. We would also like to thank Julie Demuth and Rebecca Morss for reviewing and commenting on the entire document.

## Foreword

From the beginning of weather forecasting, national meteorological and hydrological services (NMHS) around the world have worked to protect lives and property from the vagaries of weather. As we look to the future, these weather services will work closer than ever with their constituents to provide accurate timely information for the benefit of all of society. Economic analysis of NMHS and their services can help governments understand the value of these services and provide support for these critical activities.

As a supporter of the March 2007 World Meteorological Organization International Conference on ‘Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services’ organized by the World Meteorological Organization in Madrid, the National Oceanic and Atmospheric Administration (NOAA) is committed to “the secure and sustainable living for all the peoples of the world by evaluating and demonstrating, and thence ultimately enhancing, the social and economic benefits of weather, climate and water services.”

This primer on economic analysis is provided to increase the general understanding of economic methods in evaluating both the impacts of national meteorological and hydrological services (NMHS) and the associated benefits and costs of those services. The document provides a foundation for those not familiar with economic science to better understand the needs and capabilities of integrating benefit-cost analysis into NMHS activities.

## Executive Summary

The National Oceanic and Atmospheric Administration's mission is "To understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs." This mission is built on 38 years of NOAA's dedicated scientists use of cutting-edge research and high-tech instrumentation to provide citizens, planners, emergency managers and other decision makers with reliable information they need when they need it. Throughout this history, NOAA has been a leader in multilateral and bilateral efforts supporting international meteorological and hydrologic communities improving the levels of science, technology, operations, and services worldwide.

Committed to providing leadership and support in the international community, NOAA was a major supporter of the March 2007 International Conference on 'Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services' organized by the World Meteorological Organization in Madrid, Spain. The purpose of the Conference was to contribute to secure and sustainable living for all the peoples of the world by evaluating and demonstrating, and thence ultimately enhancing, the social and economic benefits of weather, climate and water services. The outcome of the conference, The Madrid Action Plan, strongly supports efforts to integrate an understanding of the societal and economic benefits of National Meteorological and Hydrological Services (NMHSs) into decision making to support NMHS efforts. A set of actions was agreed to that include a range of efforts to enhance the understanding of the economic benefits of NMHS. Action 11 specifically states that the participants of the conference will work to:

> Encourage the NMHSs and social science research community to develop knowledge and methodologies for quantifying the benefits of the services provided by NMHSs within the various socio-economic 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 use and practical application of economic assessment of the benefits of services provided by NMHSs;
> - present results of economic assessments to governments and donors/International Financial Institutions with the goal of modernizing the infrastructure of NMHSs and strengthening their service delivery capacity.

This document is offered to support these important efforts to develop capacity in economic methods and applications. This primer on economic theory, methods, and applications is primarily for members of the weather community. It is intended to increase their understanding of economic methods and their applicability in evaluating both the impacts of NMHS and the associated benefits and costs of those services. To this end, the document (1) explains the concept and practice of an economic benefit-cost analysis (BCA); (2) discusses why conducting such economic analyses is important and useful; (3) offers guidance on how to conduct BCAs and document and communicate the inputs and outputs of such analyses; and (4) presents illustrations of economic analysis for NMHS projects in the form of case studies.

This document is provided to WMO’s The Observing System Research and Predictability Experiment (THORPEX) Societal and Economic Research and Applications (SERA) working group and WMO’s Public Weather Services Task Force on Social and Economic Applications of Meteorological and Hydrological Services to support their efforts and for dissemination to the hydrometeorological community worldwide. The WMO THORPEX Program aims to “accelerate improvements in the accuracy of one-day to two-week high-impact weather forecasts for the benefit of society, the economy and the environment. Economic analysis is a major component of THORPEX’s SERA working group efforts. WMO’s Public Weather Services Program (PWSP) which is part of its Applications of Meteorology Programme (AMP) aims “to strengthen the capabilities of WMO Members to meet the needs of the community through provision of comprehensive weather services, with particular emphasis on public safety and welfare, and to foster a better understanding by the public of the capabilities of national Meteorological Services and how best to use their services”

Economic information is critical to support the developing role of the Global Earth Observation System of Systems (GEOSS) in fostering increased coordination and interoperability amongst atmospheric, oceanic and terrestrial observing systems to support the delivery of information and services to nine major socio-economic benefit areas.

NOAA will continue to encourage efforts to demonstrate the socio-economic benefits of NMHSs as a critical component in supporting the allocation of resources for research and operations and improving the benefits to societies and economies worldwide.

We hope this primer will encourage a dynamic effort where users provide feedback on the usefulness of this information and indicate their needs for additional or alternative information and support for undertaking assessments of the economic benefits and costs of NMHSs.

# Contents

## Front Matter

# List of Figures

# List of Tables

# Abbreviations and Acronyms

| | |
|---|---|
| AMP | Applications of Meteorology Programme |
| BCA | benefit-cost analysis |
| BT | benefits transfer |
| DOE | U.S. Department of Energy |
| IAO | International Activities Office |
| NCAR | National Center for Atmospheric Research |
| NMHS | national meteorological and hydrological services |
| NOAA | National Oceanic and Atmospheric Administration |
| NPV | net present value |
| NWS | National Weather Service |
| OMB | Office of Management and Budget (United States) |
| PV | present value |
| PWSP | Public Weather Services Programme |
| SERA | Socio-Economic Research and Applications |
| THORPEX | The Observing System Research and Predictability Experiment |
| VSL | value of a statistical life |
| WERF | Water Environment Research Foundation |
| WMO | World Meteorological Organization |
| WTP | willingness to pay |

# Introduction

We designed this document to serve as a primer on economic theory, methods, and applications. Developed for members of the weather community, it is intended to increase their understanding of economic methods in evaluating both the impacts of national meteorological and hydrological services (NMHS) and the associated benefits and costs of those services.[1] To this end, the document:

- Describes the concept and practice of an economic benefit-cost analysis (BCA)
- Discusses why conducting such economic analyses is important and useful
- Offers guidance on how to conduct BCAs and document and communicate the inputs and outputs of such analyses
- Presents illustrations of economic analysis for NMHS projects in the form of case studies.

Given the quasi-public good nature of weather forecasts,[2] the economic value of most weather forecasting services is not directly observed in the market. For this reason, it is difficult to determine the economic value of improvements in weather forecasting. In this primer, we offer guidance on the theories, methods, and applications that can be applied to valuing projects or programs that improve hydrometeorological forecasts. This section briefly describes the main rationale of this document and sets forth a roadmap for the rest of this document.

## The Rationale for Conducting Economic Analyses

Many NMHS programs face limited budgets, and economic analysis, particularly BCAs, can be helpful tools for

- **Justifying programs:** Showing net positive economic benefits of NMHS projects and services is critical for justifying the budgets for these services. Economic assessment of the value of such services often carries significant weight for policy decision making and budget setting.

---

[1] We use the term "NMHS" to refer generically to the body of weather-water-climate–related services and informational products provided by the agencies or entities responsible for such services. Although many countries have both public- and private-sector entities that deliver hydrometeorological services, we focus primarily on public provision of weather-water-climate–related services and informational products. Different countries offer different sets of services under different program names, but all countries provide hydrometeorological services in some form. As indicated by the World Meteorological Organization (WMO), "NMHSs constitute the single authoritative voice on weather warnings in their respective countries, and in many they are also responsible for climate, air quality, seismic and tsunami warnings." http://www.wmo.int/pages/governance/policy/ec_statement_nmhs.html

[2] Weather-water-climate–related services and informational products are referred to as quasi-public goods because of their nonrival and limited-excludability nature. For further information on public goods see the text box on page 3.

- **Evaluating programs:** More and more local, national, and international funding agencies require an economic assessment of the net benefit of hydrometeorological programs—a BCA—when determining whether to invest in, or continue investing in, a specific program.
- **Guiding research investment:** Economic assessments can be used to guide agencies in deciding what investments (e.g., observations, modeling, computing, research, technology) to undertake to improve (or perhaps even maintain) hydrometeorological services. Understanding, identifying, and quantifying likely outcomes of alternative investments and associated benefits and costs can help guide choices among research investments. Even when rigorous economic analysis or quantification is not possible because of uncertainties or the lack of economic information, framing the decision in terms of benefits and costs can help identify projects to undertake and those to put aside.
- **Informing users about benefits:** Potential users need to understand the use and benefits of forecasts so that they know how and why they could use hydrometeorological information. Demonstrating economic or financial value to the users may help in gaining their involvement and support for projects.
- **Developing end-to-end-to-end systems:** The ideal use of economic information will combine all these approaches into integrated end-to-end-to-end hydrometeorological forecast and warning systems. In such a system, the preferences, needs, and values of users guide decision making throughout the system. Understanding user needs and values can help prioritize the types of information to generate and determine how best to disseminate that information. In addition, this understanding can indicate what research to undertake and what programs to support.

## Document Roadmap

In the next section, we give an overview of how to conduct an economic analysis, structured along these lines:

- The importance of economic analysis to NMHS
- The steps to conducting an economic analysis
- The methods and analysis options
- The ways to assess the distribution of benefits and costs

In the section that follows the overview, we explore the economic analysis process as applied to NMHS programs in more detail.

The last section of the document summarizes five studies in which analysts looked at NMHS programs from an economic standpoint:

1. Sensitivity of the U.S. Economy to Weather (Larsen et al. 2007)
2. The Economic Value of Temperature Forecasts in Electricity Generation (Teisberg et al. 2005)
3. Heat Watch/Warning Systems Save Lives: Estimating Costs and Benefits for Philadelphia 1995-98 (Ebi et al. 2004)
4. Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector (Lazo and Chestnut 2002)

5. Benefit Analysis for NOAA High Performance Computing System for Research Applications (Lazo et al. 2003)

These case studies are based on work conducted in the United States. As we develop this primer further, we will seek out and include work from other countries, especially less developed countries. This work will also be extended to explicitly discuss issues and barriers with respect to economic analysis, again with special emphasis on developing countries.

### What Is a Public Good?

As cited by Doering (2007: 3) "Baumol and Blinder (p. 256) defines a public good 'as a commodity or service whose benefits are not depleted by an additional user and from which it is generally difficult or impossible to exclude people, even if people are unwilling to pay for the benefits. These are socially valuable commodities whose provision cannot be financed by private enterprise, or at least not at socially desirable prices." The market, then, tends to lead to the underprovision of public goods and the government must pay for them if they are to be provided.

Economists often refer to two characteristics as making a good a *public good* are:

- Nonrival: One person's use of the good does not reduce the value of that good to someone else.
- Nonexclusive: Once the good is provided it cannot be excluded from anyone who would like to use it, or equivalently, it is not worth the cost of excluding someone from using the good once it is provided.

Weather forecasts are often considered public goods. For example, one person knowing what the high temperature forecast for tomorrow does not reduce the value to someone else of also knowing it (nonrival). Nor is it worth the cost to exclude someone from using the forecast (nonexclusive).

This is important because, if the weather forecasts are nonexclusive, producers cannot prevent anyone from using the good once it is provided. And if they cannot prevent anyone from using it, they cannot charge a price and collect revenue and thus will not provide the good in the first place.

