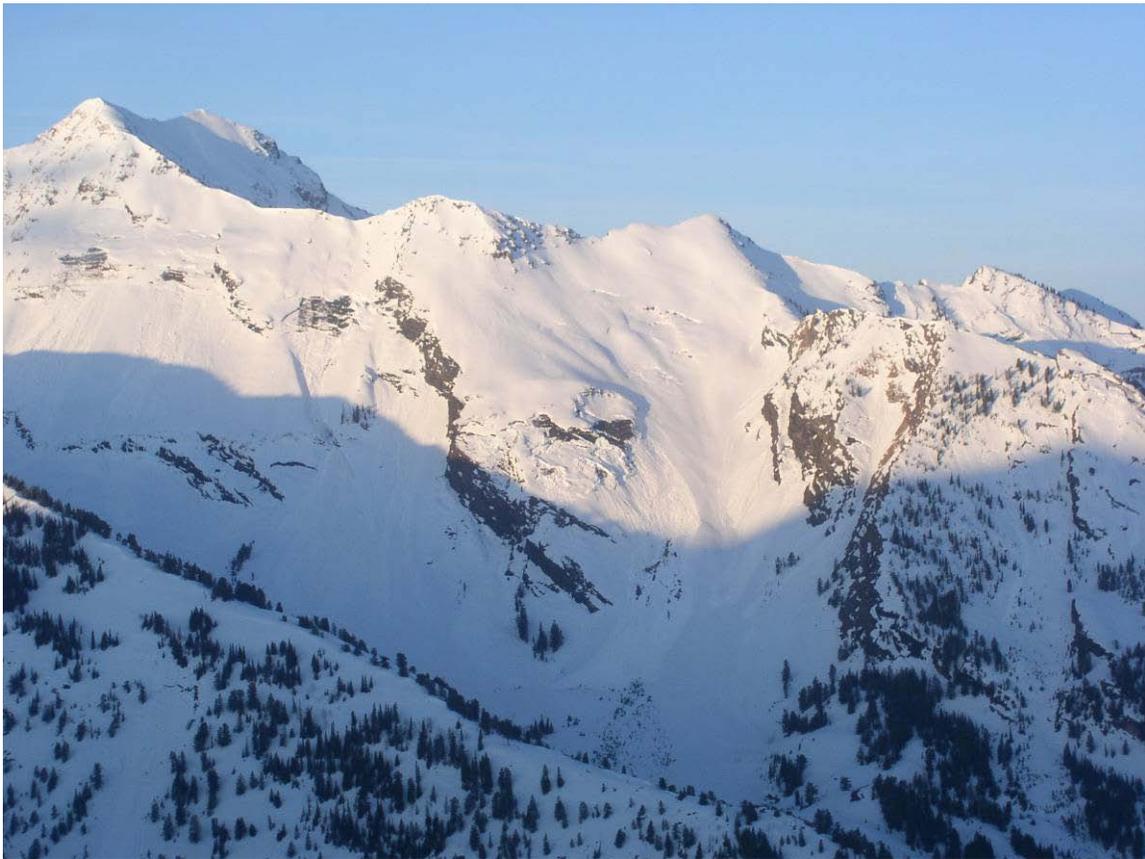


A Measure of Snow: Case Studies of the Snow Survey and Water Supply Forecasting Program



NRCS Photo

September 2010

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or a part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410 or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

Table of Contents

ACKNOWLEDGMENTS.....	3
SUMMARY	7
CHAPTER 1. INTRODUCTION	9
THE VALUE OF SNOW SURVEY AND WATER SUPPLY FORECASTING DATA	10
CONTENT OF SUBSEQUENT CHAPTERS	11
CHAPTER 2. PUBLIC GOODS AND SNOW SURVEY AND WATER SUPPLY FORECASTING	13
PUBLIC GOODS THEORY	13
ALTERNATIVE MODELS FOR SNOW SURVEY AND WATER SUPPLY FORECASTING SYSTEMS	15
SOCIAL WELFARE ECONOMICS	16
CHAPTER 3. BENEFICIARIES AND USERS	19
PRIMARY BENEFICIARIES AND USERS OF SNOW SURVEY AND WATER SUPPLY FORECASTING DATA	19
PRIMARY TYPES AND METHODS OF USE OF SNOW SURVEY AND WATER SUPPLY FORECASTING DATA	21
CHAPTER 4. PRIVATE INDUSTRY	25
IRRIGATED AGRICULTURE	25
<i>Irrigation Districts and Canal Companies</i>	26
<i>Individual Farmers</i>	26
AGRICULTURAL CONTRACTING	36
CROP INSURANCE RISK MANAGEMENT	37
RECREATION	37
<i>The Ski Industry</i>	37
<i>Power Boating, the Houseboat Industry, and Other Reservoir-Based Recreation</i>	38
<i>River Running</i>	39
FINANCE AND BANKING	42
<i>Risk Management Related to Agricultural Loans</i>	42
<i>Federal Reserve Board</i>	42
<i>Commercial News Media</i>	42
CHAPTER 5. GOVERNMENT	45
FEDERAL AGENCIES	45
<i>U.S. Department of Agriculture</i>	45
<i>U.S. Army Corps of Engineers</i>	45
<i>U.S. Bureau of Reclamation</i>	47
<i>National Weather Service</i>	51
<i>USDA Forest Service</i>	53
STATE AGENCIES	54
<i>Idaho Department of Water Resources</i>	54
<i>State of Oregon</i>	55
<i>Utah Division of Emergency Services and Homeland Security</i>	56
LOCAL GOVERNMENTS	57
<i>Uintah County, Utah</i>	57
<i>Cedar City, Utah</i>	58
<i>Blaine and Lincoln Counties, Idaho</i>	59

CHAPTER 6. PUBLIC UTILITIES	61
POWER GENERATION	61
<i>Bonneville Power Administration</i>	61
<i>Idaho Power</i>	62
NATURAL GAS	64
<i>Intermountain Gas</i>	64
M&I WATER SUPPLY MANAGEMENT	65
<i>Denver Water Board</i>	66
CHAPTER 7. EDUCATION AND RESEARCH	69
UTAH WATER RESEARCH LABORATORY	69
CHAPTER 8. PRIVATE CITIZENS	71
CHAPTER 9. MULTIPLE-CATEGORY ENTITIES	73
COMMUNITY OF OAKLEY, IDAHO	73
TRUCKEE RIVER WATERSHED WATER USERS	75
IDAHO WATER USERS ASSOCIATION	77
COLORADO RIVER BASIN IN 1983	78
CHAPTER 10. COMPARISON OF ALTERNATIVE FUNDING AND OPERATION FORMATS ...	81
INTRODUCTION TO ALTERNATIVES	81
<i>Alternatives Eliminated from Detailed Analysis</i>	81
<i>Alternatives Considered</i>	82
COMPARISON OF ALTERNATIVES	83
<i>Evaluation in Terms of Public Goods Theory</i>	84
<i>Evaluation in Terms of Science</i>	85
<i>Evaluation in Terms of Social Welfare</i>	86
<i>Evaluation in Terms of the Perpetuation of Snow Survey Operations</i>	87
SUMMARY COMPARISON OF ALTERNATIVES	87
CHAPTER 11. CONCLUSION	91
INTRODUCTION TO SUMMARY ECONOMIC ANALYSIS	91
ECONOMIC VALUE OF THE PROGRAM	91
MARKET AND NON-MARKET BENEFITS	91
<i>Directly Calculated Market Benefits</i>	91
<i>Estimated Market Benefits</i>	93
<i>Other Market Benefits</i>	96
<i>Non-Market Benefits</i>	96
<i>Summary of Benefits</i>	96
CONCLUSION	100
REFERENCES	101

ACKNOWLEDGMENTS

Many individuals and organizations contributed to the content included in this report or assisted in its preparation. Without their efforts, this study could not have been completed, and their contributions are gratefully acknowledged. The names of many who assisted in the completion of this study do not appear on the list below. Thanks to them as well.

Principal Researcher and Author

Julie A. Suhr Pierce, NRCS, Utah

Contributors

Ron Abramovich, NRCS, Idaho
Arthur Armour, U.S. Army Corps of Engineers
David Buland, NRCS, Central National Technology Support Center
Tom Carroll, National Weather Service, Minnesota
Sylvia Gillen, NRCS, Utah
Mike Gillespie, NRCS, Colorado
Dan Greenlee, NRCS, Nevada
David Grider, USDA Forest Service
Randy Julander, NRCS, Utah
Jon Lea, NRCS, Oregon
Bruce Newton, NRCS, West National Technology Support Center
Phil Pasteris, NRCS, National Water and Climate Center (retired)
Scott Pattee, NRCS, Washington
Ryan Pierce, NRCS, Utah
Jared Richmond, Student Intern, University of Utah
Jerry Schaefer, NRCS, Montana
Michelle Schmidt, National Weather Service, Colorado Basin River Forecast Center
Sara Schmidt, NRCS, Washington, DC
Felix Spinelli, NRCS Washington, DC
Nathaniel Todea, NRCS, Utah
Ed Vidmar, U.S. Bureau of Reclamation
NRCS, National Water and Climate Center Staff
 Jan Curtis
 Dave Garen
 Laurel Grimsted
 Jolyne Lea
 James. Marron
 Tom Pagano
 Tom Perkins

Editors, Reviewers, and Administrative Staff

Mark Bushman, NRCS, Washington DC
Dee Cummings, NRCS, Utah
Denis Feichtinger, NRCS, Idaho
Noel Gollehon, NRCS, Washington, DC
Marie Gonnella, NRCS, Utah
Melanie Green, NRCS, Utah
Claudia Hoeft, NRCS, Washington, DC
Stacy Mitchell, NRCS, West National Technology Support Center
Phil Pasteris, NRCS, National Water and Climate Center (retired)
Jerry Schaefer, NRCS, Montana

Individuals Interviewed for the Study

Amir Eshraghi Azar, Research Associate, City University of New York
Julie Ammann, U.S. Army Corps of Engineers
Terry L. Bingham, Bureau of Homeland Security, State of Idaho
Jay P. Breidenbach, National Weather Service, Idaho
Chris Cutler, U.S. Bureau of Reclamation
Steve Daly, U.S. Army Corps of Engineers, New Hampshire
Bryan Dangerfield, City of Cedar City, Utah
Frank Gehrke, State of California Cooperative Snow Survey
Marianne Hallet, NRCS, California
Roger Hansen, U.S. Bureau of Reclamation, Utah
Cathy Hlebechuk, U.S. Army Corps of Engineers
Jagath Kaluarachchi, Utah Water Research Laboratory, Utah State University
Michael Loring, U.S. Bureau of Reclamation
Kent C. McBride, Sheriff, Lincoln County, Idaho
Bryan McInerney, National Weather Service, Utah
Mac McKee, Director, Utah Water Research Laboratory, Utah State University
Jerry Miller, U.S. Bureau of Reclamation Utah (retired)
Wally Otto, Tualatin Irrigation District
Ray Owens, Upper Sevier River Commission
James Porter, New York City Snow Survey
Dallas Riegle, Salt River Project, Arizona
Robert Steger, Denver Water Board
David R. Vallee, National Weather Service, Northeast River Forecast Center
Jeane Wallace, National Weather Service, Northeast River Forecast Center
Kit Wareham, City Engineer, Cedar City, Utah
Steven Weiser, Bureau of Homeland Security, State of Idaho

Organizations Participating in Interviews for the Study

A&B Irrigation District
Alta Ski Resort

American Falls Irrigation District
Anheuser-Busch Corporation
Aspen/Snowmass Mountain Resort
Bogus Basin Ski Resort
Bonneville Power Administration
Burley Irrigation District
Department of Economics, Utah State University
Idaho Outfitters and Guides Association
Idaho Bureau of Homeland Security
Idaho Department of Water Resources
Idaho Power
Idaho Water Users Association, Inc.
Intermountain Gas Company
Jackson Hole Mountain Resort
Milner Irrigation District
Minidoka Irrigation District
Northside Canal Company
PacifiCorp
Salmon Falls Canal Company
Sevier River Water Users Association
Snowbird Mountain Resort
State of Oregon Emergency Management Division
State of Utah Emergency Services
TV6, Boise, Idaho
Twin Falls Canal Company
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
Weber River Water Users Association
Various River Running Outfitters

**Snow Survey and Water Supply Forecasting Program State Conservationist
Advisory Committee**

Noller Herbert, NRCS, Washington, DC
Claudia Hoeft, NRCS, Washington, DC
Sylvia Gillen, NRCS, Utah
Allen Green, NRCS, Colorado
Michael Strobel, NRCS, National Water and Climate Center
Dave White, NRCS, Montana

Additional Support

Laurel Grimsted, NRCS, National Water and Climate Center
Garry Schaefer, NRCS, National Water and Climate Center
Steven Schuyler, NRCS, Idaho
Dave Thackeray, NRCS, Washington, DC

SUMMARY

Snow depth and snow water content data have been collected and disseminated throughout the Western United States for over 100 years. Early Snow Survey and Water Supply Forecasting data were gathered through the efforts of university scientists. In 1935, the Soil Conservation Service (SCS) was given \$36,000 to establish a formal cooperative Snow Survey and Water Supply Forecasting (SSWSF) Program. The agency was charged with the responsibility for “conducting Snow Survey and Water Supply Forecasts and forecasting of irrigation water supplies.” The new program would also develop consistent methods for measuring snow and reliable models for water supply forecasting.

Using a case study approach, this report assesses the various uses of data gathered and published by the SSWSF Program and estimates the value of those data in terms of both the market and non-market values of the information. Additionally, it evaluates the relative merits of maintaining the program as a publicly funded program as opposed to privatizing the program.

This study finds that the SSWSF Program is generating both market and non-market benefits to the U.S. economy and to U.S. society as a whole that are worth significantly more than the cost of the program. Should climate variability increase—as is expected by many of those interviewed in the course of completing this study, and as current climate research strongly suggests—the value of the information provided by the SSWSF Program will increase accordingly.

With adequate time and budget, it would be possible to define the benefits to other users and beneficiaries of the information not included as case studies in this analysis. Also, additional, more thorough modeling could be undertaken in an effort to understand the more complex impacts of changes in agricultural operations and other industry activities that occur in response to SSWSF Program data. Absent those additional analyses, it will suffice to say that, at a minimum, the program more than pays for itself in terms of dollar-valued economic benefits, and the program also generates significant non-market benefits in public safety, recreation, and other non-monotized benefits. Further study would shed more light on these topics as well.

For an Executive Summary of this report, including selected case studies, see a summary report based on this study published by the Natural Resources Conservation Service (NRCS) in November 2008. It is available via the NRCS Web site.

CHAPTER 1. INTRODUCTION

With the pioneering work of University of Nevada scientist Dr. James E. Church in 1906, snow depth and snow water content data have been collected and disseminated throughout the Western United States for over 100 years. Early SSWSF data were gathered through the efforts of university scientists. In 1935, the U.S. Department of Agriculture's (USDA) SCS, now NRCS, was given \$36,000 to establish a formal cooperative SSWSF Program. The agency was charged with the responsibility for "conducting Snow Survey and Water Supply Forecasts and forecasting of irrigation water supplies." The new program was also tasked with developing consistent methods for measuring snow and reliable models for water supply forecasting.

The SSWSF Program is designated *cooperative* because it operates with assistance from, and in cooperation with, both public and private entities that have a stake in ensuring that consistent and reliable water forecasts are readily available to cooperators and water managers. These entities fund a portion of the costs for the SSWSF Program activities when they have a specific interest in obtaining snowpack, water content, and soil moisture data about a specific geographic location. Primary among these entities are producers in the agricultural industry, both large and small, whose needs for water supply forecasts constitute the central purpose for the establishment of the SSWSF Program.

The NRCS SSWSF Program has grown into a network of more than 900 manually measured snow courses and over 750 automated Snowpack Telemetry (SNOTEL) weather stations in 12 Western States, including Alaska. The program now issues streamflow forecasts for over 740 locations in the West. The program issues three primary types of data: snow course, SNOTEL, and water supply/streamflow volume. These data, and related reports and forecasts, are made available—mostly in real time—to private industry; Federal, State, and local government entities; and private citizens via extensive Web pages and many other primary and secondary channels of distribution.

This study was conducted in order to achieve two objectives: first, to assess the various uses of data gathered and published by the SSWSF Program and then estimate the value of those data in terms of both the market and non-market values of the information; and second, to evaluate the relative merits of maintaining the program as a publicly funded program as opposed to privatizing it.

With adequate funding and time, it would be possible to establish a reasonably accurate economic value for the program as a whole within the U.S. economy. Absent the availability of those resources, a more limited approach was necessary. Accordingly, the economic analysis was conducted using a "case studies" approach.

THE VALUE OF SNOW SURVEY AND WATER SUPPLY FORECASTING DATA

It is crucial to state at the outset that this report does not concern the value of either snow or water *per se*. Rather, it addresses the value of *timely, accurate information about* snow and future water supplies. It is also important to mention that whatever value the program provides to society today will increase over time as climate variability increases. According to researchers from multiple U.S. and international agencies, research centers, and academies, changes in the world's climate have resulted in a loss of predictability in weather, precipitation, and water transport and accumulation patterns (Mille et al., 2008). This loss of predictability means that the mathematical, probabilistic models used in the past—which were based on fairly stable historic patterns and which served as the basis for modern water system design and water management modeling—are in danger of losing their predictive value. Fluctuations in water-cycle patterns are at risk of becoming too unpredictable for current regional-level models to provide a means of reducing risk. Instead, new models must be developed that are based on detailed representations and localized data on existing and dynamic water systems, real surface and groundwater processes, and actual water users. Continuity of data is crucial to establishing new models that can incorporate and respond to a widening range of observations and increasing degree of stochasticity in weather and climate events. The snowpack and water supply data-gathering system of the SSWSF Program has the potential to provide important components of the needed continuity of information. More important, as randomness increases, real-time, localized data will emerge as an absolutely essential element in any water-management decision-making process.

From a fundamental standpoint, the value of the information generated by the SSWSF Program lies in the contribution it makes to the decision-making process. Information produced by the program feeds into four primary types of decisions:

1. Long-term strategic-planning decisions;
2. Logistical, tactical, and operations planning decisions;
3. Short-term planning decisions; and
4. Immediate, reactive decision-making.

Long-term strategic plans drive logistical, tactical, and operations planning, which in turn drive short-term planning and, consequently, routine operations decisions. When situations arise which have not been anticipated either in the long-term or short-term planning process—especially when these situations involve public safety—immediate reactive decision-making must take place. In those cases, the availability and accuracy of data can sometimes be a matter of life and death for members of the benefiting public.

There are two types of water-management scenarios within which the planning and decision-making processes take place. First and foremost is the reservoir-management scenario. The majority of beneficiaries and users of SSWSF data gain their benefits through the ability to manage their public or private water-storage facilities and their

associated water-distribution systems. Second is the case where there is no water storage facility involved and the snowpack itself serves as the water storage. In some of these situations, for example the case for an irrigation system with no water storage, the central benefit lies in knowing approximately how far into the irrigation season an adequate water supply will be available. In the case of public safety agencies, the central benefit lies in being able to anticipate the volume and timing of the peak of spring snowmelt and runoff so as to prepare for any necessary flood protection measures.

Another dimension in these decision-making contexts and scenarios is the overall status of the water supply in terms of volume. In common terms, this dimension can be divided into three rough potential circumstances:

1. Below the average amount of water (“short”);
2. An average amount of water (“normal”); and
3. Above the average amount of water (“high”).

Any specific entity can and often must define for itself what each of these three water supply circumstances actually *is* from its perspective (such as how many seasonal or annual acre-feet of runoff are considered “normal” by a municipal water reservoir system). Generally speaking, in an effective strategic planning process an organization or agency will analyze prospective future conditions and decide ahead of time how they will respond to various circumstances that might be expected to arise in the future. In the case of the SSWSF Program, a data user might make decisions far ahead of time as to how they will respond in the short-term to each of these three water supply circumstances as they arise. These strategic decisions will drive monthly, weekly, and daily operations.

The means by which SSWSF data are accessed, the methods by which the data are incorporated into the decision-making process, and the overall value of the data to users depend on the operational time horizons as well as the purpose and circumstances surrounding the planning and decision-making processes of the various entities that use the data. The more accurate and consistent the data generated by the program, the more useful and beneficial it is in making both short- and long-term decisions. Recent climate data have shown that climate variability is increasing over the recent past, resulting in more extreme temperature changes, more volatile weather patterns, and fewer historically “normal” years in terms of precipitation amounts and snowmelt timing. These factors make it more important than ever to obtain accurate, consistent, and timely snowpack and water supply forecast data.

CONTENT OF SUBSEQUENT CHAPTERS

Chapter 2 presents the basic concepts of public goods analysis and social welfare economics. This chapter includes a comparison between the national SSWSF Program and two existing snowpack data collection systems that use alternate approaches to SSWSF work and data distribution. In comparison with the readily available “public good” approach taken by the NRCS SSWSF Program, these two systems—the New York

City snowpack data system and the California Cooperative Snow Surveys Program, in which NRCS participates as a partner—provide examples of different approaches to funding a SSWSF system and sharing the generated data.

Chapter 3 consists of an outline and explanation of the basic categories of beneficiaries and users of SSWSF data. These include private industry, government agencies and other government entities, public utilities, educational and research institutions, private citizens, and entities that fit into multiple user-group categories. The same chapter provides an overview of the primary ways in which these beneficiaries use information generated by the SSWSF Program.

The following six chapters present a variety of case studies showing how specific businesses, organizations, agencies, and individuals use and benefit from SSWSF data. Within these case studies, specific dollar values of benefits to particular data users are calculated where possible and meaningful, and these specific values are then used to extrapolate outward and estimate total potential dollar benefits to the applicable category of beneficiaries. These benefits are evaluated within a risk and uncertainty framework, taking into consideration probability distributions and accuracy ranges for SSWSF data. In addition, non-market, non-dollar qualitative benefits are identified for each case study, as appropriate.

Chapter 10 presents a range of alternative formats—public, private, or cooperative—in which snow survey programs in general might be funded and operated. This chapter compares eight alternative formats with the current, cooperative format of the SSWSF Program and addresses many of the related implications and issues. Factors discussed include quality, reliability, and accessibility of data, potential biases in privately funded data gathering and reporting, strategic release and/or sharing of data, the continuity of the national snowpack and water supply record, issues related to the profit imperative of private firms and the provision of long-term data (such as vulnerability to cost-cutting in the case of short-term market fluctuations), and the probability of long-term tenure of SSWSF personnel.

Chapter 11 of the report summarizes the results obtained in the economic analysis and provides an estimate of the economic benefits generated by the program compared with its cost in budget dollars.¹ The final chapter also presents an estimate of several “worst-case” scenarios as a means of estimating a potential upper bound to the economic benefits provided by the existing program.

Unless otherwise noted, all reported dollar values are nominal values.

¹ This summary is not to be construed as providing a total and encyclopedic economic value for the program. To develop an accurate estimate of the total economic value of the SSWSF Program would require a budget and quantity of staff hours that exceed those available for completion of this study.

CHAPTER 2. PUBLIC GOODS AND SNOW SURVEY AND WATER SUPPLY FORECASTING

PUBLIC GOODS THEORY

Economists divide goods and services into four main categories:

1. Private goods;
2. Natural monopolies;
3. Open-access goods; and
4. Public goods.

The defining differences among these four categories are based on whether or not they are rival in nature, and whether or not people can be excluded from enjoying their use. A good or service is rival if one person's use of that good diminishes or completely eliminates the ability of another to also use it. For example, if one consumer eats a particular apple, that apple is no longer available for another consumer to enjoy. A good or service is excludable if it is possible to prevent individuals from consuming it or enjoying its benefits. An example of a good that is excludable is a shirt on a rack at a retail store. Unless a given consumer pays for the shirt, the store has a right—as well as the physical ability, for the most part—to prevent that consumer from taking and wearing the shirt.

Private goods are both rival and excludable. Most consumer goods and services, such as food, automobiles, doctor visits, and so on, fall into this category. Natural monopolies arise when a good or service is not rival but is excludable. Cable television service falls into this category. If a new customer ties into a cable hook-up, the signal to other cable customers is not diminished. (Another definition of natural monopolies relates to the lower cost of having one seller provide the good or service in comparison with having multiple sellers provide it.) Open-access goods are rival but not excludable. An example of this is a crowded, free public road. As additional cars squeeze onto the road, the ability of all drivers to enjoy the benefits of the road is diminished. But no law, physical barriers, or tolls exists that could exclude the additional cars from turning onto that road. Public goods are neither rival nor excludable. An example of a true public good is a street light. If a street light is installed and maintained by one individual, he or she has no way of preventing others from using it. Absent government intervention, the providing individual also has no way of requiring others to pay for the use of the light generated by the lamp. Once the street light is installed and turned on, the light it generates is available for use by all who happen to pass by. One person's use of the light does not affect other consumers' ability to enjoy the benefits provided by the light. And if the lamp is available for use by even one member of the community, no other member of the community can be prevented from enjoying its use. In other words, once a public good is made available for one person's use, it is available for all too freely use and enjoy. Generally speaking, the individual who cares the most about the provision of a particular public good will be the one who ends up providing that good for all affected individuals,

assuming that no government or other entity is providing the good. Once the good is provided for one beneficiary, there is no incentive for any others to contribute to the effort or expenses associated with the provision of the good.

Because of the non-excludable nature of public goods, they tend to be provided in quantities lower than those that would optimize social well-being. If the community does not provide a public good by means of social or governmental action, the good will be provided only if one or more members of the community with the financial ability and the motivation to provide it do so in spite of the fact that others will then “free-ride” by using the good free of charge. In the case of a true public good—a good that possesses the characteristics of being non-rival and non-excludable—if it is provided to one person, it is automatically available for all to use regardless of whether or not they pay for it. In addition, economists recognize that attempts to provide public goods by private means will result in provision of lower quantities of those goods than would be socially optimal. In other words, if a good has the characteristics of a public good, the private sector will not provide as much of the good as society in general would desire in comparison with other goods. Cooperative or government provision of the good would result in a greater amount of the good being made available, to the benefit of all.

Basic research and the information generated are acknowledged within formal economic theory as having the nature of public goods. Information is difficult to protect from being re-distributed by initial users and so is subject to externality effects, meaning that benefits can accrue to people who have not contributed any financial resources to the process of data development. Once the data are gathered, they can be freely used by anyone who has access to them. Unlike the “natural monopoly” of goods produced and sold by regulated utilities, such as power and natural gas, information—by its very nature—can be used by limitless numbers of individuals at any given time without loss of usefulness. This ability for a good to be used by multiple individuals at the same time without any compromise in its usefulness is termed “non-rival” in nature. Once the good is provided for one individual, it can be made available for all others at a marginal cost that is equal to only the cost of distribution. Although there are indisputable private benefits that can be obtained through the *use* of the data once they are generated, the data themselves can be used over and over, endlessly, without any loss of value to others who may use them. In some cases, private providers of specific types of information form subscription services through which they obtain compensation for developing and distributing the information. Members of the subscription service are under strict contractual obligation to refrain from sharing data with others, sometimes under threat of legal action should they fail to keep those provisions of the contract. Maintaining such a contract requires willingness on the part of the information provider to vigorously and publicly pursue legal action against any who “defect” from his or her contract. While this is, in theory and reality, a feasible option, given today’s information technologies, it is, in practice, very difficult to protect data from universal distribution once they are created and released to any given entity.

