Geostationary Operational Environmental Satellite System (GOES)

GOES -R Sounder and

Imager

Cost/Benefit Analysis (CBA)

Prepared for the

Department of Commerce

by

National Oceanic and Atmospheric Administration (NOAA)

National Environmental Satellite, Data, and Information Service (NESDIS)

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Executive Summary

Approximately 20 percent of the United States economy, or two trillion dollars per year [Dutton] is weather sensitive. Each year, the U.S. suffers billions of dollars in losses due to lost time; property and crop damage and lost lives due to weather and environmental conditions, e.g.,

- In the commercial aviation community, weather is responsible for approximately two-thirds of air carrier delays, a cost of $4 billion annually, $1.7 billion of which is *avoidable* [National Aeronautics and Space Administration, http://awin.larc.nasa.gov].
- In 1997, the Red River Floods caused more than $400 million in losses when the Red River rose several feet above projected levels [Disaster Information Task Force].
- In 2000, $9 billion in crop damage was incurred due to weather (e.g., floods, convective weather, winter storms, drought, and fire weather) [National Weather Service].

However, some proportions of these losses are avoidable with improved environmental information, and some proportion of the improved environmental information is attributable to enhanced satellite technology and performance. Improvements in satellite performance that, for example, (1) result in the ability to better predict with increased lead time and accuracy, the location of severe weather manifestation; (2) provide increased temperature accuracy; and (3) offer improved monitoring of volcanic ash, can result in substantial economic benefits to a variety of public sectors. These economic benefits result from the ability of the data users to improve their operational decision-making. For example, airlines will make safer and more efficient routing decisions; the agricultural sector can make crop selection decisions and realize irrigation efficiencies; and, the utilities industries can improve the accuracy of their energy load forecasting decisions.

The National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) is developing the next-generation Geostationary Operational Environmental Satellites (GOES -R), which are expected to provide significant advances in earth coverage and weather and environmental information and prediction capabilities. Two of the key instruments within this GOES suite of sensors are the Advance Baseline Imager (ABI) and Hyperspectral Environmental Sounder (HES). To provide a firm foundation for the formulation of instrument development and procurement budgets, NOAA initiated an analysis of the marginal cost and benefit differences (in economic terms) between continuation of instruments with similar performance to today's imager and sounder and the planned GOES-R imager and sounder. The benefits from improved data and products will not only be critical to the economic well being of our users but will further national interests such as homeland security and national well being. New instruments for the GOES -R series will need to be developed because the imagers and sounders in service from now through 2012 cannot be replicated due to obsolescence of key components. Off-the-shelf instruments with similar capabilities would not allow us to incorporate any new technologies.

From a benefits perspective, selected case studies were developed that describe changes in economic impacts (i.e., marginal benefits) due to the proposed changes in the instruments. The expert knowledge and judgement of NOAA engineering staff, scientists, and product managers provided information on ABI and HES performance changes relative to the current imager and sounder and product improvements based on these performance changes. Information on economic benefits (primarily *avoided* costs) from these product improvements were obtained via public meetings, discussions, and interviews with GOES constituents and published literature and economic data pertaining to decisions based on this weather data. Published economic data used in the benefit analysis were not independently validated.

The case studies presented in this report represent key economic sectors (agriculture, aviation, electric power and natural gas generation, recreational boating, and trucking) and ***constitute a fraction of potential benefits*** that can be realized from improved GOES data. Thus, notwithstanding the limitations of the estimation techniques used, these estimates represent a ***lower bound*** to the true dollar value for potential benefits.

All costs are presented in fiscal year 2002 dollars, and the time frame under which the analysis is considered is 2012 to 2027 (15-year lifecycle). It was assumed that the advanced imager and sounder instruments will be launched in mid-2012 and the required infrastructure to make effective use of improved data from these instruments will be in place in the 2012 time frame. However, it was further assumed that benefits do not begin until 2015 to allow lag time for model revision and testing to take advantage of and have more confidence in the improved instrument data. Time will be needed after launch, checkout, and calibration before better economic decisions are likely to commence based on the new data. There is a limit to how much can be done to modify forecast models and products prior to launch. Time is needed to complete these modifications, and to test, validate, and verify improvements in forecasts and other products using actual advanced imager and sounder data. It will also take time to educate users and constituents as to the improvements.

Finally, it will take time for users to gain confidence in the real-world accuracy and applicability of the improvements before they will be willing to make potentially costly economic decisions based on these product improvements. These processes can proceed in parallel to some extent, and some benefits could start earlier and some later.

Summary of Results

This study contains eight case studies of the marginal economic benefits from ABI and HES. Below is an overview of the qualitative benefits of each case addressed. The results of the quantitative analysis are summarized in Table ES-1. The dollars are annual 2002 dollars and total discounted benefits for the 13-year effective lifecycle. (The lifecycle of 15 years has been adjusted to reflect the assumption that time will be needed to realize product improvements based on data from the new sensors.)

1. **Convective Weather Products: Benefits to Aviation.** GOES advanced sounder data are expected to provide substantially better ability to predict where convective weather such as thunderstorms will initiate within broad regions of unstable air. This information will reduce the cost of operational delays because air carriers will be able to make better tactical dispatch and routing decisions and avoid last-minute actions to bypass these storms.

2. **Volcanic Ash Advisories: Benefits to Aviation.** GOES advanced imager data will provide more accurate and timely warnings of the presence of airborne volcanic ash plumes that can seriously damage aircraft and jet engines and have the clear potential to cause serious aviation accidents. Winds derived from GOES advanced sounder data will enable more accurate and timely forecasts of the speed, altitude, and direction of these plumes. More accurate and timely volcanic ash advisories will reduce the cost of repairs and engine replacement from ash encounters and reduce the risk of catastrophic loss of aircraft, passengers, and crew from this hazard.

3. **Temperature Forecasts: Cost Savings to Electric Utilities.** GOES advanced imager data on clouds and winds and advanced sounder data on humidity profiles are expected to substantially reduce both the average and variance in error in short-term (3-hour) temperature forecasts. Improved temperature forecast accuracy will increase the accuracy of electric utilities' short-term electricity load forecasts. Improved load forecasts will enable utilities to reduce their costs by reducing the average amount of generating capacity they keep in ready reserve (spinning reserve) and the average amount of spot-power purchases they make in order to meet customer demand.

4. **Temperature Forecasts: Benefits to Agriculture/Orchard Frost Mitigation.** As in Case Study 3, GOES advanced imager data on clouds and winds and advanced sounder data on humidity profiles are expected to substantially reduce the amount of error in short-term (3-hour) temperature forecasts. The increased data density provided by ABI and HES will also improve forecasters' ability to provide forecasts tailored for particular agricultural districts and areas. Improved temperature forecasts will improve orchardists' decisions about how much to spend on frost mitigation on a given night during sensitive budding and flowering periods and will decrease the average amount they spend on mitigation activities over time.

5. **Soil Moisture Measurements: Benefits to Agriculture – Improved Irrigation Efficiency.** The GOES-R sounder will improve the accuracy of evapotranspiration (ET) estimates because of its ability to

discriminate temperature and humidity changes of the lowest layer (boundary layer) of the atmosphere where plants and soils interact with air masses. In addition, the GOES-R sounder (if it uses the GIFTS sampling interval of 4 km) will provide these data with much more spatial detail than the current GOES sounder. The soil scientists at U. of Wisconsin (Norman and Diak) who are developing this technique state that the GOES-R sounder data will provide the greatest contribution to improving estimates of ET. In addition, they state that the GOES-R imager thermal channel will provide data on surface temperature changes (between sun-up and mid-morning) on a substantially finer scale (2 km) than the current GOES imager (4 km). This is a four-fold improvement in spatial data and, when integrated with the GOES-R sounder data, will provide additional ability to discriminate ET at a scale closer to that of typical irrigated fields.

6. **Hurricane Landfall and Intensity Improvements: Benefits to Recreational Boating – Damage Avoidance.** The increased spatial resolution and update cycle for GOES-R sea surface measurements will enable GOES-R to capture sea surface temperature (SST) readings more often, providing the opportunity to re-initialize the SST data into models more frequently, helping to improve hurricane intensity forecasts. Rapid scan winds, tested on GOES 10 helped to better understand the divergence, or lift, of the storm and thus the potential for intensification. Rapid scan winds will be the norm on GOES-R. GOES-R improvements in the frequency and spatial resolution will improve the accuracy and density of wind-speed measurements (may double the number of wind vectors and double the accuracy of wind-speed estimates). Improved knowledge of the location of the centers of circulation winds (storms) as well as the speed at which they are traveling (steering winds) will provide better information on when and where a particular storm will make landfall.

7. **Temperature Forecasts: Benefits to Natural Gas – Load Forecasting Efficiency.** More rapid updates of clouds from the GOES-R imager, when assimilated into forecast models, will improve model predictions about temperature maximums and minimums because clouds moderate temperature peaks and lows. More detailed data on the lower layer of the atmosphere from the GOES-R sounder, combined with more frequent updates, and smaller sampling intervals will, when assimilated into forecast models, also improve the parameterization (input of data on temperature, humidity, winds) of the boundary layer in forecast models. In turn, the models should produce more accurate and specific predictions of temperature, humidity, winds, and precipitation. These potential improvements are based on studies of the contribution of current GOES data to the forecast accuracy of Eta and RUC2 models (Zapotocny, Benjamin and others).

8. **Winter Weather Forecasting: Benefits to Trucking – Accident Reduction**. GOES-R will better anticipate near-term ice formation conditions: better models of precipitation as well as more timely and accurate information on land surface temperature to indicate when the ground temperature is below freezing. GOES-R will also provide a higher resolution real time fog product that will allow drivers to more efficiently reroute.

It is important to note that the case studies developed and presented in this paper represent just a sampling of economic sectors and domains within those sectors from which economic benefits can be realized. The *total* potential marginal discounted benefits to the United States from GOES-R have not been estimated in this paper. However, the total annual marginal benefits from the eight cases discussed in this report show combined annual marginal economic benefits from ABI and HES are approximately $638 M annually (2002 dollars) and a discounted (present value) sum-of-direct benefits of approximately $3.1B across a 13-year effective benefit lifecycle. The Office of Management and Budget (OMB) guidance in circular A-94 states that the criterion to be used to decide if an investment is economically justified is whether or not the estimated Net Present Value (NPV) is positive (greater than zero). To appropriately calculate the NPV, the present value of benefits must be reduced by the marginal costs for ABI and HES (that is, the costs over an above what it would cost to reproduce the current imager and sounder capability). These costs are currently being calculated.

It should be noted that these benefits do not include the potential benefits from the consumer value of water, which is briefly addressed at the end of this paper and which has been valued [Booth] in the billions of dollars.

Table ES -1. Advanced Imager and Sounder Benefits Analysis Results

Application/Benefit Areas	Marginal Annual Benefits $M (2002)	Present Value (discounted) Sum of Marginal Benefits $M (2002)*
Commercial Aviation	$55	$205
Utilities - Electric Power Fuel Cost Reduction	$479	$1,944
Agriculture	$40	$695
Orchard Frost Mitigation (in Washington State)	$9	$33
Irrigation Efficiency (50 States)	$31	$662
Recreational Boating	$29	$108
Utilities - Natural Gas	$7	$34
Commercial Trucking	$28	$104
Total (Direct Benefits)	**$638**	**$3,090**

*Present value estimates are not uniformly larger than marginal annual benefits because some benefit areas incorporate growth factors or assumptions about the rate of technology adoption. See Benefit Calculation section for details.

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Section 1

GOES-R Cost/Benefit Analysis

1.1 Introduction

The National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) is developing the next-generation Geostationary Operational Environmental Satellites (GOES)-R, which is expected to provide significant advances in earth coverage and weather and environmental information and prediction capabilities. Two of the key instruments within this GOES suite of sensors are the Advanced Baseline Imager (ABI) and Hyperspectral Environmental Sounder (HES). To provide a firm foundation for the formulation of instrument development and procurement budgets, NOAA initiated an analysis of the marginal cost and benefit differences (in economic terms) between continuation of instruments with similar performance to today's imager and sounder and the planned GOES-R imager and sounder. The benefits from improved data and products will not only be critical to the economic well being of our users but will further national interests such as homeland security and national well being. New instruments for the GOES-R series will need to be developed because the imagers and sounders in service from now through 2015 cannot be replicated due to obsolescence of key components. Off the shelf instruments with similar capabilities could be purchased but this would not allow us to incorporate any new technologies.

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However, some proportion of these losses are avoidable with improved environmental information, and some proportion of the improved environmental information is attributable to enhanced satellite technology and performance. Improvements in satellite performance that, for example, (1) result in the ability to better predict with increased lead time and accuracy, the location of severe weather manifestation; (2) provide increased temperature accuracy; (3) and offer improved monitoring of volcanic ash, can result in substantial economic benefits to a variety of public sectors. These economic benefits result from the ability of the data users to improve their operational decision-making. For example, airlines will make safer and more efficient routing decisions; the agricultural sector can make crop selection decisions and realize irrigation efficiencies; and, the utilities industries can improve the accuracy of their energy load forecasting decisions.

This paper will present the methodology used to establish the linkage from satellite performance improvements to product improvements to user operational decision making that results in economic benefits to each industry discussed. It will also present the results of eight case studies that represent a diversity of economic sectors in this country, including, agriculture, aviation, electric power and natural gas, recreational boating and trucking. Economic benefits are presented in annual savings ($2002) and discounted present value (representing the discounted benefits over the life of the program).

Section 2

Background

2.1 Environmental Monitoring and the Role of GOES

A number of different sensor systems are deployed by NOAA to measure and monitor specific weather phenomena such as severe storms, winds, and temperature. [National Weather Service, *Operations of the National Weather Service*] These sensors measure different physical phenomena such as visible light, infrared radiation (IR), reflected microwaves, in-situ temperature, humidity, and pressure; and have differing measurement precision, range, resolution, and timeliness. As a result, these sensors compliment and supplement one another to measure weather and environmental phenomena. The focus of this analysis is on the GOES satellite system. The GOES is an integral part of the global observing system and offers high temporal and spatial measurements. NOAA's weather satellites are an essential part of the overall NOAA system of weather sensors. The integration of data from multiple systems produces the depth and breadth of data needed for forecasting and environmental monitoring.

Operating the country's system of environmental weather satellites is one of the major responsibilities of NESDIS. NESDIS operates the satellites and manages the processing and distribution of the millions of bits of data and images these satellites produce daily. The primary internal customer is NOAA's National Weather Service (NWS), which uses satellite data to create short-range warnings, "nowcasts" and forecasts for the public, television, radio, and weather advisory services. Satellite information is also shared with various Federal agencies, such as the Departments of Agriculture, Interior, Defense, and Transportation; with other countries throughout the western hemisphere and other countries world-wide such as Japan, India, and Russia, and members of the European Space Agency (ESA) and the United Kingdom Meteorological Office; and with the private sector.

GOES satellites provide the kind of continuous monitoring necessary for intensive data analysis. They circle the Earth in a geosynchronous orbit, which means they orbit the equatorial plane of the Earth at a speed matching the Earth's rotation. This allows them to remain continuously over one position above the surface. The geosynchronous plane is about 35,800 km (22,300 miles) above the Earth, high enough to allow the satellites a full-disc view of the Earth. GOES satellites provide a variety of information across many application areas. One key area is severe weather. Because the satellites stay above a fixed spot on the surface, they provide a constant vantage point to watch for atmospheric "triggers" for severe weather conditions such as tornadoes, flash floods, hail storms, and hurricanes. When these conditions develop, the GOES satellites are able to monitor storm development and track their movements. Figure 1 [NOAA/NESDIS, *NOAA Satellite Products and Services—Office of Satellite Data Processing and Distribution, Global Coverage by GOES and Other Geostationary Environmental Satellites as of March 2000*] illustrates the areas over which GOES provides coverage.

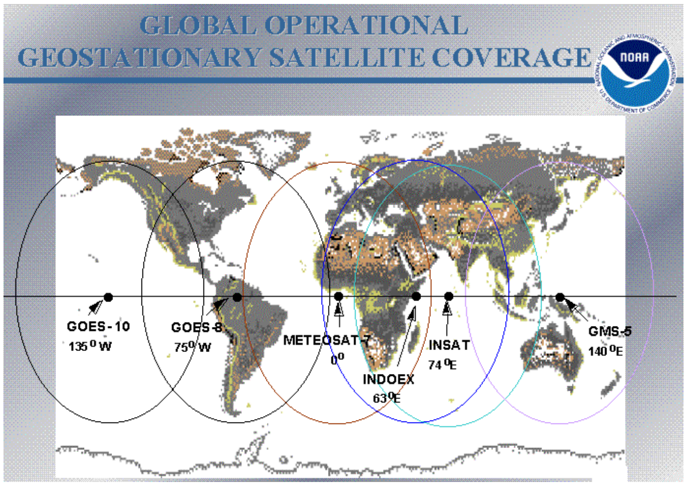

Figure 1. Global Operational Geostationary Satellite Coverage

Section 3

Methodology

3.1 Benefits Analysis Overview

In FY02, a study was initiated to estimate the marginal benefits obtained by using the planned GOES-R imager and sounder as the primary GOES-R weather sensors in place of technological equivalents to the current GOES imager and sounder. The overall study objective was to estimate the marginal cost benefit obtained by using the ABI and HES as the primary GOES weather sensors in place of equivalents to the current GOES imager and sounder and compare these benefits to the marginal costs of developing and pricing ABS and HES. These benefits are net of the marginal costs of developing and acquiring the GOES-R imager and sounder. The marginal benefits are based on case studies that estimate economic changes (primarily cost reduction) due to the changes in the performance of the GOES-R imager and sounder. These benefits are those expected to be achieved over and above current or future benefits from the current imager and sounder or future instruments with the same performance as the current instruments. The case study results are based on interviews with internal NOAA engineering staff, scientists, and product managers; public meetings and discussions with external constituents who use the data provided by these instruments, as well as published economic data pertaining to decisions based on this weather data.

In general, changes in products using GOES-R imager and/or sounder data over current sensor data can be attributed to: (1) more frequent refresh rates; (2) finer horizontal resolution; and, (3) finer spectral resolution. More frequent updates provide valuable information on phenomena that change quickly, such as thunderstorm formation. Faster coverage rate also allows more regions to be scanned. Finer horizontal resolution allows for observation of phenomena of a smaller scale (usually of a few kilometers or less) with more accuracy. Finer spectral resolution allows scientists to observe phenomena that might not have been observable before (for example, super cooled water in clouds, or temperature inversions).

3.2 Benefit Analysis Constraints and Assumptions

Below are assumptions and constraints under which this CBA was developed**.**

1. Required infrastructure to maximize use of, and therefore benefits of, more and improved data from the ABI/HES will be in place in the 2012 time frame.

2. Benefits are presented in 2002 year dollars.

3. The time frame under which the analysis is considered is 2012 to 2027 (15-year lifecycle).

4. There will be a lag time for model revision and testing to take advantage of and have more confidence in the better data. (If the ABI and HES follow the same course as when the current imager and sounder first were launched, then some products, for example, the higher resolution imagery, will be ready for use much sooner than the more quantitative products, for example derived from the sounder.) Time will be needed after launch, checkout, and calibration before better economic decisions are likely to commence based on ABI and HES data. There is a limit to how much can be done to modify forecast models and products prior to launch in anticipation of ABI and HES data. Time is needed to complete these modifications, and to test, validate, and verify improvements in forecasts and other products using actual ABI and HES data. It will also take time to educate users and constituents as to the improvements. Finally, it will take time for users to gain confidence in the real-world accuracy and applicability of the improvements before they will be willing to make potentially costly economic decisions based on these product improvements. These processes can proceed in parallel to some extent, and some benefits could start earlier and some later. As a result, benefits are assumed to begin mid-2015.

5. The expert judgement of NOAA system engineers, scientists, and product managers provided the information on sensor performance changes and product improvement. The information on avoided costs and benefits was obtained from constituents and published literature.

6. Published economic data (e.g., cost of acreage) used in the benefits analysis were not independently validated. It was assumed these costs were reasonable for their intended purposes and use in the CBA.

7. Other sensor systems may change over the course of the time frame of this analysis. However, their contributions to the overall benefits to the industries in this CBA have not been assessed.

3.3 Benefits Analysis Methodology

Aggregate benefits from use and application of weather information are well documented and significant in economic value. Figure 2 illustrates the overarching steps for the benefits analysis that are needed to identify marginal operational benefits resulting from and traceable to advanced GOES Sensor technologies. The four steps are discussed in more detail following Figure 2. This figure summarizes the primary objective of each phase. It is important to point out that these phases were not always accomplished in serial. In fact, during several of the discussions with NOAA scientists (Steps 1 and 2), for example, information on constituent operations (Step 3) were often discussed together with discussions on product improvements.