# Economic Analysis and NMHS: An Overview

First, a few words of definition and explanation are in order. An *economic analysis* is a comprehensive investigation of the benefits and costs of potential projects. Economic analysis takes into account not only the financial costs and revenues, but also the wider range of benefits and costs of a project, from all perspectives including the user and society (i.e., the broader community) as a whole. For example, in the NMHS arena, these can include direct impacts, such as reduced or avoided costs of hurricane evacuation, and nonmarket costs, such as reduced anxiety in anticipation of a storm.[3]

BCA is used to determine whether significant programs should proceed. The analysis method is also used for choosing among alternative approaches to achieving program goals. BCA involves a systematic appraisal of the program's overall benefits and costs in order to quantify the full range of social, economic, and environmental benefits and costs in monetary terms (when possible).

## Why Is Economic Analysis Appropriate for NMHS?

NMHS options typically produce a wide range of benefits to society, many of which may not be fully acknowledged or appreciated, in part because they are of a less tangible, less quantifiable nature. All of these benefits need to be considered to determine if a project makes economic sense. Omitting some benefits can lead to an erroneous conclusion that benefits are outweighed by costs, when in fact the opposite might be true. Ideally, areas of greatest potential public benefit would be used to guide research investments, as well as to justify and evaluate current forecasting programs. Economic analysis can help governments better understand and manage the impacts of weather and climate on a wide range of economic activities, such as natural disaster mitigation strategies and drought relief, among others (Zillman 2005).

Although some categories of benefits might not seem suitable for quantification or monetization, a well-established tool kit of economic valuation approaches can be used in many cases. In addition, a wealth of economic literature contains experience with and examples of the use of these techniques, and some sources offer useful empirical information on the potential magnitude of the values. Even if a specific effort has not been analyzed before, similar or equivalent issues may have been addressed in a different context. Some of the resulting insights may be transferable to a given forecast context.

Ideally, economic analysis allows the full range of costs associated with a project to be compared with the full range of benefits. Without recognizing and considering all the benefits and all the costs, policy makers may make inefficient decisions (e.g., a project with positive net social benefits may be judged to be economically unjustified). The goals of economic analysis of

---

[3] The term "nonmarket" means that there are no market prices to observe for many key outcomes (e.g., for a reduction in the number of people evacuating from a hurricane warning, the reduction in pollutants from fuel savings with better flight planning, or the time savings for people commuting to and from work).

NMHS options depend on the intended use of such an analysis. Currently, such analysis is most commonly used for justifying program budgets to decision makers.

Economic analysis also takes into account the timing of benefits and costs by expressing each in terms of its present value (PV) over the life of the project (we describe present values and discounting in greater detail later in the document). If the PV of the benefits is higher than the PV of the costs, the net present value (NPV) is greater than zero and the project is considered beneficial on net. This type of evaluation can also be useful for determining the allocation of costs and funding responsibility on an equitable basis.

## The Steps to Conducting an Economic Analysis

In the subsections that follow, we present a step-by-step guide to conducting economic analysis of NMHS projects. Figure 1 summarizes these steps. For some projects, certain steps will not be feasible with the amount of information that is available, or necessary, or both. This material is based on Raucher et al (2007) and other source material cited in that work. Later in this document, we offer additional guidance on how to implement each step.

The vertical box on the right side of Figure 1 emphasizes that stakeholder involvement should be sought throughout the project identification and valuation process. We recommend stronger involvement (represented by the solid-line arrows as opposed to the dashed-line arrows) at certain junctures in the process (e.g., especially at the outset and again to review and discuss findings).

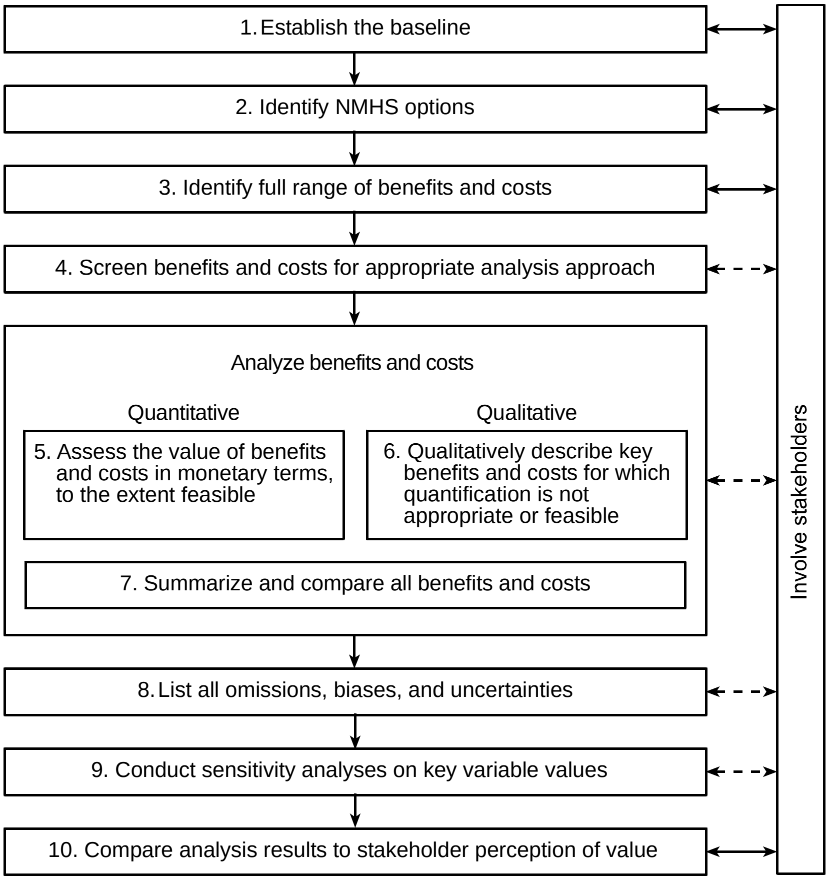
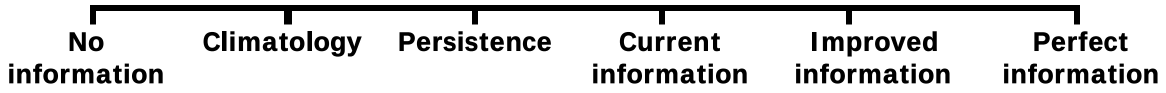


**Figure 1. Steps in Conducting an Economic Analysis**

## *Step 1: Establish the Baseline*

To establish the base case or baseline, we first define the outcomes associated with the "no action" status quo (i.e., what would happen without the forecasting option or options being considered). This base case may entail doing nothing differently, undertaking actions that are already planned, or simply not implementing an effort. The baseline is the mark against which we measure changes resulting from the proposed NMHS program. It is important to define the scale and timing of the impacts of the baseline, articulate what problems the proposed program is intended to resolve, and be explicit about assumptions.

Valuation is always a comparison of the value in one situation to that in another situation. With respect to NMHS and valuing weather forecasts, we often want to compare two different levels, qualities, or types of weather information, with all else being equal. Figure 2 shows a continuum of weather-information quality, beginning with no information and ending with perfect information. When we speak of the value of weather information, we must specify what is being compared to what along such a continuum. The baseline for most cases of NMHS service improvements may be current information or the likely future path of the quality of forecasts under current funding and development programs. The baseline in this case may thus include improvements in the near future, but the program being evaluated may involve accelerating those improvements or providing a different set of forecast improvements.



*Note:* The value of climatology may be higher or lower than persistence but is shown as lower for our purposes.

**Figure 2. Continuum of Hydrometeorological Information Quality**[4]

The baseline must also specify what NMHS activities are being evaluated and to what they are being compared. Meteorological systems and services, as defined by the World Meteorological Organization (WMO) and cited in Zillman (2005), include the following:

- **Basic systems** make up the basic national data collection and processing infrastructure that underpins the full range of services available at the national level. This infrastructure may itself be regarded as a basic service to present and future generations.

---

[4] Climatology refers basically to longer term average weather for the specific location. Persistence refers to the expectation that recent daily weather will continue for the near term.

- **Basic services** are provided in discharging a government's sovereign responsibility to protect the life and property of its citizens, to contribute to their general welfare and the quality of their environment, and to meet its international obligations under the Convention of the World Meteorological Organization and other relevant international treaties and agreements. Basic services in general include information on immediate threats to life or property as well as aviation forecasts as required under international agreements.
- **Special services,** which are those beyond the basic services, are designed to meet the special needs of individual users or user groups. They can include special data and products and their interpretation, distribution, and dissemination, along with special purpose investigations and consultative advice. Such services may include tailored forecasts for specialized agricultural or construction activities.[5]

In general, when we evaluate the value of the output of an NMHS, we are interested in the value of specific products or programs and changes in the quality of available forecasts and services. 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 would be a conceptually different problem 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. Referring to Figure 2, the total value of an NMHS would be the difference between current information and either persistence or climatology (whichever we would assume 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 (e.g., from a neighboring country).

### *Step 2: Identify NMHS Options*

To determine what is being valued, we must determine the primary options being considered and what reasonable or potential alternatives should also be considered in the analysis. Options often of interest to NMHS include changes or improvements in

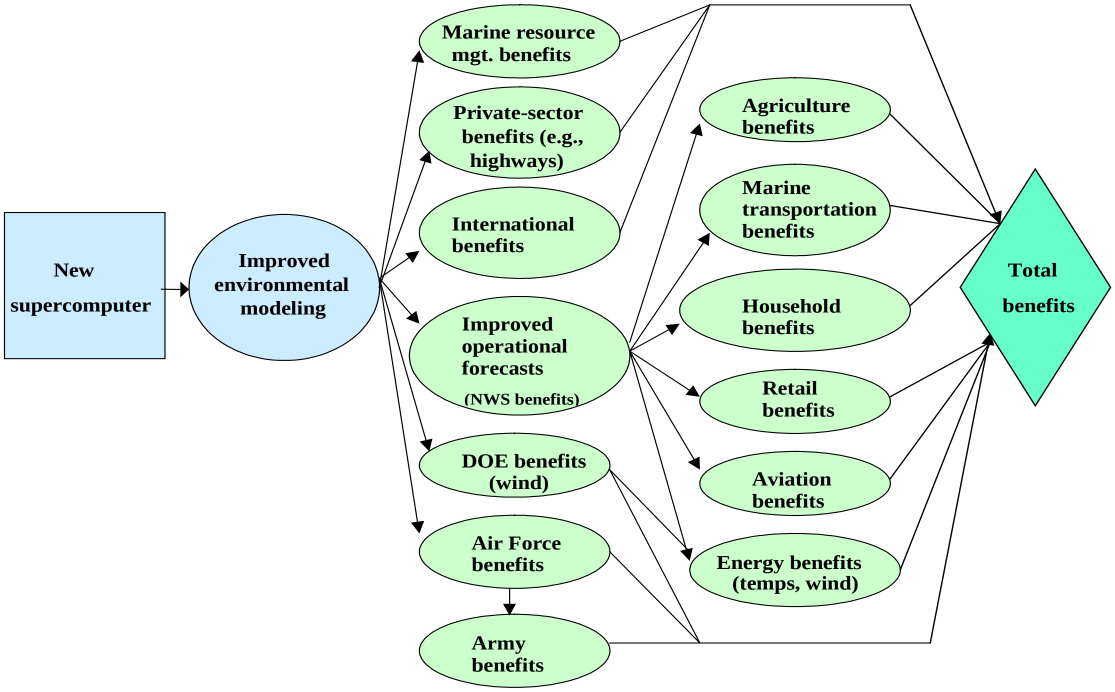
- Observation systems
- Data assimilation
- Forecasting models
- Computer facilities and capacity
- Forecast dissemination.