There are some goods which are somewhat public in nature but which can be transformed into private or quasi-private goods by means of exclusion techniques. Research is one

example of this. Results from basic research can be openly and publicly shared, or they can be hidden or withheld from public use by means of patent protection, through subscription service charges, or by other methods of concealment or restriction of use. When these types of goods are limited in their availability to the public, usually for the purpose of maximizing profits for the entities that generate them, total public welfare is sometimes diminished in comparison with what it would have been had the good been made freely available to all members of the public.

ALTERNATIVE MODELS FOR SNOW SURVEY AND WATER SUPPLY FORECASTING SYSTEMS

The collection and distribution of snowpack and water supply and streamflow data has been treated as a public good within the 12 Western States participating in the SSWSF Program. Data generated by the program have been made readily available to all users via a wide variety of means of distribution. NRCS is not the only entity that produces snow level and water supply data as a public good. For example, the Northeast Regional Climate Center at Cornell University, in cooperation with the National Oceanic and Atmospheric Administration, operates a cooperative snow survey program that produces information that is treated as a public good in much the same way as the NRCS program. The State of Maine, as well, produces snow survey data based on a public goods model of information collection and distribution.

The public good model, however, is not the only way in which snowpack and water supply data can be gathered, distributed, and used. The State of California operates a cooperative snow survey program that is organized and operated on a model that differs slightly from that applied in the USDA-based SSWSF Program, as will be described below. New York City also operates a separate snow survey program that gathers and distributes snow depth, water content, and precipitation data. This program supplies its data to the public via surface mail and through the Northeast Regional Climate Center. The operating methodology of the New York City snow survey program differs somewhat from that of the NRCS SSWSF Program both in terms of the data-gathering technology used and in that the data are not available to the public in real time. It is anticipated that at some point in the near future, New York City's snow survey program will create an Internet interface through which the public will be able to access the program's data.

In the early 1900s, in the State of California, natural resource professionals and leaders in agriculture and other industries, as well as government officials, realized the value of snowpack and water supply data. Acting on this realization, California commenced operating its own cooperative snow survey program in 1930, five years before the national, federally led SSWSF Program was formally launched. Because California already had its own system in place, California and the partners in its system chose not to participate in the new Federal system. In addition to California's own cooperative snow survey program, the NRCS SSWSF Program operates within California boundaries in much the same way as in other States. The difference lies in that the SSWSF Program in

California operates only in those watersheds that either drain into an adjoining State—such as watersheds in the Sierra Nevada that drain into Nevada—or drain into California from another State—as does the Klamath River Basin in Oregon.

Although the California Cooperative Snow Surveys Program, for the most part, uses the same techniques and methods of snow survey and water supply analysis used by the NRCS SSWSF Program—incorporating data from both manually measured snow courses and automated snow sensing sites—there is one key difference in how the two systems are operated. The NRCS system is a publicly funded system that distributes information in real time through a data network that is available to anyone with Web access. In contrast, approximately one-half of the expenses of the California system are funded by private interests who own and operate data collection sites within the system. Partners participating in the system include California State agencies, Federal agencies (including USDA and the U.S. Department of the Interior), private utilities, municipalities, local water and power districts and agencies, and water associations. Data for a portion of the privately controlled sites in the system are entered directly into the California database by the owners. Within the power generation industry, a fraction of owners strategically withhold data for some number of days because of the proprietary nature of the information they gather. These withheld data points are limited to reservoir storage and streamflow information. All snowpack system-wide data are released as quickly as the technological limits of the system will allow.

The New York City snow survey program differs from the NRCS SSWSF Program in that its information-gathering technology does not use the same type of information transmission system and, as a result, does not generate real-time data. In addition, limitations created by information system complications within the New York City government have prevented data gathered by the New York City snow survey from being released to the public in a timely manner. Currently, daily reports generated by the program are distributed—to all who request them—by means of U.S. Postal Service surface mail.

Although the California and New York City models provide a means of comparing the existing NRCS SSWSF Program with alternative ways of obtaining and distributing the same basic types of data, there are no known snow survey systems in operation that treat the data gathered as a private good. No known system is operated as a for-profit entity, supporting the notion that such data are public in nature.

SOCIAL WELFARE ECONOMICS

The field of social welfare economics has been divided into various schools of thought. A detailed discussion of the distinctions between these schools of thought would not add to the current analysis, but it *is* important to understand that public choice generally deals with balancing the needs and desires of society as a whole against the needs, desires, and rights of individuals. The objective of this analysis is not to evaluate the relative merits of how the users of SSWSF products apply the data in order to meet their own social and

economic goals, whether those are profit-driven, are driven by a public-service mandate, or are driven by some other purpose. The objective of this analysis is also not to judge the social value implications of who does versus who does not benefit from the use of SSWSF data. Rather, it is to evaluate the value of the program to society as a whole—as it is currently constituted and being applied—in comparison with the total tax dollars spent to fund the program.

CHAPTER 3. BENEFICIARIES AND USERS

PRIMARY BENEFICIARIES AND USERS OF SNOW SURVEY AND WATER SUPPLY FORECASTING DATA

The value of SSWSF data is determined by the ways in which it is applied by users in their decision-making processes. Some individuals and organizations use SSWSF data directly and enjoy the benefits of that use. Some individuals and organizations benefit from the data indirectly as a result of others' use of those data. Although this analysis will focus for the most part on direct beneficiaries and users of SSWSF data, it will also include a selection of indirect beneficiaries.

In 1976, studies of potential SNOTEL sites were conducted in the 12 Western States in preparation for installation of the proposed automated system. In Utah, for example, of the 24 sites examined in detail, 8 were described as being moderate or average in priority, with the remaining 12 sites rated as high or very high in priority. In addition to identifying the number of acres and types of crops that would be served by each SNOTEL site, the survey documents list other users that would benefit from the data provided by the SSWSF Program. The list of these users includes both specific organizations and general categories of uses. Organizations in Utah that at the time were expected to benefit from the new system included the National Weather Service (NWS), the U.S. Army Corps of Engineers (USACE) and other reservoir operators, USDA's Forest Service (FS), the National Park Service (NPS), tribal entities, the Bear River Commission in operation of an intrastate water compact, the Central Utah water project, Utah Power and Light (now Rocky Mountain Power), Kennecott Copper and other industrial users, the Utah State Division of Wildlife Resources, Utah State University, county and State road management divisions, cities, municipal water districts, water conservancy districts, water users associations, and irrigation companies.

A list of the more general anticipated uses of the data includes water supply forecasting, snow cover analysis, cloud-seeding analysis, recreation planning and management, streamflow and flood forecasting, flood control and prevention, power generation, planning for culinary/agricultural water exchanges, academic research, snow removal and avalanche hazard analysis, municipal and industrial water supply analysis, cross-basin water exchanges, lake and reservoir management, and the provision of high-altitude snowpack and general precipitation data.

Additional documents from the 1976 Utah study list users who either requested the installation of specific SNOTEL sites or requested the addition to planned SNOTEL equipment of special sensors that would provide specific data needed by those entities. Some of the requested sites were installed, but many were not. NWS requested data collection and direct electronic access to data for 41 sites. They planned to use the requested data in streamflow and flood forecasting. FS requested access to data from all SSWSF data collection sites as well as the addition of special sensors to SNOTEL sites, including sensors for relative humidity, maximum-minimum temperatures, wind speed,

wind direction, and possibly solar radiation. FS planned to use the data in fire suppression and pre-suppression (fire weather), hydrology and water management, and for planning in its engineering division. Utah Power and Light requested access to data at planned sites and requested the installation of SNOTEL sites in 13 additional locations. They expected to use the data to augment existing monthly data sources in order to better operate power plants and reservoirs. The Salt Lake City Department of Water Supply and Water Works requested direct electronic access to SNOTEL sites within the watersheds above Salt Lake City. Additional entities requesting either access to data or the installation of specific SNOTEL sites included USACE, the Soil Conservation Service in the State of Wyoming, the Bureau of Indian Affairs, the Bonneville Unit of the Central Utah Project, the Bureau of Reclamation (USBR) reservoir regulation branch, the Weber River Distribution System, the Provo River Distribution System, the Sevier River Distribution System, the Pineview Water Users Association, the Bear River Water Users Association, and the Utah Division of Water Resources, which at the time held statewide responsibility for cloud-seeding operations.

To put these users into a larger context, decisions based on SSWSF Program information affect millions of acres of surface-water-dependent irrigated agricultural lands in the West. The 2002 Census of Agriculture estimated that in 2003 there would be 299,583 irrigated farms in the United States. Of those projected farms, 90 percent were expected to be in areas benefiting from SSWSF data. In 2002, there were 55,311,236 acres of irrigated land in the United States, producing \$51.1 billion in agricultural output. Of the water applied to those acres, half came from surface sources. With respect to power generation, of the more than 75 power companies in the United States that rely on hydroelectric sources for some or all of their power generation capacities, at least 29—more than one-third—operate within States that are served by the SSWSF Program.

The information gleaned from these SNOTEL planning documents shows that potential users of the new system had a clear picture of the benefits that the information could provide to them. Those benefits have been realized through both the implementation of the initial system and the addition of more SNOTEL sites over time.

The primary beneficiaries and users of SSWSF data can be divided into six main categories:

1. Private industry, which includes agriculture, the recreation industry, transportation, and banking and finance, among other industry sectors;
2. Government, which includes Federal, State, and local agencies and entities;
3. Public utilities;
4. Educational and research institutions;
5. Private citizens; and
6. Multiple-category entities such as water users' associations and entire communities, which cross public-private boundaries.

In the six chapters that follow, these categories of beneficiaries and users will be analyzed in detail to estimate some of the benefits derived from their use of SSWSF data.

To lay the basic groundwork for that analysis, it is necessary to first delineate the primary types and methods of how SSWSF data are used. As mentioned in Chapter 1, there are two primary scenarios within which use of SSWSF data occurs. The defining difference between these two scenarios is whether or not the decisions to be made involve water storage or, in other words, reservoir management. In some cases involving reservoir management, data users have the authority and responsibility for making all decisions as to whether to fill or spill the reservoir or reservoirs under their jurisdiction. In other cases, data users have some input—either by virtue of ownership of water shares, through court-recognized legal standing, or due to some other means of direct influence—into how a particular reservoir is operated. In other cases, certain decision-makers are affected by reservoir management decisions made by others but have no legal standing that would allow them to influence how that management takes place. Instead, they must make decisions in response to reservoir management decisions made by those in authority.

In circumstances in which reservoir management decisions are publicly available or distributed to stakeholders, the secondary decisions of dependent water users can be made with a minimized level of uncertainty. In circumstances in which reservoir management decisions are not made available to the public and are not distributed to stakeholders, the decisions of dependent entities must be made through strategic anticipation of how reservoir management is most likely to proceed, given existing conditions. In this case, affected entities can make direct use of SSWSF data in order to optimize their estimates of which reservoir management scenario or scenarios are most likely to be realized, thereby reducing the amount of uncertainty they face in their own decision-making processes.

PRIMARY TYPES AND METHODS OF USE OF SNOW SURVEY AND WATER SUPPLY FORECASTING DATA

Data gathered and distributed by the SSWSF Program are used to inform decision-making processes in a variety of ways. There is a great deal of uncertainty in annual and multi-year water supplies and streamflow within specific watersheds and sub-basins. If the future were certain in terms of water supply and streamflow, there would be no need for SSWSF data. SSWSF data can contribute to various decision-making processes by reducing uncertainty in decision-making processes that hinge on those pieces of information. Uncertainty can be organized into the following categories:

1. Uncertainty related to feasibility;
2. Uncertainty related to accuracy or completeness of data, information, or models;
3. Uncertain outcomes;
4. Uncertain activity durations; and
5. Uncertainty related to decisions that have not yet been made.

SSWSF data contribute to water-supply-related decision-making processes by reducing the degree of uncertainty in all of these categories. This is related to both reservoir

management and non-reservoir decision-making within the contexts of short-, average-, and high-water years. The part that the SSWSF Program plays in reducing the second type of uncertainty is perhaps its most significant role in informing the decision-making process. When faced with inaccurate information, completely absent information, or limited amounts of accurate information regarding existing water supplies or potential streamflow, managers of resources that are affected by either water supply or streamflow (or both) face a corresponding degree of uncertainty and potential for making errors in their decision-making. The availability of SSWSF data reduces the potential for uncertainty-driven errors. By narrowing down the known range of probable future water supply conditions and streamflow, the use of SSWSF data also reduces the range of actions that any given water-dependent entity must be prepared to take.

Take, for example, the case of an individual water-storage reservoir manager. The manager is usually charged with the task of balancing the goal of maximizing the amount of water stored with the need to avoid being forced to “dump” water in the spring, thereby damaging riparian zones and running the risk of causing flood damage to properties downstream. If the manager has either no information or limited information as to the amount of water contained in the snowpack and soils above that reservoir, decisions as to whether to fill or spill will be plagued by a high degree of uncertainty. If the manager allows too much water to pass through the reservoir and then fails to fill it to its optimal level in the spring, the manager will have failed in meeting the primary objective of the reservoir. On the other hand, if the manager fills the reservoir too early in order to guarantee maximum water stored, the manager runs the risk of having to run excessive and damaging amounts of water over the auxiliary spillway and into the drainage below, causing unnecessary riparian damage and flooding nearby properties. By providing information that gives the manager better information upon which to base management decisions, SSWSF data enable the reservoir manager to make and act on better choices as to whether to fill or spill, optimizing reservoir operations given available information about current and possible future conditions.

In general, as a water year unfolds, the SSWSF Program combines information about the state of the existing water supply with probabilities for future conditions in the remaining weeks of the precipitation season to generate water supply and streamflow forecasts. As the weeks of a water year pass by, these forecasts—which are updated on a monthly basis—allow decision-makers to incrementally reduce uncertainty and increase the accuracy and validity of the decisions they make.

The use of SSWSF data to reduce uncertainty tends to fall into one or more of the following decision or analysis contexts:

- Reservoir management
- Irrigation water management
- Cropping decisions
- Crop futures forecasting
- Risk management related to agriculture in general and agricultural finance in particular
- Planning and scheduling of water-related business and/or government activities
- Flood damage prevention
- Drought risk reduction
- Climate change risk assessments for long-term water availability
- Emergency response and emergency preparedness
- General public safety
- Protection of threatened and endangered species
- General environmental protection
- Power generation and other energy contracting and management
- Recreation management and other recreation-related decision-making
- Municipal and industrial water supply management
- Research and education.

Within each of these contexts, there are general categories of costs—both market and non-market—associated with being wrong about water supply. In some cases, the worst-case situation is to base decisions on the assumption that the water supply will be high when, in fact, it is short. In other cases, the worst-case situation is to base decisions on the assumption that water supply will be either normal or short when, in fact, it is high. The timeframes within which these decisions and outcomes take place can vary from a very short time horizon, occurring in a matter of a few days, to a very long time horizon, taking a decade or more to be realized. For most water supply-related decision-making, the time horizon of interest ranges from a month or two to several years. Early and accurate knowledge about the current state—and probable future states—of snowpack, water content, and soil moisture content is key to many types of irreversible decisions. Once real resources have been irretrievably committed—such as the seeds, petroleum products, wear and tear on equipment, and time invested in planting a crop—they cannot be recovered if the decision is found to have been made in error. There is value in eliminating uncertainty and error from these types of decisions.

The chapters that follow will present a series of case studies showing how specific organizations and individuals use SSWSF data to reduce uncertainty and generate benefits within a selection of the decision contexts listed above.

CHAPTER 4. PRIVATE INDUSTRY

Private industry is defined as the sector of the productive side of the economy that is privately owned. Entities within private industry operate so as to maximize profits and, at times, to maximize the value of assets owned by the company as well as the market value of the company itself in terms of stock prices. Some private businesses try to maximize short-term profits whereas others focus on the objectives of maintaining long-term profitability and perpetuating their own existence as a corporation.

Within this study, private industry is divided into five main categories:

1. Irrigated Agriculture;
2. Recreation;
3. Transportation;
4. Finance and Banking; and
5. News Media.

IRRIGATED AGRICULTURE

Within the irrigated agriculture industry, there is a full spectrum of types of operations and types of ownership. There is a wide variety of configurations of size of operations and type of owner-operator relationships from very small “hobby” farms that produce small quantities of agricultural goods to vast, industrial-scale farming and ranching operations, from individual ownership to shareholder ownership, and from owner-operated to leased farm and ranch lands. In spite of this variety, in the Western United States, one common denominator among these farms and ranches is some degree of dependence on a diverted and stored water supply. In the Great Plains, a significant portion of irrigation water comes from ground-water sources, although a portion of irrigation water does originate in mountainous States upstream.

In some areas of the far Western States, snowpack is the only significant water storage available. In other areas, reservoirs provide a means of stretching water storage into the summer and sometimes into the fall growing and harvesting seasons. There are also a few, geographically limited regions in the West, such as parts of the Snake River plain in Idaho, where there are substantial—but limited, nonetheless—ground-water resources. Although there is a large amount of dry (non-irrigated) cropland within the Western United States., water is *the* essential resource in producing agricultural output grown in many parts of the region and, given the limited natural provision, irrigation is the essential agricultural production practice.

The primary use of SSWSF data within agriculture is in water supply forecasts, which contribute to crop planting decisions, along with crop prices and other information. These decisions, in turn, entail determining what crops to plant, what quantities to plant, and when to plant them. Cropping decisions are made before the growing season, in late

winter or early spring for warm weather crops. Farmers, irrigation districts, and water companies pay very close attention to the amount of water that is stored in each season's snowpack. In addition, SSWSF data are used in agricultural contracting decisions and USDA crop insurance risk management.

Irrigation Districts and Canal Companies

For most irrigation districts and water companies, the primary use of SSWSF data is in making canal company-level water supply forecasts for producers. In winter, canal companies provide advisories to shareholders informing them of the water supply outlook per share or per acre. These advisories give shareholders the information they need in order to make decisions about how many acres to plant, what crops are most likely to succeed in the upcoming growing season, and which crops to contract on. Irrigation district and canal company managers and shareholders have participated for years in cooperative snow survey programs, collecting data from snow courses, and working with NRCS SSWSF Program hydrologists in interpreting snowpack and soil moisture content data to provide the water supply information of the highest possible quality to farmers and ranchers.

Individual Farmers

Alfalfa Farming in Northern Utah

One example of how SSWSF data are used is a case in which one producer works with his local water users association, United States Bureau of Reclamation (USBR), and dam operators in order to optimize the storage and delivery of water. USBR coordinates with the local water users association and dam operators to determine how much water to allow to either store or spill from the reservoir system during the spring runoff season. The water users association pays close attention to soil moisture content numbers from SNOTEL sites and provides "fill or spill" advice to USBR on the basis of whether or not the soil profile is saturated early in the season. If the profile is dry, they recommend against spilling.

In his own farm and ranch operations, this producer operates on 650 acres with no personally owned reservoir storage for irrigation. He reports that all of his planting decisions are contingent on SNOTEL-based streamflow forecasts. In addition, he bases decisions about fertilizer application on soil moisture content data generated by SNOTEL.

Within the climate regime of this particular part of northern Utah, total potential alfalfa yield is approximately 5.9 tons per acre (based on NRCS 2005 consumptive use data). Where water is the limiting factor (as opposed to fertilizer or some other factor of production), the total that can actually be grown depends on how much water is available. There are three sources of water to support plant growth: winter snowpack and subsequent melt water, precipitation during the growing season, and diverted irrigation water held in reservoirs and then distributed through canal and irrigation pipeline

systems. Of the total potential tons of yield in this case study, there is enough water from winter snowfall and growing season rainfall to support approximately 2.5 tons of alfalfa yield during a normal precipitation year. This amount is called the base yield. In theory, an additional 3.4 tons of alfalfa can be grown using irrigation water. In practice, with a high-quality pivot sprinkler system, which is typically 85 percent efficient, the irrigated yield potential is 5.4 tons, for an increase attributable to irrigation of approximately 2.9 tons. In low-precipitation years, stored irrigation water can be used to supply the naturally supplied water to provide the base yield.

In a water-short year, low winter and early growing season precipitation can leave the soil moisture profile (the amount of water held in the root zone of the alfalfa) mostly dry. In agronomy, the term “fill the soil profile” is used to describe the process under which water infiltrates from the surface downward until the amount of water in the root zone reaches its optimal amount. A “full soil profile” contains the ideal amount of water within the root zone. Under the circumstances in this case study, where a lack of data leads to an erroneous reservoir-management decision to release too much water from upstream reservoirs during runoff season, allowing it to run downstream, that water would then be unavailable for irrigators to use to fill the dry soil moisture profile. This, in turn, would result in alfalfa yields that were sub-optimal. The magnitude of the loss would depend on the degree to which the profile failed to fill. A completely dry profile and minimal growing season precipitation would reduce tons of alfalfa by the 2.5 per acre base yield amount. The 10-year average market price for alfalfa in Utah is approximately \$90 per ton. Accordingly, the value of lost yield in this geographic area due to an erroneous “spill” decision is potentially as high as \$225 per acre, assuming a completely dry soil profile. Thus, the potential cost of a reservoir spill that resulted in not filling the soil profile for the producer in this case study could be as much as \$146,000 or more in gross revenue over the producer’s 650 acres. This figure assumes that there was sufficient water content in the upstream watershed snowpack to capture enough acre feet reservoir storage to fill the soil profile, and that the lack of information prevented the optimal management of the runoff.²

Twin Falls, Idaho, Agricultural Producers

In southern Idaho, shareholders in the Salmon Falls and Twin Falls irrigation tracts rely on SNOTEL data in making decisions about what, when, and how much to plant. In the Salmon Falls tract, which is dependent on limited reservoir storage for its water supply, access to SSWSF data is particularly important to agricultural producers. In contrast, the neighboring Twin Falls tract has access to both reservoir storage and ground-water sources, providing a somewhat more stable water supply than exists in the Salmon Falls tract.

² The degree to which this effect will occur depends on the relative seniority of the water right held by the individual producer. In the Western United States, water law is primarily based on diversion for beneficial use—defined as using the water to generate economic benefits—and the date when the right was obtained. The primacy rule is sometimes over-ridden by legal rulings that take precedence over the “first in time” establishment of water rights.

Irrigation districts within this region inform their shareholders early in the season as to the percentage of their full irrigation allotment they should expect to receive in the upcoming growing season. These predictions are based on SSWSF data showing the probability of varying levels of water supply given existing snowpack, soil moisture, and water content and using historic probabilities for additional snowpack and water content accumulations. These reports are crucial to producers, who use them to make cropping and operations decisions well in advance of the growing season.

Producers typically choose from among six standard crops, some of which are completely dependent on late-season water for their success. If a producer plants sweet corn or beans in a year when the irrigation water supply runs out early, those crops will be a complete loss. Other crops depend on early season water and are not as vulnerable to failure in water-short years. Still, these crops will be damaged by drought and will not reach their full yield potential when water is short. A complicating factor in this is that producers put a great deal of effort into optimizing their yield per acre for each crop in order to maintain a production record that will support full crop insurance payments in years when a disaster affects their crop production numbers. In water-short years, producers who are informed as to water supply, and who take advantage of the existence of that information, will reduce the number of planted acres by the degree to which the water supply is short. In other words, if the expected irrigation allocation is half of normal, farmers will plant fewer acres than they normally plant, leaving remaining acres fallow with only a cover crop planted to prevent erosion. They could also choose to maintain the same number of acres in production and grow crops with a lower water consumptive use. In water-short years, either cutting back on planted acres or changing the mix of crops grown enables producers to take all of the crops they plant to their full yield potentials.

As a general rule, producers in the area supplement their farm incomes by holding second jobs. Although they consider themselves first and foremost to be farmers, many of them rely on second incomes in order to protect themselves from financial uncertainty and risk associated with agricultural production. Early in each production year, producers use SSWSF data to make operations decisions, including determining how many workers to hire—if they hire any at all—and whether to increase their non-farm income for that year. Producers report that in true drought years, they “go into survival mode.” Their goal in such a year is to minimize farm losses and to maximize outside income, implying that under these conditions fewer farm workers will be hired and that producers will seek to increase their income from off-farm activities, thus reducing both the time they will spend on the farm and the associated agricultural production expenses.

Cropping Decision Income Analysis

The analysis below is based primarily on information provided by producers in the Twin Falls and Salmon Falls irrigation districts in southern Idaho. Additional data were obtained from various sources, including USDA's National Agricultural Statistics Service. The approach used in the analysis was to interview the producers in the irrigation districts to find out how they operate in both normal and low water years. The producers provided information regarding the cropping patterns they use in normal and low water conditions with access to SSWSF data. They also provided data on how their cropping pattern would change if they did not have access to the data. During meetings with these producers, a representative farm unit of 160 acres was developed in writing. The producers described in detail how often they would plant different crops under different conditions.

Once these typical cropping patterns were identified, crop budgets from the region and data from the Census of Agriculture were used to determine the costs and revenues of producing these crops. The representative 160-acre farm was then used to extrapolate total cost and revenue values for the irrigation districts. It is important to note that relative seniority of water rights would play a significant role in determining which farms would be forced into implementing drought-based operations in any given year. Under the condition of access to data, the model is a representation of actual typical producer decision-making. Under the condition of no access to data, the model is a representation of a loss-minimization strategy. Each condition is modeled for a single year of production, and all scenarios evaluated are simple mathematical extrapolations based on behavior reported by actual producers. The analysis did not attempt in any way to evaluate or establish what the profit-maximizing cropping patterns would actually be under the varying conditions in the model.

Four scenarios are included in the model:

- Normal water year with SSWSF data;
- Normal water year without SSWSF data;
- Water-short year with SSWSF data; and
- Water-short year without SSWSF data.

Assumptions of the model:

- A water-short year is defined as a season with a 50-percent water allotment.
- With access to SSWSF data, the producer will tailor planting patterns to match the amount of water available by planting the number of acres that reflect the expected percent of full water allocation.
- In the water-short year in the model, the producer will plant 50 percent of total acres (In actuality, there is a continuum of conditions and outcomes. This particular set of conditions has been chosen to represent drought conditions that have arisen, historically, in approximately 1 year out of 10.)
- Without access to SSWSF data, the producer operates under a "hedged" operation, meaning that, whereas a variety of crops will be planted, most acres will be put into

crops that do not require late-season water to hedge against the impacts of a water-short year.

- The operation comprises 160 acres.
- Historic normal and dry year commodity prices hold.
- In a water-short year, some prices increase and others decline.
- Production costs are equal to historic average production costs in the State of Idaho for each crop. (Based on standard crop budgets, under the no data/short water year scenario, production costs for crops that fail are 25 percent lower than normal due to the fact that normal harvest operations will not be necessary.)
- Crops requiring full-year water will fail in a water-short year.
- Once the producer has committed to a specific cropping pattern, there will be no opportunity to adjust or change crops, and it is not possible to make mid-season adjustments based on new information about water.
- Resources committed at the beginning of the growing season are sunk costs.
- No water transfers.

The values in Tables 3 through 6 show the value of having access to SSWSF data when making cropping decisions. Market prices for the various crops are based on actual market prices during normal versus drought conditions.