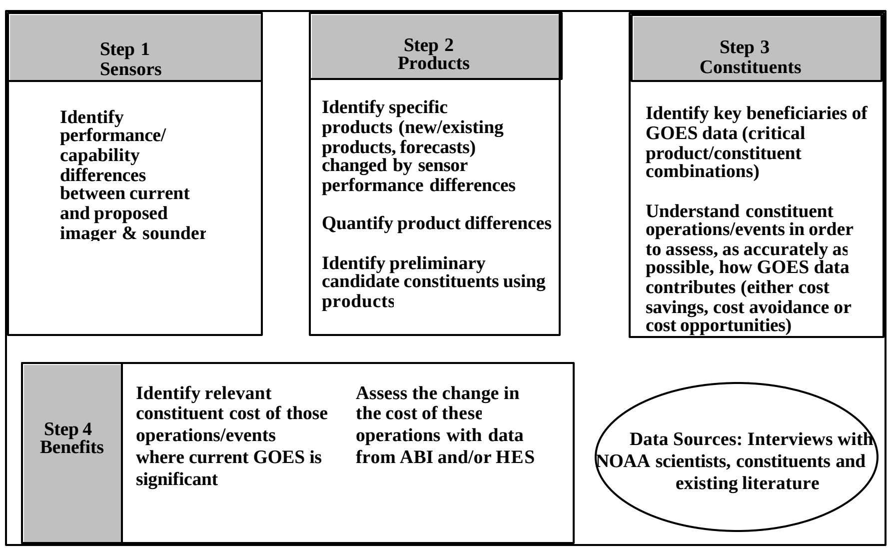

Figure 2. Steps of the Benefits Analysis Process

Step 1: Determine the marginal improvement in the sensors. There are technological differences between current technology GOES sensors and advanced technologies. These differences result in potential differences in lifecycle costs and benefits to the end user community.

The technical differences between imagers and sounders are described in terms of specification characteristics, such as, spatial coverage, resolution, more frequent updates, and number of channels. These differences arise from new and improved technological advances. These performance and capability assessments are based on technical analyses, primarily from the Cooperative Institute for Meteorological

Satellite Studies (CIMSS). The details for the comparison between the ITT imager and ABI and the ITT sounder and ABS appear in Section 4.1.

Step 2: Determine the marginal changes in the quality of products. The differences in the sensor characteristics identified in Step 1 result in improvements in the quality of products [see Table 3] derived from the GOES Sensors. Several meetings with NOAA scientists [Appendix A] were conducted to assess the magnitude of these improvements and discuss the scientific basis for these assessments.

During discussions with NOAA scientists, applications of the products were often discussed in addition to the product improvements. NOAA scientists translated differences in sensor capabilities into differences in products derived from GOES data. New products were also discussed. The changes in products are identified in Table 3. End-user applications of satellite products are very much integrated into the product development process within NOAA. This provided NOAA with the context of constituent operations and valuable insight into potential constituent groups, thereby focusing investigations into potential benefit areas.

Step 3: Determine the relevant application areas, constituents, and conduct interviews. The challenge of this phase was to "match up" those products where improvements could be explicitly stated and quantified with constituents who have intimate knowledge of how the product supports their operations and/or industries where cost data of their operations could be obtained publicly.

In discussions with NOAA scientists on product improvements with ABI and HES, some application areas where GOES contributes significantly surfaced regularly. These application areas included aviation weather (including impacts of phenomena such as fog, icing, and volcanic ash), agricultural weather, and severe weather. Ideally, the CBA should consider total expected benefits across all industries and applications. To put a perspective on the magnitude of the number of beneficiaries, consider the taxonomy in Figure 3 [NPOESS Cost, Operational Benefit, and Requirements Analysis (COBRA)]. Notice that this taxonomy captures beneficiaries ranging from preventable loss of life and property resulting from infrequent but catastrophic events to the general public benefiting in everyday decisions related to weather. This listing also provides examples of industry-specific decisions (in this case, for aviation), illustrating again the enormity of the problem if one were to enumerate all decisions and potential costs involved for each application area.

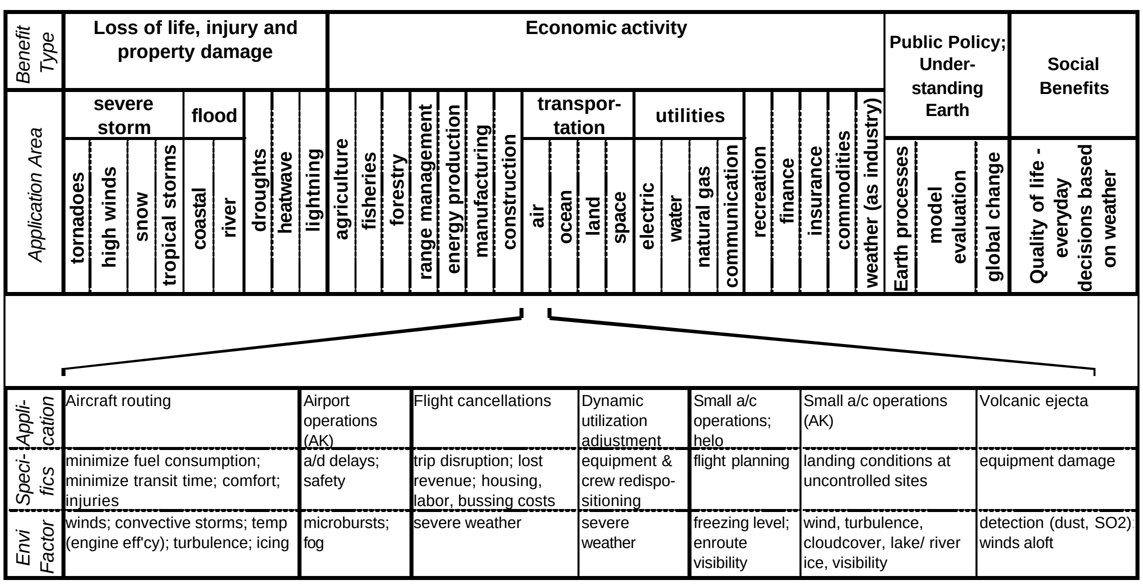

Figure 3. Taxonomy of Potential Beneficiaries of Weather Information

Estimating total benefits on this scale requires a macro-economic model that has not been developed. An alternative solution to estimating total benefits would be to enumerate all case studies which, as seen in the breadth of application areas listed in Figure 3, would involve considerable research and analysis.

Since estimating total benefits remains well outside the scope of this study, estimating partial benefits in select application areas was conducted to meet the needs of this Cost Benefit Analysis (CBA). Therefore, the next step was to identify application areas that would be the focus of this benefits analysis.

The application areas listed under "Loss of life, injury, and property damage" are familiar, and the loss of life and dollar value of damages due to weather is well documented. However, it is difficult to extract *preventable* loss of life and/or damages. Furthermore, it is even more difficult to determine the fraction of these damages that are *preventable with improved information from GOES*. Despite these constraints, there is compelling scientific evidence that GOES is currently used in many of the forecasts for these events, that there is significant room for improvement in these products, and that the ABI and/or HES are likely to provide measurable improvements. For these reasons, benefits in this category are not included but may be investigated in the future.

Other areas of well-documented economic impacts of weather [Societal Aspects of Weather] are major industries, such as, general transportation (mostly aviation), agriculture, and utilities. Motivated by safety, customer satisfaction, and profit, these industries have the tools and expertise in place to use weather information in their monthly, daily, hourly, and in some cases, minute-by-minute decision making. As a result, data on the economic value placed on weather information are more likely to exist for these industries. Consequently, it is more likely that costs can be estimated for benefits from improved weather data. **This CBA considers benefits for only those industries, applications, and decisions where it can be shown that GOES data contribute to operational decisions.**

In summary, based on interviews with NOAA personnel (matching products with constituents) and the feasibility of getting cost data on benefits from other industries, the following benefit areas were investigated:

- Agriculture (Frost Freeze Mitigation and Irrigation Efficiency)
- Aviation (Convective Weather and Volcanic Ash Avoidance)
- Recreational Boating (Hurricane Damage Reduction)
- Trucking (Accident Damage Reduction)
- Utilities (Electric Power and Natural Gas Load Forecasting)

<u>Step 4: ABI/HES benefits calculation.</u> Once product improvements have been quantified and constituents, potentially benefiting from these improvements, were identified, the final step was to calculate the dollar value of the benefit.

As stated previously, whereas the economic impact of weather in this country is significant and well documented, attributing economic benefits (either in the form of cost savings, cost avoidance, or cost-making opportunities) to one contributor in the information stream used by decision makers, can be difficult. In all case studies in this report, weather-dependent industry operations costs have been obtained from existing sources, but the estimates of the portion of benefits attributed to improved knowledge from ABI and/or HES were obtained through interviews with NOAA scientists or estimated using engineering judgement. The justification for these assumptions is discussed in the case studies sections.

There are two sources of constituent operations costs. They are obtained either directly from constituents or they were taken from existing data sources (such as, related web sites, reports, and statistical databases). Cost data used in this analysis were not independently validated. Rather, it was assumed that these costs were reasonable for their intended purposes.

Annual Benefits Estimation Method

The process for estimating the discounted benefits of an advanced instrument relative to a current instrument is as follows:

- Calculate the annual economic benefit due to better data, information, or products from the advanced instrument. This computation is a marginal or differential calculation since the benefits from advanced instruments are those expected to be achieved in addition to current or future benefits from the current imager and sounder or a future instrument with the same performance as the current imager or sounder. For each case study, annual marginal benefits are computed, in general, as follows:

ACT_{AV}	=	Annual avoidable activity with better environmental information (e.g., # of delays, # of hours)
NP_T	=	Net proportion of time-related costs avoided due to ABI or HES
NP_M	=	Net proportion of material costs avoided due to ABI or HES
C_O	=	Cost of operational activity (e.g., $/delay, $/hr)
C_M	=	Cost of materials (e.g., $/entity)

$$\text{Annual Benefits (\$)} = ACT_{AV}*NP_T*C_O + ACT_{AV}*NP_M*C_M$$

- Increase the value of benefits annually over the effective lifetime of the advanced instrument used in this study if the economic activity underlying the benefits is expected to continue to grow during the ABI lifecycle (per OMB Circular A-94).
- Discount each year's benefits to a 2002 present value using the OMB-mandated discount rate (per OMB Circular A-94).

Each case study in this report is different because of differences in the specific activities or resources analyzed. As a result, the detailed computation of the elements in each case study is different. However, the end result, being stated in terms of dollars per year, can be summed together to yield a total net present value for each instrument and alternative analyzed.

For many operations where weather plays a significant role, benefits are typically realized in terms of savings of time and savings in material expenditures. In some cases, savings of time or material might be zero. Time is money, so time saved is typically translated into cost of operations per unit time (for example, per hour, per day, or per month). These cost savings in turn have the potential to increase profitability for the economic entity in question, or, given competition, result in reduced prices of goods and services to consumers, or some combination of these two benefits. However, knowing that the cost of operations is dependent upon some weather event is not sufficient. What must be shown is that better information, in the form of improved accuracy or timeliness, would facilitate actions to improve efficiency of operations. The actions might not have been taken with information of lesser quality.

Once the operational case can be made that actions could be taken to save money (or avoid costs), provided that the decision maker has better information from GOES, the number of occurrences of such cost saving (or cost-avoiding) actions must be estimated. Not all potentially cost-avoiding actions due to weather are preventable. For example, some airline delays, diversions, or cancellations may be preventable with better information, but some of these costly actions due to weather may be unavoidable. Therefore, it is unreasonable to assume that *all* such cost-avoiding actions would be taken solely because of improved weather information. On the other hand, given that there are preventable actions that can be taken, it is unreasonable to assume that improved weather information would have no impact at all. Based on facts established that GOES information is critical to profit-making decisions, it is reasonable to assume that there would be some measurable benefits. The challenge that remains is to determine the magnitude of these costs.

In summary, the benefits methodology relies on the data provided by expert judgement of a number of NOAA scientists and operational users of GOES products (Appendix A). A variety of existing cost data and statistical data collected on industry operations and the impact of weather on these operations was also critical input into the analysis.

3.4 Treatment of Inflation and Present Value Calculation

This report treats inflation and calculates present values in accordance with guidance issued by OMB in Circular A-94 [Office of Management and Budget]. Per OMB's guidance, costs and benefits in this analysis are compared using nominal, current year (2002) dollars using the gross domestic product (GDP) deflator as appropriate. Historical cost data used to compute potential future-year avoided costs (counted as benefits) were inflated to 2002 dollars using the historical GDP deflation index published in the President's Budget. For example, Federal Aviation Administration (FAA) data on hourly average cost of aircraft operations reported in prior year dollars were inflated to 2002 dollars.

In accordance with OMB guidance, costs and benefits are discounted using a real (deflated) discount rate of 7 percent. Discount factors are computed according to the OMB formula: $1/(1+I)^n$, where I is the real discount rate (7 percent) and n is the number of years spanning the time period of interest. All costs and benefits are assumed to occur at the beginning of each year and are discounted to 2002 present values.

Benefits were distributed evenly over the periods during which they are expected to occur. We assumed that the instruments are launched mid 2012 but do not begin to provide benefits until mid 2015. The total lifetime used in this analysis is 15 years, and the effective lifetime during which benefits are obtained in this analysis is 13 years (2015 to 2027).

Section 4

Benefits Analysis and Results

Benefits are received across a variety of application areas and to many individuals and organizations in the public and private sector. In general, benefits are derived from an improved ability to:

- Predict ***when*** and ***where*** severe weather will manifest itself;
- Predict farther ***in advance*** (increased lead time) when severe weather will occur;
- Predict, with ***improved accuracy***, the characteristics of severe weather initiation (e.g., temperature, humidity);
- Observe phenomena ***more clearly***, ***sooner,*** and with ***greater frequency*** from improved imagery;
- ***Track*** weather more accurately, and
- ***Observe*** the previously unobservable.

This section identifies all the components of the benefit analysis. The section begins with the performance differences between current sensors and ABI and HES, and the resultant improvement in products. Next, individual case studies are discussed and benefits calculated.

4.1 Improvements in Sensor Capability from Current Sensors to ABI and HES

The Technical Requirements Document (TRD) prepared by NESDIS presents detailed requirements for an operational advanced imaging and sounding instruments for the GOES platform. The TRD is NOAA's statement of performance characteristics drawn from the National Weather Service (NWS) Operational Requirements Document (ORD) [National Weather Service *Operational Requirements for Future Geostationary Operational Environmental* Satellites].

Currently there are a number of shortfalls with the current GOES sensors, including the following:

- The current imager cannot monitor developing severe local weather and still provide global surveillance and products simultaneously.
- The current imager limits ability to monitor volcanic ash, aviation icing hazards, snow/cloud determination, and mid-level moisture tracking.
- The current sounder cannot see the United States and ocean areas for hurricanes and winter storms simultaneously.
- Image resolution is currently insufficient to see details that prelude storm formation.
- Wind accuracies are too low for new model requirements.
- Moisture structure is inadequately measured in the vertical.
- Improvements to flash flood forecasts and severe weather formation need more accuracy.

The planned ABI and HES instruments will be a major source of hemispheric/domestic forecast information, providing high temporal and spatial resolution; increasing vertical resolution; and, providing good cloud/surface detail. The ABI and HES instruments will also capture diurnal changes, providing the only observations available of detailed horizontal moisture structure and time changes.

In general, changes in products using ABI and/or HES data over current sensor data can be attributed to: (1) more frequent updates; (2) finer horizontal resolution; and, (3) finer spectral resolution. More frequent updates provide information on phenomena that change quickly, such as thunderstorm formation. This faster coverage rate also allows more regions to be scanned. Finer horizontal resolution allows for observation of phenomena of a smaller scale (usually of a few kilometers or less) with more accuracy. Finer spectral resolution allows scientists to observe phenomena that might not have been observable before (for example, super cooled water in clouds, or temperature inversions). Further discussion on the resulting improvements in specific products appears in Section 4.2.

Discussions with the GOES program manager, scientists from NOAA and the CIMSS, and NASA [Appendix A] provided critical performance information on the current imager and sounder as well as the expected performance of the ABI and HES. These improvements in performance will generate products with improved quality, as will be shown in Section 4.2. Table 1 presents the imager comparison [NOAA/NESDIS/ORA, *Thoughts on the Advanced Baseline Imager for a Cost-Benefit Analysis*]. Table 2 presents the sounder comparison [NOAA/NESDIS/ORA, *Thoughts on the Advanced Baseline Sounder for a Cost-Benefit Analysis*].

Table 1. Imager Comparison

	Current GOES	**ABI**
Spatial Resolution		
Visible (0.64 mm)	Approx. 1.0 km	0.5 km
All other Bands	Approx. 4.0 km	2.0 km
Spatial Coverage		
Full disk	Every 180 min.	Every 15 min.
CONUS	Every 15/30 min.	Every 5 min.
Operating During an Eclipse	No	Yes
Spectral Coverage	5 Bands	12 bands

Table-2. Sounder Comparison

	Current GOES	HES
Coverage Rate	CONUS 60 minutes	CONUS 12 minutes
Horizontal Resolution		
Sampling Distance	10 km	4 km
Individual Sounding	30-50- km	4 km
Vertical Resolution	~3 km	1 km
Accuracy		
Temperature	2 deg. K	1 deg. K
Relative Humidity	20 percent	10 percent

4.2 Improvements In Selected Forecasts and Warnings That Use GOES Data

The expectation is that most of the current GOES products will improve with the movement to ABI and HES. A sampling of current GOES products are shown in Appendix B. This reference list provided the baseline set of products from which interview questions were developed for our discussions with NOAA scientists.

Based on these discussions, particular products that were deemed most relevant in terms of impact and ability to quantify impact within the study time frame were chosen for case studies. Table 3 identifies GOES products and expected quality changes due to use of the new sensors. Two of these products, the Collaborative Convective Forecast Product (CCFP) and temperature forecasts are also considered as part of this study and are discussed in the following section. The information in Table 3 and the following section was developed from discussions with NOAA scientists [Appendix A].

Table 3. Selected Products and Expected Product Quality

Product	Current Imager and Sounder	GOES-R Imager and GOES -R Sounder
1. Real-time Imagery (visible-channel)	1 km spatial resolution. One channel in visible spectrum CONUS Update every 15-30 minutes Full disk update every 3 hours, Up to 3-hour blackouts around equinox periods.	½ km spatial resolution. Two channels in visible spectrum CONUS update every 5 minutes, Full disk update every 15 minutes. No blackout periods.
Real-time Imagery (IR channels)	4 km IR spatial resolution. Four IR channels. CONUS Update every 15-30 minutes Full disk update every 3 hours, Up to 3-hour blackouts around equinox periods.	2 km IR spatial resolution. Ten IR channels. (12 channels total). Increased spatial and temporal resolution will enable GOES-R to detect rapid, small-scale changes in severe weather systems such as hurricanes, thunderstorms, and winter storms. For example, over-shooting (cold) cloud tops that identify—and, in some cases precede—intense convective activity at the surface will be seen more accurately and more quickly. GOES-R will also provide severe weather imagery updates to non-CONUS areas every 15 minutes—about 12 times faster than today. Non-CONUS severe weather imagery benefits both foreign countries and U.S. citizens and companies living and working in these areas. For example, U.S. airlines operating in South America rely on GOES images and data.
2. Cloud Drift Winds **Water-vapor Winds**	Cloud-drift (imager) wind speed has a root mean square error of about 3 m/sec (about 7 mph). Sounder-based water-vapor winds are constrained by the low spatial resolution, limited geographic coverage, and infrequent update cycle (1 per hour). Sounder (water vapor) winds have a root mean square error of about 7.5 m/sec (17 mph).	Increasing the frequency and spatial resolution of imager and sounder measurements could double the accuracy and density of wind-speed measurements. In addition, the GOES-R Sounder with 5 per hour update, and 1-2 km vertical resolution will permit timely assignment of water-vapor winds to 1-2 km elevation accuracy, a 3 to 5 fold increase in wind vector elevation data.
3. Effective Cloud Amount and Cloud Top Height	Cloud imagery accurately shows the location of clouds, but assignment of cloud-top elevation is limited by number of IR channels.	Cloud-top elevations will be much more accurate with the use of advanced sounder data (1-2 km vertical resolution in flight levels).
4. Volcanic Ash Advisory Statements	Current imagery accurately detects dense ash clouds in visible imagery, but has limited ability to detect attenuated ash. Eruptions and plumes that develop outside of CONUS may be missed due to infrequent update cycle.	GOES-R Imagery will add an IR channel that will show attenuated ash plumes. The imagery will also be more able to see initial eruptions due to 5 to 15 minute update cycles. Small-scale eruptions will be more readily detected due to higher spatial resolution. More frequent, accurate assignment of winds to specific to specific elevations (see cloud drift and water vapor winds above) will also allow the direction and speed of ash plume movement to be

Product	Current Imager and Sounder	GOES-R Imager and GOES -R Sounder
		forecast much more reliably than today.
5. **Tropical Cyclones**	GOES imagery and sounder data is the best platform for the estimation of storm intensity, location, and storm environment—especially for storms in the data-sparse oceanic areas outside the range of in-situ observation platforms such as aircraft and associated dropwindsondes. However, the current GOES has limited ability to measure atmospheric parameters in the lower atmosphere, only provides updates every three hours for non-CONUS and is subject to equinox black-outs during the fall hurricane and cyclone season. Intensity errors are about ½ T number and the average tropical cyclone position error for Atlantic storms is about 20 nmi, although the error can be much larger for weaker systems.	GOES-R data will provide much more information on the environment of tropical storms—the temperature, humidity, and winds that feed and steer tropical storms. In addition, more frequent GOES-R updates (once an hour) and higher spatial resolution will enable more accurate location of storms and estimates of intensity—especially for poorly defined storms and storms beyond the range of in-situ observing systems.
6. **Lifted Index**	The Lifted Index is a useful product showing lower-level (500 Mb level) atmospheric instability derived from imager and sounder data. GOES currently has limited ability to accurately estimate lower-level instabilities that trigger convective weather.	See discussion on (5) above. GOES-R will provide much more data and more frequent data on instabilities in the lower atmosphere.
7. **Total Precipitable Water**	Today's GOES sounder provides useful information on the quantity of water vapor in the atmosphere but can only assign this water vapor to 3 layers in the atmosphere. Accuracy of the precipitable water is ± 10 percent.	GOES-R Sounder data will be able to assign water-vapor quantities to 7-12 specific elevation layers. This will improve estimates of the amount of water that will likely precipitate. Improved information on layers of water vapor will also improve our ability to forecast thunderstorm development.
8. **Fog Products**	Today's GOES provides useful early-morning fog imagery based on IR-absorption. However, the image resolution is coarse (4 km) and the current imager cannot readily distinguish different cloud layers.	GOES-R fog products will have higher resolution (2 km) and much better discrimination between snow, fog, and cloud.
9. **Vertical Temperature and Moisture Profiles**	GOES sounder moisture profiles are key inputs into NWS forecast models and convective weather forecast products. Current horizontal resolution is 30 to 50 km; humidity accuracy 20 percent; temperature accuracy 2 deg. K. Vertical resolution is currently 3 km layers.	GOES-R Sounder vertical and temperature profiles will be improved in horizontal resolution to 4 km (a factor improvement of 56-156 times); in humidity accuracy to 10 percent and temperature accuracy to 1 deg. K. Resolution will improve to 0.5 to 1 km layers.
10. **Sea Surface Temperature**	GOES today provides useful information on sea surface temperatures.	The increased spatial resolution and update cycle for GOES-R sea surface measurements will enable GOES-R to capture surface temperature readings through cloud-gaps for areas often obscured for extended periods—especially in winter months. This ability will increase the accuracy of key measurements needed to estimate certain precipitation forecasts, such as lake-effect snowfall.