---

[5] Note that many special services, especially those provided at a charge or provided by private-sector forecasters, are often traded within a market framework and as such, may not be considered public goods.

Extending the traditional realm of many NMHS may involve improvements or implementation of new or better uses and responses to information including

- Forecast communication
- Development of decision support tools
- Emergency response activities for severe weather or flood warnings.



## *Step 3: Identify the Full Range of Costs and Benefits*

In this step, we develop a thorough inventory of all likely costs and benefits associated with the proposed program. In general, costs and benefits should be included regardless of to whom they may accrue or where they might be realized. In some circumstances a government may only be concerned with benefits and costs to the citizens of its own jurisdiction. If decision makers elected to include only a limited set of benefits or costs in an analysis, this should be made explicit in the discussion. Figure 3 illustrates an example of efforts to identify the stakeholders and potential beneficiaries of investments in a supercomputer to improve weather forecasting research (Lazo et al. 2003; see Case Study 5).

**Figure 3. Benefits of Improved Weather Modeling**
***Note:* DOE = U.S. Department of Energy**
***Source:* Lazo et al. (2003)**

### *Step 4: Screen Benefits and Costs for Appropriate Analysis Approach*

In the screening step, we determine which costs and benefits can and should be analyzed quantitatively and which should be described only qualitatively. Those that are truly insignificant can be eliminated from further analysis. We discuss the screening process in detail later in the document.

## *Analyze Benefits and Costs*

For an NMHS program, costs are typically the monetary costs of funding the program.[6] Some initial costs, including those for capital items, will be required to get the program started. Once the program has been launched, there will be continuing costs for running it.

The benefits of an NMHS program typically arise from information the program produces. We can usually characterize this information directly (e.g., a precipitation forecast with a certain time horizon and accuracy). It is more difficult, though ultimately more important, to characterize the information in terms of its potential users and what they use information for in decision making. For example, a long-range precipitation forecast would have uses in agriculture and water resource management, and likely in other areas as well. Although it may be difficult to determine the ultimate impacts of an NMHS program on users (e.g., determining the impacts of investments in an observing system on forecast quality and ultimately on decision making may prove problematic), we must understand the causal link in order to assign an economic value to such efforts.

To determine the benefits of a project, then, we must understand the following aspects of the valuation problem:

- The type of information being valued (e.g., all hydrometeorological information or just high temperature information)
- The types of decisions being made using the information and how the information affects these decisions
- The beneficiaries of the value (e.g., the users of the information)
- The temporal and spatial scales of the values being generated.

We must also understand the hydrometeorological information process and the associated value chain—as shown in Figure 4—before we can estimate economic value. Although NMHS programs focus mainly on activities in the hydrometeorological forecast enterprise box, much of the value added or lost occurs in the communication and the users and decision-making boxes. Ultimately, value accrues from the behavior of users and the outcomes of their decisions.

---

[6] In this document, we use the term “dollars” to refer to quantified monetary units for convenience. Valuation will, however, be undertaken primarily in the national currency of the country in which the NMHS program is being analyzed.

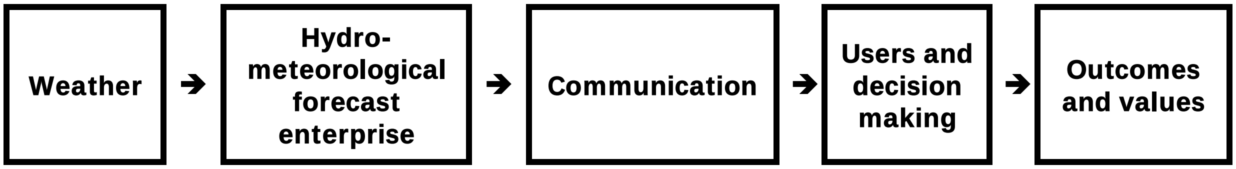


**Figure 4. Value-Added Chain for Hydrometeorological Information**

### *Step 5: Assess the Value of Benefits and Costs in Monetary Terms*

In this step, to the extent possible, we express the costs and benefits of a proposed NMHS program in monetary terms (quantitatively). Costs are typically already in monetary terms, but expressing benefits in this way is the central challenge for NMHS programs.

The information produced by a NMHS program typically has more than one use (and more than one user). NMHS information can also be transformed or augmented before final users receive the information. This will be the case when media and broadcasters add additional formatting or perhaps even different information than the basic information provided by an NMHS. Ideally, we should identify all uses and determine the benefit accrued from each use. This often requires both expertise or understanding with respect to specific uses (e.g., water resource management) and proficiency with respect to methods used to value information. Attributing the contribution to value from the NMHS versus intermediaries can be a difficult task in valuing NMHS programs.

Valuing information essentially requires that we understand how users of information would act, both with and without access to the information. Next, we must find a way to estimate the increase in value produced, or the reduction in costs incurred, that results when the information is available and used.

Commonly, we employ three general methods to estimate value of information in the NMHS context. One is economic modeling of the situation in which the information is used (Teisberg et al. 2005; see Case Study 2). Economic modeling involves mathematically representing decision making and the value or cost outcomes that result, both with and without information. This makes it possible to calculate the value increase or cost reduction attributable to the information. A second method is data analysis, in which we analyze historical records to determine the actual difference made by that information (Ebi et al. 2004; see Case Study 3). 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. In the third method, we directly ask users of the information (Lazo and Chestnut 2002; see Case Study 4), or more rarely, experts familiar with use of the data (see Case Study 5), to subjectively assess the value of the data. This last method must be carefully designed and executed or the results may not be credible.

### *Step 6: Qualitatively Describe Key Benefits and Costs*

For some types of benefits and costs, expressing their value in quantitative or monetary terms may not be feasible or desirable (as per the screening in Step 4). It is always important, though, to describe these nonquantified benefits and costs 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 project benefits. We can qualitatively rank impacts on a 5-point scale, ranging from –2 to +2, to reflect unquantified relative outcomes that span from very negative to very positive (e.g., a "–1" may signify an outcome with moderate unquantified costs, and a "+2" may represent a high unquantified benefit). Qualitative ratings should be accompanied by descriptions of the impact, and should be explicitly carried through the analysis.

### *Step 7: Summarize and Compare All Benefits and Costs*

If possible, we discount quantitative benefit or cost projections over time (from Step 6) to PV at an appropriate discount rate. The discount rate, which is similar to an interest rate, is described in detail later.

Typically, we summarize the net monetized benefits and costs (either annual or present value) in one location (i.e., a summary table), along with the listing and ranking of those benefits that can be described only qualitatively (from Step 6). One summary table must include the monetized benefits and costs, along with a listing and some qualitative assessment of the nonquantified benefits and costs, so that reviewers do not overlook potentially important outcomes when reviewing the empirical results. Distributional aspects should also be presented, as discussed later.

### *Step 8: List All Omissions, Biases, and Uncertainties*

In this step, we explicitly document all omissions, biases, and uncertainties associated with the estimated benefits and costs. The impact that these may have on the final outcome of the analysis (e.g., in terms of their likelihood of increasing or decreasing net benefits, or an uncertain direction of change in net benefits) should be noted.

### *Step 9: Conduct Sensitivity Analyses on Key Variable Values*

Here, we conduct sensitivity analyses on key variables or benefit and cost estimates, with the aim of exploring and communicating the impact of assumptions, uncertainties, or natural variabilities. We use sensitivity analyses to identify which assumptions or uncertainties have the largest impact on the outcome of the analysis (e.g., 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). We discuss this further in the next section.

### *Step 10: Compare Analysis Results to Stakeholder Perception of Value*

In the final step, we compare the quantitative and qualitative values that result from the analysis and from the various sensitivity analyses with stakeholder expectations of values. This comparison can be informative both as a check on the reasonableness of the analysis results and as a process for working with stakeholders to help them realize (or at least better articulate) the values they obtain from the project. This understanding of values can become the basis for cost-sharing agreements with stakeholders according to the relative shares of benefits derived from the project.

In the NMHS context, stakeholders are typically the users of the information that is to be produced by the program under consideration. These users will often be diverse and perhaps hard to identify. Sometimes, they will not yet have developed the systems or behaviors that will allow them to take advantage of new information.

# Economic Analysis and NMHS: The Details

In this section we present additional detail for some of the steps outlined above. We also discuss additional information on economic methods for evaluating benefits and costs and for comparing these over the lifetime of a project.

## Defining the Baseline

As we touched on in the last section, defining the baseline is the first and critical step in the economic analysis. Not only does the baseline establish the “accounting stance” within which we evaluate and compare NMHS systems and services, it also determines the problem-solving context within which we—the particular agency, the community as a whole, or both—consider the NMHS option (and possibly other alternatives). The baseline, then, must be defined carefully, explicitly, and in a manner suitable for local circumstances. It is the pivotal foundation for conducting the BCA itself, as well as for framing the policy-making dialogue with governing officials, customers, and other stakeholders.

From the technical perspective of establishing the suitable accounting stance for the economic analysis, we typically define the baseline as the status quo or “do-nothing” alternative to a particular system or service (and/or other alternatives) being evaluated. For example, consider a relatively simple circumstance: An NMHS agency is considering moving beyond a current service (e.g., offering hurricane forecasts, watches, and warnings) and pursuing a new and improved system (e.g., installing a new observation and modeling system to accelerate increases in lead time of watches and warnings). Here, the baseline should reflect the *future* situation for the community, assuming that the NMHS continues its current service. In other words, we view a future with the current alert system through the lens of likely future conditions (e.g., change in climate, population, or vulnerability to severe weather events). Even in relatively simple contexts, the baseline must reflect the future—it is *not* the same as the current situation. Even though the baseline may entail no new system or service, it must take future implications into account.

Defining the baseline means looking into the years ahead, and because different NMHS programs have varying lifetimes, we must apply a matching long-term time frame to the baseline and alternative options. In most circumstances, then, we need to consider potential changes in weather patterns (such as an increased number and intensity of hurricanes) over the useful life of the system or service. We must also clearly state the assumptions underlying these future projections, which can become a focal point for discussions with stakeholders, serve as a basis for sensitivity analyses, or both.

## Choosing Which NMHS Options to Consider

This economic framework is designed to be general, and therefore suitable for use in

- Comparing different NMHS systems or programs
- Evaluating and or justifying a current NMHS system

- Evaluating a system or service relative to a baseline that might reflect what is likely to happen in the future if no additional NMHS programs are launched.

Obviously, considering a greater number of different options will increase the complexity of the analysis. The results, though, will be more valuable if all the relevant feasible options are evaluated. Also, it is typically most useful to limit the analysis to options that are technically, politically, and legally feasible. If we include options that are not feasible, we must clearly label them as such and articulate the cause (e.g., technical, ethical, or legal).