Table 3. Normal year with access to Snow Survey and Water Supply Forecasting Data

160 Acres Planted									
	Crop	% of Acres	Acres Planted	Yield per Acre	Units	Market Price	Production Costs (Per Acre)	Total Production Costs	Gross Revenue
With Data	Alfalfa - Feed	20	32	6	tons	\$91.41	\$325.00	-\$10,400.00	\$17,550.72
	Beans - All	20	32	1	tons	\$385.00	\$600.00	-\$19,200.00	\$12,320.00
	Sweet Corn	20	32	9.5	tons	\$78.50	\$290.00	-\$9,280.00	\$23,864.00
	Peas - Dry	20	32	0.85	tons	\$163.60	\$250.00	-\$8,000.00	\$4,449.92
	Barley - All	20	32	114.7	bushels	\$2.70	\$224.00	-\$7,168.00	\$9,910.08
	Winter Wheat	0	0	68	bushels	\$3.13	\$220.00	\$0.00	\$0.00
	Fallow	0	0	0		\$0.00	\$100.00	\$0.00	\$0.00
									-\$54,048.00
Approximate Net Income per Acre:									\$88

Table 4. Normal year without access to Snow Survey and Water Supply Forecasting Data

160 Acres Planted - "Hedged" Operation									
	Crop	% of Acres	Acres Planted	Yield per Acre	Units	Market Price	Production Costs (Per Acre)	Total Production Costs	Gross Revenue
W/Out Data	Alfalfa - Feed	20	32	6	tons	\$91.41	\$325.00	-\$10,400.00	\$17,550.72
	Beans - All	10	16	1	tons	\$385.00	\$600.00	-\$9,600.00	\$6,160.00
	Sweet Corn	10	16	9.5	tons	\$78.50	\$290.00	-\$4,640.00	\$11,932.00
	Peas - Dry	30	48	0.85	tons	\$163.60	\$250.00	-\$12,000.00	\$6,674.88
	Barley - All	30	48	114.7	bushels	\$2.70	\$224.00	-\$10,752.00	\$14,865.12
	Winter Wheat	0	0	68	bushels	\$3.13	\$220.00	\$0.00	\$0.00
	Fallow	0	0	0		\$0.00	\$100.00	\$0.00	\$0.00
									-\$47,392.00
Approximate Net Income per Acre:									\$61

Table 5. Water-short year with access to Snow Survey and Water Supply Forecasting Data

80 Acres Planted/80 Acres Fallow									
	Crop	% of Acres	Acres Planted	Yield per Acre	Units	Market Price	Production Costs (Per Acre)	Total Production Costs	Gross Revenue
With Data	Alfalfa - Feed	20	32	6	tons	\$105.58	\$325.00	-\$10,400.00	\$20,271.36
	Beans - All	0	0	1	tons	\$419.40	\$600.00	\$0.00	\$0.00
	Sweet Corn	0	0	9.5	tons	\$78.50	\$290.00	\$0.00	\$0.00
	Peas - Dry	5	8	0.85	tons	\$143.60	\$250.00	-\$2,000.00	\$976.48
	Barley - All	5	8	114.7	bushels	\$3.02	\$224.00	-\$1,792.00	\$2,771.15
	Winter Wheat	20	32	68	bushels	\$3.43	\$220.00	-\$7,040.00	\$7,463.68
	Fallow	50	80	0			\$100.00	-\$8,000.00	\$0.00
									-\$29,232.00
Approximate Net Income per Acre:									\$14

Table 6. Water-short year without access to Snow Survey and Water Supply Forecasting Data

160 Acres Planted - "Hedged" Operation									
	Crop	% of Acres	Acres Planted	Yield per Acre	Units	Market Price	Production Costs (Per Acre)	Total Production Costs	Gross Revenue
W/Out Data	Alfalfa - Feed	20	32	4	tons	\$105.58	\$325.00	-\$10,400.00	\$13,514.24
	Beans - All	10	16	0	tons	\$419.40	\$450.00	-\$7,200.00	\$0.00
	Sweet Corn	10	16	0	tons	\$78.50	\$217.50	-\$3,480.00	\$0.00
	Peas - Dry	30	48	0.56	tons	\$143.60	\$250.00	-\$12,000.00	\$3,859.97
	Barley - All	30	48	76	bushels	\$3.02	\$224.00	-\$10,752.00	\$11,016.96
	Winter Wheat	0	0	0	bushels	\$3.43	\$220.00	\$0.00	\$0.00
	Fallow	0	0	0			\$100.00	\$0.00	\$0.00
									-\$43,832.00
Approximate Net Income:									-\$97

Based on this form of modeling, the value of SSWSF Program data to producers in this region is estimated as ranging from approximately \$27 per acre in a normal year to \$111 per acre in a water-short year. Producers who have access to SSWSF data, but who do not make use of the data in their cropping decisions, are depriving themselves of potential income, even in normal water years, due to sub-optimal cropping patterns.

The Salmon Falls irrigation tract comprises 35,000 acres of irrigated cropland. To determine the total value of the data within the irrigation district, the results shown for 160 acres in the single-farm model were multiplied by the total number of acres in the Salmon Falls tract. Thus, the total value of the data within the irrigation district ranges from approximately \$945,000 in a normal year to approximately \$3,885,000 in a water year with a water supply that was 50 percent normal. The Twin Falls tract supports 190,000 acres of irrigated farmland, 95 percent of which, or 180,500 acres, benefit from access to SSWSF Program data during normal years. Due to the availability of well water, during water-short years, the percentage of acres benefiting from the data is reduced to 85 percent of total irrigated acres, or 161,500 acres. The potential value of SSWSF data to producers in the Twin Falls tract ranges from \$4,873,500 in a normal year up to \$17,926,500 in a water-short year.

Within the Twin Falls tract during normal years, approximately 95 percent of irrigation water comes from surface sources. A few producers own water in supplementary wells, and in water-short years, they are able to plant some acres of crops that require late-season water and then pump from their wells as needed to finish those crops. During water-short years, the total amount of water coming from wells rather than the surface system increases to approximately 15 percent. A more complex model would take into account the fact that producers who have access to well water would be expected to make errors in their cropping decisions—even with access to underground water supplies—if they did not know ahead of time that it was a water-short year. This added layer of complexity will not be addressed in this report. With additional resources for completing research into this question, a more complete and accurate result could be obtained.

These results can be compared with those contained in a report entitled “Effects of Water Supply Forecasts on Conservation and Economic Use of Water,” prepared in 1963 by Morlan W. Nelson, then SCS’s SSWSF Supervisor for Idaho. Nelson’s report cites multiple studies in which farm operations in the areas served by the Oakley and Salmon Falls Creek reservoirs were evaluated for the economic benefits provided by the SSWSF Program. The study states, “...a savings and/or increased income of over \$317,000 was realized on the 31,000 acres during 1960. This was true on these two tracts of land because most of the operators reduced acreage and changed cropping patterns on the basis of the forecasts.” When this estimated difference in savings and/or income is converted to 2005 dollars, it is equivalent to approximately \$2,045,000, which is fairly consistent with the range of potential dry-year benefits reported above for the 35,000 acre Salmon Falls Tract.

Table 7. Summary of Twin Falls case study results

Scenario	Approximate Net Income per Acre	Approximate Difference in Income
Normal year with access to SSWSF data	\$88	\$27 more net income per acre when operating in a normal year with access to SSWSF data
Normal year without access to SSWSF data	\$61	
Water-short year with access to SSWSF data	\$14	\$111 more net income per acre (and a positive net return rather than a net loss) when operating in a water-short year with access to SSWSF data
Water-short year without access to SSWSF data	-\$97	

Salmon Falls Tract – 35,000 Acres in Both Normal and Water-short Years		
Scenario	Approximate Net Income	Approximate Difference in Income
Normal year with access to SSWSF data	\$3,080,000	\$945,000 more net income when operating with access to SSWSF data
Normal year without access to SSWSF data	\$2,135,000	
Water-short year with access to SSWSF data	\$490,000	\$3,885,000 more net income (and a positive net return rather than a net loss) when operating with access to SSWSF data
Water-short year without access to SSWSF data	-\$3,395,000	

Twin Falls Tract – 180,500 Acres in Normal Years, 161,500 Acres in Water-short Years		
Scenario	Approximate Net Income	Approximate Difference in Income
Normal year with access to SSWSF data	\$15,884,000	\$4,873,500 more net income in a normal year when operating with access to SSWSF data
Normal year without access to SSWSF data	\$11,010,500	
Water-short year with access to SSWSF data	\$2,261,000	\$17,926,500 more net income in a water-short year (and a positive net return rather than a net loss) when operating with access to SSWSF data
Water-short year without access to SSWSF data	-\$15,665,500	

Sevier River Basin, Utah, Alfalfa Producers

From the mid-1990s until the water year of 2005-06, the Intermountain West experienced drought conditions that ranged from mild to severe, depending on the specific location in question. In south-central Utah, the Sevier River Basin reported moderately dry conditions. In this area, water users have implemented a sophisticated, semi-automated system for tracking water supply and reservoir storage. The Sevier River Commissioner uses SNOTEL data to determine how to operate the reservoir system on the river to optimize the quantity and timing of water storage and delivery within the system.

During the recent drought, alfalfa growers within the watershed based their production decisions on the information provided by the SSWSF Program and the SNOTEL system. At the same time, the water commissioner was operating the reservoir and diversion system based on a drought-response management plan using SNOTEL data. Based on the data, many producers adjusted their cropping operations to compensate for the dry conditions and to counteract the water shortage they faced. Rather than supplying full irrigation water to grow one early cutting of hay to the usual height and maturity—and thus using up their water for the season—many of them spread their irrigation out over a longer period with less water per irrigation. This irrigation pattern causes alfalfa to grow for a longer period of time, an action which stresses the plant and results in taller, thinner alfalfa plants. This, in turn, changes the plant's protein content and makes the hay more suitable for consumption by horses than by cattle. Horse hay is baled in small bales—rather than in rolls or large bales—in order to make the hay easy for end-users to manage. Because alfalfa producers in the region already had access to the equipment necessary to produce small bales, there were no significant additional incremental costs associated with producing small bales. By growing “horse” hay for out-of-State markets—which commands a market price that is 65 percent to 80 percent higher than does standard local “cattle” hay—these producers were able to avoid suffering any economic losses as a result of the drought. When asked why the alfalfa producers did not grow horse hay every year, the Commissioner explained that the producers found it easier to manage their crops in larger bales, that they preferred not having to deal with out-of-State market deliveries, and that they preferred using the cultivation techniques, equipment, and traditions to which they were more accustomed. This is an indication that profit is not the only objective in these producers' production functions.

Two separate methods were used to assess the total value of the information provided to the region by the SSWSF Program.

First, the Sevier River Commissioner has estimated that the total tons of hay harvested were reduced by approximately 25 percent during the drought. By altering their cropping pattern, as explained above, producers in the area collectively avoided drought-related losses. In essence, this amounts to the prevention of a 25-percent financial loss, a value of approximately \$109 million, over the 7 years of drought, or an average of over \$15.5 million per year.

Table 8. Sevier River Water Users drought years alfalfa production*

Drought Year	Tons of Alfalfa Produced	Average Annual Market Price for Standard Alfalfa and Alfalfa Mixtures (per Ton)	Estimated Market Price for Horse Hay Assuming a 66% Markup over Standard Hay (per Ton)	Market Value of Alfalfa Under 100% Standard Production	Market Value of Alfalfa Under 100% Horse Hay Production	Estimated Value of Access to Snow Survey Data Assuming a 75% Rate of Switch-over to Horse Hay (Net Revenue Minus Extra Shipping Costs)
1999	731,500	\$73.00	\$121.66	\$53,399,500	\$88,995,607	\$13,347,739
2000	1,145,000	\$79.50	\$132.49	\$91,027,500	\$151,706,432	\$22,753,234
2001	643,500	\$97.00	\$161.66	\$62,419,500	\$104,028,339	\$15,602,378
2002	560,000	\$96.50	\$160.83	\$54,040,000	\$90,063,064	\$13,507,838
2003	656,000	\$82.00	\$136.66	\$53,792,000	\$89,649,747	\$13,445,848
2004	605,500	\$89.00	\$148.33	\$53,889,500	\$89,812,241	\$13,470,219
2005	692,000	\$96.00	\$159.99	\$66,432,000	\$110,715,571	\$16,605,343
Approximate Annual Averages:	719,000	\$88	\$146	\$62,272,000	\$104,974,000	\$15,570,000

*Sources: USDA National Agricultural Statistics Service 2007 QuickStats http://www.nass.usda.gov/QuickStats/Create_County_All.jsp, and "2006 Utah Agricultural Statistics and Utah Department of Agriculture and Food Annual Report." Estimated value of Snow Survey data equal to 25% of market value of total production, based on data reported by the Sevier River Commissioner and the Sevier Water Users Association. Reported dollars are nominal values (not adjusted for inflation).

To confirm the validity of this informal estimate, the value of the data was also analyzed by calculating the potential dollar benefits of switching over from producing standard cattle hay to producing horse hay. Assuming a 75-percent rate of switch-over from standard hay to horse hay, and including additional baling costs and shipping costs associated with accessing more favorable markets, the estimated value of the information is equal to approximately \$109 million in total value over 7 years. Reducing the assumed rate of switch-over and increasing baling and shipping costs results, accordingly, in lower estimates for the value of the SSWSF data. The Sevier River Commissioner reported that the equipment necessary to make the switch from large bales to small bales was already owned by producers in the area, enabling them as a group to avoid the additional capital investment expenses that would normally have been associated with the switch-over. Table 8 shows production, crop values, and an estimate of the total value of the information provided by SSWSF during the drought based on both a 25-percent loss avoidance and an estimated value of a 75-percent switch-over rate and net revenue at the time of sale equal to 80 percent of the market price for horse hay. The table also includes an estimate of the value of the data assuming a more conservative switch-over rate of 50 percent and net revenue at the time of sale equal to 75 percent of the market price for horse hay. In the latter case, the value of the data is estimated as being equal to approximately \$54 million.

AGRICULTURAL CONTRACTING

Both producers and purchasers of agricultural products have moved away from conducting market transactions in the season-end spot market and have concentrated more over time on contracted crops. Rather than subjecting themselves to uncertain market conditions at the end of the harvest season, large-scale buyers will contract directly with individual producers or cooperatives to guarantee specific grades, quantities, and prices for the products they require.

Anheuser-Busch

The Corporate Environmental Group at Anheuser-Busch depends on SSWSF data as a primary input into the decision-making process in contracting on barley in Idaho, hops in Washington State, and grain across its international operations. Although the 2002 drought in Colorado heightened brewery interest in water supply, over time upper management in the corporation realized the potential for water supply forecasts to enable better contracting with suppliers of agricultural input goods. According to Anheuser-Busch, approximately 70 percent of farmers' acres are under contract, rather than being sold on the end-of-season spot market. Currently, the Corporate Environmental Group provides a water supply report to upper management every 2 weeks. The report includes both a summary of the water supply outlook and detailed backup statistics.

According to Anheuser-Busch, SSWSF data from the agricultural production areas that rely on snowpack are crucial to them. A representative from the corporation stated that they would be "dead in the water" without SSWSF data. The primary responsibility of the Corporate Environmental Group with respect to crop contracting is to provide accurate information to upper management. The agricultural purchasers and Anheuser-Busch are now using the water supply report to determine where to buy barley and where to put out contracts on a regional basis, thus reducing their risk outlay. The Corporate Environmental Group is being challenged to provide the same type of report for China, where there are 15 operational breweries. China does not have a snow survey system, and the Corporate Environmental Group does not have access to the same type of data upon which to base agricultural outlook reports. Under these information conditions, they cannot say whether or not they are "in trouble" in China in terms of future availability of agricultural input goods. They tend, instead, to prefer entering into contracts with producers in locations where snow water content data are available. Were Anheuser-Busch willing to share internal revenue data, it would be possible to quantify the benefits to the corporation of operating in this manner.

Anheuser-Busch was originally doubtful with respect to the reliability of SSWSF data, and arranged its own water supply tours to check the validity of the data. Over time, they have come to trust the data, but because access to a reliable water supply forecast is so crucial to their overall operations, they continue to do regular onsite spot checks of SSWSF data to confirm what is reported. Being able to contract ahead of time on agricultural inputs enables Anheuser-Busch to make input, production, and supply

decisions far ahead of time, sometimes as far as 1.5 years in advance, which provides stability, predictability, and higher profitability in its operations.

CROP INSURANCE RISK MANAGEMENT

The USDA Risk Management Agency (RMA) uses SSWSF data to determine whether or not producers have made and acted on prudent operating decisions, given the climate and water supply information provided to the public by the SSWSF Program. RMA operates under the assumption that producers have accessed and applied, to a reasonable degree, the data distributed by the SSWSF Program. If a producer makes a claim on a crop failure but RMA deems that the producer has failed to make appropriate cropping decisions for that season, given the reports and forecasts distributed by the SSWSF Program that year, then the claim will be denied. SSWSF data serve as an important means of protecting against public subsidization of both unfounded claims and claims that result from careless farm management on the part of producers rather than as a result of unforeseeable climate and weather conditions.

RECREATION

The Ski Industry

Bogus Basin

According to the managers of the Bogus Basin ski resort, located north of Boise, Idaho, SSWSF data are used in making day-to-day public relations campaign and personnel management decisions. They state that the biggest benefit to them from SNOTEL data arises from the fact that the availability of data makes it possible for them to relay high quality, timely, and accurate information to the public regarding snow conditions on the mountain. Because they are able to use the water content reported by SNOTEL to evaluate the quality of snow contained in the snowpack, managers can assess from a remote location, such as downtown Boise, what type of snow has or is falling, a key determinant of what types of skiers will want to visit the resort on any given day. Being able to distribute accurate information regarding snow depth and conditions becomes vitally important to the resort in terms of generating skier days. They sometimes access SNOTEL data on an hourly basis in order to keep current on what is happening on the mountain.

It is assumed that skiing decisions are made early in the day and that early and accurate information regarding ski conditions results in an increase in overall skier days. The majority of operations costs for a ski resort are fixed costs, meaning that the resort must commit to operating at a given level during a specific day and then pay the costs associated with that level of operations, regardless of the number of skiers who choose to ski on that day. The price for 2006-2007 "Day/Night" lift tickets was \$42, so each customer responding to public relations outreach translates into 42 additional dollars of

gross revenue to the resort. If 10 additional skiers decided to purchase tickets on a given day due to information about snow conditions, their purchases would result in an increase of \$420 in total revenue. This potential difference in revenue is important in the skiing industry, in which a high percentage of operating costs—such as electricity for running ski lifts—are fixed.

Resort managers also use SNOTEL data in making a decision on any given ski day regarding how many employees to call in to work. If the data show that a significant amount of new snow has fallen overnight, they know that they will need more snowplow and lift operators to adequately respond to their snow-removal and guest services needs. Prior to the SNOTEL site, the first person to arrive at the resort called back to town to tell the managers what was going on so that they could determine how to staff the resort for that day. With the addition of SNOTEL at the resort, managers can access snow conditions data during the night and early morning hours, giving them a headstart in making daily management decisions.

Another way the resort uses SNOTEL data and SSWSF Program snowpack forecasts is in making decisions well in advance—as much as a month ahead—as to whether or not it is feasible to host previously scheduled events such as U.S. Ski and Snowboard Association youth ski races. One example is deciding whether a race should be cancelled or moved to an alternate location, thus reducing risk of losses in terms of direct and indirect costs, time invested, and enabling the resort to maintain a positive relationship with the ski racing community. Failure to determine ahead of time that there is insufficient snow cover to hold a race, followed by a cancellation on the scheduled date of the event, would result in non-trivial losses to ski racers. Based on a typical U.S. Ski and Snowboard Association Intermountain Division race roster of 65 out-of-town racers and customary per racer costs for transportation, hotel, meals, and lift tickets, potential losses for normal expenses add up to approximately \$11,000, in addition to registration fees, which can reach \$15,000 to \$20,000 for a single event. The further ahead a cancellation decision is made, the lower the actual costs incurred.

Power Boating, the Houseboat Industry, and Other Reservoir-Based Recreation

Although the degree to which the power boat industry and other reservoir-based recreation industries use SSWSF data is unknown, the opportunities for loss prevention within these industries in arid areas of the West are immense. For example, in a recent drought cycle in the West, the level of Lake Powell dropped to the point at which Hite Marina was left stranded with no lake water within reach. There are many businesses in Utah that are dependent on Lake Powell-based boating and recreation activities. For those business operators who were paying attention to snowpack levels during the years of the drought, the loss of or reduction in reservoir access at Hite and other marinas would not have taken them by surprise. Being able to anticipate the changes in demand for their products and services and, in turn, the changes in operations that would be forced upon them by the drop in the water level in Lake Powell would have enabled them to make adjustments to their business plans and/or a complete switch to a different industry in order to avoid losses to the greatest possible extent. This same scenario has

been repeated at multiple reservoirs across the West. Although no amount of information about an impending decrease in reservoir levels could stop this decrease from causing significant disruption to the businesses that depend on reservoir-based recreation, knowing that the disruption was coming would enable business owners to find more alternatives in how to respond to this circumstance.

River Running

The river running industry is extremely sensitive to changes in streamflow. Variations in volume and timing of runoff have a direct impact on river running outfitter operations. Information about water volume and timing affect seasonal hiring decisions, trip scheduling, planned trip lengths, trip locations, and equipment purchases, as well as influencing longer-term planning. The case studies that follow provide a sample of the importance of the SSWSF Program's SNOTEL data to both statewide economies and individual outfitters within the river running industry.

River Running in the State of Colorado

River running is a significant part of the tourism industry in Colorado. The Colorado River Outfitters Association lists a total of 62 members, comprising both commercial and governmental river running entities. Fifty-five members are commercial outfitters running summer-season trips on rivers in Colorado. In 2005, there were about 504,600 river runner user days on rivers within Colorado. Direct expenditures for this usage are estimated at \$52,701,000, or \$104 per user day, which includes spending on rafting, food, lodging, souvenirs, and other items or services directly associated with river running trips. Because scheduling, equipment purchase, and employee contracting decisions for these trips are heavily—if not nearly completely—dependent on predicted water levels, SSWSF data have become an integral part of operations for river running outfitters in Colorado.

River Running in the State of Idaho

Idaho is just one of many Western States in which river running is a significant part of the recreation and tourism industry. Tourism is the third largest industry in Idaho, and many categories of tourism and recreation are—in one way or another—dependent on or affected by either snowpack levels, water supply volumes, or both. In 2006, the North American Industry Classification System category of *other amusement and recreation industries* led all other employment categories in employment growth within Idaho, nearly doubling in number of workers from 2005 to 2006. The South Central Idaho Tourism and Recreation Development Association, Incorporated has stated that tourism has a half-billion dollar impact on the economy of the Magic Valley area alone.

There are approximately 150 boating, hunting, and fishing outfitters in Idaho. Of all recreation industry segments in Idaho, fishing is the largest segment in terms of overall numbers of outfitters, whereas boating comprises the largest in terms of dollars generated. Boating outfitting includes both power boating, which is the most prominent

in Hell's Canyon National Recreation Area, and non-motorized boating. The Salmon River, also referred to as "The River of No Return," is one of the most popular river-running destinations in the United States. There are more whitewater miles (32,000 miles) in Idaho than in any other of the lower 48 States. Approximately 150,000 people per year pay for a guided boating trip in Idaho. Using an estimated average trip cost of \$600, this represents \$90 million in economic activity.

Because they are legally responsible for the safety of their customers, outfitters—but especially boating outfitters—constantly check SSWSF data for safety purposes. Of the approximately 420 licensed outfitters, approximately 50 percent are water-based and are dependent on being aware of current and predicted streamflow volumes for reasons related to both achieving basic commercial success and keeping clients safe.

Guides will call out on a satellite phone to find out exactly when to run certain sections of the Salmon River. If the predicted volume of snowmelt-driven flow in the river is too high, they will stay put until the volume of water drops to a safer level.

River Running in Arizona, Colorado, and Utah

Modeling was completed using information supplied by two river running outfitters that operate on rivers within the Intermountain region in Arizona, Colorado, and Utah. One model was developed using average operations figures supplied by a major river running outfitter operating on rivers in the Intermountain region. Data for trip lengths, prices, and number of trips per season were analyzed to determine the value to the outfitter of knowing how much water would be flowing in the rivers on which they operate. Based on the typical timing and scheduling of trips and guide contracts, the model compares normal water supply years with the following:

1. Low water years in which the outfitter has access to snowpack data and an accurate water supply forecast; and
2. Low water years without the same information.

Based on water supply information, outfitters adjust their guide-contracting decisions each year in an effort to adjust to anticipated water supply conditions later in the year. Absent water supply forecast data in a water-short year, and having contracted with the number of guides that would have been hired for a normal year, an outfitter would be forced to operate without the number of guides required to operate with more and smaller boats. This, in turn, would mean reducing the number of guests per trip, resulting in lost revenue.

Table 9. Benefits to river running outfitter in the Intermountain Region

	Number of Trips	Number of Guests per Trip	Gross Revenue	Type of Boats	Number of Boats	Estimated Number of Skilled Guides	Estimated Number of Unskilled Guides	Number of Other Support Crew	Daily Payroll	Total Season Payroll	Gross Revenue Minus Guides	Approximate Loss Compared to Normal Year
Normal Water Year	3920	36	\$7,464,240	J-rig	2	4	0	0	\$480	\$453,600	\$7,010,640	\$0
Low Water Year With SNOTEL Data	3920	36	\$7,464,240	S-rig, row, paddle	6	4	2	1	\$675	\$637,875	\$6,826,365	\$184,000
Low Water Year Without SNOTEL Data	3920	18	\$3,732,120	S-rig, row, paddle	4	4	0	0	\$480	\$453,600	\$3,278,520	\$3,732,000
									Approximate Additional Loss Due to Lack of Snowpack/Water Supply Data:			\$3,548,000

Normal water year gross revenues minus guide payroll are estimated at \$7,010,640. With snowpack data and an accurate water supply forecast, total losses to a single outfitter in a low water year, as compared with a normal water year, are estimated at \$184,000. In contrast, without snowpack data and an accurate water supply forecast, total losses in a low water year are estimated at \$3,732,000. The value of SSWSF data, which is the difference in with versus without snowpack data, and an accurate water supply forecast, is estimated at an average of \$3,548,000 in avoided losses to one outfitter in a single low-water river running season.

Another outfitter operating in the same area reported that in the 2002 season, the worst season on record for rafting in the region, SNOTEL data indicated that river conditions would render them generally inoperable that season if they were to use their traditional rafting equipment. The low water levels that were projected would have resulted in a year with zero revenue had the outfitter not been made aware of the streamflow projections ahead of the beginning of the rafting season. Based on SNOTEL indicators, the decision was made in April 2002 to place an order for \$50,000 in smaller craft that would be operable under the environmental conditions predicted by SNOTEL data. That season the company experienced a 40-percent reduction in overall revenue (when compared with a normal water year) due to the reduced water volume and a low rate of patronage. The low rate of consumer demand may have been a result of changes that occurred in consumer expectations as a result of drought-related reports disseminated in the media. In a typical year, revenue is equal to approximately \$1,000,000, so overall revenue that year was equal to approximately \$600,000.

With the availability of SNOTEL data, however, the decision to purchase the smaller, more able craft resulted in a \$600,000 revenue year when little to no revenue would have been brought in had that early season purchasing decision not been made. In other words, total revenue (approximately \$600,000) for the 2002 river season is attributable to the application of SNOTEL data. The \$50,000 purchase of smaller boats can be considered a sunk cost that will enable the outfitter to respond in a similar manner in future low water years.