Benefits calculated in the case studies focus on the following GOES product improvements: imagery, cloud drift winds, volcanic ash advisory statements, lifted index, vertical temperature and moisture profiles, and sea surface temperatures. Volcanic ash advisory statements are GOES products and are directly used by the aviation community. The other products are input into end-user products, such as the Collaborative

Convective Forecast Product (CCFP) and NWS temperature and dew point forecasts. Benefits are calculated based on operational use of these end-user products.

4.2.1 Collaborative Convective Forecast Product (CCFP)

The CCFP uses GOES sounder and imager data plus other sources, such as NEXRAD, radiosondes, and surface measurement systems, to predict the extent and probability of convective weather 4 to 6 hours out. Current observational systems lack the ability to construct a detailed or comprehensive picture of the clear-air structure of the lower atmosphere in three dimensions and the ability to update this picture in near-real time. Consequently, the current CCFP product cannot predict the likely location of storm initiation today[1].

Data from the advanced sounder will measure temperature, humidity, and winds in clear air in three dimensions and will update this picture for CONUS every 12 minutes. This in essence creates a near-real time movie of atmospheric dynamics from the surface up to high elevations, and will likely enable forecasters to predict the location of initiation for convective storms to within a 50 to 100 km box 1-2 hours in advance. This is roughly an order-of-magnitude improvement over the current CCFP product.

4.2.2 NWS Temperature Forecast Improvements

NWS temperature forecasts utilize several GOES products including cloud field data, winds, moisture, and sea surface temperatures (SSTs). ABI and HES will provide improvements in these products, which will result in improved temperature forecasts [Petersen and Schmit]. This is substantiated by the fact that improvements in temperature forecasts have already been realized in the current GOES sounder. For example, with data from 3 seasons, the 24-hr temperature forecast was improved by 1-2 percent (over CONUS) with the current GOES sounder moisture data being included in the current Eta[2] model. Temperature forecasts were also improved by approximately 4 percent for the Eta domain average when GOES cloud-drift winds were included.

NOAA scientists estimate that the improved ABI/HES precipitation, winds, clouds, and moisture readings will improve the 3-hour temperature forecast by 25 percent and the 24-hour forecast by 2 percent.

In summary, based on interviews with and input from NOAA scientists, we conclude that end-user products such as CCFP and NWS temperature forecasts will improve with ABI and HES. In the next section case studies and benefits will be calculated for those industries using these products.

4.3 Select Constituent Benefits

This section presents selected case studies for constituent operations and other applications that represent processes and data that are actually used in decision making, and where the significance of GOES data is unquestioned. Table 4 summarizes these results, which are discussed in the following subsections. **Finally, only a few, out of potentially hundreds of operations nationwide that could benefit from improved GOES data, have been included here.**

Agriculture and electric power generation are believed to be two of the largest identifiable beneficiaries of improved sensor data, while airline routing and electric power are two of the industries best structured and motivated to use improved forecast information, since they already have extensive experience in profitably applying forecast information. The following sections present case studies for constituent operations and other applications that represent processes and data that are actually used in decision making, and where the significance of GOES data is identified.

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[1] Interview with Dr. Fred Mosher, Aviation Weather Service. “The Sounder could detect initial convection (as long as there is not cloud cover). We cannot do this now.”

[2] The Eta model is an operational weather forecasting model.

Many more potential benefit areas have not been quantitatively evaluated for this report. Thus, notwithstanding the limitations of the estimation techniques used, **these estimates represent a lower bound to a significantly higher dollar value for potential benefits**.

Table 4. Summary of ABI/HES Economic Benefit Case Studies

Application/Benefit Areas	Marginal Annual Benefits $M (2002)	Present Value (discounted) Sum of Marginal Benefits $M (2002)*
Commercial Aviation	$55	$205
Utilities - Electric Power Fuel Cost Reduction	$479	$1,944
Agriculture	$40	$695
Orchard Frost Mitigation (in Washington State)	$9	$33
Irrigation Efficiency (50 States)	$31	$662
Recreational Boating	$29	$108
Utilities - Natural Gas	$7	$34
Commercial Trucking	$28	$104
Total (Direct Benefits)	**$638**	**$3,090**

*Present value estimates are not uniformly larger than marginal annual benefits because some benefit areas incorporate growth factors or assumptions about the rate of technology adoption. See Benefit Calculation section for details.

4.3.1 Case Study 1: Convective Weather Products: Benefits to Aviation

Problem Statement

U.S. airlines/air-transport companies and FAA air traffic managers collaborate every day to set and modify flight plans intended to ensure that flights depart and arrive on schedule with a minimum of delays due to weather. Typically, dispatch decisions are made 1 hour to 5 hours in advance of take-off depending on the length of the flight. However, the initiation of severe convective weather, such as spring and summer thunderstorms, cannot be accurately predicted today. When these storms occur, they cause delays on the ground as flights are held or in the air as they are re-routed to avoid weather hazards. As these delays back up, flights are often diverted to different airports or cancelled.

Today, the best available 4- to 6-hour forecast product, the Collaborative Convective Forecast Product (CCFP), shows a large box within which storms have some probability of occurring. The lifted index product is currently the primary GOES sounder product that is used to produce the CCFP. This box is typically several hundred miles long and often over 100 miles wide, resulting in a watch area typically 10,000 to 30,000 square miles or more. With advanced sounder data, according to NCEP, NASA, and AWC experts, forecasters looking 1 to 2 hours in advance will likely be able to reduce the watch area significantly, by approximately 90 percent. This reduction in watch area will result in more efficient use of the air space by reducing flight delays. In addition, the greatly increased amount of information on the size and energy content of parcels of unstable air will enable forecasters to provide substantially more information about the intensity and rapidity of development of convective weather.

Benefits Calculation

This case study addresses the cost of delays that could have been *avoided* with better weather information from the advanced GOES sounder. The total number of delays for all traffic at U.S. airports in the year 2000 was 450,289, with 309,482, or approximately 69 percent, due to weather [Federal Aviation Administration, OPSNET]. An FAA aviation weather expert estimated that at least 50 percent, or 154,741, of these delays were due to convective weather. Furthermore, since the focus of this benefits study is on the impact to U.S. aviation only, it is conservatively estimated that 75 percent of the delays at U.S. airports impacts U.S. carriers. Thus, the number of delays due to weather and impacting U.S. carriers is estimated to be 116,056 in 2000. Given the potential to reduce convective weather watch areas by nearly 90 percent, it is reasonable to assume that a significant number of delays due to the over-extending of the watch area would be avoided. No research has been found to estimate this number, so for this analysis, a conservative 20 percent reduction was assumed. Although no study has been conducted to estimate the contributions of other sensor systems, the contribution of the advanced sounder is further reduced by half to allow for the potential contribution of improvements in other sensor systems.

Delay costs are assumed to be the cost of operations of the airlines, which include variable costs (such as crew, fuel, oil and maintenance) and fixed costs (such as rentals, depreciation and insurance). Operations costs for scheduled commercial service are estimated to be $3,348 per hour in 1998 dollars (assuming 50 percent with commuters ($3093 per hour in 1998) and 50 percent without commuters ($3603 per hour in 1998)). Operations costs for air taxi is $780 per hour and for general aviation is $565 per hour, all in 1998. [Federal Aviation Administration, 1998, Section 4] The weighted average operations cost used in this analysis is $2,826, based on the proportion of aircraft types experiencing delays (80 percent commercial, 16 percent air taxi and 4 percent general aviation), or $3,055 in 2002 dollars. The average delay was 45 minutes, so that the cost for three-quarters of an hour delay would be $2,291. Table 5 summarizes these data.

Table 5. Aircraft Delay Data Input Summary

Variable	Variable Description	Value
TD_{US}	Total delays for all traffic at U. S	450,289
TD_{Wx}	Total delays due to weather	309,482
PD_{CWX}	Percentage delays due to convective weather	50%
PD_{US}	Percentage of delays impacting US carriers	75%
PD_{RWA}	Percentage of delays avoided due to reduced watch area	20%
PD_{AS}	Percentage of delays avoided due to advanced sounder	50%
C_{PD}	Cost per 3/4 hour delay	$2,291

Thus, the number of avoidable delays attributed to the advanced sounder is computed as:

$$\mathbf{TD_{Wx}*PD_{CWx}*PD_{US}*PD_{RWA}*PD_{AS} = 309{,}482*0.5*0.75*0.2*0.5 = 11{,}606}$$

and the annual cost of delay reductions due to the advanced sounder would be:

11,606 * $2,291 per ¾ hour/delay
= $26.6M in 2002 dollars with a discounted PV of $98.8M.

Value of Passenger Time

As described in "Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Program," June 1998:

> "Time is a valuable economic resource which may be devoted to work or leisure activities. Because traveling consumes time, it imposes an opportunity cost equal to the individual's value of time in the forgone work or leisure activity. Moreover, since travel may take place under undesirable circumstances, including waiting or riding aboard a crowded or uncomfortable vehicle, it can impose an additional cost on travelers. Travel time saved or lost as a result of investments or regulatory actions should be valued in benefit-cost analyses to reflect both the opportunity cost and discomfort, if any, people experience when traveling."

This report also states that "… contemporary practice is to value traveler's time as a proportion of the wage rate." The guidance in this report is to use $26.70 per hour (1995 dollars) or $30.44 per hour (2002 dollars) for air carriers, all purposes (i.e., personal and business). Since weather-related delays were approximately 45 minutes, the value of passenger time per delay is ¾ x $30.44, or $22.83 per delay in 2002 dollars.

The number of delays avoided by HES was estimated to be 11,606. In order to calculate the value of passenger time, we must only consider the number of delays for aircraft carrying passengers (versus freight, for example). For this exercise, it is assumed that of the 11,606 delays, 80 percent were air carriers, with only 50 percent of these scheduled commercial aircraft, for a total of 4,642 delays involving passengers on air carriers. According to the FAA economic analysis guidance [Federal Aviation Administration, 1998, Section 4] we must consider an average passenger capacity and passenger load factor. For scheduled commercial service, the average passenger capacity is 162.3 seats and the passenger load factor is 70.7 percent, resulting in an average of 115 passengers impacted per delay of scheduled commercial service. The resulting passenger value for scheduled commercial service is:

4,642 delays * 115 passengers impacted per delay * $22.83 per delay = $12M annually in 2002 dollars with a discounted PV of $44.5M.

This estimate is likely on the low side for several reasons. First, it was assumed that only 50 percent of air carrier delays impacted scheduled commercial service, with the remaining 50 percent for freight. Second, 1995 wages, which were the basis for the value estimates in this 1998 report, have been inflated to 2002 dollars but have not been adjusted for other wage increases, such as sharper rises in corporate wages, which could also drive this figure higher. Finally, estimates for the value of passenger time for general aviation and air taxi are negligible on a yearly basis compared to scheduled commercial service, but would certainly contribute to the total over the number of years in the life cycle.

4.3.2 Case Study 2: Volcanic Ash Advisories: Benefits to Aviation

Problem Statement

Aircraft must avoid airborne plumes of volcanic ash to avoid the risk of catastrophic failure of aircraft or costly damage to engines, instruments, and airframes. Ash plumes are usually undetectable by radar and are often invisible or indistinguishable from clouds. Today, according to experts from the Aviation Weather Center, the ability of the GOES imager to automatically and unambiguously detect ash plumes or differentiate ash from other environmental conditions is quite limited due to lack of data in certain spectral bands. There is no signature to automatically detect the sulfuric acid associated with volcanic ash. Other experts have said that the ash plumes are not detectable via the current GOES once they reach a certain degree of attenuation even though they are still hazardous. Also, the current GOES imager only collects data for areas outside the continental U.S. (CONUS) once every 30 minutes to an hour—and even longer during hurricane season when the GOES imaging is concentrated on that task. However, most of the active volcanic areas that threaten aviation are outside of CONUS. When ash does erupt from volcanoes, it often reaches flight altitudes in the normal cruising range for commercial aircraft, e.g., 25,000 to 40,000 feet, within minutes. As a result, with the current GOES imager, volcanic ash may not be detected at all, or may be detected 30 minutes or more after it poses a risk. Moreover, the current GOES sensors have limited ability to assign elevations to winds, hampering ability to determine which way a plume is moving or how quickly.

Aircraft ash warnings and advisories will be improved by ABI in several ways. First, the ABI will have an 8.5-micron channel that is highly sensitive to the sulfur dioxide component of ash plumes. This means that the ABI will provide data that will support the automatic and unambiguous detection of volcanic ash, even when it becomes attenuated or diluted in the atmosphere hundreds or thousands of miles from its source. Second, the ABI will gather data from active volcanoes much more frequently than the current GOES imager and should be able to detect eruptions within minutes after they occur. Thirdly, the ABI will have more detailed resolution and be able to detect small-scale eruptions that might not be visible with the coarser resolution of the current imager. Finally, the advance sounder will provide three to five times the number of wind elevation readings, enabling much more accurate forecasts of the direction and speed of plume dispersion.

This case study addresses the cost savings associated with improved detection and avoidance by commercial aircraft. Note that, while sensors on NOAA's polar orbiting satellites are also capable of detecting ash plumes, these satellites do not revisit commercial airspace, even at high latitudes, often enough to detect ash eruptions and plumes before they reach flight altitudes. The ABI will be the only planned sensor system capable of detecting ash plumes within the time frame that they initially occur.

Benefits Calculation

Avoided Repair Costs—Avoided repair costs are estimated using the following assumptions based on data from public sources and interviews with government and industry experts.

Avoided repair costs are based conservatively on historical data for damages incurred from in-flight encounters with ash. Reported aircraft damages from volcanic ash reported for 1982 to 2000 were approximately $313M in 2002 dollars by assuming a base year of 1991 (the midpoint of 1982 – 2000). This probably is an under-estimate of total costs since the cost of one encounter alone was about $80M. Taking the average annual worldwide repair costs to be $16.5M [3] we conservatively allocated one third to airspace within GOES coverage area. Experts at NCEP and AWC have said that GOES ABI will be able to unambiguously detect concentrations of volcanic ash at flight levels that pose a hazard within 15 minutes of eruption. We conservatively assume that volcanic ash advisories based on GOES ABI will enable aircraft to avoid 50 percent of the ash they would otherwise encounter in the GOES coverage area. Annual benefit to U.S. and foreign flag carriers will therefore be about $2.75M in 2002 dollars, computed as follows:

$16.5M (avg. annual worldwide repair cost)* 1/3 (fraction of GOES coverage) * 0.5 (proportion of ash avoidable due to ABI) = $2.75M annually in 2002 dollars

U.S. airlines accounted for about 50 percent of the flights to and from the U.S. in 2000 [United States Department of Commerce]. In this analysis, it is assumed that this proportion will persist during the full lifecycle (2012 to 2027) used in this report, and that this proportion applies to U.S. airlines flying to other countries in the GOES coverage area. Thus, the annual benefit to U.S. airlines is:

$2.75M (annual benefit to all carriers) * 0.5 (proportion of US carriers) = $1.4M annually in 2002 dollars with a discounted PV of $5.2M.

[3] ($313M)/19 years = $16.5M).

Avoided Risk of Aircraft Loss—According to the International Civil Aviation Organization (ICAO), approximately 77 jet aircraft have reported encounters worldwide with volcanic ash for the period 1980 to 2000 [International Civil Aviation Organization, Appendix I, Table 2]. On at least four occasions, large commercial jetliners temporarily lost sufficient engine power to maintain flight and were able to restart only after dropping to lower altitudes [International Civil Aviation Organization, Appendix I, Table 4]. As a result of these encounters, ICAO states that volcanic ash has the clear potential to cause a major aircraft accident [International Civil Aviation Organization, Foreword]. Thus, economic benefits can be realized through volcanic ash avoidance due to improved GOES detection capability. The computation of economic benefits is as follows:

1. The replacement cost of an average commercial aircraft is valued at $38.8M (2002) dollars [Federal Aviation Administration, 1998, Table 5-1].
2. The estimated cost associated with passenger and crew loss is approximately $922 M computed as follows. Flights most likely to encounter volcanic ash are long haul, typically transoceanic flights utilizing a 747 class of aircraft. The 747 has a crew size of 12, an average capacity of 410 and a passenger load factor of 74.7 percent, resulting in an average passenger load of 410*74.7 percent =306 and a total load of 318 (i.e., 306 + 12) people. A proxy for the economic value of life lost from catastrophic aircraft failure is $2.9M in 2002 dollars, or approximately $2.9M*318 people = $922M per lost aircraft. [Federal Aviation Administration, OPSNET, 1998].
3. The expected number of annual aircraft losses (although none have been lost to date due to volcanic ash) is estimated by assuming that the 4 near fatal aircraft encounters with volcanic ash could have been lost over the 21 year period between 1980 and 2000. Thus, 4/21 = 0.19 represents the expected number of aircraft losses per year due to encounters with volcanic ash.
4. Assume that volcanic ash advisories based on GOES ABI will result in 50 percent of the losses being avoided.
5. Assume that fifty percent of the aircraft volcanic ash losses impact U.S. flag carriers.
6. Assume that one-third of the airspace is allocated to GOES coverage.

Consequently, the expected annual number of aircraft losses avoided by U.S. carriers due to improvements in GOES is

(Expected aircraft losses per year)*(Proportion of losses avoided)*(Proportion of losses impacting U.S. flag carriers)*(Proportion of airspace allocated to GOES coverage) = 0.19*0.5*0.5*(1/3) = 0.0158

The total cost per aircraft loss is $38.8M/aircraft + $922 M for loss of passengers and crew = $960.8M.

Therefore, the total economic annual benefit for U.S. carriers of volcanic ash avoidance due to GOES is

0.0158 * $960.8M = approximately $15.2M
with a discounted PV of $56.4M.

Note that (1) there are some volcanoes whose eruptions are capable of rendering large portions of major transatlantic flight routes unsafe in which the traffic density may reach 100 flights per hour and (2) future long-haul aircraft passenger capacities are expected to increase. As a result, actual loss of life due to aircraft encounters with volcanic ash could be substantially higher than estimated here.