### Determining Benefit and Cost Categories Applicable to NMHS

As illustrated in Figure 3, numerous types or categories of benefits and costs can apply to NMHS, and the potential magnitude of those benefits will be very site- and circumstance-specific. In Table 1, we have compiled a preliminary and partial list of broad benefit and cost categories. These types of important benefits are not always amenable to quantitative analysis (i.e., it often has not been feasible to assign monetary values to these benefits). Nonetheless, they are frequently stated as key reasons for selecting or justifying an NMHS program. If any or all of these issues are central values for considering a particular NMHS, it is important to identify the applicable benefit categories and carry them through the analysis. Even if some or all of these benefits cannot be readily valued in monetary terms, they may still represent important values that we should—at a minimum—describe quantitatively in the final summary of results.

### Screening Outcomes

Screening the list of potential costs and benefits for a project is useful for (1) determining which impacts are so small (or mitigated) that they can be dropped from the analysis; (2) which impacts must be qualitatively described (because quantification is not generally feasible); and (3) which impacts can and should be quantified. We describe the three screening criteria used in this step in the subsections that follow, and Figure 5 shows the screening analysis process as a flow chart. Note that the screening process described here reflects a way to assess how much effort should be devoted to estimating the various different benefits and costs.

#### *Screen 1: Is the Impact Relatively Small?*

This screen considers whether the cost or benefit will be very small, either in absolute terms or in relative terms compared to the other impacts. If the impact is small enough and insignificant, we may be able to eliminate it from the analysis in an effort to save or focus resources. This is a matter of judgment, and documenting the reasons behind such a decision is important.

#### *Screen 2: Is the Impact Uncertain or Changing?*

Here we determine whether the impact is so changing or uncertain (e.g., because of scientific uncertainty or time lags in natural processes) or sensitive (e.g., because of political considerations, legal uncertainties, or cultural sensitivities) that any attempt at economic assessment would be impossible or not useful. In this case, we must explicitly recognize that economic valuation may not be possible or useful. We must also, however, continue to recognize the impact through qualitative characterization.

**Table 1. Partial Listing of Benefits of Meteorological Services, by Category**

| Social | Environmental | Economic |
|---|---|---|
| Avoidance of loss of life from natural disasters | Long-term monitoring of basic indicators of the state of the environment | Avoidance of crop losses from frost or hail |
| Safety and security of the traveling public | Minimization of release of toxic substances and other pollutants | Increased farm production and sales |
| Improved information and data to the scientific community | Management of local environmental quality | More efficient scheduling of the use of agricultural machinery |
| Contribution to the day-to-day safety, comfort, enjoyment, and general convenience of citizens, including<br>• Recreation<br>• Travel and commuting<br>• Preparation for severe weather<br>• Home improvement decisions<br>• Other direct and indirect forms of societal benefits. | Support for addressing major global environmental issues | 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:* Adapted from Zillman (2005).

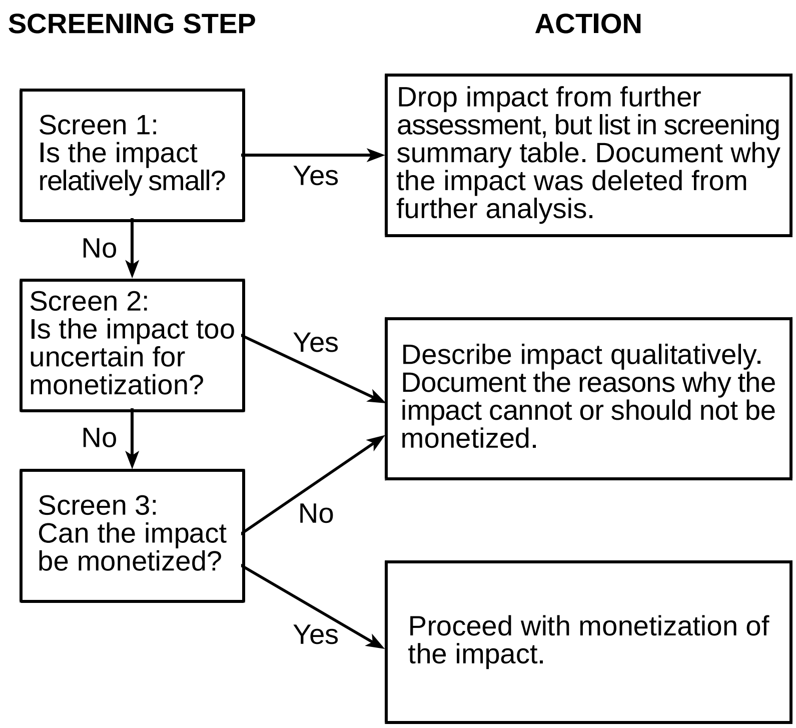


**Figure 5. Screening Analysis Flow Chart**

### *Screen 3: Can the Impact Be Quantified in Economic Terms?*

In this screening process, we determine whether available data and methods are sufficient for monetization of the impact. If the data and methods are available, we can proceed with quantifying the impact and converting the impact into monetary terms. In some instances, quantifying the impacts in physical terms will be feasible. Not all of these physically quantified outcomes, though, can then be portrayed in monetary terms. For example, the emotional/psychological effects of hurricane evacuations or of injury caused by storms might be countable in terms of the number of people affected, but these effects may be difficult to quantify in monetary terms. In these instances, we capture results in quantified physical units.

### *Describing Benefits and Costs Qualitatively*

If we cannot quantify an important benefit or cost in a reliable or readily feasible manner, we must still make sure that we retain that impact as a visible part of the analysis and routinely include it in any summary table or results documentation. Keeping a focus on “what counts” is more important that focusing only on what may be “countable.”

In developing qualitative descriptions, it is generally useful to create short but clearly stated descriptions of what type of benefit value is generated and why it is important to the community. Also, even where it may not be feasible (or desirable) to monetize some benefits, we can often convey whether the benefit (or cost) is likely to be of *relatively* high importance and value. Using some indication of relative magnitude, then, can be very useful when summarizing the benefit-cost findings, including the qualitative outcomes.

## Methods for Determining Monetized Values

Numerous approaches can be taken to develop estimates of the monetary value of many of the benefits and costs associated with an NMHS program or service. We describe the most common in the subsections that follow.

### *Market Price*

Where there is a well-functioning market for a good or service that is affected by an NMHS project, we can use the observed market price as the dollar value to insert in the benefit-cost framework (the steps we outlined previously). Market prices are typically used for the direct costs of the project (or its alternatives), such as the cost of capital equipment, labor, and so forth. These market prices are sufficient to cover the needs of a financial analysis. A difficult aspect of cost analysis may be determining what component of NMHS costs are related to existing services versus aspects of the program under consideration. For instance, it can be difficult to determine what portion of an employee's time and salary should be considered a part of the new project as opposed to prior or baseline activities. Likewise it may be difficult to determine the real total cost of using computer facilities for developing new models or forecast products when the costs of the computer, buildings, energy, and programs is divided among several different programs.

Market prices may exist for benefit estimation as well if there is private-sector provision of weather, water, or climate information. For an economic assessment of benefits and costs, however, many of the important outcomes pertain to nonmarket goods and services. As a result, nonmarket valuation approaches are required for many benefits and potentially some costs.

### *Nonmarket Valuation*

Economists use various well-established methods for nonmarket valuation. These approaches can help develop dollar estimates for some important types of NMHS benefits, thereby helping decision makers and the public better recognize the value of an NMHS option. We summarize these nonmarket valuation methods in the following subsections.[7] In this discussion, we refer to the methods as either primary—involving data collected directly from a subject or respondent—or secondary—involving data collected through literature, publications, media, or other sources.

#### Primary Methods

Many goods and services associated with NMHS are not traded in markets. For example, well-defined markets for the increased safety and security of travelers and commuters rarely exist. We can use two main approaches to estimate nonmarket values via primary research—

---

[7] Because many nonmarket valuation methods were developed initially for quantifying the value of environmental goods and services, we talk about them here in that framework. Recent work has begun to apply these methods to valuation of weather forecasts as discussed in the case studies.

**stated preference** methods and **revealed preference** methods. Stated preference methods are survey-based and include contingent valuation and conjoint analysis. Revealed preference methods include travel cost models and hedonic pricing (see summaries in Table 2).

**Table 2. Primary Economic Valuation Methods for Nonmarket Goods and Services***

| | |
|---|---|
| **Revealed Preference Methods** | |
| Travel cost models | |
| + | Uses observed tourist and recreational trip-taking behavior |
| – | Measures use values only; collecting adequate data is often expensive and time-intensive |
| Hedonic pricing | |
| + | Uses observed housing, property, or labor market behavior to infer values for environmental quality changes |
| – | Measures use values only, requires extensive market data, and assumes that market prices capture the environmental good’s value |
| **Stated Preference Methods** | |
| Contingent valuation | |
| + | Survey-based elicitation of individuals’ preferences and values (e.g., their willingness to pay [WTP]). Can estimate nonuse values; can also estimate use values |
| – | Time-intensive and expensive to implement; challenging to frame survey questions that elicit valid responses; potential response biases |
| Conjoint/stated choice | |
| + | Similar to contingent valuation, except respondents are surveyed about a set of choices instead of a single WTP question |
| – | Time-intensive and expensive to implement; challenging to frame survey questions that elicit valid responses; potential response biases |

*Comparative advantages denoted by +; comparative disadvantages denoted by –

Revealed preference methods are based on observing the behavior of individuals and the costs that they will voluntarily bear to infer the value of a nonmarket good or service. 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-use activities. For these types of uses, we can assess incurred costs to develop proxy "prices" for the activity. We then use that information to develop the demand curve—and thus value of—recreation-related services. This approach uses observations of people's behavior or their associated expenditures as indications of revealed preferences for the good. The most common revealed preference methods are the hedonic pricing method and the travel cost method. We use hedonic pricing 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).

## Why Do "Well-Functioning" Markets Matter?

Another term for what economists call well-functioning markets would be "perfectly competitive" markets. The characteristics of a perfectly competitive market include

- A large number of buyers and sellers. No one buyer or seller has enough control over the market to affect the market price—they are all "price takers."
- Freedom of entry and exit. In particular, if a firm is earning particularly high profits, there is nothing barring other firms from entering that market, which will eventually drive down prices.
- Homogeneous products. A buyer can as easily and happily buy the product produced by Company A as the one produced by Company B.
- Perfect information. Enough information exists so that all participants have the information necessary to make the "correct" choices.

The result of this interaction of a large number of buyers and sellers, each acting in their own self-interest, is an equilibrium price and quantity—the intersection of supply and demand as commonly taught in introductory economics classes.

What this means for purposes of economic analysis is that the ***price*** for a good supplied in a perfectly competitive market fully reflects the marginal ***value*** (marginal benefit) to the consumer and the marginal ***cost*** (marginal cost of production) to the producer. Prices in well-functioning markets are thus useful for BCA, as long as the situation being analyzed does not involve a large (i.e., nonmarginal) change in quantities of goods produced or used.

Based on these characteristics, NMHS products and services do not fit into the model of products that would be bought and sold in perfectly competitive markets for at least two reasons:

- With respect to "a large number of buyers and sellers": For the most part, because of the high cost of entry, there are few sellers of weather information.
- With respect to "freedom of entry and exit": The very high costs of equipment (e.g., satellites and super computers) form a barrier to market entry for the provision of weather information.