FINANCE AND BANKING

Risk Management Related to Agricultural Loans

Bankers who serve the agricultural community are keenly aware of the part water supply plays in the projected success of agricultural operations within a given growing season. Producers are also dependent on SSWSF data to help them make decisions regarding whether or not to borrow money and, if so, how much money to borrow. According to one farmer, “I look at the water first, and then I go talk to the banker.” Smaller banks and other lending institutions manage risk by monitoring the potential for revenue among producers and then by basing lending decisions, to some degree, on the probability of acceptable levels of revenue in relation to risk exposure. So both producers—on the borrowing side—and bankers—on the lending side—pay close attention to snowpack and water supply data in order to make decisions regarding risk management associated with transactions in the market for loanable funds.

Federal Reserve Board

In its own risk management activities, the Federal Reserve Branch in Salt Lake City, Utah, uses a quarterly economic report that is prepared for southern Idaho for current and future quarters. Because of the role water plays in the degree of financial risk exposure in relation to power generation in the Northwest, the natural gas market, and agricultural loans, water supply is a crucial part of the report. Bankers in the region use the report to assist them in operations, and the Federal Reserve uses the report internally to remain informed as to the health of the banking industry as related to energy markets and the agricultural sector of the economy. Being able to monitor the likelihood of financial problems and loan defaults and, therefore, instability within the banking industry is a key component of the Federal Reserve’s ability to carry out its duties in safeguarding the solidity of the banking component of the national financial system.

As is the case with many users of SSWSF data, it is important to the Federal Reserve that the information reported be as unbiased as possible. Due to the potential for manipulation of the financial system, including the possibility of fraudulent reporting of information for the purpose of distorting financial markets for personal gain, it is vitally important that the water supply data utilized by the Federal Reserve and other banking entities be as objective as possible, be reported with no degree of strategic bias, and be as accurate as possible.

Commercial News Media

In the course of completing this study, a meteorologist who reports for a commercial television station in the Rocky Mountains was interviewed in order to ascertain the value of SSWSF data to meteorologists working in the private sector. The meteorologist interviewed uses SSWSF data to prepare his reports and also as the basis for his focus on public education. At certain times of the year, he does on-camera reports on snow accumulations. He presents these reports approximately once per week during the

normal snow-accumulation time of year, but during spring runoff, he will sometimes present snowpack and snowmelt reports on a daily basis. The meteorologist's primary visual materials include a snowpack map and a representative map to display where snowpack is in the current year as compared to the last year, the historic average, and so on. He stated that he works carefully to make sure that the stories he reports are accurate and represent what is actually going on in terms of snow levels. He also said that he works hard to educate his audience, other reporters, and other people in the media so that they have a clear understanding of how to read snowpack data and understand the implications of what they are seeing. According to this particular meteorologist, the data generated by the SSWSF Program are "just critical" in figuring out "what is going on and what is going to happen" with regard to flooding.

The interviewed meteorologist stated that he depends on the NRCS data collection office within his State to pass to him information based on what is most critical. In his opinion, the expertise of SSWSF personnel is key to his ability to trust the information, and to know that the data he is presenting to the public are accurate and relevant. To him, the availability of Internet-based, real-time data is very important. According to the meteorologist, validation of data in the news business is "a daily battle." He expressed concern that if another entity were to take over the tasks performed by the SSWSF Program, the output would be "watered down." In his opinion, if there were to be any doubt as to the accuracy of the data, it would significantly reduce the value of the information. He considers the SSWSF Program to be a well-run and well-established program.

CHAPTER 5. GOVERNMENT

Federal, State, and local government agencies and other entities use SSWSF data to produce secondary products for public and private beneficiaries. The data are widely used among Federal agencies in a wide variety of decision-making processes, as shown in the examples below.

FEDERAL AGENCIES

U.S. Department of Agriculture

At the time this report was prepared USDA was expected to have disbursed over \$29 billion in direct and guaranteed loans nationwide in fiscal year (FY) 2008. In order to safeguard the value of these loans, and to manage the risk associated with them, the Federal agencies responsible for the loans must monitor the probability that producers will be able to pay back the part of the loans for which they are responsible. In order to accomplish this, it is crucial to these agencies to have a clear understanding of the predicted water supply each irrigation season for those portions of the Nation where it is necessary to irrigate. SSWSF data provide the information necessary to gaining that understanding.

U.S. Army Corps of Engineers

USACE in Portland, Oregon, provided the report quoted below to NRCS as a summary of how it uses SSWSF data in the Northwest:

“The Corps of Engineers, Portland District relies heavily on the point measurements of snow information provided by the NRCS SNOTEL network. Having an indication of the snowpack in the Willamette and Rogue Basins helps determine how USACE operates the 13 storage projects in these basins.

During the winter months, which is the time flood control is most needed, USACE uses the NRCS daily snowpack table that lists the SNOTEL sites out by basin and provided percent of normal. Knowing the amount of snow in the mountains helps to determine what the potential is for a rain-on-snow event and how much water may be released from the snowpack during such an event.

During the reservoir-filling season, the snowpack information obtained through the NRCS SNOTEL sites and NRCS web pages is used to help determine how the reservoirs are filled.

Over the past few years, higher than normal snowpacks in the Rogue River Basin at Lost Creek Dam, have changed the reservoir refill schedule, resulting in refill that is slower than the maximum fill rate. The state fisheries agency encourages this to leave room during the fill process for rain events. With a slower fill rate, river stage rises can be dampened by extra storage space in the reservoir. This is considered to be beneficial from a fish perspective. If USACE was following the maximum fill rate, excess water would have to be passed downstream. USACE agrees to the slower fill schedule as long as there is an adequate snowpack to provide ample assurance that the reservoir would be able to fill later in the early summer. Without the knowledge of the snowpack, USACE would not be able to provide this fish friendly operation.

If the snowpack is low in the Rogue or Willamette Basin, then this may provide the information needed for USACE to justify a deviation from the maximum fill rate. Filling the reservoirs earlier than usual may be advisable to make sure the reservoirs fill by the summer if the possibility of an extreme rain-on-snow event is unlikely. Having adequate water during the dry summer and fall months in Oregon provides numerous high value benefits, including better water quality for ODEQ [Oregon Department of Environmental Quality], water for cities and industries, irrigation water for farmers, adequate water for fish including some that are ESA [Endangered Species Act] listed, recreational, and meeting USACE congressionally authorized flows.

If the snowpack is extremely high then USACE may fill the reservoirs more slowly to account for the added risk of large amounts of runoff that could be produced from a rain on snow event. Knowledge of the snowpack therefore helps USACE provide better flood control operations.

During the conservation planning of the Rogue and Willamette Basins, the NRCS water supply forecast is used to adjust USACE hydrologic models. The model output is used to determine how the projects may be operated through the conservation season. Monthly and sometimes bi-monthly forecasts from the NRCS are integral to the conservation planning USACE does on an annual basis.

During the snow season, the NRCS web pages have been very useful. Plots of snow depth and snow water equivalent at individual sites have been referred to often. It is especially useful how the NRCS graphs list the normal snowpack, high and low snowpack, and last year's snowpack along with the current year information. The graphs provide a valuable view of how the snowpack compares to historical values.

The Corps of Engineers, Portland District, has appreciated the relationship with NRCS. The communication and cooperation with NRCS has been

excellent over the years. The work done by NRCS in regard to the SNOTEL program and the water supply forecast is invaluable for USACE to accomplish the mission of flood control and water management.”

U.S. Bureau of Reclamation

The U.S. Bureau of Reclamation makes use of SSWSF data in a variety of ways. According to one USBR analyst, the most important way in which his agency uses the data is indirectly through the streamflow predictions that NWS produces using SSWSF data. These predictions feed into USBR decision-making with respect to such issues as optimizing hydroelectric power generation and management of municipal and industrial water supplies. Having a real-time understanding of shifts in timing of runoff, which involves identifying “peaking point” versus “base load” streamflow volumes, is a key part of making these types of management decisions. NRCS National Water and Climate Center personnel work directly with NWS and USBR personnel to generate information that is tailored for USBR’s use. USBR directly accesses SSWSF data through the SSWSF Web site. These data are “pulled” directly into USBR’s database and are used for tracking and verifying other data sources. All hydrologists within USBR access SSWSF data for studies such as peak flow forecasting, timing of peak flow events, and reservoir management analyses. Although SNOTEL data predict the amount of water that will be contained in snowmelt flows, for USBR the timing of runoff events is the most difficult aspect of their hydrologic studies.

According to USBR, all alternative sources of snowpack and water supply data are, themselves, derived from SSWSF data. No other agency or private entity provides these data. Because of the public goods nature of the data, there is not a sufficient profit incentive to induce a private corporation to replicate or replace the work done by the SSWSF Program.

In addition to power generation and water supply management, USBR uses SSWSF data to help manage irrigation water supplies. They also use the data to anticipate incoming streamflow and, subsequently, to ensure public safety by making sure that they are not forced into choosing between either sending an excessive amount of water downstream or overtopping a dam, a circumstance that could “potentially be a disaster,” in the words of one USBR worker. With SSWSF data, they are able to release water early on in a runoff event, allowing them to fine-tune the flow of water in and out of reservoirs. The case of Scoggins Reservoir, below, highlights this type of use of SSWSF data. For USBR, being able to protect the integrity of the structures within its system is crucial in protecting the safety of all people, structures, and communities downstream.

Scoggins Reservoir, Washington County, Oregon

During a 5-day storm event in February 1996 in the watershed above Hagg Reservoir/Scoggins Dam in Washington County, Oregon, 21.2 inches of rain fell on top of an existing snowpack containing 12.5 inches of water. As the storm unfolded, the operator of the dam closely watched real-time data from a SNOTEL site that sits within

the watershed that feeds the reservoir. Based on observed SNOTEL data, the operator—in consultation with USBR and other water resource agencies—was able to calculate on an hour-by-hour basis the amount of water that had to be quickly released from the reservoir in order to contain the large amount of runoff that was on its way down from the hills above. He was able to manage releases from the reservoir so as to allow the reservoir pool to fill to within less than 1 foot of being completely full, thereby adequately managing the excess runoff.

Although there was some flooding downstream during the maximum release of water during the storm, the availability of real-time SNOTEL data enabled the reservoir operator to optimize the timing of the release and prevent the much more severe flooding that would have occurred downstream if he had been forced to suddenly release a much higher volume of water due to an inability to contain storm-event inflows. During the peak of the event, 5,600 cfs (cubic feet per second) of water was entering the reservoir. For 30 minutes, 3,000 cfs was released from the reservoir, a high enough volume to cause minor flooding of structures near the river downstream. Had the operator been unaware of the volume of water that was coming down from the watershed above—in which case he would not have released water ahead of time to make room for the oncoming volume—he would have been forced to release a much higher volume of water at the peak of the event.

Perhaps the most critical aspect of this potential high-volume release is the fact that there is a sawmill located just below the dam. The sawmill stores logs next to—and sometimes *in*—the river below Scoggins Dam. Had it become necessary to suddenly release large quantities of water from the reservoir, many large logs would have been picked up from the sawmill by the released water, carried downstream, and potentially could have been propelled through houses and other structures that would have been within the margins of flood waters along the course of the river. The reservoir operator also stated that the logs could have damaged or destroyed bridges or other downstream infrastructure. Knowing ahead of time that he needed to make room for a large volume of water enabled him to prevent these potential damages.

This event highlights the sometimes-vital importance of accessing real-time SNOTEL data versus monthly snowcourse readings. “Rain-on-snow” events have higher potential for flood damage for two reasons; the water stored in the snowpack is released when warm rain melts the snowpack and, in many cases, the ground is partially frozen by the cold weather that created the existing snowpack. The frozen ground does not absorb the rainfall and snowmelt, thus enhancing runoff. Had the only available local snowpack, water content, and precipitation data consisted of a monthly snow course reading, the reservoir manager would not have been able to respond quickly enough to the storm event to prevent more serious flooding and associated structural damages.

Hyrum Dam and Reservoir, Cache County, Utah

The Hyrum Dam and Reservoir are located on the Little Bear River in northern Utah. The dam was built in 1935 and impounds a reservoir with a total capacity of approximately 18,700 acre-feet. In 2003, a standard review of Hyrum Dam raised questions as to whether voids along the lower ends of the spillway walls, in addition to a crack that was noticed in the spillway stilling basin, would lead to failure of the floor slab under high flow conditions. A spillway slab failure could have led to an uncontrolled release which would, in essence, amount to a dam failure and a rapid draining of all reservoir contents. Consequently, a determination was made to limit releases through the spillway to no more than 50 cfs until such time as spillway repairs could be completed.

In late 2004 and early 2005, temporary repairs were made to alleviate immediate concerns over the vulnerability of the spillway. In April 2005, immediately after the temporary repairs had been completed, a once in 2,500-year rain-on-snow storm event occurred. During the early stages of the storm, USBR personnel checked U.S. Geological Survey (USGS) gages and online SNOTEL data to confirm what their own gages were telling them, which was that an unusually high streamflow event was occurring and that they needed to take action to protect the newly repaired spillway from any unnecessary stress. By repeatedly checking SNOTEL data to identify snow water content and melt rates, they were able to calculate the amount of water that would have to be released from Hyrum Dam in order to avoid an uncontrolled release. For several days, they continuously monitored SNOTEL data, NWS reports, and downstream flooding, using the data to make decisions as to how to balance the amount of water released from the dam with flood damage to farms and bridges below the dam.

During this storm event, the peak river-flow reservoir inflow was calculated to be 5,150 cfs. The reservoir was “surcharged” (filled above normal capacity) approximately 0.75 feet, and a maximum flow of 1,350 cfs was released through the spillway gates. At a release of 1,350 cfs, extensive flooding of lowland farmland downstream occurred. No damage to either the spillway or the dam was observed. By using SNOTEL data, USBR was able to execute a controlled release during which the maximum outflow released was 26 percent of the maximum inflow. Making room for the water ahead of time prevented an uncontrolled, emergency release of water. Had such a release been necessary, flooding downstream would have been far more extensive, damaging structures, farmland, bridges, and highways, and it is possible that the spillway or even the dam itself could have failed.

Glen Canyon Dam/Hoover Dam 1983/1984

During the late spring of 1983, huge amounts of snow accumulated in a very short period of time and persisted well past normal meltout dates in the Upper Colorado River Basin due to a very cold spring. In that year, the SNOTEL automated data collection system was just becoming operational. USBR analysts had no history with which to compare the data being produced by the system, and they were uncertain as to how to respond to the data they were seeing. Snow course-based data, which are gathered and reported only

once per month, were not available soon enough to be used in checking what was being reported by the new SNOTEL system. Reservoir and dam operators were doubtful that the SNOTEL data were accurate and, as a result, they did not alter operating procedures at Glen Canyon Dam and Hoover Dam on the Colorado River in northern Arizona and Nevada.

When warmer seasonal temperatures returned in early June, rapid snowmelt started soon thereafter, and the volume of water draining from the upper basin was far more than the reservoir and dam operators at USBR had anticipated. Lake Powell, the reservoir held back by Glen Canyon Dam, rose to levels that threatened the integrity of the dam. In an effort to prevent a disaster, dam engineers built a wooden structure on top of the auxiliary spillway that allowed them to raise the level of the reservoir beyond its highest designed elevation. Meanwhile, they opened the primary spillways to their maximum capacity, sending vast volumes of water through the power generation system and through huge tubes that channel water through the lateral abutment of the dam. The velocity and force with which the water passed through the tubes exceeded the engineering design which led to “cavitation,” the process of intense erosion due to the surface collapse of air bubbles found in constricted rapid flows of water which can cause the detachment of material from a surface, and the tubes began to fail. At one point, large chunks of concrete as well as red earthen material—which was eroding from the ground through which the tubes pass—were being blown out of the tubes along with the water.

Fortunately, the system held together long enough for the high runoff to pass without major incident. After the emergency passed, USBR made repairs and improvements to the spillway system. Thorough testing was completed in order to guarantee that a similar event would not lead to the same degree of stress on the system. Later on, a new operating plan was prepared for Glen Canyon Dam to apply what was learned in 1983 and to prevent a similar set of circumstances from being repeated. In the course of the near disaster, dam and reservoir operators on the system learned how to interpret SNOTEL data. In 1984, a similarly large snowpack accumulated in the upper basin. In that year, operators kept reservoir storage in Lake Powell at levels that were appropriate, given the amount of water that was expected during the runoff season. There was no emergency, and no extraordinary procedures were necessary. Based on the value of the SNOTEL data in Colorado River reservoir operations, in 1985 NWS initiated an agreement to annually transfer funds to NRCS to upgrade, expand, and maintain the SNOTEL network to support improved Colorado River water supply forecasts.

It is difficult to overestimate the value of SSWSF data in the safe operation of the Colorado River dam and reservoir system. As the events in 1983 showed, either lack of data, or failure to appropriately interpret data, can lead to a hazardous situation. Had Glen Canyon Dam failed, it is certain that Hoover Dam would have overtopped. Downstream flooding would have been catastrophic and, even assuming rapid and widespread communication about the unfolding disaster, the event would have resulted in many fatalities. Property damage to buildings, infrastructure, and agricultural lands would have been devastating.

The Glen Canyon experience highlights another important source of the overall value of the SNOTEL data and SSWSF Program: It is not enough to have access to the raw information. Experience in interpreting the data, along with length and continuity of the record, are key to using the data to the fullest advantage of its beneficiaries and users.

National Weather Service

NWS uses SSWSF data to augment its own data collection system. Different States use the data in different ways, according to local and regional circumstances.

National Weather Service, Idaho

In Idaho, NWS uses SSWSF data to augment its own data collection systems, both where they have their own monitoring stations and in situations where NRCS is the only source of precipitation data, and they consider themselves to be in a partnership with the SSWSF Program. The NWS system concentrates on lower elevation data. They rely on SNOTEL sites to provide data on what is happening at higher elevations. Personnel from NWS in Idaho have reported that they would continue to do the same work without SSWSF data but that it would be difficult for them to obtain a replacement source for the information provided by the SSWSF Program.

NWS uses SSWSF data as an integral part of its weather and flood forecasting work. There are three primary areas in which NWS in Idaho applies SSWSF data as a part of forecast operations: production of flood-threat predictions, production of fire-threat predictions, and verification of the accuracy of NWS storm-data products. NWS also uses SSWSF products, such as maps and graphs, as an integral part of public briefing materials. In addition, NWS uses SSWSF personnel as a primary source of concise information, or “sound bites,” for use in public service announcements regarding flood danger and other weather-related events. NWS uses SNOTEL data to verify its snow cover maps and to check the accuracy of its winter storm data products.

National Weather Service, Utah

NWS in Utah has stated that without the SNOTEL system, it could not do water supply forecasting “at all, period.” The NWS water supply forecast is provided to other agencies, such as USBR, which then uses the data for its own decision-making processes.

In the flood-plagued year of 1983, when the SNOTEL system was just beginning to be deployed, NWS forecasts were not very accurate. Over time, as more SNOTEL sites came online, the quality of NWS products increased accordingly. As in Idaho, NWS in Utah uses SSWSF data for verification of weather forecasts. NWS uses SNOTEL sites to check the accuracy of its winter forecasts. They rely on SNOTEL data in order to calibrate their models, and they use SSWSF data products as one of the primary inputs for peak flow streamflow forecasts and for issuing flood warnings. They look at existing streamflow water volume compared with normal streamflow volume, the rate of snowmelt, and the elevations of the gauges being monitored in order to develop accurate

flood forecasts. NWS flood predictions lead to local decisions on sandbagging, debris clearing, etc. According to NWS, the maintenance of high quality and continuity of SSWSF data is a matter of public safety.

River Forecast Centers

NWS operates River Forecast Centers (RFC) covering all of the landmass of the United States. In the mountain regions, the RFCs, which produce river flow, flood prediction, and other hydrologic and weather-related data products for the western regions of the United States and part of lower British Columbia, depend on NRCS SSWSF data for the snowpack component of their data analysis and forecasting systems. SSWSF input is an essential part of the overall flood warning system. Because NWS does not operate higher altitude data sensors, it would not be able to produce accurate forecasts without the information provided by the SNOTEL and snow-course systems.

The report quoted below was submitted by the Colorado Basin RFC, detailing how the center uses SSWSF data in producing river forecasts.

“The Colorado Basin River Forecast Center (CBRFC) is one of 13 River Forecast Centers across the country. We are part of NOAA's [National Oceanic and Atmospheric Administration] National Weather Service. Our mission is to produce river, flood and water supply forecasts for the protection of life and property and to enhance the economy and environment of the country. The CBRFC produces daily river forecasts and flood forecasts for over 125 locations in the Colorado and Great Basins, and seasonal water supply forecasts for 146 locations. SNOTEL data is a vital component of our mission.

In the spring, as the snow melts, flooding can often be a threat to property and lives. At the CBRFC, we run a model on a daily basis to provide forecasts of river levels based on current soil conditions, rainfall, and snowmelt. We provide river level forecasts out to 14 days, and therefore give the public and emergency managers advance notice of potential floods. The river forecasts, along with NWS flood warnings, help save lives, and hopefully give communities time to take appropriate actions to lessen flood damage where possible. We use SNOTEL data to validate and adjust the amount of snow and snowmelt simulated in our hydrologic model, and therefore [it] allows us to produce more accurate forecasts. These daily river forecasts are also used during non flood periods for recreational purposes (rafting, kayaking, fishing, etc.).

Water supply forecasts are seasonal, volumetric forecasts. They are a forecast of the amount of water expected to runoff during the melt season into the river basins. For example, as of January 1, 2007, forecasts indicated that between April and July 2007, 7,200,000 acre-feet of water was expected to pass through Lake Powell (were there no regulations on

the river). These forecasts are used by water managers such as Bureau of Reclamation, Corps of Engineers, local Water districts, Power companies, etc., to manage reservoirs, and allocate water. This has a very high economic value, since it dictates how water is allocated to municipalities, agriculture, recreational uses, fisheries, etc... In the Colorado Basin this has even more economic value due to the limited availability of water in arid areas growing very fast such as Las Vegas, and Phoenix. It is also a main decision tool in high water years to operate reservoirs in order to control flooding. The CBRFC uses SNOTEL data to make these water supply forecasts. We have a couple of different methods to come up with a best forecast, we then coordinate our forecasts with the NRCS (they have other methods to forecast water supply), and together we issue a coordinated official water supply forecast. All methods used in this forecasting process rely very heavily, if not exclusively on SNOTEL data.”

USDA Forest Service

Fire Response and Prevention Planning

As an integral part of its forest fire response and prevention efforts each year, FS uses SNOTEL data to track snowpack, soil moisture content, and projected snowmelt timeframes. These data become part of FS’s “fire weather” analysis and prediction. FS tracks snowpack at and above specific elevations, as well as current year precipitation amounts, humidity, and other weather-related data to assess the likelihood of fires and potential fire intensity during different time periods. When soil moisture content is high, and when snowpacks persist far into the summer, the risk of forest fires is much lower than is the case when soil moisture content is low and early-season snowmelts occur. Not only does FS predict how severe the fire season is likely to be, it also predicts the dates when it expects the earliest fires to occur. The availability of these key pieces of information, in combination with many other factors, enables FS to make personnel, contracting, and emergency-response decisions well in advance of the actual fire season.

Responses to elevated fire risk include making adjustments to previously planned management activities, engaging in additional staffing and training, tree-thinning operations, implementation of prescribed burns, carrying out public education campaigns, implementation of various restrictions on fires and other on-forest activities, and closures of areas highly vulnerable to fire.

Grazing Permits

FS in Utah uses SNOTEL site data as an input in its early-warning system for pending or persistent drought. Those drought figures may result in reduced numbers of animals or reduced grazing seasons, or both. One of the indices used in their drought early-warning system is percent of normal precipitation. If by February 1 precipitation is at or below 75 percent of normal, they initiate a drought advisory. If by March 1 precipitation is still at

or below 75 percent of normal, FS enters drought alert status. If precipitation remains at or below 75 percent of normal on May 1, FS categorizes the situation as being a severe drought. For each of these scenarios, FS requires specific response strategies, which may include shortening grazing seasons or reducing the numbers of animals that permittees are allowed to put on their grazing allotments for that season.

FS personnel report that they use the NRCS National Water and Climate Center Web site to access a variety of reports, including water-year graphs for various time periods. They consider all SNOTEL data to be valuable to them in assessing the status of grazing for a given season. They also report that SNOTEL data are the primary tool that they use for determining percent of normal precipitation and making decisions about issuing early warnings. They state that the SNOTEL data are of paramount importance to them in making drought-status and grazing-allotment determinations.

Early warnings are important to ranchers because they provide some amount of lead time, enabling them to make timely decisions about whether to reduce herd numbers and, if so, when to sell excess animals.

STATE AGENCIES

Idaho Department of Water Resources

The Idaho Department of Water Resources (IDWR) uses SSWSF data as the basis for water supply management and water-pricing decisions. A large portion of this agency's work consists of water allocation. In addition to allocating surface water resources, in conjunction with other administrative entities, they are responsible for projecting and predicting how the behavior of—and uses of—one group of water users is going to affect another group of water users. Over time, they have become much more “forward looking” in their operations, and have come to rely on SSWSF data as a primary input into their decision-making processes.

Water law in Idaho bases access to water resources on the year in which a water right was established. Since water diversion and establishment of water rights was first initiated in Idaho, the pattern of water-rights holdings on each water source has developed into a complicated mosaic of junior and senior rights. Based on SSWSF and USBR data, IDWR can—and does—issue orders to water users curtailing use of water resources in affected areas. When water is short, IDWR must determine which specific water users can continue to use water and which users must cease, based on first, the total water supply available, and second, on the year when each water right was first established. These determinations are extremely complex and highly controversial. IDWR leaders have stated that without SSWSF data, “There is no way we could be so precise as to what year of rights holders to cut off,” and that “If we had to go about gathering that information ourselves, it would take a lot of man hours and a lot of effort.” They are dependent on SSWSF products to enable them to be precise in their ability to accurately gauge, monitor, and predict the availability of water.

IDWR receives one or two inquiries per week from the public regarding snowpack and water supply conditions beginning in December each year. The number of inquiries increases as the winter season passes. IDWR accesses online SSWSF data and also maintains personal contact with NRCS SSWSF personnel to accurately respond to these inquiries.

State of Oregon

Oregon uses SSWSF data in a variety of ways. The State works closely with NRCS personnel, both in the SSWSF Program and in the National Water and Climate Center in Portland, to carefully and appropriately manage water resources in Oregon. One manager in Oregon said that information produced by SSWSF “is just an absolutely essential piece of data.” According to those interviewed, knowing precisely how much water is stored in the soil and in the snowpack in Oregon watersheds makes it possible for them, through careful management of reservoirs and careful monitoring of water rights, to provide an adequate water supply to agricultural, municipal, and industrial water users in Oregon, in spite of the limited capacity of their water storage system. Without the data produced by SSWSF, they would have to find ways to store more water due to what would amount to a loss of precision in their water management techniques. Additional research—beyond the scope of this analysis—could identify just how valuable this difference in precision actually is in dollar terms.