4.3.3 Case Study 3: Temperature Forecasts: Cost Savings to Electric Utilities

Problem Statement

Electric power is a substantial component of the U.S. Gross Domestic Product. Sales to U.S. consumers in 2000 totaled about 3,413 million megawatt hours with revenues from these sales approximately $228 B [United States Department of Energy, Energy Information Administration, *Electric Power Annual 2000,* Vol. 1, Table A-21]. Total production of electricity in the U.S. from all sources in 2000, net of power consumed by generation facilities, was about 400 million MWH higher (3,802,000,000 MWH total) when power produced and consumed without sales transactions (e.g., industrial co-generation) is taken into account [DoE/EIA Electric Power Annual 2000, Vol. 1, Table A-1 2000]. Electricity is also a unique commodity. It cannot be economically stored at the quantities demanded and production is consumed essentially instantaneously. Shortfalls in production due to equipment failure or unexpected increase in demand or load that is not satisfied with nearly instantaneous increase in production causes voltage drops, forced outages, or disconnection of interruptible customers. It takes a significant amount of time to start up generating units and bring them on line [Utility]. As a result, electric utilities typically have a portion of their generating capacity running in automatic generation control (AGC) and an additional portion in a stand-by mode known as spinning reserve [Hirst]. Units running under AGC can rapidly increase or decrease their output to respond to load changes. In addition, units running in spinning reserve can be brought on-line or taken off-line very quickly to adjust to fluctuations in demand or equipment failure or recovery [Utility]. However, it is expensive to operate this spinning reserve and it is wasteful of energy. Running units under AGC also entails costs because the units may be forced to run at an output other than the optimal level, above or below the most efficient or economic output level [Utility]. Utilities therefore have a difficult problem: how to minimize operating costs while meeting demand and maintaining frequency and voltage standards. Utility operational tactics are further complicated by the impact of uncertain weather changes. For example, afternoon clouds can sharply decrease peak demand for air-conditioning power on summer days or increase demand for lighting in the winter, but the timing, geographic extent, or magnitude of these impacts is subject to considerable uncertainty, even a few hours in advance. [Utility],[Schmit], [Brooks], [Petersen]

The North American Electric Reliability Council (NERC) requires utilities to have a certain percentage of their capacity in spinning reserve status over and above what is needed to meet current demand [Utility] [Hirst]. Utilities attempt to forecast demand or load at various intervals into the future and then schedule generation that will meet this level of demand plus the NERC-required spinning reserve. Demand for electricity typically varies cyclically over a 24 period-usually reaching a peak in the afternoon, especially in summer weather. Utilities try to arrange the schedule of generation such that the lowest cost units are used first, the next lowest cost units next, and the most expensive units are used least. However, power demands (load) can fluctuate dramatically in response to temperature changes and other factors, often requiring last-minute decisions to buy or sell power or to start relatively expensive gas-fired "peaking units". Combustion turbines are often used to replace spinning reserves (when AGC capable) once spinning reserves have been used to supply load.

Power plant operators use a variety of forecasting and demand-estimation tools to try to anticipate the amount of electricity they will need to produce, purchase, or sell. An operations manager at a large utility stated that the cost-minimizing schedule of operations is re-computed every two hours around the clock using updated load and weather forecasts, and monitored continuously [Utility]. However, forecasts of local and national hourly and daily loads are uncertain, due in part to uncertainty about ambient temperatures three hours in advance. Large utility operators have some ability to balance or average loads across their service areas. However, even a large, efficient independent service operator (ISO) such as PJM Interconnect that brokers, transmits and regulates power over large areas finds that its load forecasts are off by approximately 2.6 percent on average [PJM Interconnect].

When utility companies overestimate demand loads they incur costs associated with having more power production capability available or more purchased for use than needed. These include: (1) the commitment of too many generating resources and the associated costs of starting up, running, and shutting down these resources or (2) executing unnecessary commitments to purchase power from other sources. Sometimes utilities with too much capacity available due to overestimating demand can sell to other utilities that need additional power [Utility].

When utility forecasts underestimate the actual demand, they typically have less capacity or purchase commitments available than needed to meet demand. When this happens, utilities have several options, they can increase the output of units that are already on-line, purchase additional power on the spot market, start up additional combustion (natural gas) turbines, or execute (disconnect) interruptible loads [Utility]. Each of these options has various costs associated with them. For example, increasing the output of a unit above its optimal level will decrease its efficiency and require more input energy per MWH produced. The average market clearing price for commitment of capacity for regulation service at PJM Interconnect for the 24 months preceding June 2002 was about $41 per MWH (data compiled from PJM Interconnect). Purchasing power on the spot market is often more expensive than producing it locally. Average real-time (spot) prices at ISOs across the U.S. in 2002 ranged from less than $20 per MWH in winter months to over $140 during peak periods in the summer [Department of Energy, Energy Information Administration, Energy Situation Analysis Report, Latest U.S. Electricity Information]. Part of the cost differential in spot power is due to the higher cost of natural gas compared with coal, nuclear fuel, or hydroelectric reserves. Combustion turbines burn fuel (natural gas) which is more expensive per million Btu than coal. Finally, utilities must provide interruptible customers with substantial incentives or payments for the right to turn them off on short notice.

More drastic options, such as reducing voltage levels (brownouts) or disconnecting power to non-interruptible customers (forced outages) rarely occur due to load forecast errors alone, but load forecast errors may contribute to outages caused primarily by generation or transmission facility failures.

Benefits Calculation

The overall benefits calculation for savings to electric utilities is based on the reduction (due to GOES-R imager and sounder) in the cost for expensive electricity production (using natural gas turbines, for example) when demand is overestimated plus expensive spot market purchases when demand is underestimated.

The reduction in costs, and hence benefits, can come from two sources. First, if load forecasts are overestimated less often, a quantity of national spinning reserve that is generated with high-cost natural gas turbines could remain in cold status. In operational terms, the total national generating capacity required to meet peak demand (and the fixed costs associated with this capacity) does not decrease. In addition, the percentage of spinning reserve required by FERC also would not decrease. However, the actual amount of capacity that is kept in stand-by status as spinning reserve would decrease because utilities calculate the amount of spinning reserve in terms of the amount needed over and above that needed to meet expected or actual loads. If weather and load forecasts were more accurate on average, then on average, utilities would schedule less capacity for spinning reserve status.

Second, reductions in spot purchases will occur because utilities will commit to buying less spot power with improved temperature forecasts than they do currently. Hours in which demand is underestimated will decrease and utilities will have confidence that they will meet demand with a lower commitment on the spot market than currently.

Two simplifying, but reasonable assumptions for the calculation of these costs are as follows. First, it is assumed that annual electricity production overestimates and underestimates are equal. That is, all forecast load errors are equally divided between over- and underestimates, so that the impact of more accurate temperature forecasts from the GOES-R imager and sounder will be equally divided as well. Therefore, this analysis will consider the total load error reduction due to the GOES-R imager and sounder (both under and overestimates).

The second assumption is that the cost per MWH for reducing overestimates and underestimates are the same. The impacts of overestimates and underestimates necessitate different mitigating actions with very different costs. However, for this analysis, a conservative single cost per MWH is used as representative for all cost savings coming from reducing overestimates and underestimates of load demand, even though load forecast errors made when total demand is high cost much more than errors made when demand is low. For example, the average wholesale cost for electricity in 2000 was $48.8 per MWH [Dunn]], but the cost of spot power in summer months when total demand is high is typically greater than $100 per MWH. When total demand is low, utilities can typically satisfy most instances of under-estimation of demand by increasing the output of units already in production at a marginal cost that is less than the average cost of production. The rationale for the selection of the unit cost is provided below.

Based on these simplifying assumptions, the formula that is used to calculate benefits to utilities due to improved temperature forecasts from GOES-R imager and sounder is:

Avoided costs due to GOES -R imager and sounder = Load Reduction (MWH) * Average $/MWH

Table 6 summarizes the variables used in the following computations.

Table 6. Benefits Computation Input

Variable	Variable Description	Value
TF_{err}	Temperature Forecast error (% of load forecast error)	40%
$T_{err}R_{ed}$	Temperature error reduction for 3-hour forecasts	25%
$AvLF_{err}$	Average load forecast error	2.60%
$TProd_{2000}$	Total electricity production (MWH) that was sold to consumers in 2000	3,413,000,000
CReg Serv	Cost of regulation service (per MWH)	$41.3

Step 1. Reduction of Electric Utility Load Forecast Error Due to GOES-R Imager and Sounder. Reducing temperature forecast error would reduce electric utility load forecast error. The operational manager of a large utility stated that, based on a preliminary analysis, temperature forecast error accounts for about 40 percent of the utility's average load forecast error. In addition, we take PJM Interconnect's average load forecast error of 2.6 percent (stated above) as typical of the national load forecast error rate. Experts consulted at NCEP and CIMSS stated that errors in 3-hour temperature forecasts using data on clouds and winds from the GOES-R imager and humidity profiles from the GOES-R sounder should decrease by about 25 percent compared with 3-hour forecasts made using current GOES data [Petersen and Schmit]. These experts also said that the probability distribution of errors is expected to narrow with GOES-R imager and sounder, thus increasing electric utilities' confidence in forecast accuracy. Taking 40 percent as the average national contribution of temperature forecast error to electric utility load forecast error, electric utilities' load forecast accuracy should increase by about one-quarter of a point computed as follows:

$$\mathbf{TF_{err}*T_{err}R_{ed}*AvLF_{err} = 0.4*0.25*0.026 = 0.0026 \text{ or } 0.26 \text{ percent}}$$

That is, we estimate that an electric utility with an average 3-hour load forecast error that is 2.6 percent today would have an average load forecast error of 2.34 (2.6 - 0.26) percent starting in 2015 due to improved temperature forecasts using data from GOES-R imager and sounder.

The total electricity production that was sold to consumers in 2000 was about 3,413,000,000 MWH. If GOES-R imager and sounder will reduce forecast load error by 0.26 percent, then the amount of production avoided is computed as

$$\textbf{TProd}_{2000} \textbf{ * 0.0026 = 8,873,800 MWH}$$

Step 2. Unit Price (per MWH) of Savings in Reductions in Operating Reserve and Spot Purchases. The correct value to use for the unit price for electricity production savings is complicated by the different operational decisions that result from improved forecasts and by changes in the structure and conduct of the industry. To be conservative, we chose the lowest of three candidate prices that are representative of costs for wholesale power produced or sold under short-term conditions, $41.3 per MWH. Pricing electricity at $41.3 per MWH is the average 2001-2002 cost of "regulation" services reported by PJM Interconnect, a major Independent System Operator (ISO) that provides interconnection and energy trading services to electric utilities in the Mid-Atlantic states [PJM Interconnect]. This conservative approach is warranted because production of electricity in the U.S. is becoming increasingly competitive and deregulated, both of which will tend to drive down the long-run average and marginal cost of production. The total annual economic benefit to utilities is then:

$$\textbf{TProd}_{2000}\textbf{* CRegServ = 8,873,800 MWH * \$41.3 per MWH, or about \$366M.}$$

Although this cost represents current year (2002) dollars, it is based on the quantity of electricity produced in 2000. Electric power spinning reserve and spot purchases are assumed to grow at an annual rate of 1.8 percent through 2025, in accordance with DoE's outlook for the industry [United States Department of Energy, *Annual Energy Outlook 2003* , Table A-2. No further growth is assumed through 2027. As a result, annual cost savings that begin in 2015 are approximately $479M ($2002) with a discounted present value of $1.944B. In summary, we compute the annual economic benefit beginning in 2015 as follows:

$$\textbf{\$366M * (1.018)}^{15} \textbf{ (growth rate) = \$479M}$$

Improvements in other forecast parameters that affect demand such as humidity, wind speed, and precipitation as well as extending the forecast improvements to the realm of 24-hour forecasts and beyond will result in additional economic benefits not yet included in this analysis. Moreover, improving national demand forecasts will likely also improve system reliability (reduce unplanned or forced outages) with additional substantial economic benefits.

4.3.4 Case Study 4: Temperature Forecasts: Benefits to Agriculture /Orchard Frost Mitigation

Problem Statement

In the year 2000, Washington State had 280,900 acres producing nearly $1.18 B dollars worth of non-citrus fruit and nuts [USDA, *Washington 2001 Annual Bulletin*]. According to Dr. Robert Evans of the Northern Plains Agricultural Research Laboratory [Evans], "because of the tremendous economic consequences of not protecting crops, producers in the Pacific Northwest region have installed one of the most extensive, elaborate, and expensive frost protection networks in the world. Knowledge of the current critical temperatures and the latest weather forecast for air and dew point temperatures are important because they tell the producer how necessary heating may be at any stage of development and how much of a temperature increase should be required to protect the crop." Growers tend to err on the side of caution, applying expensive mitigation resources whenever frost threatens flower buds. Reducing the uncertainty surrounding frost forecasts (increasing growers' confidence) would enable growers to reduce the resources they expend on frost mitigation.

The purpose of the case study is to estimate the economic benefits of improved frost and freeze warnings for orchardists in Washington State. This improvement is based on improved temperature forecasts using

GOES ABI and HES data. Two methods of calculating benefits were developed. Benefits resulting from these very different methodologies are within the same order of magnitude and the lower, more conservative estimate is presented here.

Benefits Calculation (Method 1)—Value of NWS Forecast

In 1982, Katz *et al*. [Katz] used a prescriptive (or normative) Markov decision model to estimate that the annual value per acre of NWS temperature forecasts to orchardists in Washington's Yakima valley was approximately $270 for peaches, $492 for pears, and $808 for apples (all in 1977 dollars). In 1984, Stewart *et al*. [Stewart] revisited the 1982 Katz *et al*. study, using a descriptive rather than prescriptive modeling approach. Their overall results were quite similar, confirming the reasonableness of the previous estimates.

In our calculations below, the values reported in the 1982 study were used. By weighting the reported values for the several crops with their planted acreage (using 2000 acreage data, which is most currently available) [USDA, *Washington 2001 Annual Bulletin, Fruit Acreage, Production, And Value*], and assuming the calculations can be extrapolated to all of Washington state, we calculate a weighted average annual value to orchardists of $762 per acre (in 1977 dollars) for frost and freeze warnings. Assuming that the secular trend of prices and costs faced by orchardists has followed the GDP price index [Office of the Undersecretary of Defense (Comptroller)], we find that the corresponding 2002 value per acre of NWS frost forecasts is $1,867.

In 2000, there were, according to United States Department of Agriculture statistics [USDA, Was*hington 2001 Annual Bulletin, Fruit Acreage, Production, And Value*], 280,900 acres of fruit and nut orchards in Washington State. In our calculation, we make the simplifying assumptions that this acreage remains constant into the future, (in actuality, bearing acreage for apples from 1988-2000 has increased by nearly 33 percent with a slight 1.1 percent dip in 2001). We further assume that the weighted average annual value of NWS frost forecast of $1,867 per acre applies to all Washington orchard acreage.

In order to estimate the value of the new GOES instruments to Washington orchardists, we make the assumption that GOES will not have any impact on forecasts until the year 2015, at which point it will add 1.67 percent to the value of the non-GOES NWS frost forecast. The added value reflects the potential improvement in accuracy and lead-time for NWS frost forecasts. The added value is akin to the benefit of reducing the frost danger season by 1 day out of 60 (see rationale below), that is 1/60 = 0.0167.

Rationale: Washington State has two freeze seasons, Fall (between Jul 31 – Dec 31) and Spring (Between Jan 1 – July 31). Based on statistical data from http://www.wrcc.dri.edu, probability charts for these two seasons indicate that there is an 80 percent chance that the freeze/frost period for each season will be 60 days. This was reinforced by personal communication with Dr. Robert Evans, who stated that there are between 60 and 80 "days of interest" during the two freeze/frost seasons. These days of interest represent times when the buds and harvest may be at risk.

This value added of the NWS forecast is assumed to begin in the year 2015, and remains constant thereafter. We note that our sources show that the value of the then-current NWS frost forecast was substantially less than the value of a perfect forecast. In other words, the NWS temperature forecast is imperfect, and there is ample room for improvement in the frost forecasts. GOES will accomplish a bit of that improvement.

The savings per year in 2002 dollars is approximately $8.6M, computed as follows:

$1,867 ($2002)*280,900 (bearing acreage of Washington State Fruit and Nuts for 2000)*0.0167 (proportion of benefits due to GOES) = $8.6M

Benefits Calculation (Method 2)—Frost Mitigation Avoidance

In "Frost Protection in Orchards and Vineyards," June 2000 [Evans], the following costs associated with frost mitigation methods are provided.

Table 7. Frost Mitigation Costs by Method ($2002)

Method of Mitigation	Estimated Cost/Acre/Hr.
Return Stack Oil Heaters (40/acre)	$39.39
Standard Propane Heaters (62/acre)	$44.00
Wind Machine (propane)	$14.12
Over-Crop Sprinkling	$1.74
Under-Canopy Sprinkling (Unheated)	$1.80

The paper states that "there is no perfect method for field protection of crops against cold, but quite often, combinations of methods are advantageous. Active frost protection technologies will use one or more of three processes: (1) addition of heat; (2) mixing of warmer air from the inversion (under radiative conditions); and (3) conservation of heat. Options for active frost protection systems include covers, fogging systems, various systems for overcrop and under-canopy sprinkling with water, wind machines, and heaters." In a personal communication with the author, he further stated that the predominant active method of frost mitigation is the wind machine and that average mitigation duration per frost event per acre is 8-10 hours. While there is, expectedly, variation in the methods of mitigation and the duration of time over which these methods are applied, based on variables such as grower location and resources, we assume for this example that wind machines are the predominant method and 8 hours is the expected daily duration of frost mitigation per frost event. In Table 8, below, we calculate the total cost of mitigating frost for a *1-day (8-hour) frost event over the total fruit and nut acreage* (280,900 acres as of 2000) for Washington State. We assume that 6 of the 8 hours utilize a wind machine, while 1 hour each is apportioned to a heater and an under-canopy sprinkling system (this is somewhat arbitrary but conservative). If we assume that, on average, GOES is responsible for avoiding mitigation of one eight hour frost, the annual frost mitigation savings due to GOES as shown in Table 8 is approximately $35 M. (compared to $8.6 M for method 1). Given the uncertainty associated with both method 1 and method 2, we chose to use the more conservative results of method 1 in our analysis.

Table 8. Cost of Frost Mitigation: One 8-Hour Frost Event ($ 2002)

Method	Estimated Costs/Acre	Proportion of Time In Use (Hours)	Cost/Acre/ Occurrence	Total Cost per Occurrence
Return Stack Oil Heaters (40/acre)	$39.39	1	$39.39	$11,064,651
Wind Machine (propane)	$14.12	6	$84.72	$23,797,848
Under-Canopy Sprinkling (Unheated)	$1.80	1	$1.80	$505,620
Total (Assuming 280,900 acres)				**$35,368,119**

While this value alone is a significant cost benefit, it can be considered a small percentage of the likely total (all crops, all regions) national agricultural benefit; and as a very small percentage of the likely total (all impacts, all regions) society-wide benefit. The total fruit and nut acreage in Washington State is only about 7 percent of the nation's total of 3 million acres (as of 2000) [National Agricultural Statistics Service]. Other major areas of fruit production that would likely benefit from GOES, include California (apples, peaches, pears, grapes, and citrus), South Carolina and Georgia (peaches), and Wisconsin cranberry growers who have gotten forecasts with data from the current imager (solar insolation) and the current GOES sounder (cloud product) [Diak, Anderson, et al.]. In addition, there would likely be some benefit of improved frost forecasts to other crops as well.

4.3.5 Case Study 5: Agricultural Irrigation: Benefits of Increased Efficiency

Introduction

The purpose of this case study is to estimate the value of the economic benefits associated with using GOES-R satellite-based evapotranspiration (ET) information to improve agricultural irrigation efficiency. Because irrigation efficiency is a complex domain, and because of time and resource constraints during this phase of our analysis, this case necessarily cannot represent an exhaustive economic analysis of irrigated agriculture. Thus, this case was developed using the following groundrules and assumptions.

This analysis divides the U.S. into two groups; the 11 arid western states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, and the other 39 states. The 11 Western states make up a special subset of the U.S. for several reasons. These 11 states use approximately 65 percent of all irrigation water in the U.S. and about 90 percent of available water resources in the 11 Western states is consumed by irrigation. These 11 states are also among the fastest growing states in the U.S. Moreover, both the farmers and the rapidly growing urban areas in these states largely receive the water they use via run off from precipitation in the higher elevations in these states. This facilitates the transfer of water between urban and agricultural users in many parts of these states. The remaining 39 states are relatively heterogeneous. Some parts of some of the 39 states are similar to the 11 Western states, while in other states, irrigation water is primarily withdrawn from ground water aquifers or from surface water sources adjacent to farms.

The economic benefit estimates in this study do not take into account investment costs for the satellite-based ET technology itself, for agriculture-to-urban water transfers investments, for farmer training, or for irrigation system improvements. We assume that a number of capital investments in irrigation system efficiency improvements will be made irrespective and independently of satellite technology improvements, and, that the conservative estimation approach used in this case study allows for efficiency contributions from some portion of these investments. That is, we do not think that we are assigning all possible efficiency improvements just to satellite based ET. There is substantial room for contribution from investment in other approaches to irrigation efficiency. Indeed, investment in other efficiency improvements may be complementary to satellite ET if they provide farmers with greater control over the timing, location, and quantity of irrigation water they apply.

The principal beneficiaries in this study are farmers and water providers. Some additional beneficiaries, while important to water allocation decisions in these states, present complexities in assessing valuations that could not be directly addressed within the constraints of the current analysis. We also have limited information at this time on the potential extent or impact of these benefits. Other potential beneficiaries who are not included in this case study are:

- Holders of junior water rights. If holders of senior water rights are more efficient, the water they save may become available for use by holders of junior rights.
- Endangered species and habitats. Many remnant endangered species and habitats in the arid West could benefit from improved flows of water in rivers and streams that could result from improved water use efficiency by farmers.
- Native American claimants.

- Consumer's who benefit from potential water transfers from agriculture. These transfers could potentially provide significant quantities of water for use by the growing number of residents in the 11 western states.

Multiple data sources and input from subject matter experts were used to develop the quantitative analyses and the qualitative discussions presented here. Where sourced data was not available, very conservative (low estimates) of quantitative values were used.