And as described in the text box "What Is a Public Good?," hydrometeorological forecasts also take on the characteristics of public goods—another reason they are not provided in perfectly competitive markets.

For activities where there is no direct use of the resource, and thus no behaviors or expenditures available as a measure of preferences, economists have developed stated preference methods for directly eliciting preferences and estimating value.

Two common stated preference methods are the contingent valuation method and the conjoint/stated choice method. By applying contingent valuation to natural and environmental resources, we can assign value not only to direct uses, but also to nonuses (e.g., existence and bequest). Nonuse values are those elements of value that are unrelated to a current, future, or potential actual or physical use. Existence value reflects benefits from simply knowing that a certain good or service exists and bequest value refers to benefits derived from ensuring that certain goods or services will be preserved for future generations. When we use the conjoint/stated choice method, we ask for a ranking of choices instead of eliciting an answer to a single WTP question, as is common in contingent valuation studies. This method can also be applied to derive estimates of either use or nonuse values.

### Secondary Methods

Primary research is often expensive to execute correctly, and often not feasible because of budgeting, scheduling, and other constraints. It is often more practical to turn to the secondary methods we describe in this section, using an approach that helps identify the critical values in the BCA. If a particular value is identified as critical, it may become desirable to invest in a primary research study to more definitively determine that value. Secondary methods include **benefits transfer, avoided cost, response cost,** and **decision analysis.**

One common method for valuing nonmarket goods and services is known as ***benefits transfer*** (BT). Under this approach, we take the results of existing valuation studies and transfer them to another context (e.g., a different geographic area or policy context). We must consider a number of challenges and cautions when using BT. Although developing a BT-based monetary estimate of many types of benefits is relatively simple (e.g., there is a limited but relevant literature on economic values for the impact of weather 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 BT method can be challenging in that important differences often exist among the types of conditions studied in the primary empirical research (i.e., the study context for the published monetary estimate), and the NMHS context to which we 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 BT-based value such as dollars per year to improve traveler safety? Another challenge arises from the frequent need to attribute a BT estimate to a large outcome (e.g., avoiding a hurricane evacuation) using an estimate of a fractional benefit to the whole (e.g., the marginal mile of evacuation that was avoided).

Well-developed literature is available to guide us in applying BT (e.g., Desvousges et al. 1992), although obtaining relevant, high-quality existing studies can be difficult. When implemented correctly with a recognition that the estimates are not intended to be precise, BT is accepted as a suitable method for estimating the use and nonuse benefits of changes in the level or quality of NMHS products. Using BT can save time and money because conducting original research can be time consuming and expensive. When time and resources allow, however, primary research specifically tailored to the issue and site at hand is broadly considered a far better alternative.

We recommend following these steps when conducting BT (EPA 2000):

- Describe the issue, including characteristics and consequences, and the population affected (e.g., 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 BT analysis. In assessing studies for applicability, determine whether available studies are comparable to the issue at hand. Guidelines for evaluating usefulness of a particular study for BT for a particular situation (based on guidance provided in EPA 2000) 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 analyze 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 benefits estimates. This step involves the actual transfer of benefits over the affected population to compute an overall benefits 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.
- Address uncertainty. Clearly describe all the judgments and assumptions inherent in BT, as well as any other sources of uncertainty, and assess their potential impact on final estimates.

***Avoided costs*** (or ***cost offsets***) can be an important part of valuing the range of benefits likely to be generated by an NMHS program largely using market information. For instance, these benefits accrue from reducing or eliminating expenditures related to power generation (e.g., 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 allows us to compare benefits accrued in different years on an apples-to-apples basis. We must be alert to potential issues, though, 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 NMHS (e.g., a power company increases production to err on the safe side, but improved forecasting would have changed that decision).

***Response costs*** can be either **averting** or **mitigating**. When using the averting behavior approach, we examine the expenditures people make to avoid damages that could result from hydrometeorological impacts. 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. Under the mitigating behavior approach, we look at the expenditures people make to correct a problem after the fact. Mitigating behavior generally involves decision making “after the fact” and is thus unlikely to provide measures of value for weather forecasts.

***Decision analysis*** gives us ways to quantify and assess the value of information. These methods involve carefully structuring uncertainties faced, the decisions to be made, and the values obtained. In decision analysis, we analyze the decisions, uncertainties, and resulting values when people had access to the information and when they did not. Or, we can look at situations where they have one level of information quality compared to a higher level (e.g., more accurate weather forecasts). One expected value results when no information is available, and a second expected value results when information is available. Typically, value is higher (or cost is lower) when people make decisions with information or with better information. The increase in value (or reduction in cost) is the value of the information.

In economic terms, we can think of improved weather forecasts as improved information and use decision analysis to value such forecasts. Decision analysis also offers a means to determine the value of both perfect and imperfect information to the decision maker. Perfect information is always correct, which is hardly a realistic concept, but one that is very useful when we are trying to determine an upper bound on the value of additional information. In the context of weather forecasting and given that uncertainty still may exist in other non-weather aspects of his decision problem, a perfect forecast would allow the decision maker to maximize weather-related benefits and minimize weather-related costs (e.g., a farmer deciding whether or not to apply frost protection to crops).

## Additional Valuation Issues

In economic practice, we often use the **value of a statistical life (VSL)** to estimate the monetary benefit of reducing premature mortality risk using available WTP estimates for changes in mortality risks on a per-life-saved basis. Here the key point is that we are not placing a dollar value 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 are the WTP (or willingness to accept, i.e., WTA) for small changes in very small risks that are spread over a large population.

We must also consider the **distributional** or **equity** perspective when analyzing benefits and costs of a NMHS service. Here, we ask: Who benefits and who pays? For instance, a system that provides weather forecasts to remote areas has few beneficiaries although the costs may be as high as or higher than systems that deliver weather forecasts to densely populated areas. Similarly, a farmer choosing whether or not to irrigate may gain more value than a regular citizen despite paying the same tax for the service.

## Discounting Explained

Benefits and costs from NMHS projects often occur as a stream of values that can change in magnitude over time. Most NMHS options usually have large capital costs that are paid either up front or, more likely, over an amortization period at the beginning of a project. There may also be significant maintenance, data processing, and personnel costs throughout the life of a project.

Benefits, though, may not begin to be realized until well after the initial project investment and then may accrue over the remaining economic life of the project, which can be substantially longer than the amortization period. Values that occur in different time periods need to be adjusted to their comparable present value (PV).

When calculating the PV, we must consider two interrelated factors—inflation and the "time value of money." When inflation is included in recording or projecting values over time, we say that the values are in "nominal" terms. Many financial analyses are conducted in nominal dollars. For economic analyses, though, we use "real" (i.e., inflation-adjusted) dollars. This makes analyses easier and keeps inflation-related projections from clouding the analysis. In real dollars, a dollar today has the same purchasing power as a dollar 10 years from now.

Second, we must account for the fact that most people prefer a dollar today over a dollar available in the future. Most prefer to use that dollar to consume today or to invest to yield more than a dollar in the future. We call this preference for near-term consumption over deferred consumption the "social rate of time preference" or the time value of money. This social rate of time preference is the real (i.e., 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.

We call the annual rate at which PVs are preferred to deferred values the **discount rate.** 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. We can express the discount rate 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 discount rate when we analyze dollars in real terms and a nominal discount rate when we analyze values in nominal terms.

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 would come at the expense of investments in the future, we should use the opportunity cost of capital 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 is more suitable as the discount rate.

There are philosophical and practical aspects to the choice of discount rate, and economists and policy makers do not always agree about the correct discount rate to apply to project evaluations. For BCAs of NMHS, 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 discount rate that reflects the private costs of capital. For example,

- 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 (e.g., species extinctions).
- Others 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.

In the United States, various governmental entities have specified discount rates to be used in analyses. The federal Office of Management and Budget (OMB) regularly updates discount rates in Appendix C to its Circular Number A-94 on *Guidelines and Discount Rates for Cost Benefit Analyses of Federal Programs* (OMB 1992).[8] OMB recommends using real interest rates on U.S. Department of the Treasury notes and bonds matched to the project time period for the real discount rate. As of January 2008, the real interest rate on a 30-year note was 2.8%.

## Net Present Value and Project Decision Criteria

To compare streams of value over time from different projects, we use the discount rate to discount the stream of values for each project to its PV. If both benefits and costs are involved, we subtract the PV of the costs from the PV of the benefits to arrive at the NPV of the project. 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 be in the same year's dollars. Assessment of NPV of different projects allows apples-to-apples comparisons of project values regardless of possible differences in the timing of benefits and costs for each project.

The general decision criteria are that if the NPV is positive the project is acceptable and should be undertaken, and if the NPV is negative it does not provide an improvement in societal well-being and should not be pursued.

Table 3 presents a simplified numerical example of discounting and calculation of NPV.[9] The first column (Year) indicates the year during which benefits and costs are projected to occur. The next two columns under the heading "Discount rate = 0.0%" 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%. We then show the discounted benefits and costs for each year using discount rates of 3.0% and 7.0%, respectively. These are calculated using the following formula for benefits:

$$PVBenefits_t = \frac{B_t}{(1+r)^t},$$

---

[8] See http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html most recently updated January 2008.

[9] Note that the dollar values for benefits and costs are entirely made up for illustrative purposes only to show the impact of the use of different discount rates.

where *PVBenefits* is the PV of the benefits from year *t*. *B* is the current year dollar value, and *r* is the discount rate. For instance, referring to Table 3, using the PV of Year 5 benefits is

$$PVBenefits_5 = \frac{50}{(1+.03)^5} = \frac{50}{1.1593} = \$43.13\,.$$

As we would expect, the PV of costs is calculated using costs, *C*, rather than benefits.

In Table 3, 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 labeled "NPV."

We can see that without discounting (*r* = 0.0%), the NPV is $35.00. When we apply a discount rate of 3%, this NPV decreases to $20.08. At a rate of 7.0%, the NPV becomes $–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 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 3.0% to 7.0% would change the decision on whether or not to undertake this project.

**Table 3. Simplified Example of Discounting**

| | Discount rate = 0.0% | | Discount rate = 3.0% | | Discount rate = 7.0% | |
|---|---|---|---|---|---|---|
| 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 |

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

$$NPV = NPBenefits - NPCosts = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t}\,.$$

## Understanding and Using Sensitivity Analysis

We should note the two main sources of imprecision in value estimates. One is *variability*—the natural variations in an estimate resulting from its properties or the forces acting on it. The other is *uncertainty* about an estimate that arises from our lack of knowledge about the true value (e.g., is the value of improved weather forecasts $25 per household or is it $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 we can use a single "best estimate" or mean value, we should use sensitivity analysis 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 toward a desired outcome.

### *Sensitivity and Scenario Analysis*

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 BT-based estimates—or even whether an NMHS program will improve the quality of information users receive) using sensitivity analysis. Using this approach, we systematically change the value of some key input variable 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 4 shows an example of a sensitivity analysis for the discount rate applied in this fashion to the range of benefits and costs.