Oregon is dependent on SNOTEL sites and endorses adding more sites, mid-elevation sites in particular. The State oversees the activities of 20 water master offices statewide, and adjudicates water rights extending back to the 1800s. The Oregon Water Availability Committee uses the Surface Water Supply Index, which includes precipitation and snowpack data, existing reservoir levels, and streamflow data, to appropriately manage water supplies. This committee includes representatives from the State, USGS, NRCS, State Forestry, the State Climatologist, the Water Resource Department, and USACE. The committee makes recommendations to the State Drought Council, which issues drought declarations to substantiate county- or local-level requests for assistance.

Reservoir storage capacity within the Willamette River system is considered already at its maximum level. Although they are looking at all potential sites for expansion, water managers do not expect to add additional reservoirs to the system, which increases the importance of water managers to accurately monitor the watershed. Because the annual snowpack is essentially the only non-reservoir water storage in the system, adjusting within the reservoir system based on snowpack water content is crucial to optimizing the use of existing water supplies.

Additional users of SSWSF data within Oregon include State Forestry, which uses SSWSF data to estimate tree moisture and plan for forest fires, and local water masters, who use SNOTEL data to help them make decisions regarding flood forecasting and water distribution.

Utah Division of Emergency Services and Homeland Security

Utah's Division of Emergency Services and Homeland Security uses SSWSF data to assist in planning for and responding to flood events. Emergency Services relies on SSWSF data to assess the danger of flooding. In particular, they use the soil moisture content data provided by SNOTEL sites to determine how likely it is that spring runoff will exceed normal levels, leading to potential flooding. Although the SSWSF Program does not prepare or distribute flood predictions *per se*, State and local officials can use SSWSF streamflow forecasts to make decisions regarding preparations for flood waters that are generated by above-normal snowpacks and rapid snowmelt.

In the spring of 2005, Utah experienced widespread snow levels that were well above normal, threatening widespread flooding in many counties within the State. Beginning in January 2005, the Utah SSWSF Data Collection Supervisor, as well as other NRCS personnel, delivered public presentations aimed at local civic leaders, during which they informed audiences about the impending threat of flooding. These presentations included graphs showing the levels of snowpacks in the mountains of Utah, snowpack water content data, statistical predictions of the possible ranges for snowpacks and streamflow, weather maps giving drought information and weather predictions, and various maps and graphs explaining the significance of local and regional SNOTEL data.

Emergency Services used these SSWSF products—in conjunction with frequent direct communication with the SSWSF staff—to help make decisions as to what emergency resources would be needed and where they would most urgently need to be deployed. According to the director of Emergency Services, both State and local governments based their 2005 flood-preparedness decisions on information provided by the SSWSF Program. When asked whether they could have obtained that same information from another source, he stated that SSWSF “is the only source.” Responses occurred at several levels to the information presented. Emergency Services leaders in Uintah County in eastern Utah, for example, took action—based on the volume of streamflow being predicted by the SSWSF—by carrying out approximately \$1 million in flood prevention and mitigation measures, which is attributed by State Emergency Services with saving three or four bridges and many homes, as discussed in the following section. Another example is Cedar City, Utah, discussed below.

During the runoff season of 2005, the Yellowstone, Whiterocks, Uinta, Escalante, Virgin, Santa Clara, and Sevier Rivers and Mammoth and Coal Creeks all set new record-high flows. In spite of these high flow levels, flood damages were very limited in scope. Local and State officials give credit for the low level of flood damages to the advanced warnings supplied by means of SSWSF Program reports and presentations. One report from the Federal Emergency Management Agency (FEMA), regarding Payson City, in Utah County, states, “The applicant performed mitigation work prior to the events. No impact, no damages.” In the State as a whole, approximately \$4 million in emergency repairs and advance flood damage prevention measures were undertaken, and beyond these expenses, no record of flood-related losses could be found. This absence of reported flood damages to buildings and infrastructure is an indication that the dollar

value of the damages was minimal. It is possible that USGS or another Federal agency will eventually establish an official estimate of total damages for the 2005 spring runoff flood event, but no such estimate was found during the completion of this analysis. The snowmelt floods did cause damage to some streambanks and other fluvial system features within the watersheds that were the most severely impacted, and remediation work is being undertaken to repair that damage.

In contrast with 2005, during the flood years of 1983 and 1984 combined—years when the snow water content of the spring snowpack was similar to that experienced in 2005—total damages in Utah, primarily incurred in areas of northern Utah, reached over \$660 million in 1983-84 dollars. This equates to approximately \$1.252 billion in 2005 dollars. It should be noted that a key difference between the two flood events is that the 2005 event followed 7 years of drought, during which the ground had become very dry and had a large capacity for absorbing water. (Also, some of the highest 2005 snowpack was in the southern part of the State, making the 2005 event more evenly distributed across the State as compared with the 1983-84 event. Areas within all of the main regions of Utah were severely affected by high snowpack and water-content levels during the 2005 event.) This, in combination with low levels of water in reservoirs across the State, resulted in lower runoff amounts than might have otherwise occurred. Also, improvements to runoff-management infrastructure during 1983-84 (such as the improvement and/or construction of water retention basins) can be credited with some of the reduction in damage that was experienced in 2005.

Keeping these differences in mind, it is still possible to attribute to the SNOTEL system and SSWSF Program a significant portion of the ability of communities across Utah to prevent flood damages during the spring runoff of 2005. Comparing the events of 1983-84 with those of 2005, the difference in damages can be used as an estimate of the value of clearly knowing how much water was contained in the snowpack in the mountains of Utah. Based on this assumption, the flood-damage-prevention value of SSWSF data in Utah in 2005—a single-year event as opposed to the earlier 2-year event—could be estimated as being equal to approximately one-half of the 1983-84 losses, or \$626 million in 2005 dollars. This does not take into account the significant amount of urban and suburban development that occurred between 1984 and 2005 within areas of Utah that were threatened by flooding during the latter year's event.

LOCAL GOVERNMENTS

Uintah County, Utah

During the spring runoff season of 2005, local officials in Uintah County in northeastern Utah responded to SSWSF reports of extremely high snowpacks and predictions of potentially record-setting spring runoff volumes by working with USACE to make provisions for strengthening streambanks. Workers in local government agencies stockpiled sandbags in preparation for flood waters. As the anticipated flooding began occurring in May, those stockpiled sandbags were placed where they could protect the

most vulnerable properties. Several critical bridges crossing Ashley Creek were protected by the advance preparations from damage by flood waters.

The value of these bridges is included in the estimated total value of flood damage prevention stated in the preceding section on the 2005 spring runoff in Utah.

Cedar City, Utah

In mid-winter of 2004-05, much deeper than average snow—more than 300 percent of average in places—accumulated in the mountains above Cedar City, Utah (information that was available only because of the SSWSF Program). As spring approached, it became apparent to SSWSF Program personnel that the large volume of water contained in the snowpack threatened to cause widespread damage along Coal Creek, which passes through Cedar City. Anecdotal reports on snow levels were deceptive because the snowpack contained a high water content as compared with normal years. In response to a presentation made by an NWS meteorologist—using SSWSF-generated data, charts, and graphs—leaders in Cedar City and Iron County commenced flood damage prevention measures. The city began monitoring SNOTEL sites via the Internet—especially soil moisture and snow water content data—and they also accessed USGS streamflow data several times per day during the actual flood event. Along with FEMA and leaders from the Utah Division of Emergency Services and Homeland Security, local emergency services leaders put together an emergency operations center, conducted training for local personnel, and ran a mock emergency in order to test the system.

The City and County worked together with local irrigation companies to prepare for the oncoming runoff by taking flood prevention steps including clearing sediment and debris from the stream channel, constructing temporary dikes and other water diversion structures, and sandbagging where needed along Coal Creek.

In cooperation with USACE, which approved five permits for work within the streambed, city personnel completed bank reinforcement and channel cleanout projects, in addition to repairing an old power plant dam structure, in order to be prepared for the large volume of water that was anticipated during the runoff season. Crews also raised a State highway bed, cleaned out and strengthened ditches and creek beds, filled sandbags, placed portable sand barriers and water walls, and created a new course for Coal Creek to channel water away from major housing areas and into a dry lake bed.

The runoff season on Coal Creek is considered to comprise the period of January through August. Total runoff during the runoff season of 2005 is estimated as having equaled approximately 75,300 acre-feet. The historical average for the same time period is approximately 21,000 acre-feet. In spite of the extremely high volume of water that passed through the community, flood damages were minimal. A few properties, which are located in the dry lake bed into which the flood waters were channeled, experienced moderate to severe damage. During the height of the event, personnel completed three inspections of the stream channels per night. The first night that they did not perform

inspections, a streambank levee broke, flooding the Cedar City airport and a Bureau of Land Management (BLM) fire training center.

Even taking into account these exceptions, the total extent of damages, however, was much less than it would have been without the advance preparations. The City estimates the value of protection of houses alone to have been approximately \$15 million. This figure does not include the value of businesses, public facilities, schools, and infrastructure that may have been damaged by flooding had the advance measures not been taken. A representative from Cedar City stated, "If we hadn't had that information, there's no way we would have been prepared. We would have had hints, but..."

Because of the volume of water that flowed through the Coal Creek system that spring, several streambanks were damaged, requiring remediation to prevent additional erosion from future storm events that could potentially threaten infrastructure, homes, and businesses. Protection measures that would have prevented these repairs from being necessary might have been undertaken based on the advance notice had logistical and/or budgetary limits not prevented doing so. For example, had physical and financial resources permitted, either Cedar City or Iron County could have installed streambank rip-rap in key locations in anticipation of the impending high runoff. Costs associated with those repairs that were potentially preventable, given the available data, are not considered as offsetting the value of SSWSF data in 2005. Those aspects of the flood-event damages that were not preventable with advance notice are also not considered as being offsetting values.

The value of SSWSF data in prompting flood damage protection measures and subsequent avoidance of damages in Cedar City is included in the total value of the data in Utah in 2005.

Blaine and Lincoln Counties, Idaho

Blaine County, Idaho, is home to the popular resort communities of Sun Valley, Ketchum, Hailey, and Bellevue. South of Blaine County is Lincoln County, where the county seat is the town of Shoshone. The Big Wood River flows through both counties before merging into the Snake River near Gooding. In mid-May 2006, high snowpacks at high altitudes in the upper Big Wood River Watershed, combined with unexpectedly warm temperatures, resulted in very high streamflow. Just a few days prior to the expected peak of the spring runoff, emergency services officials met in Shoshone with Ron Abramovich of the Idaho SSWSF Program. Abramovich meets with Blaine and Lincoln County officials on a regular basis to discuss the Big Wood River and to look together at the latest reports and forecasts generated by SSWSF modeling. Based on the streamflow volumes predicted by the SSWSF models, the local officials participating in the May 2006 meeting came to the conclusion that flooding was imminent and that they needed to take action in order to protect homes, infrastructure, and residents along the river.

Prior to the meeting, news media in the area had posted an Internet report stating that there would be no flooding along the Big Wood River that spring. Based on the streamflow volumes predicted by the SSWSF models provided to local emergency services officials that day, the Internet news report was retracted, and a new article was released stating that there *would* be flooding and giving instructions to local residents as to how to prepare for the expected high water. Emergency services personnel activated flood prevention measures along the river and deployed county and city resources in order to minimize the amount of damage that would be incurred and to protect private citizens to the extent possible and necessary.

It must be emphasized that the SSWSF Program does not issue flood warnings. NWS, not NRCS SSWSF, is authorized to issue such warnings. SSWSF streamflow models in Idaho, however, incorporate data from high-altitude SNOTEL monitoring stations that are not included in NWS models, making the SSWSF models relatively more responsive to changing conditions in high-altitude snowpack levels. NWS models within the area are based primarily on monitoring stations that are located in valleys and foothills within populated areas of the region. NWS personnel have emphasized they do use SNOTEL data and SSWSF models to calibrate their own models, and they consider themselves to be partners with SSWSF in analyzing data and updating the models they utilize when determining whether to issue public safety notices.

CHAPTER 6. PUBLIC UTILITIES

Over the past century, public utilities in energy- and water-related industries have become increasingly more dependent on water supply data as a central component of their operations decision-making processes. It is easy to understand why producers in the hydroelectric power generation industry would be dependent on snowpack data and water supply forecasts. Although the connection to water is not as obvious, the natural gas industry is also interested in snowpack and water supply data. In contrast with the natural gas industry, the dependence of municipal and industrial (M&I) water supply companies on snowpack and water supply forecasts is obvious.

POWER GENERATION

Bonneville Power Administration

The Bonneville Power Administration (BPA) is a Federal Government entity that operates in largely the same manner as a private utility corporation. BPA operates a series of reservoirs on the Columbia River system in the Northwest. BPA is responsible for power generation, managing reservoirs for recreation and transportation (especially for barge shipping on the Columbia River), and protection of threatened and endangered aquatic species, such as salmon. BPA does not use SNOTEL data as input for its primary models because they do not consider the historic SNOTEL record to be sufficiently long for them to rely on the data set. They do, however, place a high value on the length of the manually measured snow course data record, and they use snow course data as the primary input into their water supply and power generation-capacity modeling. They input the snow course data into a model that generates a probability distribution for streamflow, which is the initial step for them in running their capacity prediction models.

According to BPA, a loss of streamflow data from NWS's RFCs would not have a serious impact on its ability to do accurate modeling. They do state, however, that a loss of SSWSF data would present a problem for them. Without access to SSWSF data, they believe their next best alternative would be to use RFC data. This assumption, however, is somewhat flawed in that RFC data are, in turn, dependent on SSWSF data. BPA is, therefore, dependent on SSWSF data for its streamflow predictions and its operations decision-making.

In years such as 1937 and 1977, which BPA refers to as "flash" drought years, the lowest ever flows were recorded on the Columbia River, resulting in low power generation capacity. Although 2001 was a similarly dry year, SSWSF issued reports informing data users in January that it was going to be a dry year. Knowing early on that it was going to be a water-short year; BPA was able to buy power ahead of time based on expected flows. BPA uses SSWSF data as the basis for its advance purchases and sales of power, depending on whether the data indicate that there will be either a shortage or an excess of water in the Columbia River system.

The biggest problem faced by BPA is not accessing snowpack and water content data. Rather, their biggest difficulty is in adequately anticipating weather conditions. In other words, weather forecasting is the single largest source of error in their overall power generation-capacity forecasting model. Observations of current on-the-ground snowpack contribute only a small percentage of the overall error term in their model because they are very dependable.

Although BPA does not use SNOTEL data as an input into its primary modeling software, they do use SNOTEL data to help track their performance as a water-management entity. The highest value to them of SNOTEL data is the late-season information on snowpack levels. They also use SNOTEL data to ground-truth their other data sources and to check the accuracy of their models. When something in their observations seems to be out of synch with their expectations, they track SNOTEL data on a daily basis to sort out what is happening in either their modeling or in the real world, or both, to determine why their predictions are not matching up with realized streamflow.

Because SSWSF data are crucial to BPA's operations decision-making, in the absence of the SSWSF Program, they would "piece something together" with the data available to them through USACE, USBR, NWS, or other sources. They do not anticipate that they would replace the SSWSF data collection system, *per se*, but all of the other sources to which they would turn are, themselves, dependent on SSWSF data and would, therefore, be unavailable should the SSWSF system be eliminated. Given how important SSWSF data are to all of these entities, it is likely they would collectively find a way to replace the SSWSF system should it be eliminated, thus shifting the expenses associated with snowpack data collection from one Federal entity to one or more other Federal entities.

Idaho Power

As of December 2006, IDACORP, Incorporated—Idaho Power Company's parent company—served approximately 472,000 customers in southern Idaho and eastern Oregon. The utility owns a system of 17 hydroelectric power generation facilities, most of which are situated in the Snake River plain in southern and southwestern Idaho. When operating at full capacity, Idaho Power can produce approximately 1,705,000 kilowatts of hydroelectric power, which is interchangeably referred to as hydropower.³ Generally speaking, with the advent of competitive markets for wholesale electricity, power companies of all types have become reluctant to share information related to the wholesale price of power. Due to the strategic nature of information regarding power supply and pricing, and due to utilities' preference for keeping such data closely held, it is difficult to obtain precise information with respect to these subjects. Subsequently, the analysis below is based on revenue figures reported in the 2006 annual report released by Idaho Power in early 2007. In the report, IDACORP outlines its dependence on snowpack for its hydropower generation abilities. In 2006, which was an above-normal water year (as much as 40 percent above normal), Idaho Power was able to produce 9.2

³ A kilowatt (kW) is a measure of the energy being generated or used based on joules of energy per second. A kilowatt hour is equivalent to 1 kilowatt of power running for 1 hour. One megawatt is equal to 1000 kilowatts.

million megawatt-hours of hydropower. In the same year, their revenue from the generation and sale of hydropower was approximately \$511,340,000. This information constitutes an estimate of the value of water used in generating power, and it was used in this analysis in order to estimate the value of SSWSF Program data to Idaho Power.

Because snowpack is extremely critical to its operations, Idaho Power monitors SSWSF data on a daily, if not hourly, basis. In order to have access to the latest data as soon as it is available, they subscribe to a service which enables them to receive direct data “dumps,” giving them access to the most recent SNOTEL reports in real time. During the winter, they engage in strategic cloud-seeding operations, based on what they learn from the SNOTEL system, in order to bring snowpacks up to the highest possible levels in locations above the reservoirs where their power generation facilities are located. They also use the data to help them make optimal “fill and spill” decisions, which entail either filling a particular reservoir or allowing water to run downstream to other reservoirs (or downstream altogether). By engaging in calculated fill and spill operations, Idaho Power can move water around within its system to take advantage of differences in snowpacks across watersheds within the region. Without the data produced by SSWSF and the SNOTEL system, they would not be able to optimize their fill and spill decisions. In interviews, personnel from Idaho Power stated that if the existing SSWSF system were to go offline, they would replace parts of the system by installing their own snow-monitoring equipment. They also stated that if they were to install their own system, it would be much less extensive than the existing system and that it would be less useful to them, leading to reductions in accuracy and resulting in non-optimal reservoir operations. In addition, they made it clear that Idaho Power would not share data with outside entities but would, instead, completely privatize the data that would be collected.

Not only does Idaho Power use SSWSF data in its reservoir operations and cloud-seeding operations decision-making, it also uses the data in long-range planning and forward contracting for purchasing and selling power in the wholesale market. Because changes in reservoir levels and, in turn, hydropower generation capacity are cumulative over multiple years, the utility can use SSWSF historical data to predict these variables more than a year in advance. For example, after a low water year has occurred, the utility can predict—based on reservoir storage levels and historic streamflow—what the range of possibilities is in probability terms. This enables them to decide how much power to contract in forward markets, either committing to sell surplus power or locking in additional power that they might need to purchase. Being able to make these arrangements ahead of time enables Idaho Power to keep retail power prices relatively stable and to engage in rational rather than reactionary financial and logistical planning. This, in turn, enhances their ability to act in the best interest of their customers as mandated by their status as a regulated public utility.

Nominal Error Analysis

Assumptions of the model:

- Based on long-term average streamflow and corresponding power generation capacity, and based on 2006 reported annual revenue, the expected value of annual

revenue from the generation of hydroelectric power is estimated as being equal to approximately \$365,245,000 (based on the assumption that the 2006 level of revenue at just over \$511,342,000 was 40 percent greater than normal due to the 40-percent higher-than-normal snowpack that year); and

- Absent the SSWSF system, Idaho Power would replace some SNOTEL sites but would experience some degree of diminished accuracy in its operations decision-making.

Table 10. Potential revenue lost during a normal water year due to reduced power generation capacity caused by varying degrees of fill and spill errors based on errors in snow water content estimates

Size of Error as a Percent of Total	Kilowatts of Power Generation Capacity “Lost” Per Year	Approximate Potential Annual Revenue Loss
1 %	17,092 kW	\$3,652,000
5 %	85,461 kW	\$18,262,000
10 %	170,922 kW	\$36,524,000

NATURAL GAS

Intermountain Gas

Because natural gas is currently used for both heating and power generation, the natural gas market is closely tied to the power industry. Power generation is considered to be a sub-optimal use of natural gas, and it has been stated by a source within the natural gas industry that the use of natural gas for producing power should be limited to peak power production only, when demand for power reaches its short-term highest levels. From the standpoint of thermodynamics, the most efficient use of natural gas is to burn it for the purpose of providing heat for buildings. Because of lower demand for heat, the price of natural gas has traditionally been lower during the summer. Increasing demand for electricity in the summer—primarily driven by increased use of air conditioning units—has led, however, to higher summer demand for natural gas by the power industry. This, in turn, has resulted in higher summer-season wholesale prices in the market for natural gas.

In order to minimize the impact of these developments on the price faced by its retail customers, Intermountain Gas arranges pricing and buying well ahead of when it will actually sell the contracted gas. Contract decisions are based on the amount of water projected to be available for hydroelectric power generation during specific future seasons. Depending on whether water supply forecasts—in conjunction with existing reservoir storage—indicate that hydroelectric power will be plentiful or in short supply, the gas company enters into contracts that minimize to the best of its abilities the prices it will need to charge its customers. Intermountain Gas sets an average retail price for

natural gas each year, and must accurately project ahead of time how it will be affected by fluctuations in power generation, the power market, and the wholesale natural gas market. To remain informed as to how water supply is likely to affect this process, managers at Intermountain Gas monitor SSWSF data via the Internet. Although they do watch monthly reservoir data, they are much more interested in daily SNOTEL reports, of which they keep close track in order to obtain a continuous stream of information on snowpack levels and projected water supply. Intermountain Gas is a closely held corporation with limited resources for development of capital infrastructure. The company has stated that if SSWSF data were not available through a public source, it would have to do without, affecting its ability to keep prices at optimally low levels. They would not have the financial resources available to install their own water supply monitoring system.

Fluctuations in the natural gas market are affected by both regional and national developments in energy markets and water supply conditions. In addition, conditions in the overall U.S. economy have a significant impact on energy markets. SSWSF data clearly play a key role in making it possible for companies within the energy industry to respond to changing economic and climate conditions in optimizing both profitability (within the constraints of operating as a regulated public utility) and service to their customers.

MUNICIPAL & INDUSTRIAL WATER SUPPLY MANAGEMENT

In all Western States, municipal water supplies compete with irrigated agriculture for limited water supplies. In each of these States, information on current snow water content is essential to water supply-and-demand management for competing uses. Among other benefits, knowing ahead of time approximately how much water is contained in annual snowpacks helps municipalities and water districts put needed conservation measures in place in a timely manner; assists them in making advance plans for tapping into alternative water sources, such as underground aquifers, when necessary; and enables them to estimate the impacts of low or high snowpack on subsequent years' water storage levels. Real-time data also enable some utilities to manage existing reservoir systems and perform their fill and spill decision-making, so as to optimize their reservoir operations. With the recent trend toward increased weather and climate variability, real-time data have become correspondingly more important to decision-makers charged with managing the multiple water systems upon which millions of lives in the West depend. Historical SSWSF data enable States and communities to plan for future years' water needs and give them the information they need to make long-term decisions regarding the development of new water storage capacity, and the acquisition of water rights to support the needs of new urban and suburban development. The case study below addresses only one of the many values of SSWSF data to municipal water utilities.

Denver Water Board

The Denver Water Board serves the water consumption needs of municipal and industrial customers within the Denver metropolitan area. Denver Water also sells excess raw (untreated) water outside of its retail system. The utility owns water rights and storage capacity for approximately 673,000 acre-feet of water per year but has treatment capacity to produce only 445,000 acre-feet of treated water. Current demand within the system is equal to approximately 265,000 acre-feet of treated water per year, leaving an estimated 408,000 acre-feet (total water rights and storage capacity minus current demand for treated water) of raw, untreated water above and beyond the utility's treatment capacity available for sale to entities outside of the utility's internal customer distribution system. Through a combination of supply management decisions and water conservation measures (demand management), the utility has been able to meet within-system demands for treated water in both normal and dry years. The market price for raw water at the time of this analysis is \$247.65 per acre foot. Four hundred and eight thousand (408,000) acre-feet of raw water available for outside sale multiplied by \$247.65 equals approximately \$101 million in potential revenue from the sale of surplus untreated water.

Denver Water's reservoir system straddles the Front Range of the Rocky Mountains west of Denver. Part of the system lies east of the ridgeline of the mountain range, and part of the system lies to the west. As is the case with Idaho Power, Denver Water can move water within its system to optimize operations and, therefore, revenue. The utility is able to transfer water from one side of the system to the other by means of the Moffat tunnel, which takes water from the Dillon Reservoir on the Colorado River system to the west and transfers it to the South Platte River system on the east side of the mountains.

Because Denver Water's reservoir system is spread over a somewhat large and varied geographic area, in a typical year the snow water content and the total inches of snowfall—as a percent of normal—vary from one sub-basin to another within the system, both from east to west and from north to south. This variation—in combination with the ability to transfer water from one basin to another—creates an opportunity for Denver Water to engage in strategic fill and spill decision-making in order to optimize its access to sellable water. Access to SSWSF, data generated at the sub-basin level is essential to the utility's ability to make sound decisions regarding how much water to allow to flow downstream, how much water to capture, and how much water to transfer from one sub-basin to another. It would not be sufficient for Denver Water to know how much water is stored in the snowpack in only one part of the Front Range.

Estimation of how valuable SSWSF data are to Denver Water can be approached in several ways. A simple estimate of the potential ranges of values of the data can be developed by estimating revenue losses under varying degrees of severity of “mistakes” that the utility might make, absent SSWSF data and given the total acre-feet of water available for sale. For example, if the utility makes errors of 1 percent, 5 percent, or 10 percent magnitude in its fill and spill decisions, this error translates into varying amounts of lost revenue to the utility. Another, more complicated way of estimating the value of the data is to set up a model that shows the impact on total revenue if Denver Water fails

to respond to differences in water content across sub-basins. Both forms of analysis follow below:

Nominal Error Analysis

Assumptions of the model:

- 408,000 acre-feet per year of raw water available for sale outside of the Denver Water Board treated water customer base;
- Market price of \$247.65 per acre-foot for raw water; and
- Total potential revenue from surplus raw water equal to approximately \$101,000,000.

Table 11. Potential dollar value of water lost due to varying degrees of fill and spill errors based on misestimated snow water content

Size of Error as a Percent of Total	Approximate Acre-Foots of Water “Lost” Per Year	Approximate Potential Annual Revenue Loss
1	4,080	\$1,010,000
5	20,400	\$5,050,000
10	40,800	\$10,100,000

In-depth Water Transfer Model

Assumptions of the model:

- Water can be transferred from the Colorado River system to the South Platte River system when differential snowpacks, water content, and storage capacity exist;
- Water allowed to run downstream in the Colorado River is not available for sale;
- All captured water can be sold;
- Reservoirs are expected to fill to capacity in normal years (with the exception of the Gross Reservoir);
- Total system capacity is 673,113 acre-feet per year;
- Denver Water Board owns water rights equal to total capacity in the system;
- Total demand for treated water is 265,000 acre-feet per year;
- Market price of \$247.65 per acre-foot for raw water;
- Model is based on mid-April 2006 reported reservoir levels as compared with historical median data for April 15 reservoir levels; and
- SSWSF data are not available, and so fill and spill decisions are based on historical reservoir data.

Potential dollar value of water lost due to varying degrees of fill and spill errors based on errors in snow water content estimates:

- Historically, the South Platte River system snowpack water content peaks in mid-April, and the Colorado River system snowpack water content peaks near the end of April. In contrast, in mid-April 2006, the South Platte River system snowpack had

already peaked and was declining while the Colorado River system was at its peak, 2 weeks early.