Background

Agriculture is the largest single user of water in the United States [Anderson and Heimlich, 2000]. Irrigated agriculture in the U.S. is also very productive, with crop sales of about $43 B in 2000 (about half of all crop receipts) from just 16 percent of all U.S. cropland in agriculture [USDA/ERS Farm Income and Anderson and Heimlich, 2000]. According to the USDA National Agricultural Statistics Service's 1998 Farm and Ranch Irrigation Survey (USDA, NASS, FRIS), about 90 million acre-feet (MAF) of water were consumed by irrigating about 50 million acres nationwide [USDA, NASS, FRIS, Table 10]. An acre-foot is the amount of water needed to cover one acre to a depth of one foot, which is 43,560 cubic feet of water or 325,851 gallons.

Irrigation water used on farms is subdivided into on-farm water and off-farm water. On-farm water is water that comes from sources that the farmer owns or has direct access to, such as wells, surface catchments, or rivers or streams from which the farmer directly withdraws water. Farmers own and operate the equipment used to pump or move on-farm water into their fields. Off-farm water refers to water that is supplied to farms from sources outside of the ownership or control of the farmer such as reservoirs and water projects owned and operated by various federal, state, local or private agencies.

About 35.3 MAF of water from off-farm sources was applied in 1998 in just the 11 western states (listed in the Introduction) out of a total for the U.S. of 38.5 MAF from off-farm sources. Water in these states is scarce and demand from residential and industrial/commercial users is increasing rapidly due to population growth in these states [USDA, NASS, FRIS, Table 10; Campbell; and USDA, Forest Service].

Agriculture is both the largest and lowest value water consumer in these states, typically using about 90 percent of water in these states and paying much less than the price paid by other, non-farm users [Anderson and Heimlich, 2000, Table 2.1.1]. Prices for irrigation water from off-farm sources (e.g., water projects or irrigation districts) ranged from about $5 per acre-foot in Wyoming to about $30 per acre-foot in Oklahoma, with the average price for the country of about $17 per acre-foot (inflated to 2002 dollars) [USDA, NASS, FRIS, Table 20]. In contrast, customers of large municipal water utilities in western states typically pay from about $400 (Salt Lake City) to about $800 (Los Angeles) for an equivalent amount of water [www.dced.utah.gov/factbook/utility_.pdf]. The cost of water for municipal customers also reflects the cost of additional treatment and the capital costs of the infrastructure needed to deliver water to individual businesses and homes.

Another important consideration for irrigated agriculture is the cost of energy that farmers use to pump water from ground or surface sources. Nationally, farmers that irrigate their crops using on-farm pumps paid about $1,233M nation-wide for the energy used to power these pumps in 1998 [USDA, NASS, FRIS, Table 17] or $1,322M in 2002 dollars.

Problem Statement

Studies and field experience have shown that farmers typically apply 15 to 20 percent more irrigation water than needed for optimal yields due to limits on their knowledge of actual soil moisture levels [Penning, Pogue, Norman, Diak, and Moran]. Farmers lack perfect information about actual soil moisture levels due to the cost of making field-by-field and crop-by-crop measurements on a frequent basis. There are a variety of information sources that can be combined in various ways to estimate soil moisture and irrigation needs (soil moisture deficit) for any specific field and crop. Some of the key methods are given below:

1. Direct, in-situ measurements using various instruments,

2. Direct observation of plant condition or apparent wetness of sub-surface soil samples,
3. Satellite-based estimates of latent energy (a direct measure of how much soil moisture has been consumed via evaporation and vegetative transpiration, or evapotranspiration),
4. Ag-weather ground stations that estimate total evapotranspiration (ET) at various points in arid states, and
5. Farmers' knowledge of the water needs of different plants at different developmental stages and typical irrigation schedules.

In addition, farmers need to take other factors into consideration such as the water-holding characteristics of different soils, the amounts of water already applied or received via rainfall, and requirements for flushing excess salinity out of certain soils [Howell]. The economically optimal strategy for improving irrigation efficiency through improved estimates of soil moisture is likely some combination of these types of information [Howell]. For example, in-situ measurements, while the most accurate means of determining soil moisture for the immediate vicinity of the sensor, may not provide an accurate measure for a whole field due to variability of soils and topography [Norman]. In-situ sensors are typically also the most costly. Satellite-based estimates of ET are much cheaper, provide a better reading of average ET across the scale of typical fields, but are less accurate than in-situ sensor for spot measurements. Satellite-based ET also benefits from calibrations and corrections that can be supplied by in-situ instruments or readings at regular intervals. Direct observation of plant or soil conditions can also be quite accurate, but is also time consuming, expensive or impractical for many agricultural operations, especially for large farms or geographically distributed operations.

Benefit Areas

Benefits from improved irrigation efficiency are potentially applicable to all farms that use irrigation, but the potential benefits are greatest in the 11 arid western states listed above. Farms in these states use a much higher proportion of off-farm water than farms in other states (roughly 90 percent), and it is relatively easy and inexpensive to physically reallocate water that is provided to farms in the 11 states from off-farm sources. For these reasons, the potential benefits to water suppliers from water transfers from agriculture to non-farm consumers was estimated for the 11 Western states, but not for the remaining 39 states.

Before we discuss beneficiaries and how to quantify benefits for the surplus water attributed to GOES data, we first take a closer look at the potential uses and dispositions of surplus water. Figure 4 depicts the potential uses of surplus irrigation water from on-farm and off-farm sources. Although the benefits shown on this figure are valid , not all of these benefits are estimated in this analysis. Benefits were calculated and included in this Phase II analysis only for those uses where a straightforward, but appropriate, high-level methodology could be developed and where data exist.

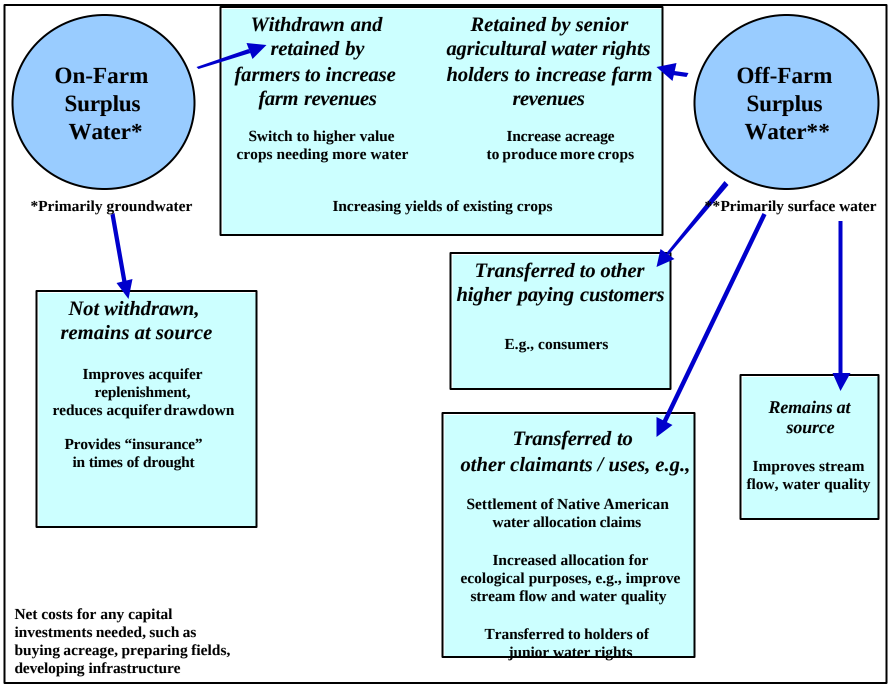

Figure 4. Disposition of Surplus Water Saved Due to GOES

For on-farm water, it is likely that farmers will either use less water while maintaining current crops and yields, use the surplus water to increase farm revenues, or some combination of the two. First, using less water to irrigate the same amount of acreage with no crop loss would result in a reduction in purchases of energy (e.g., electricity, natural gas, diesel fuel) used to run irrigation pumps on-farm. If farmers in all 50 states pump less water for irrigation because of better information on soil moisture, while holding yields and revenues constant, then their variable operating costs (primarily for various forms of energy) will be lower. This is a transfer of income from energy suppliers to farmers. In this study however, we value this transfer as the total reduction in cost to farmers. This is appropriate for two reasons. First, the decrease in demand for energy by farmers would be small compared with total U.S. demand for energy and energy suppliers would likely find other buyers at nearly the same price. Second, there is a long-standing national priority to make economic investments to conserve non-renewable energy resources through increased end-use efficiency.

There are additional benefits resulting from on-farm water that is simply not withdrawn and remains at its source. In conserving this natural resource, aquifers are replenished and water quality improves, and the surplus can provide relief to farmers in times of drought. The value of this benefit is outside the scope of this Phase II analysis and may be pursued for Phase III.

The second option is that farmers could choose to continue to pump this surplus on-farm water and use it to increase revenues. They could accomplish this in several ways, for example, switching to higher value crops which may require more water, or increasing their irrigated acreage. This option primarily benefits farmers in arid areas of the country or in areas affected by drought. Farmers who irrigate with on-farm water in areas where surface water is abundant, such as the Mississippi valley, would not likely have as much opportunity to increase revenues using water savings. For simplicity, we are restricting this benefit to the 11 Western states listed in the introduction, even though there are many farmers in the dry-land portions of Texas, Oklahoma, Kansas, Nebraska, and North and South Dakota who could potentially increase revenues via increased efficiency of on-farm water usage.

For off-farm water, we consider that there are three potential dispositions of the surplus: transfer, retention, or remaining at source. First, we consider that farmers in the 11 Western states may choose not to exercise their rights to this water, leaving it available for transfer. By using less off-farm water, the avoided costs due to satellite data would be the reduction in the purchases of water and the on-farm costs of energy required to pump this off-farm source water. In this analysis, we assume that off-farm water in the non-western states is not transferred. However, off-farm water not used in the non-western states also results in savings from reduced purchases of water and reduced on-farm costs of pumping off-farm water.

Transferred water in the 11 Western states has several possible destinations and uses. Some portion of this transferred water may go to higher paying non-farm customers, such as consumers or used for industrial processing. Entities that supply off-farm water in these 11 states would realize additional revenues from the quantity of water transferred from agriculture to non-farm uses. Increased revenues are calculated as the delta between the total average price per acre-foot that non-farm consumers are willing to pay and the price farmers pay for the same amount of water. In economic terms this is equivalent to reducing the opportunity cost of water, by transferring sales from customers who place a low value on additional consumption to those who place a higher value on additional consumption. Some portion may be transferred to junior water rights holders or to satisfy Native American claims on water. The value of these latter benefits are outside the scope of this Phase II analysis and may be pursued for Phase III.

However, not all off-farm water saved via increased irrigation efficiency in the 11 Western states is likely to be transferred to non-farm uses. Barriers such as regulatory constraints, physical impediments (i.e. lack of transfer infrastructure), or insufficient increase in demand for transfers would likely result in surplus water retained and used to increase irrigated acreage or to improve crop yields or receipts. Those farmers who retain the excess water realize benefits in the form of revenues from additional acreage, or from growing higher valued crops made possible from increased irrigation efficiency, similar to what was described for uses for surplus on-farm water.

Finally, surplus off-farm water may not be used by the farmers or made available for transfer, but simply remain at its source. Ecological benefits, such as improved stream flows, improved quality of water, and improved habitats for endangered species, may be substantial, but are not estimated here, and may be investigated further in Phase III.

Beneficiaries from improvements in satellite estimates of ET estimated in this Phase II analysis are summarized in Table 9.

Table 9. Irrigation Benefit Recipients

Benefit Recipients	Benefit Description
Farmers in all 50 states who reduce their purchases of off-farm water without impacting crop yields	B_1 = Savings in the cost of purchasing off-farm water plus savings in cost of energy to operate pumps
Farmers in all 50 states who reduce their withdrawal of on-farm water and the energy to operate pumps	B_2 = Savings in cost of energy to operate pumps
Farmers in the 11 Western states who retain the surplus off-farm water and increase their production	B_3 = Revenues of increased production and/or higher-valued crops
Farmers in the 11 Western states who retain the surplus on-farm water and increase their production	B_4 = Revenues of increased production and/or higher-valued crops
Water suppliers in the 11 Western States who transfer off -farm surplus water to non-farm uses	B_5 = Revenues of transfer of water from farmers to higher-paying customers

Benefits Variables – Data and Assumptions

The following sections describe the data and assumptions used to derive the variables critical to the above calculations. The most critical variable to calculating benefits is:

- Irrigation efficiency rate (IER). This is the percent reduction in farm irrigation per acre that can be attributed to improvements in GOES satellite data.

Additional important variables are:

- Quantities of off-farm and on-farm water ($Q_{Woff\text{-}11states}$, $Q_{Won\text{-}11states}$) (in acre-feet) used by farmers in the 11 western states and subject to efficiencies resulting from improved satellite data.
- Quantities of off-farm and on-farm water ($Q_{Woff\text{-}39\ states}$, $Q_{Won\text{-}39\ states}$) (in acre-feet) used by farmers in the 39 non-western states and subject to efficiencies resulting from improved satellite data.
- Rate of adoption (R_{AT}) of new technologies by farmers.
- Percent of off-farm water retained by farmers ($P_{R\text{-}off\text{-}11\ states}$) and percent not retained ($P_{NR\text{-}off\text{-}11\ states}$) in the 11 Western states and made available for other uses in these states, such as the transfer to non-farm consumers ($P_{TC\text{-}off}$).
- Percent of on-farm water in the 11 Western states saved that continues to be withdrawn and is used to increase production ($P_{W\text{-}on\ 11\ states}$) and the percent that is not withdrawn ($P_{NW\text{-}on\ 11\text{-}\ states}$), and left at its underground source.
- Cost to farmers for on-farm irrigation water (C_{IW}) in all 50 states and of increased revenues to water suppliers for transferred water (IR_{TW}) in the 11 Western states.
- Value of increased production to farmers in the 11 Western states (V_{IP}) from more efficient use of on and off-farm water.
- Cost of energy to operate on-farm irrigation pumps for both on and off-farm water for the 11 Western states and the 39 non-western states ($C_{E\text{-}on\ \text{-}11\ states}$, $C_{E\text{-}off\ \text{-}11\ states}$ $C_{E\text{-}on\ \text{-}39\ states}$, $C_{E\text{-}off\ \text{-}39states}$).

Irrigation Efficiency Rate (IER)

The most accurate means of determining soil moisture deficits (in inches of water per acre) in the root zones of crops is the use of in-situ instruments such as tensiometers or soil conductivity probes that directly and accurately measure the amount of moisture at different depths. However, even if every field was instrumented and each instrument read daily during the growing season, farmers still would not have perfect information due to variability of soils and topography within fields [Norman]. Moreover, the sensors are difficult and time consuming to maintain, calibrate, and read [Norman].

A major manufacturer of in-situ moisture meters told us that growers using these instruments typically reduce the amount of irrigation water by 15 to 20 percent without yield losses. However, while warranted for some high-value fruit, nut, and vegetable crops, sole reliance on this approach is expensive and may not be cost-effective for many types of irrigated crops, especially field crops such as cotton, alfalfa, corn, rice, and soybeans that are grown extensively in western states. As an alternative, most growers use a combination of local observations of plant or soil conditions and estimates of the amount of evapo-transpiration (ET) (in inches per acre) provided by state agencies, which operate sparse networks of ground-level weather stations in arid agricultural areas. For example, the California Extension Service operates a statewide network of 100 ground stations called the California Irrigation Management System (CIMIS) that take readings of temperature, humidity, solar radiation and other factors and generate local estimates of evapo-transpiration.

According to soil scientists, the ground-based approach using weather stations is subject to substantial error; typically around 30 percent due to a combination of imprecision of measurement at stations and the average distance between stations and fields [Diak and Norman]. Even though prices paid for water by farmers have been increasing in recent years, it is still cheaper for most farmers to compensate for uncertainty about actual soil moisture levels by applying additional irrigation water than to risk loss of crop yield due to insufficient water. However, if additional information about ET or soil moisture deficits were available at low cost, many farmers would have significant incentive to reduce their usage, if they were confident that crop yields would not be reduced.

One promising technique for improving farmers' information about irrigation requirements has been developed by researchers at the University of Wisconsin. This technique, called Atmosphere Land Exchange Inversion (ALEXI) currently uses a combination of GOES thermal IR data and POES AVHRR vegetation indices, as well as inputs from Rawindsonde Observation Data (RAOB), ground stations, LANDSAT, and numerical models, to generate a variety of outputs of value to agricultural decision making [Anderson, Mecikalski, Diak]. For irrigation scheduling, ALEXI's daily map of latent energy (LE) is especially useful. In this context, LE is the amount of energy absorbed at the earth's surface to convert liquid water to water vapor, and is therefore a good measure of the amount of evapo-transpiration (ET) in inches per acre that has occurred [Norman and Diak]. When daily data on ET from such an approach is combined with farmers' knowledge of the amount of water they have applied, the typical requirements of their crops, and the water-holding capacity of their soils, farmers can more accurately estimate the amount of water they need to apply to maintain optimal plant development. The scientists developing this satellite-based approach say that this approach currently has root mean square (rms) error rates in the 15 percent range [Diak, Norman]. They say that the accuracy of the ALEXI approach is limited by both the spatial resolution of the current GOES IR data and by the spectral resolution of this data. In particular, the spectral resolution of the current GOES sensors prevents them from directly measuring the energy content of the boundary layer, the lowest layer of the atmosphere that directly interacts with the Earth's surface. In addition, the current spatial resolution of the GOES imager (4-5 km depending on latitude) limits the spatial accuracy of their results. Ideally, the spatial resolution of satellite data would enable them to estimate LE/ET at the scale of the typical farm's field, or around 0.5 km [Moran et al. 1997, and Diak and Norman]. They also told us that planned increases in the spatial resolution and spectral data from GOES and NPOESS sounders should provide at least a doubling in the data content and accuracy of LE estimates, resulting in substantial improvements in the ET rms error rates [Diak and Norman]. Norman expects that the average improvement in irrigation efficiency due to the use of satellite-based ET in the future would be comparable to that achieved with in-situ sensors, or about a 15 percent reduction in water use without yield reductions. Norman explained that while in-situ sensors provide the most accurate measure of soil moisture, the accuracy of their measurements is confined to the immediate vicinity of the sensor and may not provide an accurate measure of the average soil moisture in a field.

A 15 percent reduction in irrigation, from satellite-based ET estimates using GOES-R and NPOESS would translate into huge savings in the approximately 35 MAF of irrigation water from off-farm sources used annually in the 11 arid western states, as much as 5.25 MAF per year. However, for the purpose of this analysis, we conservatively constrain the water savings from satellite-based ET to 10 percent. This reflects the possibility that other technologies and agricultural management practices will also contribute to significant improvements in irrigation efficiency. Since the focus of this study is in the contribution of GOES data, and it is assumed that GOES and NPOESS would contribute equally to improvements in ET, the irrigation efficiency rate (IER) attributed to GOES is assumed to be 5 percent.

<u>Quantities of Off-Farm Water Subject to Efficiencies ($Q_{W\text{-off-11 states}}$,$Q_{W\text{-on-11 states}}$)</u>

As stated earlier in this report, 11 arid western states use approximately 90 percent of off-farm water nationwide [USDS, NASS, FRIS, Table 10] and the populations in these states are also growing rapidly and are projected to continue growing through the period of analysis in this report. Consequently, growth in consumer demand is likely to be significant and the need to supply water for this growing demand is likely to continue to be (as it is already) extremely competitive.

The total quantity of water from off-farm sources for these 11 western states ($Q_{W\text{-off-11 states}}$) is 35.3 MAF and the total quantity of water from on-farm ($Q_{W\text{-on-11 states}}$) sources is 27.3 MAF [USDA, NASS, FRIS, Table 10].

<u>Quantities of Off-Farm Water Subject to Efficiencies ($Q_{W\text{-off-39 states}}$,$Q_{W\text{-on-39 states}}$)</u>

The total quantity of water from off-farm sources for the remaining 39 states ($Q_{W\text{-off-39 states}}$) is 3.2 MAF and the total quantity of water from on-farm sources ($Q_{W\text{-on-39 states}}$) is 28.3 MAF [USDA, NASS, FRIS, Table 10].

<u>Rate of Adoption of New Technologies (R_{AT})</u>

Studies of adoption rates of new technology in U.S. agriculture have found that it typically takes 10 to 15 years for novel technology to reach the 50 percent level and 18 to 24 years to reach full adoption. [Y. Lu, 1983; U.S. Congress, 1986; and Anderson and Heimlich 1996-97]. In the case of adoption of satellite-based ET, we can consider that adoption of this technology has already begun, since many farmers already use estimates of evapo-transpiration provided by third-party or government sources. Future improvements in accuracy due to GOES-R or NPOESS data will be an enhancement of an existing technology and should require only marginal investment in new training and implementation by existing users.

To account for the time needed to adopt technologies and, hence, benefit from its use, we further allow for an extended, ten-year adoption period of this technology. The assumption made is that 10 percent (R_{AT}) of all farms in these states adopt the technology for each year for 10 years in the lifecycle, reaching 100 percent adoption by all farms in 2024. Figure 5 depicts the quantity of on-farm and off-farm water assumed to be saved due to GOES, beginning in 2015 with adoption of this technology by only 10 percent of farms and rising to full adoption by 2024. Notice that out of a total of approximately 59 MAF in irrigation water applied in 1998, GOES savings is conservatively estimated at 1/2 of 1 percent in 2015.