**Table 4. Sensitivity Analysis Applied to Discount Rate**

| Discount Rate (%) | PV Monetized Benefit* | PV Cost* | Monetized Net Benefit (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 |

*In thousands of dollars

Sensitivity analysis (also called “scenario analysis”) is an important tool for helping us understand the effect of uncertainty. By examining different scenarios 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 topics, improving the BCA at the same time. One useful approach to scenario analysis is called a **Monte Carlo simulation.**

This type of simulation is useful in situations where multiple sources of variability or uncertainty can have profound impacts on estimates of benefits, risks, costs, or all three. We can apply the Monte Carlo approach when we understand the range and likelihood of plausible values for the key variables well enough to characterize those values with a probability distribution. We can also use the approach when we can easily reproduce the analysis itself in a computerized algorithm. Monte Carlo analysis can be especially useful when multiple variables can potentially interact to establish the true character of the risk being studied.

Using data and knowledge developed through experience, we start by characterizing probability distributions for key input variables. For first approximations, it is often sufficient to assume relatively simple distributions for many types of phenomena (e.g., uniform, triangular, normal, or log-normal distributions). The distributions of any two variables, though, must be independent of each other. If the variables always move together—either in the same or opposite direction—the variables may not be independent and we must account for their joint relationship in the analysis. Monte Carlo simulation uses computers to draw a large number of (e.g., more than 1,000) 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 low probability outcomes. The analysis is then replicated for each sample draw of input variables, and a particular 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 decision makers useful insights about the likelihood of a given outcome (e.g., 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).

### Handling Uncertainty

In an ideal situation, data would be available for statistically estimating confidence intervals for benefit or cost estimates. Statistically estimating confidence intervals, however, is usually not possible. When data are available to make this possible, we develop ranges 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 (see Step 9 of the framework process described earlier).

# Case Studies

In this section, we present five examples of economic analyses that relate to the value of NMHS. These analyses span the entire range of estimation methods—from economic modeling through data analysis to subjective assessment. They also span a range of objectives. For instance, the objective of Case Study 1 is to estimate the possible magnitude of impacts from weather variability, as well as to indicate the sectors of the economy where those impacts are likely to be greatest. The objective of Case Study 3 is to provide a traditional assessment of the costs and benefits of a particular program.

## Case Study 1: Sensitivity of the U.S. Economy to Weather

**Reference**: Larsen, P.H., M. Lawson, J.K. Lazo, and D.M. Waldman, 2007: *Sensitivity of the US Economy to Weather*. Boulder, CO: NCAR.

### *Summary*

This study uses statistical analysis to estimate the degree to which economic output in states, economic sectors, and the overall U.S. economy depends on weather variables. Temperature- and precipitation-related weather variables are considered in the analysis. The authors conclude that total annual U.S. economic output can vary by as much as $260 billion depending on weather conditions.

In this analysis, the authors use output, by economic sector, for each of the 48 states in the continental United States over a period of 24 years, as basic data. Output is statistically related to inputs used—capital, labor, and energy—and to four measures of weather and weather variability—precipitation, variability of precipitation, heating-degree days, and cooling-degree days. The authors use a regression equation that incorporates both direct effects of the independent variables and interaction effects (in which output may depend on the product of pairs of independent variables).

From results of the regression analysis, the authors calculate “elasticities” of output with respect to inputs and weather variables. These numbers represent the percentage change in output attributable to a 1% change in the corresponding input or weather variable. These elasticities, calculated for each of 11 major sectors of the U.S. economy, show that weather-related variables have statistically significant effects on output in all these sectors.[10]

To assess the effect of weather variability on the economy, the authors conducted a sensitivity analysis. In this analysis, production inputs were set to their recent average values over the last 5 years of the estimation period. Weather data were then obtained for a 70-year period from 1931 to 2000. Using these weather data, the statistically estimated relationships between output, inputs, and weather were used to calculate the outputs that would be expected for each year’s weather, given current inputs and technology. These outputs, “predicted” by the statistically estimated equations, were then aggregated in various ways to show how weather affects economic output for each sector, for each state, and for the United States as a whole.

By aggregating predicted outputs across sectors for each state, the authors obtained an estimate of the sensitivity of state output to weather. This indicates that in absolute terms, California’s output is most sensitive to weather; the range of variation in California’s output is

---

[10] The 11 sectors are (1) agriculture; (2) communications; (3) construction; (4) finance, insurance, and real estate; (5) manufacturing; (6) mining; (7) retail trade; (8) services; (9) transportation; (10) utilities; and (11) wholesale trade.

estimated at $111.9 billion. In percentage terms, however, New York is most sensitive, with a range of variation in output of 13.5%.

By aggregating predicted outputs across states for each sector, estimates of sectoral sensitivity to weather variation were obtained. In absolute terms, the finance, insurance, and real estate sector is the most sensitive, with a range of variation of $132 billion. Percentage sensitivity was also calculated, and the investigators found that agriculture is highly sensitive to weather on a percentage basis. On this basis, however, mining is the most sensitive sector. Mining includes production of energy outputs, such as natural gas, whose price and demand may be highly sensitive to weather because these products are used for heating and cooling.

Finally, the researchers aggregated predicted outputs across states and across sectors to estimate the overall sensitivity of the U.S. economy to weather. This overall sensitivity is estimated to be $260 billion, or 3.36% of output. This is the range of output from the lowest predicted amount to the highest predicted amount for the 70 years of weather data used.

These results, which quantify the sensitivity of U.S. economic output to weather, suggest that there are significant benefits to weather forecasts. Forecasts have value if weather affects economic welfare and if it is possible to respond to forecasts in ways that mitigate the impacts of bad weather or capitalize on favorable weather. The contribution of this study is that it clearly shows that weather does have a significant effect on welfare as measured by economic output.

### *Methods Used*

This study uses data analysis, though the nature of the analysis here is somewhat different than it would be if this were a study to determine the difference that a forecast makes in observed economic outcomes. The data analysis here focused on quantifying the relationship between weather variables and economic outcomes, which serves to suggest the possible importance of weather forecasts.

### *Resources Used*

This work was data intensive and relied mainly on the collection of published data and econometric analysis. Data were obtained from a variety of government sources including the Bureau of the Census, the Department of Agriculture, the Labor Department, the Bureau of Economic Analysis, the Department of Energy, and the National Climatic Data Center. Data were compiled and adjusted in a spreadsheet using Microsoft Excel and analyzed using SAS.

The study required approximately 200 hours of work from the study leader, a professional economist, at a cost of approximately $40,000 over a time period of 2 years. A research assistant did the primary literature review, data collection, and econometric analysis over the course of a year at a cost of approximately $117,000. An econometrician and additional SAS programming and analysis were subcontracted at a cost of about $39,000 for a total project cost of approximately $196,000. With the methodology and programs developed for this project, it may be possible to undertake similar efforts for considerably less cost.

### *Data Requirements*

Data are critical to a study of this nature. The existence of national income accounting data and weather data, carefully collected by government agencies over many years, was essential for this study.

### *Economic Expertise Required*

For a project of this nature, the analysts must possess comprehensive expertise in statistical analysis. In-depth understanding of the economic models underlying the analysis is necessary to develop a valid statistical estimation approach. Familiarity with the relevant data—on national income accounting and weather—is also important.

## Case Study 2: The Economic Value of Temperature Forecasts in Electricity Generation

**Reference:** Teisberg, T.J., R.F. Weiher, and A. Khotanzad, 2005: The economic value of temperature forecasts in electricity generation. *B. Am. Meteorol. Soc.* **86,** 12, 1765–1771.

### *Summary*

This study estimates the cost savings from using 24-hour temperature forecasts to plan the next day's production of electricity in the United States. Such savings are possible because electric power can be generated by a variety of different types of generating units. In addition, these units typically have different production costs and lead times, as well as different operations costs once in production. With a good 24-hour temperature forecast, it is possible to make a better electricity demand forecast, and thereby reduce generation costs by choosing the best way to meet that electricity demand. This study's key finding is that the availability of 24-hour temperature forecasts produces annual cost savings in the United States of $166 million, relative to persistence temperature forecasts.

In this study, the authors needed to model complex economic behavior. Conceptually, three steps are involved in modeling the cost savings from temperature forecasts used by electricity generators. Representations must be made for (1) the relationship between temperature forecasts and electricity demand forecasts; (2) the selection of generation units to use, given forecasted electricity demand; and (3) the adjustments that must be made to deal with the inevitable discrepancies that will arise between the actual power demand and the power demand forecast used in selecting generating units. Because these are complicated decisions that electricity generators must make each day, decision tools have been developed to help.

A key study by Hobbs et al. (1999) estimated the cost savings in electricity generation that accrue from better electricity demand forecasts. In making this estimate, Hobbs and colleagues used a previously published "unit commitment model" for selecting generating units based on an electricity demand forecast. They also developed a "recourse model" to deal with discrepancies between forecasted and actual demand. Hobbs et al. used these models to estimate the cost savings in electricity demand as a function of the quality of electricity demand forecasts for four representative electricity systems. These systems were defined by two different configurations of generating units and two different patterns of electricity demand, one for a northern utility and the other for a southern one.

Building on the work of Hobbs et al. (1999), Teisberg et al. (2005) estimated the relationship between 24-hour temperature forecasts and electricity demand forecasts. For this analysis, they drew on another type of existing model, similar to that described in Khotanzad et al. (1995), which helps electricity generators forecast electricity demand based on a variety of factors, including temperature forecasts. Using this model, Teisberg and coworkers constructed temperature forecasts to represent different forecast accuracies, ranging from a "persistence" forecast (the next day's temperature will be the same as today's) to a perfect forecast (where the next day's temperature is precisely known in advance). These were used to determine the implications of these alternative temperature forecasts for the accuracy of electricity demand forecasts. Next, again drawing on the Hobbs et al. work, Teisberg et al. estimated the cost savings associated with these temperature forecasts for the four representative generating systems in the Hobbs study. Finally, these results were extrapolated to the United States as a whole. This was done by averaging the cost savings in the Hobbs et al. work across that study's two types of generating systems, and applying these averaged results to regional electricity generation amounts in the United States as appropriate for northern and southern demand patterns.

Teisberg et al. concluded that the overall annual electricity generation cost savings from using 24-hour temperature forecasts of current accuracy, relative to a persistence forecast, is $166 million. They also estimated that a 1% improvement in forecast accuracy would add $1.4 million to this annual savings, and that a perfect forecast would add $75 million to this savings. These numbers imply that the bulk of the potential savings from temperature forecasts has already been captured using forecasts of the current quality.

### *Methods Used*

These investigators used economic modeling methods, which involve representing the behavior of economic actors or systems with sets of mathematical relationships. If such models are to be useful in estimating the value of information, they must be specified in ways that allow weather information to play a role in the behavior being modeled. In this way, the model can be used with different information (i.e., amounts or types of information), to simulate the implications of these different information structures. This allows the economic benefits that result from different information structures to be estimated.

### *Resources Used*

This study was able to build on previous work, which substantially reduced the resources that would otherwise have been required to accomplish the study. Drawing on the previous work made it possible to estimate the cost savings from better information about electricity load or demand. Thus the remaining modeling required for the study was to build the relationship between the quality of weather information and the resulting quality of load information.