- If water system managers assumed that the 2006 pattern of snowpack water content accumulation had followed the historical pattern (meaning that snowpack water content in the Colorado River system would have been assumed as not having yet peaked), in mid-April they would have decided to allow excess water accumulating in the Colorado River reservoir system to run downstream rather than transfer it to the South Platte River system.
- The potential resulting loss of revenue under these circumstances is equal to approximately \$5,594,000.
- The potential for this type of revenue loss exists whenever actual geographic differentials in snowpack water content vary from historical differentials. An engineer from the Denver Water Board reported that using SSWSF Program data in order to respond to cross-basin differentials in water content is crucial to the utility's fill and spill decision-making processes. The above analysis addresses only one of many potential benefits to the utility having access to SSWSF data.
- This estimated potential loss is in line with the estimates generated by the more rudimentary nominal error analysis.

Table 12. Denver Water Board Reservoir System, April 2006

	Total Acre-Foot Stored in System	Mid-April 2006 Reservoir Levels as a Percent of Historical April 15 Median Levels	Storage Differential/Water Transfer Opportunity	Estimated 1-Year Loss of Revenue if Transfer is not Completed due to Erroneous Assumptions About Water Content in River Basin Snowpacks
South Platte System	258,079	87	38,563 acre-feet in capacity available to receive transferred water from the Colorado River reservoir system	22,588 acre-feet (sent downriver and "lost" to transfer and subsequent sale opportunities) multiplied by \$247.65 market price for raw water equals approximately \$5,594,000 in lost revenue
Colorado River System	399,059	106	22,588 acre-feet of water available to be transferred to the South Platte River reservoir system	

CHAPTER 7. EDUCATION and RESEARCH

The SSWSF Program had its earliest beginnings in the higher education system on the Nevada-California border when Dr. James E. Church at the University of Nevada began tracking snowpack depths in the Sierra Nevada. After its inception, the SSWSF Program developed over time into a cooperative effort between various university researchers and the Soil Conservation Service. A key participant in the evolution of the science of snowpack analysis and water supply forecasting—as well as in the original organization of the university/State/Federal/private cooperative of which the cooperative SSWSF Program still consists today—was George D. Clyde, a professor of engineering at Utah State University in Logan, Utah. Drs. Church and Clyde were just the first two of countless researchers in universities, government agencies, and research institutes who have included SSWSF data in their research programs over the past century.

Academicians and professionals at institutions, including universities across the United States, Federal agencies such as USGS, and research institutions such as the National Center for Atmospheric Research and the Desert Research Institute use SSWSF data on an ongoing basis in support of research programs in diverse topics such as weather forecasting, geography, civil defense and emergency management, urban planning, civil and environmental engineering, and others.

UTAH WATER RESEARCH LABORATORY

One example of a research institution that uses SSWSF data as a part of standard operations is the Utah Water Research Laboratory at Utah State University, a land-grant institution with a university-wide focus on agriculture. In its hydraulics laboratory, the lab performs research and development of new design and construction techniques for hydraulic structures of all types, including pumping systems, pipes, dams, and other water-related engineered structures. The lab is one of only a handful of facilities in the United States that has the capacity and the facilities to perform large-scale testing on such structures. The lab, which sits next to the Logan River in northern Utah, is located just below a reservoir that supplies water for the facility. The main research facility at the lab contains a network of flumes, channels, pumps, pipelines, and other equipment necessary to conduct hydraulic experiments and testing. The lab also has a rainfall simulator and a sunlight simulator, enabling researchers to conduct studies related to erosion, runoff, infiltration, and crop production.

The Utah Water Research Laboratory conducts physical and numerical modeling and testing of physical structures—by conducting testing on both scale-model replicas and actual structures—as well as performing computer model development, calibration, and simulation studies to evaluate structures for potential failures. The lab also tests valves and flow meters for durability and accuracy. Lab customers include architectural and engineering firms, construction companies, energy companies ranging in scale from small to very large (including nuclear power generation facilities), private manufacturing firms, irrigation companies, and a wide variety of other private and public entities at the local,

State, and Federal levels. The lab also houses research projects on water supply in general as it relates to engineering and agriculture in the intermountain west. The lab's ability to perform this research and testing work is dependent on streamflow in the Logan River; so lab operators pay close attention to water supply forecasts provided by the SSWSF Program. Laboratory researchers also stated that Utah State University, in general, is very interested in snowpack and water supply data, as these datasets provide information that is key to much of the research conducted in agriculture at the university.

CHAPTER 8. PRIVATE CITIZENS

Many opportunities exist for private citizens to use SSWSF data in their recreational and other personal activities. The majority of potential personal uses are not externally trackable, and in a study of this scope individual users cannot be readily identified. Personal uses of the data will be discussed as *potential* uses without documentation of actual incidences or dollar values of those uses. Potential private users of SSWSF data include recreation associations, hunters, fishermen, boaters, skiers, snowmobilers, campers, tourists, and others whose recreational activities or travel plans might be affected by snow depths or streamflow in one way or another. These users' interests in SSWSF data are expected to fall into two main categories that are not necessarily mutually exclusive: those related primarily to safety and those related primarily to the quality of a planned recreational experience.

In the same way that commercial recreational outfitters access online SSWSF sites to make decisions regarding where to take clients, private individuals may access SSWSF data for specific SNOTEL sites to determine whether it is safe or prudent to travel to or cross a given area. They may also look at the online data to check snow depths, changes in snow depths, and snow water content to determine whether the quantity and quality of snow meet their requirements for snow-related recreational activities such as backcountry skiing or snowmobiling.

Alternatively, the relatively new sport of ultrarunning is defined as running events that are contested at distances longer than standard marathon distance (26.2 miles). Many ultramarathons, or "ultras," as these races are alternately called, are staged on trails in mountainous areas of the Western United States. At least two nationally prominent 100 mile ultramarathons' Internet Web sites link to SSWSF data so that participants can access data regarding snow depths on the race courses. The Western States Endurance Run in California and the Hardrock Hundred Endurance Run in Colorado have been profiled in magazines such as *Outside*, *Sports Illustrated*, and *Runners' World* as well as being featured on national television programs such as *CNN Sports Illustrated*. These events take place at high elevation (much of the Hardrock course is above 13,000 feet and in one section goes above 14,000 feet). Because the safety and difficulty of these events are directly affected by snowpack levels—both with respect to the events themselves and with respect to individuals who want to do prior training on the race courses—snow depth information is crucial to event organizers and participants alike. This information is used for logistics planning in terms of safety measures and race support, for potential alterations to race courses, and for estimating how long it will take for participants to cover specific stretches of the race courses.

Backcountry skiers are known to access SSWSF data for specific SNOTEL sites to check snow depths, both base and new snow, to determine whether or not they want to go skiing on a given day. Not only does snow depth matter to them, but snow water content gives them a relatively good idea as to the quality of the existing snowpack in terms of where it falls in a continuum ranging from relatively dry, powdery snow to heavy, wet snow.

Skiers use this information to decide whether existing snow conditions are sufficiently favorable to make it worth incurring the time, effort, and financial expenses of a ski outing on a given day. Real-time SNOTEL data can also augment official avalanche forecast data and can provide backcountry skiers additional information they can use to assess the risk of an avalanche occurring within a particular mountain basin.

CHAPTER 9. MULTIPLE-CATEGORY ENTITIES

COMMUNITY OF OAKLEY, IDAHO

In 1913, construction was completed on a new dam and reservoir—Lower Goose Creek Reservoir, also known as Oakley Reservoir—in the watershed above the town of Oakley, Idaho⁴. Although the new reservoir had been promoted on the basis of the benefits it would provide to farmers in the area, whose stock purchases helped to fund the project, the reservoir failed to fill, and the projected benefits were not initially realized. Over subsequent years, the water level in the reservoir remained lower than capacity. In 1921, Oakley Reservoir filled to capacity for the first time. It would not reach capacity level again until 1984. Each year, all of the water that collected in the reservoir was distributed to farmers via the irrigation canals that were fed by the reservoir. The original Goose Creek channel no longer had any water flowing in it. Over time, farmers filled in the portions of the streambed that passed through their land, and they began farming those acres. In Burley, Idaho, downstream from Oakley, homes, businesses, a school, and a cemetery were built within the natural streambed. In the 1970s, a court ruling declared the natural stream channel “dry” and legally prohibited the City of Burley from using the channel as a place to route excess storm water runoff, effectively leaving Oakley Reservoir with no natural outlet.

During the winter of 1983-84, record amounts of snow accumulated in the hills above Oakley Reservoir. Kent Foster, who was the SCS District Conservationist for Oakley, monitored the snowpack above Oakley as part of the Cooperative SSWSF Program. He and others began to become concerned about the amount of snow that was building up in the watershed. In January 1984, SCS issued an SSWSF bulletin stating that snowpack amounts in southern Idaho were as much as 300 percent of normal in places. Above Oakley Reservoir, approximately 240 percent of normal snowpack had accumulated by early January. One hundred fifty percent would have been enough to cause Oakley Reservoir to flood. SCS personnel were dispatched to double-check snow course data, and they found that the lower elevation snowpack contained an unusually high level of water content, creating even more concern about the potential for flooding.

Throughout winter and early spring of 1984, repeated storm events piled even more snow on top of what had already fallen. By March, it had become clear to Foster, canal company officials, civic leaders, and local farmers that Oakley Reservoir would not be able to contain the water that was coming. The estimated amount of water contained in the watershed above the reservoir was immense. Not only would the reservoir not be able to contain the runoff, the amount that was anticipated would cause widespread damage along the entire abandoned Goose Creek stream channel over a distance of more than 20 miles.

⁴ This case study is based on information reported in the book, *A Flood Cannot Happen Here*, by Kathleen Hedberg.

In order to make room for incoming flows, the canal company began sending large amounts of irrigation water to canal company shareholders. Even if a farm did not need or want additional water, the company sent water to it for the water to be dispersed and evaporated. It soon became clear, however, that these measures would be insufficient to accommodate the amount of water that was on its way. In April 1984, new SSWSF reports indicated that the snowpack was still increasing, contrary to normal years. It was clear that a flood was imminent. In response to this looming flood event, leaders from Federal, State, and local entities began active discussion as to how to respond. The decision was made to enlarge existing and abandoned canals to send as much water as possible into gravel pits and nearby Murtaugh Lake. There was also discussion about building a reservoir on Federal lands to contain most of the remaining flood waters.

In an unprecedented effort, USACE; the National Guard; SCS; canal companies; State and local government entities; and local civic, business, and religious organizations and individuals worked together to design and build a 23-mile canal. The canal was designed to send water from the Goose Creek drainage across the nearby Cottonwood Creek drainage and into Murtaugh Lake. Rights-of-way were obtained primarily through personal negotiations facilitated by local leaders. At the same time that the canal was being built, the spillway on the dam at Oakley Reservoir was raised 3 feet, 1 foot of which was concrete and 2 feet of which were wooden planks held in place by sections of channel iron. This 3-foot extension was put in place to buy a few days of construction time for the new canal. The level of water in the reservoir reached the bottom of the new extension just as its construction was completed.

Construction of the canal was a round-the-clock effort. Large numbers of massive earthmoving equipment were brought in from across the region. Businesses contributed machinery, supplies, and labor. Youth groups filled sandbags. Local churches prepared meals to feed workers. Landowners watched as their farms were bisected by the canal.

Less than 2 weeks after the start of construction, the hastily planned canal was finished. Unfortunately, it did not accomplish what was needed. Like Goose Creek, Cottonwood Creek was flowing at record levels. The water from Cottonwood Creek alone took up all of the capacity of the new canal, and once again there was nowhere for the water from the Goose Creek watershed to go. Plans were quickly drawn for an additional section of canal to divert Goose Creek water around the west side of Burley and into the Snake River. The entire distance of the new canal system would end up being approximately 42 miles. Roads and utilities were cut and culverts were installed over existing canals that would have to be crossed by the new canal. On May 20, 1984, less than 3 weeks after initial construction began, the gates that would release water into the old streambed—into the new canal—were gradually opened. At the time when the gates were opened, the last mile of canal had not yet been completed. It was finished just in time for the water to reach the Snake River.

On June 8, 1984, the gates that had been releasing water into the new canal were once again closed. In the 19 days that it flowed, the canal system is estimated to have carried 37,500 acre-feet of water to Murtaugh Lake, onto farm and range lands, and into the

Snake River. Additional water from the Cottonwood Creek drainage was diverted into Murtaugh Lake, preventing flooding in that watershed as well. One SCS estimate put the value of damage protection for farmland alone at \$60 million—\$111.73 million in 2005 dollars—a figure that does not include the damages to buildings and infrastructure that would have been incurred within the city of Burley had the canal not been built. Had SSWSF failed to alert local leaders early in the year, it is not likely that the resources necessary to complete the canal could have been gathered and organized in time to prevent the flood that would have occurred. A key point that is brought to light by this case study is that it is not sufficient to simply know the depth of the snowpack in a given watershed: It is also necessary to know the water content of the snowpack to make sound decisions regarding the necessary extent of flood damage prevention measures.

TRUCKEE RIVER WATERSHED WATER USERS

The Truckee River originates in the eastern Sierra Nevada and flows down through the Sierra foothills into Nevada and through the Reno/Sparks metropolitan area before terminating at Pyramid Lake. The lake is completely surrounded by tribal lands owned by the Pyramid Lake Band of the Northern Paiute Tribe. The Tribe owns rights to water storage in Stampede Reservoir, one of several reservoirs in the Truckee River reservoir system, and exercises these rights in order to maintain sufficient flows to protect the endangered cui-us fish that live in Pyramid Lake and spawn in the Truckee River.

Lake Tahoe sits within the Truckee River Watershed and is of sufficient concern to merit its own attention with respect to water management. Lake Tahoe has a 6.1-foot-high dam at its outlet at Tahoe City. Although this is a small dam by many standards, Lake Tahoe covers a large geographic area and is the largest reservoir in the Truckee River system, with storage potential of 744,600 acre-feet. Lake Tahoe is world renowned for its clarity and beauty. Millions of dollars have been spent managing the area around the lake to protect this resource. One concern is beach erosion. Because the level of this lake can fluctuate by 6.1 feet, management of this fluctuation is of concern due to its potential contribution to erosion and, subsequently, its impact on water quality.

The Carson River is located immediately south of the Truckee Watershed. It has one significant reservoir near its lower end, Lahontan Reservoir. There are a few small reservoirs near its headwaters, but they hold only a few hundred acre-feet of water. This watershed ends at the Stillwater Wildlife Refuge, which is a valuable area for waterfowl. The first-ever USBR water development project, called the Newlands project, consisted of two components. One was a small diversion structure called Derby Dam on the Truckee River, located below Reno but above Pyramid Lake, which was built in the early 1900s. This structure was used to divert water out of the Truckee River over to the Carson Watershed, putting water into the second project component, the newly created Lahontan Reservoir. This water was in turn used for irrigation in the Fallon area at the terminal end of the Carson River Watershed.

The Federal Government's objective in building the Newlands project was to make it possible for people to establish successful agricultural operations in the area. After the project's completion, people moved into the Fallon area, built ranches and farms, and became dependent upon the water diverted by the project from the Truckee River and into the Carson River Watershed. People who settled along the unlined ditch that carries this water also began to depend upon ditch leakage to recharge their ground water and to keep the water table close to the surface of the ground.

When the Endangered Species Act was passed and the tribal rights of the Pyramid Lake Tribe began to receive more respect than they had in previous decades, matters became more complicated. Due to the Newlands project diversion, the level of water in Pyramid Lake began to fall drastically. The cui-ui began to have a harder time making it into the Truckee River. Diversions during spring runoff left too little water in the Truckee River between Derby Dam and Pyramid Lake for the fish to spawn. Die-offs occurred, and the population of cui-ui began to decline, leading to the fish being listed as an official endangered species. Lawsuits began to be filed over the issue several decades ago, and legal battles over the fish and water continue to this day.

Within this context, the Nevada SSWSF Program issues forecasts that are used to manage the reservoirs in both the Truckee River and Carson River watersheds. SSWSF has begun issuing forecasts for the Truckee River and Carson River each year in late December because decisions are made at that time as to whether or not to allow water to be diverted at Derby Reservoir and moved over to Lahontan Reservoir. This annual decision is based upon forecast storage values for Lahontan, which are, in turn, based upon SSWSF snowpack forecasts and forecasted flows for the Truckee River. The Tribe has fisheries set up to help with the fish recovery and, depending upon the forecast, will decide whether or not to have a fish spawning run. If the annual SSWSF forecasts are wrong, fish will be stranded in the river and die-offs would occur.

Another category of benefits generated through management of the watersheds in the area surrounding Reno, Nevada, is recreation. Boca Reservoir, southwest of Reno, is a popular location for water skiing. SSWSF forecasts determine how this reservoir is managed and whether or not boaters can physically get to the water. River running outfitters also use the data to make operations decisions on a section of the Truckee River just below Lake Tahoe, where rafting is a very popular activity. Because river running companies in the area receive advance notice with respect to summer season water releases, they are able to avoid losses that would be associated with opening for business in a year when there will not be enough streamflow for them to run rafts on the river. Recreational fisheries below Lake Tahoe—and associated businesses—are also affected by streamflow and benefit from advance planning based on SSWSF data.

Pressures on water supplies from growing development in the Reno/Sparks area and increased tensions between competing users, including agriculture, urban and suburban development, and the various users mentioned above, make the management of water supplies in the area a complex, controversial, and difficult endeavor. Having access to SSWSF data makes it possible for water managers to optimize reservoir operations in

such a way as to accommodate these competing demands much more efficiently than they could without the data.

IDAHO WATER USERS ASSOCIATION

The primary membership of the Idaho Water Users Association is made up of 166 entities, including canal, ditch, and irrigation companies and districts, reservoir districts, and other water supply organizations. Members of the Idaho Water Users Association—some of which appear in other case studies within this report—use SSWSF data to help them make water allocation decisions which, in most cases, translate into planting decisions on the part of their shareholders and other customers. Producers adjust which crops they plant based on which they will be able to “finish” given the amount of water available in their specific system. Without the data provided by the SSWSF system, all users would be left to guess how much water there would be and when it would flow.

The degree to which SSWSF data are important to a given water supply system depends on whether their system is based on natural flow. A system with some amount of storage capacity is less dependent on current flows than is a system with no storage, but all are dependent on runoff for their primary source of irrigation water and water for municipal and industrial uses. The need to understand well ahead of time how long and how much natural flow will be available is essential to the process of deciding which crop to plant.

In urbanizing areas such as Nampa-Meridian, a high percentage of the overall water supply is used by homes, parks, and so on. In dry years, rationing decisions need to be made very early in the season. The availability of SSWSF data makes it possible for municipalities to determine early in the year the degree to which rationing is likely to be necessary. This lead time gives them the opportunity to involve all stakeholders in the process of laying out a set of rules or regulations for water rationing, as well as allowing time for the political processes that may need to take place before new rationing rules can be implemented. According to the Idaho Water Users Association, in areas such as Nampa-Meridian, where the M&I customer base increased from 3,000 to approximately 60,000 customers in recent years, it is very important for planners to have access to SSWSF data in planning for the needs of this growing customer base.

In agriculture, Idaho Water Users Association members rely on SSWSF data to help them in the early-season contracting process. Mint growers’—whose crop value is maximized when they have water available to them through the month of August—contracts are based on water use. The primary buyer of mint crops has implemented a policy of only contracting with producers whose water supplies are predicted by SSWSF data as being sufficient to carry their crops through the growing season.

COLORADO RIVER BASIN IN 1983

“Worst-case” scenarios provide a perspective that is quite different from the values shown above, both in terms of their source (imaginary versus actual) and their confirmability. Because they are developed on the basis of imagined events, they must be treated with caution. Nevertheless, they do have value in that they can establish the absolute highest level of economic benefits that could be attributed to the data generated by the SSWSF Program.

For example, as mentioned previously in this study, in 1983 Glen Canyon Dam came perilously close to failing as a result of excessive snowpack combined with a lack of understanding of or appropriate interpretation of data being generated by the then-new SNOTEL system in the Upper Colorado River Basin. Had snowpack conditions upstream been even marginally heavier, the dam is likely to have failed. This would have sent a huge volume of water downstream where it would have pushed through Lake Mead, overtopped Hoover Dam, and caused catastrophic flooding throughout the Colorado River corridor in communities in California, Arizona, and Mexico. The capacity of the reservoir behind the dam is reported by USBR as being 27 million acre-feet. This is enough water to cover 27 million acres of land with water that is 1 foot deep. If these events had occurred during the night, hundreds—if not thousands—of deaths could have resulted. Even if it had occurred during the day, the loss of life would have been staggering. Property damage would have been extensive and devastating. Damage to infrastructure, including bridges, roads, utilities, and—possibly—additional dams and power plants, would have been widespread and long lasting in impact.

A former employee of the NPS made the following statement: “Following the near failure of the dam in 1983, the Bureau of Reclamation prepared a flood inundation model for the failure of Glen Canyon Dam (S. Latham, USBR 1990). According to this study, in the event of overtopping or breaching of the dam the crest of the flood would be over 500 feet high when it reached the Grand Canyon and 230 feet high when it reached Lake Mead. The study concludes: ‘The failure of Glen Canyon Dam due to overtopping would produce catastrophic flooding with unprecedented flood depths and discharges all the way to Lake Mead and Hoover Dam. Even if Hoover Dam did not fail, there would be unprecedented flooding downstream of Lake Mead as well’.” The study citing these figures does not provide details regarding the exact conditions that would result in this magnitude of event, but it confirms that others who have studied Glen Canyon Dam have concluded that a dam failure would cause significant damage downstream.

In addition to losses due to downstream flooding, a failure at Glen Canyon Dam would mean the loss of all power generation capacity at the dam. Power generation facilities at the dam produce approximately 4,800,000 megawatt hours per year. One megawatt hour is currently worth approximately \$56 in the Intermountain regional power market. Using this figure, the power generating capacity of Glen Canyon Dam is valued at as much as \$268,800,000 per year. In addition to the economic value of the power generation provided by the dam, the loss of boating and other recreation expenditures is estimated as being worth approximately \$2,500,000 per year. These values, in combination with all

other losses that would occur due to a dam breach, give an indication of how valuable it is to know how much water is contained in the Upper Colorado River Basin in any given year.

CHAPTER 10. COMPARISON OF ALTERNATIVE FUNDING AND OPERATION FORMATS

INTRODUCTION TO ALTERNATIVES

The objective of this chapter is to provide information to decision-makers regarding the relative benefits provided by public involvement in funding and operating a program that gathers and distributes SSWSF data. Multiple hypothetical alternatives to the existing format of the SSWSF Program in the Western United States have been identified and in this chapter will be discussed with respect to their relative merits. This chapter has been included in the analysis to address the degree to which public involvement in the provision of snow supply and water forecast data generates benefits in comparison with the alternative formats under which a snow survey program could, in theory, be funded and operated. Each of the alternatives will first be evaluated with respect to practical feasibility, based on the public goods theory outlined in Chapter 2. In addition, the alternatives will be compared both with each other and with the existing Federal system in terms of the relative advantages of their formats. Other than continuing the existing system, implementation of any of the alternatives would be expected to result in a decrease in Federal expenditures in an amount that would vary depending on the degree to which the alternative is expected to reduce Federal spending on snow survey activities. These changes in cost, which would vary from one alternative to another, will not be addressed in detail within this document. The following chapter will address the issue of overall benefits of the existing program.

Alternatives Eliminated From Detailed Analysis

Two alternatives to the existing system were eliminated from the detailed analysis that follows. These two, which are *complete elimination of the SSWSF Program without replacement* and *reverting to a snow-course-only NRCS cooperative system*, were eliminated on the basis that neither holds any advantages when compared with the other alternatives considered.

Complete elimination of the SSWSF Program—without provision of either a public or private replacement—is one possible alternative to the continued operation of the existing system. This alternative would entail the decommissioning of all physical and electronic infrastructure associated with the existing program, and would also require the re-assignment or lay-off of all program employees with no replacement by either a publicly or privately funded and operated system. Because this alternative offers no identified advantages over any of the other alternatives considered, it has been eliminated from further evaluation.

It would also be possible to return to the type of system that existed prior to the adoption of the SNOTEL plus snow course model of SSWSF operations, which would entail utilizing only snow course data. A snow course consists of a type of measurement within a specific location where NRCS personnel, in cooperation with local volunteers or

personnel from other Federal, State, or local entities, use tubes and weight scales to measure snow depths and water content at each set of fixed-location sample points at that location. Reverting to a snow-course-only model would involve decommissioning of the SNOTEL system, and would require extensive additional on-the-ground field work during snowpack months on the part of NRCS and cooperating entity personnel as compared with the current system.

Should the program return to using the snow course operations model that was in place prior to the adoption of SNOTEL technology, individual snow course locations would be limited to one sample per month during the snow year. Data could still be distributed electronically via the Internet, but all data would be lagged by 1 or 2 days, at an absolute minimum, and could be lagged by as many as 30 days. Because this alternative offers no identified advantages over any of the other alternatives considered, and due to safety and other personnel considerations, in addition to a loss of real-time snowpack and water supply reporting, this alternative was dropped from further consideration.

Alternatives Considered

Nine alternative variations on how snow survey work is funded and operated were identified as meriting detailed evaluation within this analysis. They can be grouped into nine categories, categorized by whether they would be publicly, cooperatively, or privately funded or operated, as shown in Table 13.

Public funding of snow survey activities could be provided by a Federal, State, or local government agency, or by some combination of the three. Public operation of a snow survey system, similarly, could be executed by Federal, State, or local government agencies or by some combination of the three in cooperation. Private funding could be provided by private entities, such as corporations and/or non-governmental organizations, either collectively or independently. Private operation of a snow survey system could be accomplished either through direct corporate control, such as the case in a closely held private system, or through procurement of one or more contracts with private entities. Private operation of an alternative system could be organized as a collective, joint enterprise among multiple corporations or other private entities, or it could consist of a proliferation of separate, independent efforts by individual corporations. It should be noted that no purely private, formal snow survey program is currently known to exist within the United States. Whether in terms of funding or operation, or both, each of the identified snow survey systems in operation today functions as either a public or cooperative system that is funded in part—50 percent at a minimum—by tax revenues and is operated primarily by a Federal, State, or local government agency.

Table 13. Alternative formats for funding and operation of snow survey and water supply forecasting

		Funding		
		Fully Public	Cooperative	Fully Private
Operation	Fully Public	Publicly Funded and Operated	Cooperatively Funded, Publicly Operated	Privately Funded, Publicly Operated
	Cooperative	Publicly Funded, Cooperatively Operated	Cooperatively Funded and Operated	Privately Funded, Cooperatively Operated
	Fully Private	Publicly Funded, Privately Operated	Cooperatively Funded, Privately Operated	Privately Funded and Operated

The nine configurations of funding and operations were evaluated in detail. These nine categories, however, do not represent a complete breakout of all possible systems. Rather, each alternative system that could be created would fall within one of the nine categories. It is recognized that there would be some degree of variety in the specific characteristics of systems that differ in specifics. For example, a State-funded snow survey program would be somewhat different from a federally funded program in terms of the advantages of the two programs compared to each other. For the sake of simplification and clarity, however, only the nine general categories of possible programs in the table above were examined in the detailed analysis.