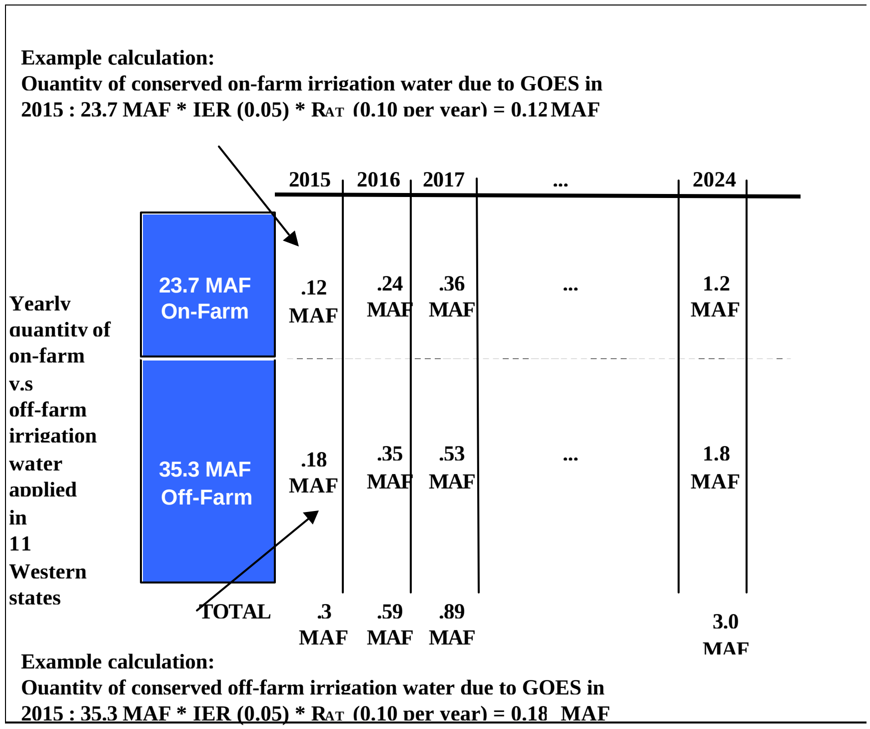

Figure 5. Quantities of Surplus Water Due to GOES – Accounting for Rate of Adoption of Technology Beginning in 2015

Percent of Water by Disposition ($P_{R\text{-}off}$, $P_{NR\text{-}off}$, $P_{TC\text{-}off}$, $P_{W\text{-}on}$, $P_{NW\text{-}on}$)

The amounts of water estimated to be saved due to GOES (shown in Figure 5) are not valued equally. Earlier in this report (Figure 4) several possible uses of the surplus water were identified. Since these uses have different beneficiaries and values, in order to estimate value, it is necessary to first make some reasonable assumptions regarding the relative proportions of water going to each use. Figure 6 shows these relative proportions assumed for this analysis and the rationale for these conservative amounts.

Due to long-standing statutory, regulatory, and administrative constraints at the Federal, State, and Local levels, only a portion of off-farm water conserved due to improved decision-making or other conservation measures is likely to be transferred to other uses. For example, in some states, farmers are vested to consume a certain amount of water, and lose this right if they use less in a given year due to conservation or other reason [Anderson and Heimlich, 1996-97]. In addition, physical constraints such as lack of pipelines or pumping facilities to move water from some irrigation districts to urban areas will further limit water transfers from farmers. According to the USDA [Anderson and Heimlich, 1996-97] there is a trend in arid states to reduce barriers or disincentives to water transfers from farms to other users. However, it is prudent to assume that some of these impediments will remain.

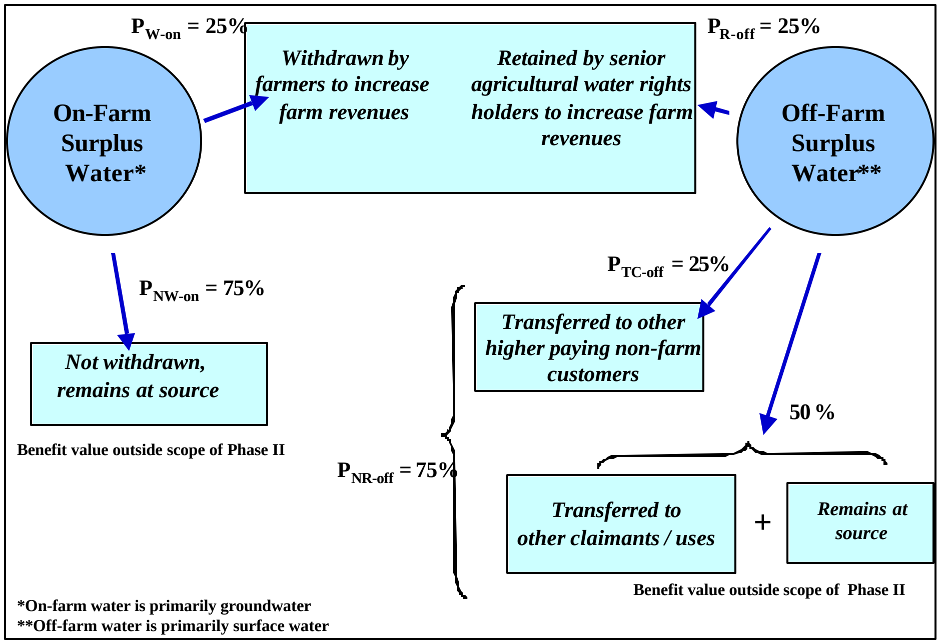

Figure 6. Assumptions – Percent of Surplus Water by Disposition for the 11 Western States

Although barriers may discourage transfer, there are also likely to be capital investment costs associated with some methods of increasing production (such as, the cost of developing an infrastructure for increased acreage), which we have not estimated here. Consequently, we conservatively assume that only 25 percent of the farms in the 11 Western states will retain off-farm water ($P_{R\text{-off -11 states}}$) to increase their production. Of the remaining 75 percent that is not retained in the 11 Western states ($P_{NR\text{-off -11 states}}$), we assume that a subset of 25 percent will likely be transferred to higher-paying non-farm consumers ($P_{TC\text{-off}}$) and the remaining 50 percent will either go to other transfers or be left at the source. Benefits in this last group have not been estimated for Phase II.

For off-farm water in the 39 non-western states, it is assumed that none of the water saved is transferred or used to increase production; 100 percent of the savings are left at the source. Farmers benefit from reduced water and energy purchases while maintaining crop yields.

For on-farm water in the 11 Western states, it is also assumed that 25 percent will continue to withdraw this water and use it to increase farm revenues ($P_{W\text{-on 11 states}}$), and the remaining 75 percent ($P_{NW\text{-on -11 states}}$) will remain at its source. Again, the benefits associated with water left at its source can be significant, but are not addressed in this Phase II analysis.

For on-farm water in the 39 non-western states, it is assumed that 100 percent of saved water will remain at its source, and that farmers in these states benefit from reduced energy purchases while maintaining crop yields.

Cost of Irrigated Water and Valuation of Increased Water Transfer Revenues (C_{IW}, IR_{TW})

For the purpose of estimating the increased revenues from water transfers, we need to calculate the difference between an average price for water transfers to non-farm consumers and the average price for water to farms. According to a USDA study of the quantity and price of transfers of water in 1996 and 1997 from agriculture to other uses in the arid west, about 92 percent of transfers were in the form of annual (temporary) contracts. About 8 percent were in the form of permanent transfers of water rights [Gollehon]. Temporary contracts had an average value of $233 per acre-foot, while permanent transfers had an average value of about $1,360 per acre-foot (in 1997 dollars). Using these relative amounts and prices as representative of potential future transfers, an average acre-foot would be worth about $323, or slightly less than $1 per 1000 gallons, if transferred to non-farm consumers. Inflated to 2002 dollars, this value becomes $354 per acre-foot. The weighted average price for farm irrigation water (C_{IW}) for the 11 western state subset was $16 per acre-foot in 1998 [USDA, NASS, FRIS, Table 20] or $17 in 2002 dollars. Hence, the increased revenue (IR_{TW}) as a result of transfer of off-farm water from farm to non-farm use would be $354 - $17, or $337 per acre-foot, in 2002 dollars.

Valuation of Increased Production to Farmers (V_{IP})

For those farms in the 11 Western states using the saved off-farm and on-farm water to increase production, this increased production value (V_{IP}) is conservatively valued at 30 percent of the value of water transfers calculated above, or $354 * 0.3 = $106. Valuing increased production much lower than this would substantially increase the incentive to transfer, and therefore the likelihood that barriers to transfer would be removed. Valuing it much higher, say 50 percent of the value of water transfers, would result in an equal total value for both uses and imply that there is little incentive or cost involved in removing remaining barriers.

For farmers using saved on-farm water, since we are assuming transfer is not an option, (although possible if the infrastructure exists), relating the value of increasing production to the value of transfers is not appropriate. However, given that the average revenue from irrigated agriculture in the U.S. was about $860 per acre in 1998 [Anderson and Heimlich], the net value of increasing production is likely to be significant. For the purpose of this analysis, we conservatively use the $106 per acre calculated above for off-farm water.

Valuation of Energy Consumed for Irrigation Pump Operation ($C_{E\text{-on- 11 states}}$, $C_{E\text{-off -11 states}}$ $C_{E\text{-on -39 states}}$, $C_{E\text{-off -39states}}$)

Total energy costs for irrigation in all 50 states states was about $1.223B in 1998 [USDA, NASS, FRIS, Table 17], or approximately $1.322B in 2002 dollars. In many cases it requires substantially more energy to pump ground water for use as on-farm irrigation water compared with energy used for within-farm pumping of water from off-farm sources. This is especially true for those farms that pump ground water from deep acquifers, where the water table may be 1000 feet or more below the surface. However, the USDA, NASS, FRIS does not provide a tabulation of costs along these lines. As an approximation, we divided energy expenses between on-farm and off-farm water in proportion to the number of pumps reported being used for on-farm wells and other irrigation pumps. (We assume that other irrigation pumps are primarily used for pumping off-farm water, although this number would include any other on-farm, non-well irrigation pumps.) In 1998, 330,000 well pumps were identified for irrigation [USDA, NASS, FRIS, Table 13], out of a total of 454,000 irrigation pumps on-farm [USDA, NASS, FRIS, Table 17]. About 61,000 pumps were used to discharge water from surface sources, such as ponds, reservoirs, rivers, and streams [USDA, NASS, FRIS, Table 16]. We counted these as belonging to the on-farm pool of pumps, for a total of 391,000 pumps used to pump on-farm water. About 65,000 pumps are classified as booster, relift, or tailwater pumps [USDA, NASS, FRIS, Table 16], and we put those into the off-farm water pumping pool. Therefore, we use 391/454 = 86 percent as an estimate of on-farm pumps and 14 percent as the estimate of pumps used for off-farm water pumping. This results in estimates of $1.138B M for energy used to pump on-farm water ($1.322B * 0.86), and $185 M fonergy used to pump off-farm water ($1.322B * 0.14). It should be noted that there may be additional energy savings on the part of water suppliers who provide off-farm water, but these savings are not estimated in this analysis.

We further divided energy costs between the 11 Western states and the 39 non-western states in proportion to the relative amounts of on-farm and off-farm water used by these two groups. About 8.3 percent of off-farm water is used in the 39 non-western states and about 54 percent of the on-farm water is used by these states. The resulting allocation is then, $523 M for the energy used to pump on-farm water in the 11 Western states, and $614 M to pump on-farm water in the 39 non-western states. The energy cost to pump off-farm water is $170 M for the 11 Western states, and $15 M for the 39 non-western states.

Summary of Variables

The parameter values shown in Table 10 were used for the irrigation case study. Again, these values reflect only estimates for the 11 western states identified in the introduction.

Table 10. Summary of Irrigation Benefits Parameters and Values

Parameter	Description	Value for this Analysis
IER	Improvement in irrigation efficiency due to improvement in GOES data	0.05
$Q_{W\text{-off -11 states}}$	Quantity of water from off-farm sources in the 11 Western states subject to potential efficiencies with improved ET	35.3 MAF
$Q_{W\text{-on -11 states}}$	Quantity of water from on-farm sources in the 11 Western states subject to potential efficiencies with improved ET	23.7 MAF
$Q_{W\text{-off -39 states}}$	Quantity of water from off-farm sources in the 39 non-western states subject to potential efficiencies with improved ET	3.2 MAF
$Q_{W\text{-off- 39 states}}$	Quantity of water from on-farm sources in the 39 non-western states subject to potential efficiencies with improved ET	28.3 MAF
RAT	Rate of adoption of new technologies by large farms	0.10 per year (for ten years)
$P_{W\text{-on -11 states}}$	Proportion of surplus on-farm water in the 11 Western states withdrawn and used by farmers to increase farm revenues	0.25
$P_{NW\text{-on -11 states}}$	Proportion of surplus on-farm water in the 11 Western states not withdrawn (left at source) thereby saving on-farm pumping energy costs	0.75

$P_{NW\text{-}on\ \text{-}39\ states}$	Proportion of surplus on-farm water in the 39 non-western states not withdrawn (left at source) thereby saving on-farm pumping energy costs	1
$P_{R\text{-}off}$	Proportion of surplus off-farm water retained by the farmers and used to increase farm revenues	0.25
$P_{NR\text{-}off\ 11\ states}$	Proportion of surplus off-farm water in the 11 Western states not retained by the farmer (either transferred or left at its source) thereby saving off-farm pumping energy costs	0.75
$P_{NR\text{-}off\ \text{-}39\ states}$	Proportion of surplus off-farm water in the 39 non-western states not retained by the farmer (either transferred or left at its source) thereby saving off-farm pumping energy costs	1
$P_{TC\text{-}off}$	Proportion of surplus off-farm water in the 11 Western states not retained but transferred to non-farm, higher paying consumers	0.25
CIW	Cost to farmers for water for irrigation (in 2002 dollars)	$17 per acre-foot
IRTW	Increased revenue per acre-foot to water suppliers in the 11 western states for transferred water (in 2002 dollars)	$337 per acre-foot
VIP	Value of increased production to farmers (in 2002 dollars)	$106 per acre-foot
$C_{E\text{-}off\text{-}\ 11\ states}$	Cost of energy to operate irrigation pumps for off-farm water in 11 western states (in 2002 dollars)	$170 M
$C_{E\text{-}on\ \text{-}11\ states}$	Cost of energy to operate irrigation pumps for on-farm water in 11 western states (in 2002 dollars)	$523 M
$C_{E\text{-}off\ \text{-}39\ states}$	Cost of energy to operate irrigation pumps for off-farm water in 39 non-western states (in 2002 dollars)	$15 M
$CE_{\text{-}on\ \text{-}39\ states}$	Cost of energy to operate irrigation pumps for on-farm water in 39 non-western states (in 2002 dollars)	$614 M

Benefits Calculations

Note that all equations include the factor for efficiencies due to improved GOES data (IER) = 0.05 and a per year adoption rate for technology, (R_{AT}) = 0.10 beginning in 2015 through 2024 (for a total of ten years).

Economic Value to Farmers of Off-farm Water and Energy Savings

The benefit to those farmers who avoid purchasing off-farm water without crop loss is the sum of the savings of the cost of this surplus water plus the cost of the energy required to pump this off-farm water. These benefits are given by the following equation:

$$
\begin{aligned}
B_1 &= Q_{W\text{-off-11states}} * P_{NR\text{-off-11 states}} * C_{IW} * IER * R_{AT} + C_{E\text{-off}} * P_{NR\text{-off-11 states}} * IER * R_{AT} \\
&+ Q_{W\text{-off-39 states}} * P_{NR\text{-off-39 states}} * C_{IW} * IER * R_{AT} + C_{E\text{-off}} * P_{NR\text{-off-39 states}} * IER * R_{AT} \\
&= (35.3\ MAF) * (0.75) * (\$17\ /acre\text{-}foot) * (0.05) * (0.10) + (\$170\ M) * (0.75) \\
&* (0.05) * (0.10) \\
&+ (3.2\ MAF) * (1.0) * (\$17\ /acre\text{-}foot) * (0.05) * (0.10) + (\$15\ M) * (1.0) * (0.05) * (0.10) \\
&= \$\ 2.3\ M + \$\ 0.64\ M + \$\ 0.27\ M + 0.075\ M \\
&= \$\ 3.3\ M \text{ in 2015, increasing to } \$\ 32.9\ M \text{ in 2024.}
\end{aligned}
$$

Economic Value to Farmers of Energy Savings from Pumping On-farm Water

The benefit to those farmers who use increased irrigation efficiency to grow the same crops using less water is primarily a reduction in the amount of energy purchased to run pumps for on-farm water. As discussed above, we assume that 50 percent of farmers who use on-farm water for irrigation will use increased irrigation efficiency to grow the same crops with less water, thereby not withdrawing additional water and saving on energy costs to run these pumps. These benefits of reduced energy purchases are given by the following equation:

$$
\begin{aligned}
B_2 &= C_{E\text{-on-11 states}} * P_{NW\text{-on}} * IER * R_{AT} \\
&+ C_{E\text{-on-39 states}} * P_{NW\text{-on}} * IER * R_{AT} \\
&= (\$523\ M) * (0.75) * (0.05) * (0.10) \\
&+ (\$614\ M) * (1.0) * (0.05) * (0.10) \\
&= \$1.96\ M + \$3.07\ M \\
&= \$5.03\ M \text{ in 2015, increasing to about } \$\ 50.3\ M \text{ in 2024.}
\end{aligned}
$$

Economic Value to Farmers of Increased Production Using Off-farm Water in the 11 Western States

The benefits to those farmers retaining the surplus off-farm source water in the 11 Western states and using this surplus to increase productivity is:

$$
\begin{aligned}
B_3 &= Q_{W\text{-off-11 states}} * P_{R\text{-off-11 states}} * V_{IP} * IER * R_{AT} \\
&= (35.3\ MAF) * (0.25) * (\$106\ /\ acre\text{-}foot) * (0.05) * (0.10) \\
&= \$4.7\ M \text{ in 2015 increasing to about } \$46.8\ M \text{ in 2024.}
\end{aligned}
$$

Economic Value to Farmers of Increased Production Using On-farm Water in the 11 Western States

The benefits to those farmers using increased irrigation efficiency in the 11 Western states with on-farm water to increase productivity is:

$$
\begin{aligned}
B_4 &= Q_{W\text{-on-11 states}} * P_{W\text{-on-11 states}} * V_{IP} * IER * R_{AT} \\
&= (23.7\ MAF) * (0.25) * (\$106\ /\ acre\text{-}foot) * (0.05) * (0.10) \\
&= \$3.1\ M \text{ in 2015 increasing to about } \$31.4\ M \text{ in 2024.}
\end{aligned}
$$

Increased Suppliers' Revenues from Transferred Water in the 11 Western States

The benefits to water suppliers in the 11 Western states from transferred water is calculated as the increase in water suppliers revenues from transfer of water from farm to non-farm use, defined by the equation:

B_5 $= Q_{W\text{-off-11 states}} * P_{TC\text{-off-11 states}} * IR_{TW} * IER * R_{AT}$

$= (35.3 \text{ MAF}) * (0.25) * (\$337 / \text{acre-foot}) * (0.05) * (0.10)$

= \$ 14.9 M in 2015, increasing to about \$ 148.7 M in 2024.

Benefit Summary

Direct Benefits

Table 11 summarizes direct irrigation benefits due to better information on soil moisture from GOES for the subset of geographical areas and uses identified in this report. These estimates ($31.0 M in 2015 rising to $310.3 M in 2024) are partial benefits to the U.S. and are conservative because only a small portion of the end uses of surplus water (Figure 4) were estimated. Ecological values of improving stream and aquifer quality were not estimated, nor were values associated with other potential transfers and water claim settlements.

Table 11. Irrigation Benefits Summary for 11 Western States* (Millions 2002$)

Benefit Areas	Benefit Recipients	1st Year Benefits (2015)	Per Year Benefits in Full Adoption Years (2024-25)	Present Value (2015-2027)
Benefits from savings of off-farm water	Farmers – reduced purchases of water and energy, all 50 states	$3.3	$32.9	$70.2
	Farmers – use water savings to increase production and revenues, 11 Western states	$4.7	$47.0	$99.9
	Water Suppliers –increased revenues from water sales, 11 Western states	$14.9	$148.7	$317.4
	Sub-Total	***$22.9***	***$228.6***	***$487.5***
Benefits from savings of on-farm water	Farmers – increased production using savings per acre in on-farm water, 11 Western States	$3.1	$31.4	$66.7
	Farmers – energy savings, all 50 states	$5.0	$50.3	$107.4
	Sub-Total	***$8.1***	***$81.7***	***$174.1***
	Total Benefits	**$31.0**	**$310.3**	**$661.6**

*These states are: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

Indirect (Consumer) Benefits

Potentially, a very large indirect benefit can be realized by considering the increased non-farm consumers' utility or welfare from the increased supply of low-cost water. It is not unreasonable to assume that the growing population of the 11 Western states would be willing to pay to be able to continue to consume as much water as consumers in this region do currently. Since market forces tend to drive prices down to the point where marginal value of the last unit consumed is equal to the marginal cost of supplying that last increment, there is usually a substantial difference between what most people *would* pay for a good and what they actually *do* pay. This situation is certainly true for water, where consumers currently pay only about $1-2 per *thousand* gallons, but most would likely pay much more for lesser quantities under conditions of increased scarcity. This concept of consumers' welfare or utility is also known as consumers' surplus, for the surplus value most consumers receive from the low prices they pay for many goods. As a limited natural resource in demand, the consumer value of increasing the water supply can be considerable.