Modeling the relationship between weather information and load information was also simplified by the existence of models already in use by the electricity generating industry. In their daily operations, electricity generators routinely use models that forecast the next day's electricity load, and these models typically use next-day weather forecasts as one of the inputs from which the next-day load forecast is generated. Teisberg and coinvestigators used a model of this type to make the connection between weather information structures of interest to the researchers and the load forecasts that resulted.

The study required approximately 250 hours of work from the study leader, a professional economist, at a cost of approximately $30,000 over a time period of 4 years. This is the total effort involved from initial conception of the project design to completed publication in a leading, peer-reviewed meteorological journal. Approximately 60% of this time and effort was required to do the actual analysis and to write a first draft of the results; the remainder of the time and effort went into refining and publishing the paper in the peer-reviewed journal.

In addition to the cost for the lead economist, approximately $9,000 was used to fund the work of a coauthor with access to a commercial electricity load forecasting system as well as the data required to use this system to model the implications of alternative weather forecasts.

### *Data Requirements*

This study required data on electricity load and factors that can be used to forecast electricity load, including weather forecasts. Such data tend to be available for specific electricity generating companies, usually because those data were used in the initial development of the load forecasting system that the company would later use in its day-to-day operations.

For this study, the researchers identified the role that a commercial load forecasting system could play in the analysis, and then sought out someone with expertise with such systems. This individual, who became a coauthor of the final published paper, was in a position to supply the necessary data, as well as make the model runs to determine the implications of different weather forecasts for certain specific electricity generating companies in various locations around the United States. As a condition of using what would be considered proprietary company data for this study, the researchers were not allowed to reveal specific data or the names of the companies who owned the data.

### *Economic Expertise Required*

For a project of this nature, three kinds of expertise are necessary: (1) familiarity with the kinds of weather forecast information used to forecast electricity demand; (2) familiarity with the electric power generation industry; and (3) general expertise in the economics of the value of information.

## Case Study 3: Heat Watch/Warning Systems Save Lives: Estimating Costs and Benefits for Philadelphia 1995–98

**Reference:** Ebi, K.L., T.J. Teisberg, L.S. Kalkstein, L. Robinson, and R. Weiher, 2004: Heat watch/warning systems save lives: Estimating costs and benefits for Philadelphia 1995–98. *B. Am. Meteorol. Soc.* August, 1067–1073.

### *Summary*

This study examines mortality data for the city of Philadelphia during heat waves that occurred from 1995 through 1998. It finds that mortality was lower when authorities declared a heat wave warning and took actions to mitigate the effects of extreme heat. It estimates that during this 4-year period, 117 premature deaths from heat were prevented by heat wave warnings and the associated actions. The dollar benefit of these prevented deaths, estimated to be $468 million over 4 years, vastly exceeds the modest cost of the actions taken.

When Philadelphia experienced a severe heat wave in 1993, the Medical Examiner’s Office determined that at least 118 deaths resulted. Starting in 1995, Philadelphia implemented a heat watch/warning system to alert residents about dangerous conditions and set in motion a variety of mitigation actions. Because of the way that the heat wave warnings were actually issued, such warnings were not called on all days when potentially threatening conditions existed. As a result, mortality data from this period contain dangerous days when a heat wave warning was in effect, along with dangerous days when a warning was not in effect. This makes it possible to examine these dangerous days with statistical tools to determine whether warnings affected observed mortality.

For this statistical analysis, the investigators used mortality data for people aged 65 and older for a total of 210 days of potential heat danger (including the 3 days following each heat episode to account for the lag between a heat event and resulting mortality). Within this set of days, there were 21 days when a heat wave warning was in effect and 45 days (including lag days) when the warnings may have reduced mortality. Statistical analysis revealed that two variables were consistently correlated with observed mortality within this data set. One was the time within the summer season that the heat wave occurred (heat waves earlier in the season are more dangerous because people are not yet acclimated to the heat) and the other was whether or not a heat wave warning was in effect. The coefficient on the heat wave warning variable indicated that warnings tended to reduce mortality by about 2.6 lives on each day the heat wave warning was in effect (including the 3 days after the heat wave ended). The probability of a statistical result this positive occurring by chance, if warnings actually make no difference, is 8%. This is above the conventional 5% threshold for declaring a result statistically significant. Ebi et al. argue, however, that this is a situation where the potential benefits of warnings so vastly exceed their costs that a warning system is warranted unless there were compelling statistical evidence that warnings do not reduce mortality.

The study reviewed other published work on what people are willing to pay to avoid risks of dying, and how this WTP might change as people get older or their health declines. Based on this review, the researchers concluded that premature deaths within this over-65 age group should be valued at $4 million per death, implying that avoiding 117 heat-related premature deaths has a total value of $468 million.

When a warning is declared in Philadelphia, city authorities initiate a variety of mitigation actions. These range from making public announcements through television, radio, and newspapers that increase the public's awareness of dangerous heat conditions and suggest ways to deal with the heat, to increasing emergency medical service staffing to respond better to heat-related medical problems. Many of these steps have no direct cost, and those that do were estimated to have a cost of $10,000 per day, or a total cost of $210,000 for all the days when a warning was in effect during the study period. Relative to the estimated $468-million benefit of the system, this cost is so small as to be essentially negligible.

### *Methods Used*

These investigators used data analysis methods, which are applicable when a set of data exists that represents relevant consequences in the presence and absence of a particular factor of interest. In this case, the factor of interest was warnings, and because of the way decisions to declare warnings were made, warnings were sometimes issued and sometimes not issued during periods of potentially dangerous heat. This allows analysts to examine such data to see if the factor of interest—the existence of warnings in this case—has any effect on measured consequences.

### *Resources Used*

The data for this study had already been collected and assembled in spreadsheet form before the study began. The study itself involved developing a plan for data analysis, conducting that analysis, presenting the results in a paper, and seeing the paper through the review process to publication in a peer-reviewed journal. This process took about 2½ years.

Planning and executing the data analysis and writing the results required approximately 340 hours of time from a professional economist at a cost of approximately $42,000. The study leader spent time managing the project and contributing to the paper (writing and editing), and also spent lesser amounts of time in planning and oversight of reviews by other study participants, some of whom may have been paid as consultants.

### *Data Requirements*

Data were of central importance for this study. One of the coauthors (L. Kalkstein) had worked on heat-related health risks and mitigation systems—including the Philadelphia system—for many years. In the course of this work, he had gathered the data used in this study.

### *Economic Expertise Required*

For a project of this nature, two kinds of economic expertise are necessary: (1) expertise in the application of statistical techniques and (2) familiarity with the literature on the value of reductions in mortality risks.

## Case Study 4: Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector

**Reference:** Lazo, J.K., and L. Chestnut, 2002: *Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector.* Boulder, CO: Stratus Consulting.

### *Summary*

This study employed survey methods in which people were asked questions designed to reveal the values that they place on weather forecasts they use or on possible improvements to those forecasts. The study estimates that the total annual value of current weather forecasts to U.S. households is $109 per household, or $11.4 billion for the United States as a whole. For a package of possible improvements to current weather forecasts, the estimated annual value is $16 per household, or $1.73 billion for the entire nation.

Survey results indicated that people most wanted (1) improvement in 1-day forecast accuracy, followed (in descending order of importance) by (2) improvement in multiday forecast accuracy, (3) increased geographic detail, and (4) increased frequency of forecast issuance.

The questions used in this survey were designed in a process that began with focus group discussions. From this, the investigators designed, tested, and refined an initial survey instrument in a series of one-on-one interview sessions. During these sessions, the interviewers remained with the interviewees as they were completing the survey. The interviewees verbally expressed their thoughts as they took the survey, which gave insight into how survey respondents would understand and interpret the survey questions and how those questions could be improved.

Next, 84 subjects completed a pilot survey in a single location. At this point external survey experts were asked to evaluate the survey and the pilot study results and suggest any additional refinements. Finally, the evolving survey instrument was tested again in a different region of the country to determine whether there were any location-related issues that needed to be addressed.

The final survey was given to groups of individuals in nine cities around the United States. Each of these cities was within one of the nine National Climatic Data Center regions to sample across geographic regions with differing types of weather. Within each geographic region, the specific location for the survey was chosen with an eye to sampling across a range of social, economic, and demographic variation.

Individuals were recruited to take the survey at a central site not more than 7 to 10 miles from the participant’s home. Recruitment of survey respondents began with random digit dialing of telephone numbers within each survey city. Approximately 1,500 numbers were dialed in each location. Many of these numbers were not viable (e.g., fax numbers and disconnected numbers), and many individuals refused to participate, which is common. Ultimately, about 40 recruits took the survey at each of the nine sites. Completing the survey typically took from 30 minutes to 1 hour, and participants were paid $40 each for their time.

Survey results indicated that a household’s valuation of a package of possible forecast improvements is related to that household’s social, economic, and demographic characteristics, such as income, education, and time spent outdoors at work or in recreation. Participants placed the most value on increasing next-day forecast accuracy. Relatively little value was placed on increasing forecast frequency, but this may be because the survey focused on day-to-day weather forecasts, rather than on severe weather where update frequency can be critically important. Survey participants were also asked if the forecast services they receive now are worth what they pay in taxes for these services. By varying the amount participants were told they paid in taxes, it was possible to estimate how much value is placed on current weather forecast services. This includes the entire range of forecast services people use directly or indirectly, such as day-to-day weather forecasts, severe weather warnings, and marine and aviation forecasts. Also, this value does not distinguish between forecast services provided publicly and privately (e.g., through The Weather Channel).

### *Methods Used*

This study used survey methods, which involved asking carefully crafted questions of carefully chosen individuals in order to elicit from them the values they place on weather forecasts. Questions asked were of two types—stated choice and stated value. In stated choice, people are asked which of two or more alternatives they would most prefer. In stated value, people are asked how much they would be willing to pay for specified alternatives. Econometric analysis was used in data analysis and to derive value estimates.

### *Resources Used*

Researchers at Stratus Consulting in Boulder, Colorado, led this study over several stages of survey design, survey testing and revision, primary data collection, data entry, econometric modeling and data analysis, and reporting. Additional resources used included consultation with survey design experts and employment of commercial survey research organizations to recruit subjects and implement the data collection. The approximate total cost of this study over the course of 3 years—including staff time, survey design and implementation, along with subcontracts to meteorology experts—was probably close to $400,000. The survey instrument developed in this study could be adapted for other similar efforts, providing a significant cost savings in future studies of households' values for weather information.

### *Data Requirements*

This research can be characterized as primary data collection, although the National Climatic Data Center supplied a small amount of existing meteorology data.

### *Economic Expertise Required*

For a project of this nature, three kinds of economic expertise are necessary: (1) expertise in survey design for eliciting valuations, (2) expertise in statistical analysis of survey results, and (3) general familiarity with weather forecast attributes and forecasting capabilities.

## Case Study 5: Benefit Analysis for NOAA High Performance Computing System for Research Applications

**Reference**: Lazo, J.K., M.L. Hagenstad, K.P. Cooney, J.L. Henderson and J.S. Rice, 2003: *Benefit Analysis for NOAA High Performance Computing System for Research Applications.* Boulder, CO: Stratus Consulting.