COMPARISON OF ALTERNATIVES

The alternatives described above were evaluated in terms of how they differ from one another in specific characteristics, and how important their relative advantages are judged as being from the assumed viewpoint of the public in general. Differences in these characteristics hinge, to an extent, on the degree to which each alternative is market based as opposed to being a public-sector alternative. The factors used to evaluate the alternatives were divided into the following categories, focusing on issues related to:

1. Public goods theory;
2. Science;
3. Social welfare; and
4. The perpetuation of snow survey operations.

Evaluation in Terms of Public Goods Theory

It is important to note that, although theoretically possible, some of the alternatives evaluated may not be feasible for the very reason of the public goods nature of snow survey data. Snow survey programs gather and distribute various types of information through direct acquisition and analysis of data, a process that can be categorized as “basic research.” Within the field of economics, basic research is acknowledged as being a public good, indicating that snow survey data will be subject to the issues that accompany all goods that are public in nature. Among these issues is the difficulty with which individuals are prevented from enjoying the benefits generated by a public good once it has been produced and then provided to even a single user. These “positive externalities” are considered by economists to be market failures that cause disincentives within private industry. These, in turn, cause deadweight losses in overall social welfare. If an entity cannot protect its financial interests in a good, it is unlikely to fund the development of that good. This scenario is often true of systems generating information that cannot easily be withheld from widespread public distribution. The very nature of the information gathered makes it unlikely that the owners of any system funded by a coalition of private entities would succeed in preventing the re-distribution of data generated by their system after its initial release.

Within game theory, it is recognized that it is very difficult to manage the behavior of members of coalitions or cartels. Pressure on coalition members by way of what is termed a “credible threat” is usually necessary to obtain compliance with coalition rules. To be credible, a threat must be backed by visible examples of its implementation. For example, in the case of a coalition-based system such as a subscription-funded information service, the subscription contract would have to contain the threat of some type of financial penalty or legal action to be levied on subscribers who were found to have released coalition-owned data to anyone outside of the subscription. In order for this threat to have the desired effect, it would have to be carried out on occasion in a public manner so as to serve as a warning to other subscribers who might be tempted to “defect” from the terms of their subscription contract.

Even if a coalition-based system were able to function profitably—in spite of the legal expenses and operational burdens associated with this set of conditions—the sheer public nature of the data would eventually result in losses of potential revenue and profit. The temptation to sell data at a discount to non-subscribers could be expected to eventually erode the monopoly power held by the controlling coalition. Once available outside of the subscription, the data could quickly and easily be made freely available to the public at large via electronic media.

Closely controlled individual private systems would be able to collect and successfully control data to the extent that they were able to impose privacy restrictions on their own employees. They would, however, lose the private economic benefits that would be gained through cooperation with others who had an interest in gathering data from the same geographic locations. In addition, there would be a substantial loss of potential benefits to society, both public and private, outside of the funding and controlling entity.

An interesting scenario to consider is that at geographically and meteorologically strategic locations, multiple SNOTEL-style installations would exist within a few feet of each other. Each duplicate installation would represent a market failure, as well as indicate losses of both overall economic efficiency and benefits to society.

A key characteristic for evaluating alternatives, based on the public goods theory, is the degree to which alternatives provide the availability of data to entities not directly contributing to the funding of the system, both members of the public at large and non-participating private entities. Should the system be privatized, it would be unlikely that any of the funding organizations would be willing to share the data generated by the system with non-paying entities. Interviewed representatives from one of the utility companies included in the study stated that should the existing system be discontinued, and should their company replace critical SNOTEL sites with their own system, they would keep the generated data private and not make them available to other data users. Under the category of public goods theory, the factors within which the alternatives were evaluated included: vulnerability to “free rider” problems, vulnerability to public goods-related market failures, vulnerability to legal expenses associated with protection of confidential data, feasibility with respect to public goods issues, and the probability of obtaining future continuing returns on past public investments in the SSWSF system.

Evaluation in Terms of Science

Scientific considerations were frequently mentioned by those interviewed during the completion of this study. Data users repeatedly expressed a high level of interest in the quality of data produced by potential alternate snow survey systems in comparison with the existing system. One of the key characteristics in which the alternatives are expected to differ from one another is that of continuity of the historical data set. A corporation running a snow survey program for the purpose of short-term profit maximization will have no incentive to protect the overall long-term viability or continuity of the system and its associated data. This issue was raised repeatedly by many of the individuals who were interviewed in the process of conducting this study. The concern expressed was generally the fear that any discontinuity or disruption of the data stream that has been gathered over the past century would result in losses in the value of the data. For example, the reason given by BPA for not using SNOTEL data in its most important internal operations modeling is the fact that continuous SNOTEL data sets are fewer than three decades old. The snow course data used by BPA, in contrast, had been gathered, in some cases, for several more decades. These data are considered by BPA as providing a more helpful source of information for use in modeling the patterns of the snowpack and water content accumulation and runoff.

An additional concern mentioned by data users is that of trust in the data generated by the system. Beneficiaries reported that a significant portion of the value to them of the data is dependent on the degree of familiarity and trust they have with and in the NRCS personnel who operate and maintain the data collection system, organize and distribute the data, and provide analysis for users. Multiple interviewed users stated that without the amount of trust that has been achieved to date, the value of the data to them would be

diminished to a large degree. They expressed some fear that, should data be made available to them in the case of privatization of the system, they would not be able to rely on the data and associated information products—such as water supply forecasts—for accuracy and consistency with past data sets. In addition, many data users reported that it is very important to them that the data are collected and distributed by a neutral source. They stated that any private snow survey entity, operating for profit, would be suspect due to the possibility that one or more of their customers could be motivated to exert pressure on them to distort or manipulate the data in order for them to obtain strategic advantage. Even a private contractor working on behalf of a coalition of private corporations, or for the public, could be vulnerable to incentives to collect or release data in a manner that would benefit one member of the coalition—or the public—disproportionately. The consensus among those interviewed for this study was that having the Federal Government continue to lead the operation of the SSWSF Program would be the best possible way to guarantee neutrality in how data are collected, analyzed, and distributed. Without this neutrality, much of the value of the data in terms of trustworthiness would be lost.

Based on the concerns reported by those interviewed, the factors within which the alternatives were evaluated in the area of scientific considerations included:

- The expected general quality of data;
- The probability of future continuity of the data set;
- The probability of adequate maintenance of the existing historical data set;
- The expected longevity and expertise of the personnel operating the system; and
- The ability to do effective regional- and national-level analysis.

Evaluation in Terms of Social Welfare

In the area of overall social welfare, the alternatives were evaluated using the factors of:

- The ability of data users to access information across geography and/or time;
- The ability of snow survey data-dependent government agencies to achieve their respective missions;
- Efficiency in the use of natural resources and productive capital;
- The optimization of food production as related to food security as a national issue;
- The overall contribution of the alternative to profitability within the private sector; and
- Public safety (dam operations, flood preparations, etc.).

The alternatives were also evaluated in terms of how well they generated benefits for the overall categories of users included in this analysis. These included:

- Private industry;
- Government;
- Public utilities;
- Educational and research institutions;
- Private citizens; and
- Multiple-category entities, as defined in Chapter 3 of this study.

In addition, the alternatives were compared with respect to the probability that snow survey data in general would be produced in an amount sufficient to optimize opportunities for generating benefits for society as a whole.

Evaluation in Terms of the Perpetuation of Snow Survey Operations

Finally, the alternatives were compared in terms of how likely each would be to contribute to the long-term perpetuation of snow survey operations in one form or another. Data users and SSWSF Program personnel alike expressed the concern that any degree of privatization of the system would result in tying the stability of the system and the data gathered to fluctuations in conditions within the markets in which the funding entities participate. Issues related to market fluctuations are generally related to basing snow survey operations on the profit motive as compared with the motive of providing public benefits and overall social well-being. A further concern that was expressed was that the tendency for corporations to come and go would leave the snow survey system open to disruption or discontinuation at any time. In comparison, the longevity of the Federal Government is expected by data users to provide stability that no private entity would be able to match under normal market conditions. The two factors included in this category of evaluation were:

- Vulnerability to fluctuations in general market conditions; and
- Vulnerability to government budget cuts.

SUMMARY COMPARISON OF ALTERNATIVES

The attributes or, in other words, characteristics of the alternatives within these factors served as the basis for their comparison. The results of this comparison are shown in the table below.

The alternative that generates the most benefits, based on this analysis, is for snow survey activities to be cooperatively funded and operated. All of the known existing formal snow survey programs in existence within the United States today fall into this category. This could be interpreted as a confirmation that the existing configurations of snow survey programs across the United States have evolved into the most beneficial and efficient model. It also supports a position that it is not expected: that the benefits provided by the existing SSWSF system could be matched by a privately funded alternative.

Based on the results shown below, there is little or no difference between some of the alternatives in terms of the importance of the advantages they offer. This is explained by the minimal variability between those alternatives in their attributes in the factors used in their comparison. It is also an indication that the majority of benefits are derived from protecting the system from market failures by publicly funding its operations. This is consistent with the public goods theory outlined within this report. The very large difference in expected benefits when comparing publicly funded with privately funded systems also reflects the public goods nature of snow survey data.

Table 14. Attributes of the Alternatives

Alternatives:	Publicly Funded and Operated	Publicly Funded, Cooperatively Operated	Publicly Funded, Privately Operated	Cooperatively Funded, Publicly Operated	Cooperatively Funded and Operated	Cooperatively Funded, Privately Operated	Privately Funded, Publicly Operated	Privately Funded, Cooperatively Operated	Privately Funded and Operated
Factors									
Public Goods Issues									
Vulnerability to free-rider problems	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Very vulnerable	Very vulnerable	Very vulnerable
Vulnerability to public goods-related market failures	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Very vulnerable	Very vulnerable	Very vulnerable
Vulnerability to legal expenses associated with protection of confidential data	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable	Very vulnerable	Very vulnerable	Very vulnerable
Feasibility with respect to public goods issues	Very feasible	Very feasible	Very feasible	Very feasible	Very feasible	Very feasible	Not very feasible	Not very feasible	Individual: very feasible; coalition: unlikely
Probability of obtaining future continuing returns on past public investments in the system	Very high probability	Very high probability	Very high probability	Very high probability	Very high probability	Very high probability	Somewhat low probability	Somewhat low probability	Very low probability
Scientific Issues									
Expected general quality of data	Moderately high	Moderately high	Somewhat high (concerns about quality of private/contractor work due to profit motive)	High	Very high	Somewhat high (concerns about quality of private/contractor work due to profit motive)	Low to high, depending on type of system. Inconsistent.	Low to high, depending on type of system. Inconsistent.	Low to high, depending on type of system. Inconsistent.
Probability of future continuity of the data set	High probability	High probability	High probability	High probability	High probability	Moderately high Probability	Low probability	Low probability	Low probability
Probability of adequate maintenance of the existing historical data set	High probability	High probability	High probability	High probability	High probability	Moderately high Probability	Low probability	Low probability	Low probability
Expected longevity and expertise of personnel operating the system	Medium to high, depending on funding levels	Medium to high, depending on funding levels	Medium to high, depending on funding levels	Medium to high, depending on funding levels	Medium to high, depending on funding levels	Medium to high, depending on funding levels	Low to high, depending on market fluctuations and corporate environment. Inconsistent.	Low to high, depending on market fluctuations and corporate environment. Inconsistent.	Low to high, depending on market fluctuations and corporate environment. Inconsistent.
Ability to do effective regional- and national-level analysis	High ability	High ability	High ability	High ability	High ability	Moderately high ability	Low to high ability, depending on market fluctuations and corporate environment. Inconsistent.	Low to high ability, depending on market fluctuations and corporate environment. Inconsistent.	Low to high ability, depending on market fluctuations and corporate environment. Inconsistent.

Table 14. Attributes of the Alternatives (continued)

Alternatives:	Publicly Funded and Operated	Publicly Funded, Cooperatively Operated	Publicly Funded, Privately Operated	Cooperatively Funded, Publicly Operated	Cooperatively Funded and Operated	Cooperatively Funded, Privately Operated	Privately Funded, Publicly Operated	Privately Funded, Cooperatively Operated	Privately Funded and Operated
Social Welfare Issues									
Overall benefits to society									
Ability of data users to access information across geography and/or time	High ability	High ability	High ability	High ability	High ability	High ability	Low ability	Low ability	Low ability
Ability of government agencies to achieve their respective missions (Reclamation, etc.)	High ability	High ability	High ability	High ability	High ability	High ability	Low to high ability, depending on the level of willingness to share data. Inconsistent.	Low to high ability, depending on the level of willingness to share data. Inconsistent.	Low to high ability, depending on the level of willingness to share data. Inconsistent.
Efficiency in use of resources (electricity, ag resources, water resources, etc.)	High efficiency	High efficiency	High efficiency	High efficiency	High efficiency	High efficiency	Low to high ability, depending on the level of willingness to share data. Inconsistent.	Low to high ability, depending on the level of willingness to share data. Inconsistent.	Low to high ability, depending on the level of willingness to share data. Inconsistent.
Optimization of food production/food security as a national security issue	High degree	High degree	High degree	High degree	High degree	High degree	Low degree	Low degree	Low degree
Overall contribution to profitability within the private sector	High	High	High	High	High	High	Low to high, depending on the level of willingness to share data. Inconsistent.	Low to high, depending on the level of willingness to share data. Inconsistent.	Low to high, depending on the level of willingness to share data. Inconsistent.
Public safety (dam operations, flood preparations, etc.)	High	High	High	High	High	High	Low to high, depending on the level of willingness to share data. Inconsistent.	Low to high, depending on the level of willingness to share data. Inconsistent.	Low to high, depending on the level of willingness to share data. Inconsistent.

CHAPTER 11. CONCLUSION

INTRODUCTION TO SUMMARY ECONOMIC ANALYSIS

In the previous chapter, various alternative configurations of public versus private funding and operation of snow survey programs in general were evaluated to assess their respective expected contributions to public and private benefits. This final chapter includes summaries of the benefits provided by the existing SSWSF Program, as identified in the case studies conducted for this analysis.

ECONOMIC VALUE OF THE PROGRAM

In the course of the completion of this study, basic, empirical estimates of the value of SSWSF Program data to a variety of actual beneficiaries and users of the data were developed. The table below summarizes a variety of the values provided by the program to various users.

The analysis produced two main products: 1. An analysis of market and non-market benefits generated by the program, based on the case studies conducted; and 2. An evaluation of how the overall benefits of the program would be affected if the current public/private configuration of the SSWSF Program were to be altered.

MARKET AND NON-MARKET BENEFITS

Market benefits are defined as those benefits for which a market value can be established. In this study, there are three types of market benefits: Directly calculated benefits associated with case studies in which SSWSF Program data generated benefits in actual events, estimated market benefits—developed within “what if” scenarios using economic modeling, and “other” market benefits that either could not be estimated given available resources or that were not included in the summary values in the report. Non-market benefits are those benefits that can be identified as having value to society, but to which a market or dollar value cannot readily be assigned or cannot be assigned at all.

Directly Calculated Market Benefits

Sevier River Basin, Utah, Alfalfa Producers

From the mid-1990s until the water year of 2005-06, the Intermountain West experienced drought conditions that ranged from mild to severe, depending on the specific location in question. During this drought, alfalfa growers within the Sevier River watershed based their production decisions on the information provided by the SSWSF Program and the SNOTEL system. At the same time, the water commissioner operated the reservoir and diversion system based on a drought-response management plan using SNOTEL data.

Based on the data, many producers adjusted their cropping operations to compensate for the dry conditions and to counteract the water shortage they faced. By growing “horse” hay for out-of-State markets—which commands a market price that is 65 percent to 80 percent higher than does standard local “cattle” hay—these producers were able to avoid suffering any economic losses as a result of the drought. The average annual benefit to these producers during the drought was approximately \$15.57 million, and the total benefit during the drought was approximately \$109 million.

Utah Flood Preparation

During the runoff season of 2005, many streams set new record high flows. In spite of these high flow levels, flood damages were very limited in scope. Local and State officials give credit for the low level of flood damages to the advanced warnings supplied by means of SSWSF Program reports and presentations. On one particular stream, Coal Creek, which flows through the town of Cedar City, Utah total runoff during 2005 is estimated as having equaled approximately 75,308 acre-feet. The historical average for the same time period is approximately 21,000 acre-feet. In spite of the extremely high volume of water that passed through the community, flood damages were minimal due to advance preparations taken in response to SSWSF Program data. The city estimates the value of protection of houses alone to have been approximately \$15 million. This figure does not include the value of businesses, public facilities, schools, and infrastructure that may have been damaged by flooding had the advance measures not been taken.

In contrast with 2005, during the flood years of 1983 and 1984 combined—years when the snow water content of the spring snowpack was similar to that experienced in 2005—total damages in Utah, primarily incurred in areas of northern Utah, reached over \$660 million in 1983-84 dollars. This equates to approximately \$1.252 billion in 2005 dollars. The flood damage prevention value of SSWSF data in Utah in 2005—a single-year event as opposed to the earlier 2-year event—could be estimated as being equal to approximately one-half of the 1983-84 losses, or \$626 million in 2005 dollars. Although some of this amount is offset by infrastructure improvements made in response to the 1983-84 floods, it does not take into account the significant amount of urban and suburban development that occurred between 1984 and 2005 within areas of Utah that were threatened by flooding during the latter year’s event.

Intermountain River Runners

An outfitter operating in the Intermountain region reported that in the 2002 season, the worst season on record for rafting in the region, SNOTEL data indicated that river conditions would render them generally inoperable that season if they were to use their traditional rafting equipment. The low water levels that were projected would have resulted in a year with zero revenue had the outfitter not been made aware of the streamflow projections ahead of the rafting season. Based on SNOTEL indicators, the decision was made in April 2002 to place an order for \$50,000 in smaller craft that would be operable under the environmental conditions predicted by SNOTEL data. That season, the company experienced a 40-percent reduction in overall revenue (when compared with

a normal water year) due to the reduced water volume and a low rate of patronage. The low rate of consumer demand may have been a result of changes that occurred in consumer expectations as a result of drought-related reports disseminated in the media. In a typical year, revenue is equal to approximately \$1million, so overall revenue that year was equal to approximately \$600,000.

With the availability of SNOTEL data, the decision to purchase the smaller, more-able craft resulted in a \$600,000-revenue year when little to no revenue would have been brought in had that early season purchasing decision not been made. In other words, total revenue (approximately \$600,000) for the 2002 river season is attributable to the application of SNOTEL data.

Other river running outfitters reported similar outcomes during low-water years. The value of SSWSF data is estimated at \$3,548,000 in avoided losses to one of those outfitters in a single low-water river running season.

Oakley, Idaho

During the winter of 1983-84, record amounts of snow accumulated in the hills above the Oakley Reservoir. In January 1984, SCS issued an SSWSF bulletin stating that snowpack amounts in southern Idaho were as much as 300 percent of normal in places. Lower Goose Creek Reservoir, also known as Oakley Reservoir in the watershed above the town of Oakley, Idaho, had filled only one time since its construction. Over many decades, its natural outlet channel was filled in by farms, homes, businesses, and infrastructure. It became apparent that due to the high snowpack, the reservoir was going to spill, leading to widespread and devastating damage in the community. In an unprecedented effort, USACE; the National Guard; SCS; canal companies; State and local government entities; and local civic, business, and religious organizations and individuals worked together to design and build a canal to safely channel water to the Snake River. The project succeeded, preventing any serious damage from occurring, other than that caused by the construction of the canal itself.

One SCS estimate put the value of damage protection for farmland alone at \$60 million—\$111.73 million in 2005 dollars—a figure that does not include the damages to buildings and infrastructure that would have been incurred within the city of Burley had the canal not been built.

Estimated Market Benefits

Alfalfa Farming in Northern Utah

One example of how SSWSF data are used is a case in which one producer works with his local water users association, USBR, and dam operators in order to optimize the storage and delivery of water. The USBR coordinates with the local water users association and dam operators to determine how much water to allow to either store or spill from the reservoir system during the spring runoff season. The water users

association pays close attention to SNOTEL's soil moisture content numbers and provides "fill or spill" advice to USBR on the basis of whether or not the soil profile is saturated early in the season. If the profile is dry, they recommend against spilling.

In his own farm and ranch operations, this producer operates on 650 acres with no personally owned reservoir storage for irrigation. He reports that all of his planting decisions are contingent on SNOTEL-based forecast streamflow. In addition, he bases decisions about fertilizer application on soil moisture content data generated by SNOTEL.

Within the climate regime of this particular part of northern Utah, total potential alfalfa yield is approximately 5.9 tons per acre (based on NRCS 2005 consumptive-use data). Where water is the limiting factor (as opposed to fertilizer or some other factor of production), the total that can actually be grown depends on how much water is available. There are three sources of water to support plant growth: winter snowpack and subsequent meltwater, precipitation during the growing season, and diverted irrigation water held in reservoirs and then distributed through canal and irrigation pipeline systems. Of the total potential tons of yield in this case study, there is enough water from winter snowfall and growing season rainfall to support approximately 2.5 tons of alfalfa yield during a normal precipitation year. This amount is called the base yield. In theory, an additional 3.4 tons of alfalfa can be grown using irrigation water. This maximum yield could only be reached, however, if the irrigation system were to operate at 100 percent efficiency, an impossibility given today's technology. Under a high-quality pivot sprinkler system, which is typically 85 percent efficient, the irrigated yield potential—above and beyond the base yield—is approximately 2.9 tons. The base yield of 2.5 tons added to this 2.9 tons of irrigated yield means that an alfalfa producer in this locale can expect to obtain approximately 5.4 tons of yield per acre under a well-managed pivot sprinkler system. In low precipitation years, stored irrigation water can be used to make up the difference and bring total yield up to its full potential.

In a water-short year, low winter and early growing season precipitation can leave the soil moisture profile (the amount of water held in the root zone of the alfalfa) mostly dry. In agronomy, the term "fill the soil profile" is used to describe the process under which water infiltrates from the surface downward until the amount of water in the root zone reaches its optimal amount. A "full soil profile" contains the ideal amount of water within the root zone. Under the circumstances in this case study, were a lack of data to lead to an erroneous reservoir-management decision to release too much water from upstream reservoirs during runoff season, allowing it to run downstream, that water would then be unavailable for irrigators to use to fill the dry soil moisture profile with water. This, in turn, would result in alfalfa yields that were sub-optimal. The magnitude of the loss would depend on the degree to which the profile failed to fill. A completely dry profile and minimal growing season precipitation would reduce tons of alfalfa by the 2.5 per acre base yield amount. The 10-year average market price for alfalfa in Utah is approximately \$90.00 per ton. Accordingly, the value of lost yield in this geographic area due to an erroneous "spill" decision is potentially as high as \$225.00 per acre, assuming a completely dry soil profile. Thus, the potential cost of a reservoir spill that

resulted in not filling the soil profile for the producer in this case study could be as much as \$146,000 or more in gross revenue over the producer's 650 acres. This figure assumes that there was sufficient water content in the upstream watershed snowpack to capture enough acre-feet reservoir storage to fill the soil profile, and that the lack of information prevented the optimal management of the runoff.

Twin Falls, Idaho, Agricultural Producers

In southern Idaho, shareholders in the Salmon Falls and Twin Falls irrigation tracts rely on SNOTEL data in making decisions about what, when, and how much to plant. Irrigation districts within this region inform their shareholders early in the season as to the percentage of their full irrigation allotment they should expect to receive in the upcoming growing season. These predictions are based on SSWSF data showing the probability of varying levels of water supply given existing snowpack, soil moisture, and water content, and using historical probabilities for additional snowpack and water content accumulations. These reports are crucial to producers, who use them to make cropping and operations decisions well in advance of the growing season.

Based on modeling of the typical cropping patterns in the area, the value of SSWSF Program data to producers in this region is estimated as ranging from \$27.00 per acre in a normal year to \$111.00 in a water-short year. Producers who have access to SSWSF data, but who do not make use of the data in their cropping decisions, are depriving themselves of potential income, even in normal water years, due to sub-optimal cropping patterns.

The Salmon Falls irrigation tract comprises 35,000 acres of irrigated cropland. Multiplying the results shown for 160 acres in the single-farm model by the total number of acres in the Salmon Falls tract, the total value of the data within the irrigation district ranges from approximately \$945,000 in a normal year to approximately \$3,885,000 in a water year with a water supply that was 50 percent of normal. The Twin Falls tract supports 190,000 acres of irrigated farmland, 95 percent of which, or 180,500 acres, benefits from access to SSWSF Program data during normal years. Due to the availability of well water, during water-short years, the percentage of acres benefiting from the data is reduced to 85 percent of total irrigated acres, or 161,500 acres. The potential value of SSWSF data to producers in the Twin Falls tract ranges from \$4,873,500 in a normal year up to \$17,926,500 in a water-short year.

Denver Water Board

If Denver Water did not have access to real-time snowpack and water supply forecast information, and instead based its reservoir management decisions on historical water supply averages, it could expect to lose approximately \$5,594,000 in potential revenue during a typical year due to sub-optimal transfers of water between the various storage reservoirs within its water collection and distribution system.

Idaho Power

In the absence of SSWSF data, public utilities would be expected to make errors in their reservoir management decisions. These errors would result in lost revenue. Modeling these management decisions showed that without access to SSWSF Program data, it would be reasonable to expect an annual error factor of about 5 percent. In the case of Idaho Power Company, a 5-percent error in reservoir operations decisions would result in approximately \$18,262,000 in lost revenue in a single year.

Other Market Benefits

Additional data users obtain market-based benefits from SSWSF Program data, but specific values for these uses either could not be calculated within the scope of this study or were not included within the report summary. Some of these beneficiaries include Anheuser-Busch, the Bogus Basin Ski Resort and other commercial recreation interests, the banking industry—especially concerning risk related to agricultural loans, the news media, various beneficiaries from flood-protection measures, BPA, USBR, and the Truckee River Watershed Water Users.

Non-Market Benefits

Although many of the benefits generated by SSWSF Program data can be assigned a market value, many other benefits fall into the category of non-market benefits. Among these are benefits to private citizens who use the data to make recreation decisions, benefits to government agencies that use the data to make decisions regarding resource management (these may ultimately result in market benefits but are themselves considered to be non-market benefits), and benefits to research and educational institutions that use the data for non-market purposes. Moreover, many of the dollar-denominated benefits, such as protection of property from flooding, are associated with additional, non-quantifiable benefits, such as the prevention of human suffering and emotional losses that would have occurred without the flood-prevention measures.

Summary of Benefits

Although this study does not provide a comprehensive West-wide value of the SSWSF Program, the many users of the program identified in this study and summarized in Table 16 provide clear evidence of the substantial value of the program in both the monetary value and non-monetary benefits.