Numerous media reports indicate that the business of supplying water and the economic value of additional supplies of water to accommodate future population growth in the 11 Western states is in the billions of dollars [Booth]. Very conservatively, we think that consumers *would* willingly pay at least 4 times what they currently pay [$4-8 per thousand gallons versus $1-2 per thousand gallons today] to obtain additional supplies of water represented by the transfers estimated in this analysis, if necessary. If true, this would amount to a consumer benefit with a present value of about $1 to 2 B over and above the approximately $317 M increased revenues to water suppliers. The true value of additional water supplies to accommodate population and economic growth in the 11 Western states over the period from 2015 to 2027 is likely much higher. As corroborating evidence, we note that California recently legislated that all residential clothes washers must be as efficient as commercial machines by 2007 [Chu]. The more efficient machines are estimated to cost consumers at least $250 more than current less-efficient machines and will save about 7000 gallons per year per machine [Chu]. Over a ten-year lifecycle such machines will therefore save about 70,000 gallons of water at a cost to consumers of about $3.60 per thousand gallons. The actual cost to consumers will likely be higher if they must replace existing machines before the end of their useful life.

4.3.6 Case Study 6: Recreational Boating (RB)

Problem Statement

Recreational boating is a $20-$25 billion per year industry that, over the years, has sustained significant economic losses attributable to hurricanes. The coastal zone of the United States is home to over 17 million boats in 5,000 marinas supporting recreational boating, and, in 1997 alone, over 78 million Americans participated in recreational boating [National Maritime Manufacturers Association]. A key factor for avoiding or reducing these losses is improved forecasting of hurricane landfall and lead-time that will allow boat owners to take mitigative actions. GOES-R is expected to contribute to the improvement in these forecasts.

Hurricanes pose a significant threat of loss and damage to boats in the United States coastal communities, particularly the East Coast and the Gulf of Mexico. South Florida is one of the areas most vulnerable to hurricanes on the US Atlantic Coast [Marine Industries Association of South Florida]. Of the more than 300,000 boats registered in South Florida in 1999, more than 95% are for pleasure. Many of these vessels are moored in marinas that are very vulnerable to the destructive forces of hurricanes, namely high winds and storm surge. Table 12 lists some of the major land-falling hurricanes of the past decade and the estimates of boat damage associated with those storms. Just ten of the major land-falling hurricanes of the past decade caused approximately $837M in boat damage alone.

Table 12. Major Land-Falling Hurricanes and Associated Boat Damage from 1991 to 1999 [Boat/U.S.]

Year	Hurricane Name	Boat Damage Estimate (US$M2002)
1991	Bob	$61
1992	Andrew	$255

1996	Fran	$57
1996	Bertha	$11
1997	Georges	$78
1998	Bonnie	$16
1999	Irene	$39
1999	Dennis	$20
1999	Floyd	150
Total		**$837**

Of the 17 million boats moored in marinas, many are moored in marinas that are very vulnerable to the destructive forces of hurricanes, namely high winds and storm surge. However, some portion of the losses and damages that occur as a result of these hurricanes can be avoided with timely warnings of where and when the storms are expected to make landfall. Hurricane preparation calls for owners of recreational boats to have a Hurricane Plan. Part of this plan is for boat owners (particularly those moored in water) to have several alternative mooring places, called "hurricane holes", to protect their boats in the event of an approaching tropical storm or hurricane. The handbook titled *Recommendations for Hurricane Preparations and Responses for Boating Communities and Industries* recommends that emergency management officials advise boaters to evacuate coastal marinas when they announce *hurricane watches*, rather than waiting until a *hurricane warning* is issued [Marine Industries Association of South Florida]. The case of Hurricane Andrew in 1992 indicates that evacuation to safe havens should have been initiated at least 72 hours prior to landfall, instead of the 24 hours that was given.

GOES-R is expected to produce more accurate and frequent measurements of key tropical cyclone parameters that will, in turn, produce more accurate and timely estimates of hurricane landfall and intensity. The increased spatial resolution and update cycle for GOES-R sea surface measurements will enable GOES-R to capture sea surface temperature (SST) readings more often. This will provide the opportunity to re-initialize the SST data into models more frequently, thus improving hurricane intensity forecasts. Rapid scan winds, tested on GOES 10, helped to better understand the divergence, or lift, of the storm and thus the potential for intensification. These winds will be the norm on GOES-R [Velden]. GOES-R improvements in the frequency and spatial resolution will also improve the accuracy and density of wind-speed measurements, potentially doubling the number of wind vectors and the accuracy of wind-speed estimates. Improved knowledge of the location of the centers of circulation winds (storms) as well as the speed at which they are traveling (steering winds) will provide better information on *when* and *where* a particular storm will make landfall.

Benefits Computation

The Boat Owners Association of the United States [Boat/U.S.] has compiled estimates of average annual weather related losses for the recreational boating industry. Table 13 contains the annual dollar value of boat losses and damage by weather event.

It is reasonable to assume that given better track and intensity forecasts of land-falling hurricanes, in particular, improvement in the 48-hour and 72-hour forecasts, some proportion of boat losses and damages can be avoided by providing boat owners more lead-time to move their boats to safety.

Table 13. Cost ($2002) of Annual Boat Losses and Damage (Based on the Range $510M - $765M) [Adriance]

Weather Event	% of Dollar Losses	Cost of Losses (Low)	Cost of Losses (High)

Hurricanes	34.2%	$174,420,000	$261,630,000
Tornadoes	3.8%	$19,380,000	$29,070,000
Lightning Strikes	15.0%	$76,500,000	$114,750,000
All Others (e.g., wind, rain, snow, ice, sleet)	47.0%	$239,700,000	$359,550,000
Total		**$510,000,000**	**$765,000,000**

Benefits to the recreational boating industry attributed to GOES-R data are calculated as avoided hurricane-related loss and damage costs. These benefits are specifically calculated as a function of:

(Total cost of hurricane-related losses and damage) * (Percent reduction attributed to GOES-R)

In this analysis, a distinction is made between a boat loss, which is a total loss, and boat damage, which is assumed to be reparable damage. A source at BOAT/U.S. [Adriance] indicated that the proportion of annual avoidable losses and damage to recreational boats are both approximately one third of the total of all losses/damage. Using the summary data presented in Table 14, we can calculate the dollar benefit of avoiding recreational boat losses and damage due to improved hurricane warnings. We have made the conservative assumption that the annual dollar property losses/damages are at the low end of the range provided, e.g., $510,000,000.

Table 14. Benefits Computation Input and Output

Variable Name	Variable Description	Value
APL	Annual $ Property Loss/Damage	$510,000,000
P_{ABL}	Proportion of Avoidable Boat Losses	0.333
P_{ABD}	Proportion of Avoidable Boat Damage	0.333
P_{CIH}	Proportion of Costs Incurred Due to Hurricanes	0.342
P_{LAG}	Proportion of Hurricane Losses Avoided Due to Improved GOES-R Data	X
P_{DAG}	Proportion of Hurricane Damage Prevented Due to Improved GOES-R Data	Y
EC_{IH}	Estimated Costs Incurred Due to Hurricanes = APL*P_{CIH}	$174,420,000
E_{AL}	Estimated Avoidable Loss ($) = P_{ABL}*EC_{IH}	$58,081,860
E_{AD}	Estimated Avoidable Damage ($) =$P_{ABD}$*$EC_{IH}$	$58,081,860

Step 1: Compute Estimated Costs Incurred Due to Hurricanes (EC_{IH}) per year:

$$\mathbf{EC_{IH} = APL * P_{CIH} = \$510{,}000{,}000 * 0.342 = \$174.4M}$$

Step 2: Compute the Estimated Avoidable Boat Losses ($) Due to Hurricanes:

$$\mathbf{E_{AL} = P_{AL} * E_{CIH} = 0.333 * \$174{,}420{,}000 = \$58.1M}$$

Step 3: Compute the Estimated Avoidable Boat Damages ($) Due to

$$\mathbf{E_{AD} = P_{AD} * E_{CIH} = 0.333 * \$174{,}420{,}000 = \$58.1M}$$

Step 4: Compute Estimated Avoidable Losses ($) and Damages ($) Due to Improved GOES-R Data (E_{ALDG}):

$$\mathbf{E_{ALDG} = P_{LAG} * E_{AL} + P_{DAG} * E_{AD}}$$

This computation is variable based on the uncertainty associated with the proportion of hurricane losses avoided due to improved GOES -R data (P_{LAG} =X) and the proportion of hurricane damage prevented due to improved GOES-R data (P_{DAG} =Y). Thus, we computed a benefits sensitivity table, where X and Y vary from 1% to 50% (see Table 15). An example of how the table values are computed is given below.

If we presume that 30% of the cost of boat losses can be avoided due to GOES-R and 20 % of the cost of boat damage can be avoided due to GOES-R, then the total cost of boat losses and damage avoided due to GOES-R is

$$\mathbf{E_{ALDG} = 0.30*\$58,081,860 + 0.20*\ \$58,081,860 = \$29M}$$

Table 15. Benefits Sensitivity Analysis Based on Percentage Allocation of Avoidable Losses and Damages ($M 2002)

	P_{DAG} (Y)					
P_{LAG} (X)	**50%**	**40%**	**30%**	**20%**	**10%**	**1%**
50%	$58.1	$52.3	$46.5	$40.7	$34.9	$29.6
40%	$52.3	$46.5	$40.7	$34.9	$29.1	$23.8
30%	$46.5	$40.7	$34.9	$29.0	$23.2	$18.0
20%	$40.7	$34.9	$29.0	$23.2	$17.4	$12.2
10%	$34.9	$29.1	$23.2	$17.4	$11.6	$6.4
1%	$29.6	$23.8	$18.0	$12.2	$6.4	$1.2

If we consider the entire range of potential benefits, e.g., $1.2M to $58.1M, the discounted present value ranges from $4.5M to $215.6M during the time frame 2015-2027. If we focus on a subset of these values, say (30%, 30%) to (10%, 10%), the potential benefits range from $11.6M to $34.9M with corresponding discounted present value ranging from $43.0M to $ 129.5M (for the period 2015-2027). For this analysis we have conservatively assumed that 30% of the cost of boat losses can be avoided due to GOES-R and 20% of boat damage can be avoided due to GOES-R, resulting in an annual benefit of $29M (see above computation).

4.3.7 Case Study 7: Natural Gas (NG)

Problem Statement

According to the Department of Energy, in the United States last year, nearly 19.5 trillion cubic feet (TCF) of natural gas was produced, while nearly 21.5 TCF was consumed at a total price of over $128 billion. Natural gas utilities served roughly 60 million residential customers and 5.3 million commercial and industrial customers. [American Gas Association]

Natural gas is considered the cleanest and most efficient fossil fuel, providing nearly one-quarter of all energy used in the United States. [American Gas Association] Natural gas is also an important source of energy for electricity production and is increasingly used to help electric utilities meet their need for relatively clean energy to meet short-term fluctuations in demand. The natural gas industry is extremely dependent on accurate weather information to run the most efficient, cost-effective operation possible while meeting the nation's energy demands. From natural gas production in the fields, to transmission through the pipelines, to distribution to end consumers, all facets of the industry rely on weather information to achieve optimal performance. Ultimately, with earlier and more accurate information on temperature (and to a lesser extent, cloud cover, humidity, precipitation, and wind speed) the natural gas industry can better anticipate when consumers will turn on their lights, power up their air conditioner, or turn up their heat. [Defonte]

In particular, two segments of the natural gas industry were identified as benefiting from improved accuracy of temperature forecasts and as such, were researched for this analysis. These two segments are (1) the pipeline companies who transmit and supply natural gas to distributors and (2) the gas utilities that sell and distribute gas to consumers.

The pipeline companies who transmit and supply natural gas to distributors incorporate temperature forecasts into their load demand forecasting models. Load demand forecasts are then used as inputs into the pipeline optimization models, the output of which controllers and operators use to determine when and how high to run the pipeline compression facilities, which are generally powered by natural gas.

There are two independent sets of load demand forecast models used by the pipeline industry: Within-Day and Day-Ahead models. [Pigott et al] Both include temperature as a significant variable, and as such, improvements in the accuracy of the temperature forecasts (i.e., reduction in the error) would lead to a reduction in the error of the forecast demand generated by the Within-Day and Day-Ahead models. These improvements would then limit the volatility of flow associated with unanticipated demand, optimizing the efficiency of compressor operations and minimizing the amount of natural gas needed to run the compressors. Thus, valuable energy resources would be freed up for consumers. The benefits from improved temperature forecasts for these pipeline companies are the energy costs they avoid as a result of more efficient use of the compressors.

Likewise, gas utilities also depend on temperature forecasts for their operations. Gas utilities need to hold certain assets in the form of quantities of gas or hydro-carbon liquids in storage, or firm commitments from suppliers in order to guarantee sufficient supplies of natural gas to meet variations in peaking demand. These "on-demand" assets are expensive to store or purchase and utilities and their customers would realize significant savings if they could reduce these "on-system assets" (for instance, Liquid Natural Gas and propane tanks and facilities) required to meet demand swings due to weather.

Based on industry research, it is clear that many players in the natural gas industry purchase weather information in the form of synthesized, pre-packaged weather products from value-added resellers, with few utilizing raw weather data directly from NOAA. Nonetheless, weather products from value-added resellers often contain data derived from GOES sensor readings, in addition to data from other weather satellites such as NPOESS, and from radar and ground sensor systems. As such, this benefits research assumes that spatial and temporal improvements to GOES-R sensor readings will result in more accurate forecasts of weather characteristics, particularly temperature readings, by value-added resellers. In turn, it is assumed that natural gas load planners will utilize the improved forecasts included in products they purchase from value-added resellers.

To build a case for economic benefits to this industry from GOES-R, participants from a number of different facets of the natural gas industry were interviewed. These participants include: pipeline transmission companies, natural gas utilities/distribution companies, natural gas marketing and derivatives trading companies, industry trade associations, industry consultants, industry forecasters, federal employees from the Department of Energy, NOAA researchers, and value added resellers of weather information. In addition, relevant industry data was culled from a number of different sources. The primary source was the Department of Energy (DOE) Energy Information Administration's (EIA) Natural Gas Annual, which reports data on natural gas production, supply, disposition, consumption, and pricing by year, geography, and type of consumer. Detailed research was also conducted via industry publications, seminars, conference presentations and research papers, and research by trade associations and their members.

Benefits Calculation - Natural Gas Transmission Companies

Costs avoided by the pipeline companies are calculated by estimating the amount of natural gas in billions of cubic feet (BCF) expected to be saved with improvements in temperature forecasts from GOES-R. This calculation is represented with the following variables:

B_{NGP}	=Total Annual Benefits to the Natural Gas Pipeline Industry
$Av_{NG}C_{on}P$	= Average annual natural gas consumption by pipeline facilities
Mod_{Err}	= Average error of load demand forecast model
$Mod_{Err}W_x$	= Fraction of load forecast model error attributed to weather forecast error
W_xFcst_{Imp}	= Expected improvement in weather forecast accuracy
C_{NGP}	= Cost to the pipelines for natural gas in $/BCF inflated to $2002

with the benefits calculation computed by the following equation:

$$\mathbf{B_{NGP} = Av_{NG}C_{on}P * Mod_{Err} * Mod_{Err}W_x * W_xFcst_{Imp} * C_{NGP}}$$

Currently, the pipeline facilities consume about 640 billion cubic feet (BCF) of natural gas per year [United States Department of Energy, *Annual Energy Outlook 2001* Reference Case Tables, Table 13] running their operations and fueling the compressors. Research revealed that the average absolute error of three different Within-Day load forecasting models from one company ranged from 0.94% to 1.24% [Piggott et al]. In addition, the average absolute error of five different Day-Ahead load forecasting models ranged from 3.62% to 5.28%. Both Day-Ahead and Within-Day models are used operationally to make transmission decisions. However, at this time the exact dynamic between the two models is unclear. So, for the purpose of this benefits analysis, benefits were calculated assuming only improvements in the Within-Day models. (The Within-Day models were used because they generated the most conservative estimate of net benefits. In reality, since temperature forecast improvements will affect all models, it is likely that the net efficiencies would be larger than what is reported here.) The midpoint of the range of Within-Day load forecast model errors is 1.09%. Further research and discussions with industry participants revealed that typically, greater than 50% of an average load forecast error can be attributed to weather forecast errors [Lamb and Montroy]. Since temperature is the most significant weather parameter used in the load forecasting models, a 50% factor is used to account for improving temperature error only. Finally, according to researchers at NOAA, the proposed enhancements to GOES-R sensors are expected to yield a 25% improvement in the 0-3 hour ahead temperature forecast.

Thus, the benefits calculation variables are defined as follows:

$Av_{NG}C_{on}P$	= 640BCF
Mod_{Err}	= 1.09%
$Mod_{Err}W_x$	= 50%
W_xFcst_{Imp}	= 25%
C_{NGP}	= $2.15M/BCF ($2002)

The equation to calculate benefits in billions of cubic feet (BCF) of natural gas saved is:

$$\mathbf{640\ BCF * (0.0109*0.5*0.25) = 640\ BCF*0.0014 = 0.872\ BCF}$$

which is the potential natural gas saved annually due to improvements in temperature forecast accuracy.

In order to conservatively value this fuel, the internal pipeline fuel price, or the price the natural gas companies pay the producers for the gas, was used. Since this price has demonstrated extreme volatility in recent years due to a number of factors including recently exposed fraudulent price inflation among other things, this analysis utilizes a more conservative rate from 1998, prior to the emergence of the energy derivatives market. The pipeline fuels price was $2.01M/BCF) in 1998 dollars [United States Department of Energy, *Natural Gas Annual*, Overview, Table 1] or $2.15M/BCF inflated to $2002. At this conservative price, the pipeline industry would save:

$2.15M/BCF * 0.872 BCF = $1.88M ($2002)

Another estimate of potential savings is calculated by valuing the fuel surplus using the price charged to residential consumers, instead of the internal price that the transmission company pays. This reflects more of an opportunity cost approach to valuing the savings. In 1998, residential natural gas prices averaged $6.82 per thousand cubic feet (or $6.82M/BCF) [United States Department of Energy, *Natural Gas Annual* Overview, Table 1]. Again, the 1998 base price was used to reflect an average price prior to the impact of the derivatives market. Based on this residential price, which totals $7.30M/BCF when inflated to 2002 dollars, the value of the benefits generated by reducing the amount of natural gas needed to fuel the compressor operations is roughly $6.36M in 2002 dollars, as illustrated in Table 16.

Table 16. Potential Annual Savings Calculation for Natural Gas Transmission Companies ($2002)

	Fuel Valuation Using $2.15 Pipeline Fuel Price ($2002)	**Present Value**	**Fuel Valuation Using $7.30 Residential Price ($2002)**	**Present Value**
Pipeline Fuel Consumed	640BCF		640BCF	
Fuel Price ($2002) ($M/BCF)	$2.15		$7.30	
Total Cost of Fuel	**$1.38B**		**$4.67B**	
<u>Scenario:</u>				
Avg. Abs. Error Min.	$1.62	$8.3	$5.49	$28.0
Avg. Abs. Error Mid.	$1.88	$9.6	$6.36	$32.4
0.1% Savings	$1.38	$7.0	$4.67	$23.8
0.5% Savings	$6.90	$35.2	$23.35	$119.1

Benefits Calculation - Natural Gas Utilities

For natural gas utilities that sell and distribute energy directly to consumers, the benefits calculation related to improved temperature forecasts from GOES-R is different. Again, in this segment of the market, utilities need to hold certain "on-system assets", as they are referred to in the industry, in order to guarantee sufficient supplies of natural gas to meet variations in peaking demand. These additional supplies are expensive to store or purchase and utilities and their customers would realize significant savings if they could reduce these "on-system assets" (for instance, Liquid Natural Gas and propane tanks and facilities) required to meet demand swings due to weather.

According to one source in the industry [Defonte], roughly 2% of the utilities daily flow during peak periods represents "swing" capacity needed to meet unexpected demand related to weather. In other words, if utilities had a 100% accurate weather forecast, they could eliminate the need to carry this extra 2% capacity that is generally supplied by the above mentioned, relatively expensive "on-system assets". Industry interviews revealed that potential savings related to this swing can be proxied by taking 2% of the utility's flow and applying their internal "balancing fee", that is, the rate that they pay their suppliers for the flexible component of their load. For one utility in New England, that balancing fee is $0.48 per decatherm (dth), where one dth is equal to one thousand cubic feet (TCF) of gas. [Defonte] This valuation price is considered conservative since an opportunity cost calculation might instead use the balancing fee that utilities are allowed to charge consumers, which is higher. This customer balancing fee, which is regulated, is calculated as a direct pass-through of the utility's own balancing fees ($0.48/dth), plus their costs to hold "on-system assets" needed to quickly meet further demand surges. However, this analysis assumes the more conservative $0.48/dth rate to value the swing, as seen in Table 17 below.