### *Summary*

This study estimates the benefits to be gained from acquiring new supercomputers to use in research that supports improvements in NWS weather forecasting as well as a variety of other programs. The investigators reviewed previous work done to estimate the benefits of weather forecasts, especially the benefits of improvements in weather forecasts. In large part, the purpose of this review is to identify the types of benefits that are either largest or easiest to use (or both), because these are the key types of benefits on which to focus in assessing the advantages of supercomputer acquisition.

For reasons of data availability, the researchers focused primarily on benefits arising from everyday weather forecasts in the household sector; however, they also estimated benefits in several agricultural sectors (orchards, alfalfa, and winter wheat) and those arising from avoided weather-related fatalities. The study concludes that adding the supercomputers would produce benefits with PVs of $69 million in the household sector, $26 million in the agricultural sectors considered, and $21 million from avoided weather-related fatalities.

The benefits from supercomputers are inherently difficult to assess because these computers are used in research programs designed to produce better systems for forecasting weather. By their nature, primary research activities are one-time events, so there can be no historical record available to predict the outcome of any prospective research program. And because the inputs to research activities include more than just supercomputing capability, the specific contribution of supercomputers is difficult to discern. These issues make it more difficult to assess the benefits of supercomputers used in research than, say, the benefits of a daily weather forecast that is produced and used repeatedly by easily identified individuals and industries.

To deal with these issues, these investigators adopted a somewhat different approach to the problem at hand. They conducted interviews with National Oceanic and Atmospheric Administration (NOAA) personnel to generate a subjective assessment of the relative importance of supercomputing to the research program. This interview process resulted in an assessment that having new supercomputers would add about 5% to the output of the overall research effort. The researchers then subjectively estimated the amount of improvement in weather forecast quality that would result from the research effort, arriving at an estimate of a 2.5% to 10% improvement in weather forecast accuracy with a base case amount of 4.5%.

Next, the investigators drew on their early literature review to obtain estimates of the dollar benefits of improvements in weather forecast accuracy. For the household sector, an earlier study (Lazo and Chestnut 2002; Case Study 2) contains a very useful estimate of the WTP of households for improvement from current forecast accuracy to (near-) perfect forecast accuracy. With some additional assumptions about the amount of time over which accuracy improvements would be forthcoming and about the discount rate, the researchers arrived at a PV estimate of

$69 million. Similarly, for the crops considered, the authors used existing estimates of the benefits of perfect forecasts to generate a PV of $26 million.

For weather-related fatalities, the literature does not contain estimates of the reduction in fatalities that might result from improved weather forecasts. As a result, the investigators took an illustrative approach to this study element. To provide a rough sense of the magnitude of benefits, the study assumes that improvements in weather forecasts from supercomputers might reduce weather-related fatalities by 10%. Using the same assumptions as for households and the three agricultural sectors, the authors arrived at a PV estimate of $26 million.

### *Methods Used*

This study used literature review and subjective assessments to fill in key missing data. The literature was reviewed to determine the most important types of benefits on which to focus and to identify existing estimates that could be used in the study. Subjective assessments by knowledgeable experts were used to obtain certain key data that are not available in the literature and that, in some cases, cannot be obtained by analytical methods.

### *Resources Used*

This study was able to build on previous work that substantially reduced the resources that would otherwise have been required to accomplish the study. From the previous work, these researchers were able to estimate the benefits to the U.S. household sector of improvements in everyday weather forecasts and of (near-) perfect forecasts in certain agricultural activities, along with reductions in total weather-related fatalities in the United States. The total cost of this study, which was performed over 3 calendar months, was about $24,000. This did not include the value of the time of NOAA personnel during the expert interviews.

### *Data Requirements*

The study required data on the contribution of supercomputers to NOAA research efforts, the contribution of research to improvements in weather forecasts, and the benefits of improved weather forecasts to individuals and industries that use them. Some of these data were readily available in published literature, and some of the information had to be produced in the course of the study.

### *Economic Expertise Required*

For a project of this nature, critical expertise includes an understanding of how benefits are estimated and a comprehensive familiarity with the existing benefit estimation literature. In addition, expertise in eliciting reasonable informed judgments from knowledgeable experts is essential.

# Resources

Some useful resources on economic analysis and relevant literature are listed here. If you are aware of other relevant resources please contact the lead author (Jeff Lazo) at lazo@ucar.edu to have these included in future editions of this report or in online resources to be developed.

***US Environmental Protection Agency***: "EPA's Guidelines for Preparing Economic Analyses establish a sound scientific framework for performing economic analyses of environmental regulations and policies. They incorporate recent advances in theoretical and applied work in the field of environmental economics. The Guidelines provide guidance on analyzing the economic impacts of regulations and policies, and assessing the distribution of costs and benefits among various segments of the population, with a particular focus on disadvantaged and vulnerable groups." http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html#howproduced

***The State of Queensland - Queensland Treasury:*** "The Project Assurance Framework sets the foundation for ensuring that project management is undertaken effectively across the Queensland Public Sector, and that the Government achieves value for money from its significant investment in project activity." http://www.treasury.qld.gov.au/office/knowledge/docs/project-assurance-framework/. This includes a guide to BCA which is available in a pdf format at: http://www.treasury.qld.gov.au/office/knowledge/docs/project-assurance-framework/cost-benefit-analysis-guidelines.pdf

***US Federal Emergency Management Agency (FEMA):*** "FEMA has developed a suite of Benefit-Cost Analysis (BCA) software for a range of major natural hazards: earthquake, fire (wildland/urban interface fires), flood (riverine, coastal A-Zone, Coastal V-Zone), Hurricane Wind (and Typhoon), and Tornado." http://www.fema.gov/government/grant/bca.shtm

***Benefit-Cost Analysis Center of the Daniel J. Evans School of Public Affairs at the University of Washington:*** "The core aim of the Center will be to help improve the use of benefit-cost analysis, BCA, which involves not only recognition of its limitations and an expansion of its use where appropriate, but also the improvement and standardization of its methodology so that BCA can be more usefully applied. This will involve working with a variety of government agencies towards greater agreement on standards to be followed in applying BCA. Another central purpose of the Center will be to disseminate information to government agencies and to government and academic employees about the use and misuse of BCA and to help them improve its use." http://tools.evans.washington.edu/research/bcac/

***NOAA Economics & Social Science website:*** "An element of the Office of Program Planning and Integration (PPI) at NOAA headquarters in Silver Spring, Maryland. This site is intended to be a resource for those within NOAA as well as those outside of it to communicate to the importance of Economics at NOAA and share the Social Science Perspective that we believe is essential for the world's leading Earth science agency. The Library that we have established is likely to be of most value to the majority of our visitors. In it you will find a collection of papers, articles and analyses on the socioeconomic impact of oceanic and atmospheric science and related technologies." http://www.economics.noaa.gov/

***Ecosystem Valuation Website:*** Describes how economists value the beneficial ways that ecosystems affect people – ecosystem valuation. It is designed for non-economists who need answers to questions about the benefits of ecosystem conservation, preservation or restoration. It provides a clear, non-technical explanation of ecosystem valuation concepts, methods, and applications. http://www.ecosystemvaluation.org/index.html

**Books:**

A large published literature exists on theory, methods, and applications of benefit-cost analysis. We list a few books here simply as examples.

Earl, Clifford J. 2003. Cost-Benefit Analysis: Just the Basics! 244 pages. Resource Management Systems, Inc. ISBN-10: 0970773331 / ISBN-13: 978-0970773333.

> "This is a step-by-step "how to" guide for anyone tasked to prepare a cost-benefit analysis for a project or acquisition. Designed for technical and business pros with little or no economics or finance training. Includes real-world examples and templates. Suitable for business and government use."[11]

Boardman, Anthony E., David Greenberg, Aidan Vining, and David Weimer. 2000. Cost-Benefit Analysis: Concepts and Practice. Prentice Hall; 2nd edition. 526 pages. ISBN-10: 0130871788 / ISBN-13: 978-0130871787.

> "A college textbook showcasing the theories and techniques of cost-benefit analysis. Includes updated information and examples applying the theories and techniques presented. Includes a new chapter on social discount rate."

Gramlich, Edward M..1997. A Guide to Benefit-Cost Analysis. 246 pages. Prentice Hall.ISBN-10: 0130747572 / ISBN-13: 978-0130747570.

> "Updates the author's previous work with new material and examples--including acid rain, minimum wages, public employment, matching grants, national defense, and so on. Shows how the logic of benefit-cost analysis can be applied to a wide range of policy measures."

---

[11] Descriptions of these books were copied verbatim from: http://www.info-linkllc.com/cost-benefit_analysis_basics_products_m.htm.

# References

Baumol, P., and A. Blinder, 2000: *Economics, Principles and Policy*. New York: Harcourt Colleges Publishers.

Desvousges, W.H., M.C. Naughton, and G.R. Parsons, 1992: Benefit transfer: Conceptual problems in estimating water quality benefits using existing studies. *Water Resour. Res.* 28, 3, 675–683.

Doering, Otto C., III, 2007: The Political Economy of Public Goods; Why Economists Should Care. Presented as the Presidential Address at the AAEA Annual Meeting. Portland, Oregon, July 30.

Ebi, K.L., T.J. Teisberg, L.S. Kalkstein, L. Robinson, and R. Weiher, 2004: Heat watch/warning systems save lives: Estimating costs and benefits for Philadelphia 1995–98. *B. Am. Meteorol. Soc.* August, 1067–1073.

EPA (U.S. Environmental Protection Agency), 2000: *Guidelines for Preparing Economic Analyses*. EPA 240-R-00-003. Washington, DC: EPA.

Hobbs, B. F., et al., 1999: Analysis of the value for unit commitment decisions of improved load forecasts. *IEEE T. Power Syst.* **14,** 4, 1342–1348.

Khotanzad, A., et al., 1995: An adaptive modular artificial neural network hourly load forecaster and its implementation in electric utilities. *IEEE T. Power Syst.* 10, 3, 1716–1722.

Larsen, P.H., M. Lawson, J.K. Lazo, and D.M. Waldman. 2007: *Sensitivity of the US Economy to Weather.* Boulder, CO: NCAR.

Lazo, J.K., and L. Chestnut, 2002: *Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector.* Boulder, CO: Stratus Consulting.

Lazo, J.K., M.L. Hagenstad, K.P. Cooney, J.L. Henderson and J.S. Rice, 2003: *Benefit Analysis for NOAA High Performance Computing System for Research Applications.* Boulder, CO: Stratus Consulting.

Nicholson, W., 1992: *Microeconomic Theory: Basic Principles and Extensions.* Orlando, FL: The Dryden Press.

OMB (Office of Management and Budget), 1992: *Guidelines and Discount Rates for Cost Benefit Analyses of Federal Programs.* Circular Number A-94, Appendix C. Washington, DC: OMB.

Raucher, et al., 2007: *Establishing a Benefit-Cost Framework for Evaluating Biosolids Management Options*. Alexandria, VA: Water Environment Research Foundation (WERF).

Teisberg, T.J., R.F. Weiher, and A. Khotanzad, 2005: The economic value of temperature forecasts in electricity generation. *B. Am. Meteorol. Soc.* **86,** 12, 1765–1771.

Zillman, J.W., 2005: Economic Aspects of Meteorological Services. Paper prepared for the Bureau of Meteorology, WMO Workshop on Public Weather Services, Melbourne, Australia, May 23–27.