Table 16. Summary of Case Study Benefits

Summary of Benefits to Users of Snow Survey and Water Supply Forecasting Program Data			
User Categories and Case Study Data Users	Case Study Contexts	Summary of Actual or Estimated Market Benefits Within Case Study Contexts (2005 dollars except as noted)	Summary of Non-Market and/or Non-Definitized Benefits Within Case Study Contexts
PRIVATE INDUSTRY			
Agriculture			
Anheuser-Busch	Contracting for future crops in Idaho, Washington, and other States, as well as in international markets.	Non-definitized	Reduced risk to corporation due to ability to make informed input, production, and supply decisions as much as 1 1/2 years in advance.
Northern Utah Alfalfa Grower	Over 10 years of Moderate-to-Severe Drought, SSWSF information provided the basis for optimal reservoir management to maximize water deliveries.	\$1,460,000	Reduced stress on producers and their families as a result of reduced uncertainty with respect to expected income and ability to meet financial obligations. Maintenance of supply of agricultural goods to relevant markets, benefitting customers of those producers using the data.
Sevier River Water Users	Over a 7-year period of Moderate-to-Severe Drought, producers used SSWSF information to revise crop management practices and maintain income.	\$109,000,000	
Twin Falls, Idaho Farmers	During a year of Moderate-to-Severe Drought, SSWSF information provided the basis for optimal reservoir management and irrigator decisions on cropping options.	\$21,811,500	
Twin Falls, Idaho Farmers	During years of Normal Precipitation, producers use SSWSF information to fine-tune production decisions to increase returns.	\$5,818,500	
Commercial News Media			
Television Meteorologists and General News Reporters	Use SSWSF information to prepare reports for the general public regarding snowpack and water supply levels.	Non-definitized	Increased accuracy in news reporting, resulting in a higher degree of public safety.
Finance and Banking			
Multiple Lenders and the Federal Reserve Bank (West-wide)	Use water supply data to reduce risk to the financial sector by anticipating water-supply-related fluctuations in crop yields.	Non-definitized	Increased accuracy in management and lending decisions within the financial sector.
Recreation			
Individual Winter Recreationists	Casual data use during winter recreation season.	Non-definitized	Improved safety margin and enhanced quality of winter outdoor recreation experience.

River Running Outfitter A (Arizona, Colorado, and Utah)	Based on water supply information provided by SSWSF, altered business plans and activities to adjust to anticipated low water conditions during a severe drought in 2002.	\$3,548,000	Retention of opportunities for paying customers to enjoy planned river-running outings.
River Running Outfitter B (Colorado)	During a severe drought in 2002, used SSWSF information to change the types of boats purchased and number of employees contracted, enabling the outfitter to enjoy a financially successful season in spite of drought conditions.	\$600,000	
Ski Industry (Idaho)	Data used to inform day-to-day operations and future ski race planning decisions.	Non-definitized	Provision of better service to customers and improved efficiency of daily and season-long ski mountain operations.
GOVERNMENT			
Federal Agencies			
U.S. Army Corps of Engineers (Oregon)	Use SSWSF information as an input into reservoir operation decisions.	Non-definitized	Benefits generated for the public at large (water supply, recreation, and safety benefits), wildlife, and water-dependent industries (agriculture and manufacturing).
U.S. Bureau of Reclamation (West-wide)	Use SSWSF information as an input into reservoir operation decisions.	Non-definitized	
Scoggins Reservoir (Oregon)	Data used to make both everyday and emergency-prevention reservoir operation decisions.	Non-definitized	Was able to prevent potentially severe downstream flooding during unusual storm events when reservoirs were already full.
Hyrum Dam and Reservoir (Utah)	Data used to make both everyday and emergency-prevention reservoir operation decisions.	Non-definitized	
NWS and River Forecast Centers (West-wide)	Data feeds into flood-prediction models and other NWS products used by other agencies to make operations decisions.	Non-definitized	Reservoir operations, public safety, and water-allocation decisions are made with more accuracy and a higher degree of effectiveness.
FS (West-wide)	Use SSWSF data as an integral part of forest fire response, fire prevention efforts, and grazing permit decision-making.	Non-definitized	Increase in the accuracy and appropriateness of fire prevention and response, as well as more accurate decisions on issuing/renewing of grazing permits.
State Agencies			
Idaho Department of Water Resources	Uses SSWSF data as the basis of its water supply management and water-pricing decisions.	Non-definitized	Reservoir operations, public safety, and water-allocation decisions are made with more accuracy and a higher degree of effectiveness.
State of Oregon, Multiple Agencies	Uses SSWSF data in multiple water-management, flood-prevention, and emergency services operations decision-making processes.	Non-definitized	

PUBLIC UTILITIES			
Bonneville Power Administration (Washington, Oregon, Idaho, and British Columbia)	General use of SSWSF snow course data in operations modeling.	Non-definitized	Higher degree of accuracy in models used to inform daily and longer-term operations decision-making, resulting in higher efficiency in water-allocation decisions.
Denver Water Board (2006 dollars)	Using SSWSF information to base reservoir operations decisions on real-time snowpack and water supply data rather than on historic water supply averages.	\$5,594,000	Increased efficiency in allocation of resources leading to better delivery of utility services to municipal, industrial, and residential customers.
Idaho Power (2006 dollars)	Using SSWSF information to improve reservoir operations decisions by 5 percent annually.	\$18,262,000	
Intermountain Gas (Idaho)	Data used to make natural gas management and future contracting decisions.	Non-definitized	Enables utility to provide more consistent service and more stable prices to wholesale and retail customers.
EDUCATION AND RESEARCH			
Utah Water Research Laboratory, Utah State University	General use of SSWSF snow course data in water resource research.	Non-definitized	Benefits provided to public through more accurate modeling of water resources and water management structures and methodologies.
MULTIPLE-CATEGORY ENTITIES			
Truckee River Watershed Water Users (Nevada)	Use SSWSF data to inform water management decisions.	Non-definitized	More efficient use of water resources, more accurate water-allocation decision-making, protection of endangered species, reduction in tensions among competing water users, and more accurate enforcement of treaties and state laws.
Idaho Water Users Association	Use SSWSF data to inform water management decisions.	Non-definitized	
FLOOD DAMAGE PREVENTION			
Oakley, Idaho	In response to SSWSF information, constructed an emergency 42-mile canal to prevent widespread flood damage to farms and towns during the 1984 spring runoff.	\$111,730,000	Prevention of wide-spread losses in irreplaceable personal goods, time savings, and benefits in prevention of potential losses of life and protection of non-market goods.
Utah Division of Emergency Services and Homeland Security	During the 2005 spring runoff, used SSWSF information to manage necessary reservoir spills, to prevent emergencies, and to identify needed sandbagging operations.	\$611,000,000	
Blaine and Lincoln Counties, Idaho	Used SSWSF information to invoke emergency flood-prevention measures during the 2005 spring runoff.	Non-definitized	Sandbagging and other flood damage prevention measures completed in time to reduce or entirely prevent extensive damage from occurring to

Cedar City, Utah	Used SSWSF information to provide time to construct dikes and to implement other emergency flood-prevention measures during the 2005 spring runoff.	\$15,000,000	buildings and/or contents of homes, schools, government facilities, and businesses. Prevented losses of irreplaceable personal goods such as photos and other memorabilia. Time savings for those who did not have to move/repair/replace household, educational, and commercial goods.
Uintah County, Utah	The availability of SSWSF information provided time to prepare and place sandbags and to take steps to protect bridge abutments, thus preventing major flood damage during the 2005 spring runoff.	Non-definitized	

CONCLUSION

In summary, each of the approaches to evaluating the economic value of the SSWSF Program undertaken in this study has shown that the program is generating both market and non-market benefits to the U.S. economy and to U.S. society as a whole that are worth significantly more than the cost of the program. Should climate variability increase—as is expected by many of those interviewed in the course of completing this study, and as current climate research strongly suggests—the value of the data generated by the SSWSF Program will increase accordingly. If time and budget allowed, it would be possible to further definitize actual dollar benefits to other users and beneficiaries of the data. Also, additional, more thorough modeling could be undertaken in an effort to understand the more complex impacts of changes in agricultural operations and other industry activities that occur in response to SSWSF Program data. Absent those additional analyses, it will suffice to say that, at a bare minimum, the program more than pays for itself in terms of dollar-valued economic benefits, and the program also generates significant non-market benefits in public safety, recreation, and other categories of non-dollar-denominated benefits. Further study would shed more light on these topics as well.

REFERENCES

- “2005 Has Had Big Runoff But Not Big Flooding.” *Deseret News*, 2005, sec. p.
- “A Solution To Protect Stream Flows.” *Desert News Online* 21 May 2006.
<http://desertnews.com> (22 March 2006).
- “About the Hydraulics Lab at the Utah Water Research Laboratory (UWRL).” *Utah Water Research*. [online journal].
<http://www.engineering.usu.edu/uwrl/hydraulics/about/about.html> (Accessed 26 February 2007).
- “About SCITRDA.” *South Central Idaho Online*. Available
<http://www.visitsouthidaho.com/about.aspx>. Internet; accessed 1 February 2007.
- Adams, D.K., and A.C. Corrie, 2005. The North American Beagle, *Bulletin of Whatever Journal*, Vol. 23, 2124-2144.
- Adams, Richard M., Laurie L. Houston, and Rodney F. Weiher. *The Value of Snow and Snow Information Services (Final Draft)*. Report prepared for NOAA’s National Operational Hydrological Remote Sensing Center, Chanhassen, MN, under contract DG1330-03-SE-1097, 2004.
- Alberti, Vince, Randy Bingham, Ted Diehl, Lynn Harmon. *1949 and 1961 ESPA-Level Curtailment Impacts*. 2004.
- Baden, John A. “Alternatives to a Downhill Slide.” *Bozeman Daily Chronicle Online* 21 January 2004. <http://www.free-eco.org/articleDisplay.php?id=380> (1 February 2007).
- Bauman, Joe. “Water Woes: Utahns Joining to Fight Drought.” *Desert News Online* 2000. <http://desertnews.com>
- Before the Department of Water Resources of the State of Idaho. May 2, 2005.
- Bjorneberg, David L., Nathan O. Nelson, Dale T. Westermann. “Conservation Effects Assessment for Irrigated Agriculture: Upper Snake-Rock Watershed, Idaho” Paper presented at the American Society of Agricultural Engineers Meeting, July 2005.
- Bjorneberg, David L., Nathan O. Nelson, and Dale T. Westermann. “Sprinkler and Surface Irrigation Effects on Return Flow Water Quality and Quantity.” Paper presented at the *American Society of Agricultural and Biological Engineers* meeting, March 2007).
- Boal, Jed. “End of Drought Looks Likely.” *KSL News*. Available from
<http://tv.ksl.com/index.php?sid=148345&nid=5&template>. Internet; accessed 1 June 2005.

- Boal, Jed. "Flooding Possible State-wide." Available from <http://tv.ksl.com/index>. Internet; accessed 1 June 2005.
- Boal, Jed. "Flood Watch Continues as Temperature Rises." *KSL News*. Available from <http://tv.ksl.com>. Internet; accessed 1 June 2005.
- Boal, Jed. "The Big Picture for Utah's Floods." Available from <http://tv.ksl.com>. Internet; accessed 1 June 2005.
- "Bogus Basin." *Bogus Basin Online*. Available from <http://bogusbasin.org/snow-report.aspx>. Internet; accessed 1 February 2007.
- "Bogus Basin." *Bogus Basin Online*. Available from <http://www.bogusbasin.org/the-mountain/tickets/life-ticket-prices.aspx>. Internet; accessed 1 February 2007.
- Brennan, Andrew. *Stanford Encyclopedia of Philosophy*. California: Stanford University, 2003. [book on-line]; available from <http://plato.stanford.edu/entries/necessary-sufficient/>; Internet; accessed 7 July 2006.
- Calvin, Carlye. "2004 Fact Sheets: Wildfires." Available from <http://www.ucar.edu/communications/factsheets/wildfires.html>. Internet; accessed 26 February 2007.
- Carey, Marc B., Noel R. Gollehon and Michael R. Moore. "Multicrop Production Decisions in Western Irrigated Agriculture: The Role of Water Price." *American Agricultural Economics* (November 1994): 859-874
- Carroll, Thomas R., and Marshall, Russell D. "Cost-Benefit Analysis of Airborne Gamma Radiation Snow Water Equivalent Measurements Made Before the February 1985 Fort Wayne Flood." Paper presented at the Sixth Conference on Hydrometeorology, American Meteorological Society, Indianapolis, Indiana, 1985.
- "Cataract Canyon 2007 Utah." Available from http://www.utah.com/database/trip_packages/package6189.htm. Internet.
- "City of Hillsboro Emergency/Disaster Information, Hazard Analysis: Section 2." Available from <http://www.ci.hillsboro.or.us/EmergencyInfo/>. Internet; accessed 23 January 2007.
- "Continual Wet Weather Has Flood Watchers Worried." *KSL News*. Available from <http://www.tv.ksl.com/index>. Internet; accessed 1 June 2005.
- Dale, L., A. Fisher, M. Hanemann, W. Schlenker, K. Fujita, and D. Millstein. 2005. *Economic Impacts of Climate Change on Agricultural Water Use in California*.

University of California, Berkeley, for the California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-054.

Daley, John. "Utah's Water Woes Water Situation Worsens." *KSL News*. Available from <http://web.ksl.com/dump/news/cc/speical/enviro/drought1.htm>. Internet; accessed 1 June 2005.

Decker, Marin . "Flood Risk Highest at North End of Valley." *Deseret News Online* 7 May 2005. <http://deseretnews.com> (1 June 2005).

"Deere and Company." *Homestead Magazine* 1996. [online journal] http://www.deere.com/en_US/ag?homestead/articles/animals/hot_to_buy_horse_hay.html (Accessed 30 April 2007).

Denver Water Board. *Water for Tomorrow: The History, Projections and Update of the Integrated Resource Plan*. Denver Board of Water Commissioners, Denver, Colorado. 2002.

"Desolation Canyon." Available from http://www.utah.com/database/trip_packages/package6191.htm. Internet; accessed 2007.

Dinenny, Shannon. "Groups Say Fish Recovery Trumping BPA Rates." *Oregonian*, July 2006.

Dudley, Rick, Samuel J. Fuchs, and Ronda E. Hirnyck. *General Crop Production Information. Crop Profile for Peas (Green) in Idaho*. Boise, ID: University of Idaho center. June, 2000.

Earl, Philip I. "The Snow Scientist." *The Northwoods Magazine*, May 2006.

EASPE, Inc. "Use and Benefits of the National Weather Service River and Flood Forecasts." Prepared for the National Hydrologic Warning Council. 2002.

Eddington, Mark and Havens, Mark. "One Thing's For Sure: Overflow." *The Salt Lake TribuneOnline* 25 May 2005. Salt Lake City, UT. <http://www.sltrib.com> (1 June 2005).

Edwards, Captain Daniel C., Thomas B. McKee, Nolan J. Doesken, and John Kleist. "Historical Analysis of Drought in the United States. Proceedings from the Seventh Conference on Climate Variation, Long Beach, CA. 1997, pp. 129-39.

Elliott, Shirley J. "What's it Worth?" *Soil Conservation* (March 1977).

Engs, Nikki and Dick Larsen. *Idaho Water Use Has Helped Shape State*. Idaho Council on Industry and the Environment June, 2005.

- Feichtinger, Denis, and Roberts, Gale. *Benefits of Natural Resources Conservation to Blaine County, Idaho*. Blaine County Soil Conservation District, 1996.
- “Flood Fears Eases by Good Preparations.” *Daily Herald Online* 27 May 2005. <http://www.harktheherald.com> (1 June 2005).
- Foy, Paul. “Southern Utah Braces For Floods From Big Snowpacks.” *Associated Press Online* 2005. <http://www.azcentral.comphp-bin/clicktrack>.
- Foy, Paul. “Rising Rivers Put Utah Under Siege of Flood Warnings.” Available from <http://signonsandiego.com>. Internet; accessed 1 June 2005.
- Frost, W.T and R. A. Work. “The Use of Snow Survey Data for Agricultural Planning,” *Agricultural Engineering* (November 1948): Vol 29 no. 11, 490-492.
- Fuchs, Samuel J. and Ronda E. Hirnyck. *General Crop Production Information Crop Profile for Dry Peas in Idaho*. Pocatello, ID: University of Idaho. August 2001.
- Fuchs, Samuel J. and Ronda E. Hirnyck. *General Crop Production Information Crop Profile for Wheat in Idaho*. Pocatello, ID: University of Idaho. February 7, 2000
- Fuchs, Samuel J., General Crop Production Information. *Crop Profile for Dry Beans in Idaho*. Pocatello, ID: University of Idaho.
- “Go2: The Resource for People in Tourism.” Available from <http://www.go2hr.ca/CareersbrinTourism/CareerSummaryLifeOperator/tabid/953/mid/1405/Default>. Internet; accessed 1 February 2007.
- “Grand Canyon Whitewater.” Available from http://www.utah.com/database/trip_packages/package14469.htm. Internet; accessed 2007.
- Hamilton, Joel R. “Economic Importance of ESRPA-Dependant Springflow to the Economy of Idaho.” *Hamilton Water Economics*, December 2004.
- Hansen, Roger. *Sevier River Water Users Association*. [book on-line]; available from <http://sevierriver.org/webalizer/>. Internet; accessed 13 March 2007.
- “Hardrock 100 Endurance Run.” *Hardrock 100*. Available from <http://www.hardrock100.com/>. Internet; accessed 16 January 2007.
- Hardy, Rodger L., Perkins, Nancy. “Utahns Are On Edge As Flood Worries Surge.” *Desert News Online* 22 May 2005. <http://deseretnews.com> (1 June 2005).
- Havnes, Mark and Henetz, Patty. “Building a Wetter Utah: Spring Keeps Piling Up.” *Salt Lake Tribune Online* 31 March 2005. <http://www.sltrib.com>.

- Hedberg, Kathleen. *A Flood Cannot Happen Here*. Burley, ID: Magic Valley Publishers, 1984.
- Helms, Douglas. "Snow Surveying Comes of Age in the West." Paper presented at the Proceedings of the Western Snow Conference, 10-17. Jackson, Wyoming, 1992.
- "High Flows Could Peak This Weekend." *Vernal Express Online* 25 May 2005. <http://www.vernal.com> (20 January 2006).
- Hollenhorst, John. "Utah's Top Stories #8-Drought Continues." *KSL News*. Available from <http://tv.ksl.com/index.php?sid=141297&nid=5&template>. Internet; accessed 1 June 2005.
- Hollenhorst, John. "Water Outlook Worse than Expected." *KSL News*. Available from <http://web.ksl.com/dump/news/cc/special/enviro/sno0402.htm>. Internet; accessed 1 June 2005.
- "Hyrum Dam." Available from <http://www.usbr.gov/dataweb/dams/ut10123.htm>. Internet; accessed 6 February 2007.
- Idaho Outfitters and Guides Association. "Idaho: 2006 Directory of Guided Outdoor Adventures" 2006.
- IOGA: Making History for Fifty Years. "Owyhee Initiative: Preserving the Land and a Way of Life." 2005.
- Jakus, Paul, James R. Kahn, and Steven L. Stewart. *Incorporating Economic Values into TVA River Scheduling Operations*. March 2002.
- Kaibab National Forest Incident Information Plan for Wildland Fire Season 2004.
- "Lots of People." Abstract presented at the SWCS Annual Conference. June 2007.
- Maine Geological Survey. "The Maine Cooperative Snow Survey. Maine: Snow Survey." <http://www.maine.gov/mema/weather/abousus.htm> (accessed November 26, 2007).
- Mankiw, Gregory. *Principles of Economics*. Fourth Edition. Mason, Ohio, 2007.
- Mille, P. C. D., et. al.. "Stationarity is Dead: Whither Water Management?" *Science*. Volume 319, February 2008, pp. 573-4.
- Moore, Michael R., and Donald H. Negri. *Producer Behavior in Irrigated Agriculture: An Empirical Analysis with Quantity-Rationed, Stochastic Water Supply*. In *The 16 percent of the Harvested Cropland that is Irrigated Accounts for Nearly Half of the Value of All Crops Sold*. University of Michigan and Willamette University, 2005.

- Mote, Philip W., Alan F. Hamlet, Martyn P. Clark, Dennis P. Lettenmaier. *Declining Mountain Snowpack in Western North America*. American Meteorological Society, 2004.
- National Hydrologic Warning Council. "Use and Benefits of the National Weather Service River and Flood Forecasts." May 2002.
- National Weather Service. Advanced Hydrologic Prediction Service. Available from <http://ahps2.wrh.noaa.gov/ahps2/hydrograph.php?wfo=pih&gage=hali1&view=1,1,1,1,1,1>. Internet; accessed 15 May 2005.
- Nelson, Morlan W. "Social and Economic Impact of Snow Survey Data and Water Supply Forecasts." Paper presented at the Western Snow Conference, Salt Lake City, Utah, 1969.
- Northern Rockies Fire Management Strategic Plan for the 2006 Fire Season. June 16, 2006
- Olson, Kelly. *General Crop Production Information. Crop Profile for Barley in Idaho*. Pocatello, ID: University of Idaho, 1997.
- "People Deal With Once-Dry Lake." *The Spectrum Online* 29 May 2005. <http://www.thespectrum.com> (1 June 2005).
- "Rivers Rise, Mudslide Moves, Residents Worry." *Channel 4 News*. Available from <http://www.4utah.com/common>. Internet; accessed 1 June 2005.
- Sevier River Water Users Association. "Real-time Water/Weather Data." Available from <http://sevierriver.org/reservoirs/teacup.php>. Internet; accessed 13 March 2007.
- Smith, Jerd. "Signs Pointing to Return of Drought." *Rocky Mountain News Online* 22 May 2006. <http://www.rockymountainnews.com> (25 April 2007).
- "Snowpack, Federal Water Grab on the Gunnison? South Platte Running Free. Coyote Gulch." Available from <http://radio.weblogs.com>. Internet; accessed 26 Apr 2007.
- "Soggy Utah To Test California Company's Floodwall Innovation." *Daily Herald Online* 23 May 2005. <http://www.harktheherald.com> (1 June 2005).
- "Southern Utah Fearing Massive Flood." *MSNBC*. Available from <http://www.msnbc.com/id/7544900/did/7544900>. Internet; accessed 1 June 2005.
- "Southwestern Utah Braces for Flooding." *KSL News*. Available from <http://tv.ksl.com/index>. Internet; accessed 1 June 2005.

- Steffen, Constance C. "The Great Salt Lake: Major Economic Impacts of High Lake Levels" *Utah Economic and Business Review*, October 1983.
- Thiessen, Mark. Storm Forecast Renews S. Utah Flood Worries. *Standard Examiner Online* 6 May 2005. <http://www.standard.net/standard.php/news/national> (1 June 2005).
- Twin Falls County Crop Information Twin Falls, Idaho. <http://extension.ag.uidaho.edu/twinfalls/Crops/cropspage1.htm> (accessed July 6, 2007).
- University of California, Berkeley. "Economic Impacts of Climate Change on Agricultural Water Use in California." For the California Energy commission, PIER Energy-Related Environmental Research.
- U.S. Department of Agriculture. *Service Center Employee Directory*. Washington, D.C. 2007. <http://www.offices.sc.egov.usda.gov/employeeDirectory/app> (accessed January 12, 2007)
- U.S. Department of Agriculture. Division of Irrigation, Soil Conservation Service. *Summary of Show Course Histories and Snow Survey Measurements in Utah 1924 – 1947* by D.K. Furhiman. Washington, D.C. 1947.
- U.S. Department of Agriculture. Economic Research Service. *The U.S. Hay Market: Higher Prices in 1996/97*. Washington, D.C. 2006.
- U.S. Department of Agriculture. Kansas Department of Agriculture. *USDA-KS Dept of Ag Market News*. Washington, D.C. 2007. http://www.ams.usda.gov/mnreports/DC_GR310.txt (accessed April 30, 2007).
- U.S. Department of Agriculture. National Agricultural Statistics Service. *USDA-NASS Quick Stats (crops)*. Washington, D.C.; 2007. http://www.nass.usda.gov/QuickStats?PullData_US_CNTY.jsp (accessed June 20, 2007).
- U.S. Department of Agriculture. Natural Resources Conservation Service. *Focus On The Field*. Washington, D.C., 1999 <http://www.nrcs.usda.gov/news/thisweek/1999/990827.html> (accessed June 1, 2005).
- U.S. Department of Agriculture. Soil Conservation Service Program Evaluation Division. *An Evaluation of the Snow Survey and Water Supply Forecasting Program*. Washington, D.C., 1977.
- U.S. Department of Commerce. National Oceanic and Atmospheric Administration. *Flood Potential Outlook and Extended Streamflow Forecast Utah*. Washington, D.C., 2005. <http://weather.noaa.gov/pub/SL.us008001> (accessed 1 June 2005).

- U.S. Department of the Interior. U.S. Geological Survey. *Glen Canyon Dam 2005* by Laura Zink Torresan. Washington, D.C. 2005.
<http://walrus.wr.usgs.gov/grandcan/dam.html> (accessed January 3, 2008).
- U.S. Department of the Interior. U.S. Geological Survey. *Major Floods and Droughts in Utah*. Washington, D.C., 188-89.
http://geochange.er.usgs.gov/sw/impacts/hydrology/state_fd/utwater1.html (accessed 30 April 2007).
- U.S. Department of Labor. Bureau of Labor Statistics. *Ecanned: The Economy in a Can*. Washington, D.C., 2007. <http://www.ecanned.com/ID/Boise.shtml> (accessed February 1, 2007).
- Use of Climate Information in Municipal Drought Planning in Colorado. Western Water Assessment. 2006.
- “Utahns Are On Edge As Flood Worries Surge.” *Desert News Online* 2005.
<http://desertnews.com/dn/print/1,1442,60013585,00.thml> (13 March 2007).
- “Utahns Prepare Well for Coming Floods.” *KSL News*. Available from <http://tv.ksl.com>. Internet; accessed 1 June 2005.
- Vernal, UT Road Department, Uintah County.
<http://www.co.uintah.ut.us/roads/roaddept.php> (accessed March 13, 2007)
- “Visit South Central Idaho.” *South Central Idaho Tourism and Recreation Development Association, Inc. Online*. Available from <http://www.visitsouthidaho.com/about.aspx>. Internet; accessed 1 February 2007.
- Water for Tomorrow. February 10-11, 2002.
- “Weber River May Peak On Tuesday.” *Standard-Examiner Online* 23 May 2005.
<http://www.standard.net> (1 June 2005).
- Weisstein, Eric W., “Convex Function.” MathWorld Wolfram Web Resource Online. Available from <http://mathworld.wolfram.com/ConvexFunction.html>. Internet; accessed 7 July 2006.
- “Westwater Canyon Whitewater.” *Utah Adventures Online*. Available from http://www.utah.com/database/trip_packages/package6190.htm. Internet; accessed 2007.
- “Westwater Canyon Whitewater.” *Utah Adventures Online*. Available from http://www.utah.com/database/trip_packages/package6190.htm. Internet; accessed 2007.

- White Sulphur Springs, MT. *Online*. Available from <http://www.wyominghay.com/specalloffers.html>. Internet; 30 April 2007.
- “Wilderness Aware Rafting.” *Wilderness Aware Online*. Available from <http://www.wildernessaware.com/salt.htm>. Internet; accessed 23 February 2007.
- “Winter’s Record Snow Might Lead to Summer Floods.” *Miami Herald Online*. <http://www.miami.com/mld/miamiherald/news/nation> (1 June 2005).
- Work, R. A.. “Measuring Snow To Forecast Water Supplies.” Yearbook of Agriculture. U.S. Department of Agriculture, 1955.
- “Worst May Be Over at Coal Creek.” *KSL News*. Available from <http://tv.ksl.com>. Internet; accessed 1 June 2005.
- Yesterday’s Tractor CO. Washington, 1997. <http://www.tymag.com/cgi-bin/viewit.cgi?bd+ttalk&th+481536> (accessed April 30, 2007).