Table 17: Potential Annual Savings Calculation for Natural Gas Utilities ($2002)

	Value*
2001 Consumption by Consumers*	19,670 BCF
2% Peak Period Weather-Related Swing	393.4 BCF
% of Year Assumed to be Peak	25%
Price per TCF ($2002)	$0.48
Value of 2% Peak Period Weather-Related Swing	$47.21
Annual Savings Assuming 10% Improved Accuracy in 3-24 hour ahead Temp Forecast	$4.72
Present Value of Benefits with 7% discount rate	$24.1

[* United States Department of Energy, Energy Information Administration, Natural Gas Monthly July 2002, Table 3]

Based on the above calculations, the potential savings for natural gas utilities and their customers exceed $4.7 million per year ($2002) assuming a 10% improvement in weather forecast accuracy. The present value calculation, assuming that benefits begin accruing two years after launch (2015) and continue through to 2027 yields total savings of $24.1M. Again, this benefits calculation is based on a 7% discount rate, as well as DOE's natural gas consumption growth estimate that averages 2% annually through 2020. We held gas consumption constant at the 2020 level for years 2021 through 2027.

Summary Benefits - Natural Gas

By combining the benefits calculated above for both natural gas transmission companies as well as natural gas utilities, total potential savings from improved weather forecast accuracy is approximately $6.6M per year ($1.88M for transmission companies, $4.7M for utilities) based on extremely conservative assumptions, with a discounted present value of $33.8M. Relaxing those assumptions could yield in excess of $ 28M annually ($4.7M for utilities, $23.4M for transmission companies), with a discounted present value of $142.8M.

4.3.8 Case Study 8: Trucking (TR)

Problem Statement

Commercial trucks carry 60% of tonnage and 70% of the value of all US shipped goods. Twenty million trucks of all weight classes move 7.7 billion tons of freight and $485B in gross freight revenue per year. In 1999, large truck crashes caused 360 fatalities attributed to sleet/fog, rain and ice and 16,300 injuries attributable to snow, sleet, fog, rain and ice, at a cost of $5.6B for all crashes. [National Highway Transportation Safety Administration] Research found that trucking could realize economic benefits from more timely and accurate severe weather forecasts, and more accurate information on icing, high winds, and fog. Weather related trucking accidents are high (approximately 59,000 per year), the costs in lives and property are high, so there are strong incentives to avoid these losses if possible. In fact, based on the behavior of those trucking companies that lead the curve technologically, the trend is toward weather information becoming increasingly more important over time as firms jockey for competitive advantage in an industry with slim margins.

GOES-R will provide a better understanding of near term ice formation conditions through improved precipitation data as well as more timely and accurate information on land surface temperature to indicate when the ground temperature is below freezing. GOES-R will also provide a higher resolution, real-time fog product that will allow drivers to more efficiently reroute.

Relevant industry data was culled from a number of different sources. The primary source was the National Highway Transportation Safety Administration, which reports data on the number of weather-related truck crashes annually, categorizing them by type of weather and by outcome (personal injury, property damage, or fatality). This data set was instrumental in determining what opportunity exists for the industry to benefit from reduced loss of life or injuries resulting from improved weather information, particularly since operational use of weather information is considered sensitive competitive intelligence by a number of companies. A few companies who considered themselves technologically advanced with respect to operational use of weather data were willing to disclose only as much information as was necessary to demonstrate their role as industry leaders.

Benefits Calculation

According to one industry expert, without at least two hours advance notice, a driver is essentially unable to reroute. Therefore, we assume that an accurate prediction of severe weather with at least two hours advance notice provides the opportunity for operational safety decisions to reroute, and that the improved data from GOES-R will contribute to more timely notice.

Approach 1 – Extrapolating from Historical Data

Benefits to the trucking industry attributed to GOES-R data are calculated as avoided weather-related accident costs. These benefits are specifically calculated as:

(Total cost of trucking weather-related crashes) * (Percent reduction attributed to GOES -R)

Table 18 summarizes the cost of all weather-related large truck crashes in 1999 as approximately $5.6B ($2002). (Note that a large truck is defined as a truck with a gross vehicle weight rating (GVWR) greater than 10,000lbs.) Since these crashes were directly weather-related and since GOES -R products will improve the industry's understanding of these specific weather phenomena, it is reasonable to assume that some portion of these accidents, and hence costs, could be avoided with utilization of GOES -R data. Since data on avoidable crashes is not available, a range of expected benefits, as percentages of the $5.6B total, are provided in Table 19. For this analysis, an extremely conservative crash reduction percentage estimate of 0.5% was selected, resulting in $28M annual savings. Note that 0.5% of the total weather-related crashes is approximately 300 crashes per year, translating into approximately one weather-related crash per day avoided because of improved GOES -R data. These statistics are for large trucks only, so that extrapolating to the entire trucking industry would only serve to increase these benefits.

Table 18. Number and Cost of Large Truck Weather-Related Crashes By Severity and Weather Conditions

	# of Wx Losses*				
Loss Severity	**Sleet/Snow/Fog**	**Rain**	**Total**	**Avg. Cost of Loss****	**Total Cost of Losses ($M)**
Fatalities	184	360	544	$3,611,520	$1,964.67
Injuries	3,420	10,000	13,420	$229,152	$3,075.22
Property Damage	14,826	30,711	45,537	$11,933	$543.38
Total	**18,430**	**41,071**	**59,501**		**$5,583**

*[Federal Motor Carrier Safety Administration, Analysis Division, Large Truck Crash Facts, 1999, Table 33.]

**[Federal Motor Carrier Safety Administration, Office of Research and Technology]

Table 19. Trucking Industry Benefits Sensitivity Analysis
Assumption of % Avoidable Weather-Related Costs with GOES-R Data

% Accident Reduction: Assumption	Assumed Avoidable Annual Costs Attributed to GOES-R ($M)	Discounted PV ($M)
10%	$558.33	$2,071.9
5%	$279.16	$1,035.9
1%	$55.83	$207.2
0.5%	$27.92	$103.6
0.1%	$5.58	$20.7

As a reasonableness check for the above assumptions and resulting benefits cost, a subset of the above weather-related crashes is considered separately. If only the sleet, snow and fog related accidents were assumed to be avoidable with new products derived from enhanced GOES-R, those costs totaled over $1.6B in $2002. Again, assuming a conservative crash reduction percentage 0.5% translates into $8M per year (or roughly 100 snow/sleet/fog related crashes avoided per year attributed to GOES-R). One could also argue that increasing this fraction (0.5%) would be justified since crashes due to icing conditions on the road are included in this figure.

As another reasonableness check, Table 20 shows separate crash statistics attributed to icy road conditions. (Note that the road condition statistics represent a different stratification of the weather condition statistics, although total crashes remain the same.) A GOES-R icing product has been acknowledged by trucking professionals as potentially very valuable to their operations. Consequently, looking at just the crashes and costs due to surface ice conditions, a very conservative 0.5% of these costs amounts to $5M per year (or approximately 50 crashes due to icy road conditions avoided per year). Again, one could reasonably attribute even more to GOES-R given that this subset of total weather-related crashes is related to icy roads only. In addition, these statistics are for large trucks only.

Table 20. Number and Cost of Large Truck Crashes Due to Icy Road Conditions (1999)

Category	Number of Crashes Due to Icy Road Conditions	Cost ($2002)
Fatal	70	$252,806,400
Injury	3,000	$687,456,000
Property Damage Only	7,000	$79,751,000
Total	**10,070**	**$1,020,013,400**

*[Federal Motor Carrier Safety Administration, Analysis Division, Large Truck Crash Facts, 1999, Table 34.]
**[Federal Motor Carrier Safety Administration, Office of Research and Technology]

Approach 2: The case from personal interviews – Jackknife Frequency

A second approach to estimating benefits to the trucking industry with improved GOES -R products was also explored, although the estimate obtained via the approach mentioned above was adopted.

By implementing what they called their "weather program", North American Van Lines (NAVL) reduced the number of truck jackknife accidents by approximately 89% in the last five to six years. Specifically, the reduced number of accidents went from 90 jackknifes per year to 10 per year. At a cost of $14,000 per incident [Hughes], NAVL realized a savings of $1.12M per year.

The source at NAVL indicated that the reduction in jackknife incidences from 90 to 10 per year after five years was related explicitly to the implementation of the weather program. If the industry could emulate the NAVL weather program and achieve the same type of results, after 5-6 years, the 89% reduction in large truck jackknife incidents would generate an annual cost savings of $1,155M. (See Tables 21 and 22)

Table 21. Number of Large Truck Jackknifes by Severity (1999) (in $2002)

	Total Number Of Jackknifes by Severity*	Avg. Cost Per Incident by Severity**	Total Cost of Jackknifes by Severity
Fatalities	282	$3,611,520	$1,018,448,640
Injuries	2,000	$229,152	$458,304,000
Property Damage	4,000	$11,933	$47,731,200
Total	**6,282**		**$1,524,483,840**

*[Federal Motor Carrier Safety Administration Analysis Division/ Large Truck Crash Facts 1999, Table 44.]
**[Federal Motor Carrier Safety Administration, Office of Research and Technology]

Table 22. Cost Sensitivity Analysis on Percent Jackknife Reductions

Percent Jackknife Reductions	Total Cost of Jackknifes by Severity	Discounted PV ($M)
100%	$1,524,483,840	$5,655.4
89%	$1,356,790,618	$5,034.9
40%	$609,793,536	$2,262.9
10%	$152,448,384	$565.7
1%	$15,244,838	$56.6
0.50%	$7,622,419	$28.3
0.10%	$1,524,484	$5.7

However two critical factors affect the above calculation, which assumes that the industry overall can realize an 89% reduction in jackknife incidence via implementation of a weather-related incentive program. First, a portion of the trucking industry likely already has *some* weather program in place and is probably already realizing some of that 89% reduction. Second, some portion of the large truck industry will likely never adopt a weather program. In addition, keeping in mind that trucker weather products rely more on radar data and road sensors, improvements in satellite weather information may not directly generate enormous benefits to the trucking industry. However, based on how leading-edge truck companies operate today, we are assuming that over time, the vast majority of the industry will move toward utilization of weather information of some kind, with a preference toward the earlier warnings that satellite sensors can provide.

To err on the side of conservatism, we assume that benefits on the order of 0.5% of the current jackknife related industry costs could be avoided with more relevant, accurate, timely, and consistent satellite weather data. Based on this assumption, after 5-6 years, annual savings would average $7.6M. This translates into approximately 30 jackknifes avoided per year based on improved GOES-R data. (Note that the statistics on jackknifes includes more than just weather-related jackknife incidences, whereas the statistics used in the first approach looked at weather-related accidents of all kinds, including jackknifes.)

Note that at the inception of this case study, it was determined that many trucking companies do not routinely or systematically incorporate weather into overall truck network planning or scheduling in advance. Some of the logistics companies that serve the trucking industry's planning and scheduling needs indicated that they do not explicitly incorporate weather information into their models and moreover, lack the capability for the end-user (trucking network planners) to do so. For now, a significant portion of the industry still relies on radio, CB, and reports at truck-stops to get their weather information. And, for those companies that do buy services from value-added resellers of weather data, receipt of weather forecasts one or two times per day is sufficient. Based on the benefits analysis for this industry, it seems clear that there is great opportunity for this industry to benefit from the incorporation of weather data into their business model, and a need to make the industry more aware of the potential benefits that they can realize.

Section 5

Conclusions

About $2 trillion of the annual United States Gross Domestic Product is weather sensitive. The GOES satellite system, with a unique vantage point, plays a key role in continuously monitoring a wide variety of environmental phenomena and providing weather data used to generate a wide variety of products and forecasts. NOAA plans to launch these satellites with new and improved instruments in the 2012 time frame. The GOES-R imager and HES sounder instruments represent a substantial step forward in spatial, spectral, and temporal resolution compared with the current imager and sounder. NOAA expects that these new sensors will significantly improve the capability of the United States to detect, monitor, track and forecast weather phenomena of great importance to the nation.

In order to assess whether it is justified to proceed with these new instruments, a marginal cost-benefit analysis was carried out. Estimates of the cost to develop and procure the GOES-R imager and sounder, as well as other new instruments that would achieve the same performance as the current imager and sounder were developed and compared. Marginal economic benefits from improved weather information and products based on GOES-R imager, and GOES-R sounder data were also estimated.

It is important to recall that the case studies developed and presented in this paper represent just a sampling of economic sectors and domains within those sectors from which economic benefits can be realized. The total *annual* marginal benefits from these eight cases alone are approximately $638M with discounted present value (over the GOES-R series lifecycle) of approximately $3.1B. In addition, the benefits presented in this paper were based on extremely conservative (low) estimates of operational improvements, which could easily be nominally higher and result in much larger benefits. We expect to determine additional benefits in areas such as commercial shipping and emergency management as well as in a broader examination of agriculture. However, it appears evident with the existing studies that performance improvements achieved by GOES-R will result in billions of dollars in benefits to the industries and the populace of the United States.

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Appendix A

Public Meetings and Telephone Interviews

Phase I

Interviews	Organization	Name of Interviewees	Name of Interviewers	Date	Topic
1	NESDIS	"G. Dittberner, J. Gurka, C. Hostetler, J. Gurka"	MITRE	"September 7, 2001"	Forecast and other satellite product improvements
2	NESDIS	"S. Kirkner, J. Gurka, C. Hostetler"	MITRE	"September 10, 2001"	Forecast and other satellite product improvements
3	"NWS, National Centers for Environmental Prediction"	"L. Uccellini, R. Peterson, P. Menzel, C. Hostetler, K. LaSala"	MITRE	"September 17, 2001"	Forecast and other satellite product improvements
4	"NESDIS, Office of Research and Applications "	"D. Tarpley, M. Weinreb, G.Ellrod, J.Daniels, P.Menzel, T.Schmit, J.Purdom, R. Aune, C. Hostetler, K. La Sala"	MITRE	"September 17, 2001"	Potential benefits from GOES ABI and ABS to the Aviation Industry
5	National Academy of Sciences	"J. Friday, M. Crison, C. Hostetler, K. LaSala"	MITRE	"September 18, 2001"	Forecast and other satellite product improvements
6	NESDIS/Cooperative Institute of Meteorological Satellite Studies (CIMSS	T. Schmit	MITRE	"September 20, 2001"	Forecast and other satellite product improvements
7	"NESDIS, Office of Satellite Data Processing and Distribution "	"R. Lawrence, T. Renkevens, J.Gurka, S. Nauman, K. LaSala, C. Hostetler"	MITRE	"September 21, 2001"	Forecast and other satellite product improvements
8	National Weather Service	"A. Noel, J. Heil, S. Kiser, M. Andrews, K. LaSala, C. Hostetler"	MITRE	September 27. 2001	Forecast and other satellite product improvements
9	National Weather Service	"S. Lord, R. Peterson"	MITRE	"October 1, 2001"	Potential forecast and other satellite product improvements from GOES ABI and ABS
10	NASA	"W. Smith, K. LaSala"	MITRE	"October 2, 2001"	Forecast and other satellite product improvements
11	National Weather Service	"W. Smith, K. LaSala"	MITRE	"October 10, 2001"	Forecast and other satellite product improvements
12	Air Transportation Association	R. Gold	MITRE	"October 12, 2001"	Convective Weather Avoidance
13	PJM Interconnect	D. Delgiorno	MITRE	"November 2, 2001"	Electric Power Load Forecasting
14	RGA Labs	R. Abboud	MITRE	"November 2, 2001"	Electric Power Load Forecasting
15	Tennessee Valley Authority	L. Akens	MITRE	"November 7, 2001"	Electric Power Load Forecasting
16	"FAA, Air Traffic Control Command Center"	D. Rodenhuis	MITRE	"November 9, 2001"	Convective Weather Avoidance
17	"Deputy State Statistician, State of	J. McCall	MITRE	"November 12, 2001"	Frost/Freeze Mitigation in Orchards (Citrus)

	Statistician, State of Washington"			2001"	(Citrus)
18	"US Department of Agriculture, Northern Plains Agricultural Research Laboratory"	R. Evans	MITRE	"November 12, 2001"	"Frost/Freeze Mitigation in Orchards (Apples, Grapes)"
19	"Washington State University, Grant-Adams Cooperative Extension"	K. Lewis	MITRE	"November 12, 2001"	Frost/Freeze Mitigation in Orchards
Public Meetings	Sponsor	Name of Interviewees	Name of Interviewers	Date	Topic
1	"NOAA, Silver Spring, MD"	"Raymond Ban (Weather Channel), Larry Denton (Consultant to the Weather Channel), John Malay, (Ball Aerospace), Ed Miller (Airline Pilots Association)"	"MITRE, Ken LaSala"	"October 23, 2001"	Aviation
2	"NOAA, Silver Spring, MD"	"Maria Pirone, (Weather Services International)"	"MITRE, Ken LaSala"	"October 24, 2001"	Forecast and other satellite product improvements
3	"NOAA, Silver Spring, MD"	"Carlos Martinez (TMC), Marv Maxwell (Swales Aerospace), Will Merritt (Computer Sciences Corporation), John Shultz (IBM)"	"MITRE, Ken LaSala"	"October 25, 2001"	Forecast and other satellite product improvements
4	"NOAA, Silver Spring, MD"	"Russ Koffler (independent consultant, former NESDIS Deputy Assistant Administrator), Marilyn Wolfson, Mark Weber (MIT/Lincoln Labs)."	"MITRE, Ken LaSala"	"October 29, 2001"	"Aviation, Severe Weather"

Phase II

Interview	Organization	Name of Interviewees	Name of Interviewers	Date	Topic
1	CIMMS	Tim Schmit	MITRE	"April 8, 2002"	Hurricanes
2	NSSL	Steve Weiss	MITRE	"April 18, 2002"	Severe Weather
3	National Severe Storm Labs (NSSL)	Greg Stumpf	MITRE	"May 2, 2002"	Severe Weather – Impacts of improved forecasts/lead-time on Watches & Warnings
4	UPS Meteorologist – Aviation	Randy Baker	MITRE	"June 13, 2002"	Aviation & Trucking benefits from improved weather forecasting
5	Managing Director of Transportation for Fedex Ground	John Payne	MITRE	"June 14, 2002"	Trucking
6	DRI-WEFA	Ron Denhardt	MITRE	"June 18, 2002"	Assessing impact of improved weather forecasts on Natural Gas Utilities
7	" DOE, Energy Information Administration"	Phyllis Martin	MITRE	"July 17, 2002"	Natural Gas Markets
8	Energy Working Group:	"Tim Schmit, Eric Miller, Oringer, Reining, Aikens (TVA, Patrick Walsh, Harold Brooks (NSSL), Dr. Richard Carter"	MITRE	"July 18, 2002"	NOAA Researchers and power industry participants discuss impact of expected improvements in GOES-R weather data for electricity and natural gas industries.
9	" Intermodal Operations, UPS"	Bill Taylor	MITRE	"July 25, 2002"	Purpose: To determine potential benefits of improved weather information for UPS' Intermodal Operation and to identify their critical weather needs.
10	ISO New England	Mark Babula	MITRE	"July 29, 2002"	Electric Utility/Natural Gas
11	Bay State Gas	Chico Dafonte	MITRE	"July 30, 2002"	Natural Gas
12	NSSL and U of Wisconsin/Madison	Bob Rabin	MITRE	" April 10, 2002"	Ground Convective Weather
13	NSSL	Dan McCarthy	MITRE	" April 30, 2002"	Severe Weather – Impacts of improved forecasts/lead-time on Watches & Warnings
14	Williams Energy	David Montroy	MITRE	" July 2,2002"	Natural Gas
15	" North American Van Lines, subsidiary of Allied World Wide"	Tim Hughes	MITRE	" June 12,2002"	Trucking
16	Williams Gas Pipeline Transco	Paul Lamb	MITRE	" June 21,2002"	Natural Gas
17	Stoner Associates	Dr. Richard Carter	MITRE	" June 24, 2002"	Natural Gas
18	Hydro Meteorology Services – Denver	Bryan Rappolt	MITRE	" May 15, 2002"	To determine potential benefits of enhanced GOES-R data to Hydro Meteorology Services
Public Meeting	Organization	Name of Interviewees	Name of Interviewers	Date	Topic
1	"NOAA, Silver Spring, MD"	"Tom Hickey (Raytheon), Bob Plante (Raytheon) Tom Frazier, (TRW), Cassandra Ward (FEMA)"	"MITRE, Eric Miller"	"May 7, 2002"	"Aviation, Emergency Management"

		Cassandra Ward, (FEMA) "			
3		Ed Miller – Airline Pilots Association (ALPA), Project Manager for Volcanic Ash Aviation Safety, Ron Barnovsky – WSI, Jim Jansen - Airline Dispatcher Federation, Dispatcher with UAL, Leonard Salinas – U.S. Airline Dispatcher Federation, Manager of Standards and Quality Compliance at UAL, Grace Swanson – Satellite Analysis Branch, Washington Volcanic Ash Advisory Center	MITRE, Eric Miller, Colby Hostetler	May 21, 2002	"Aviation, Volcanic Ash"
4		Ed Miller – Airline Pilots Association, Ron Barnovsky – WSI, Bedford, Dan Watt –UAL, Chicago, Jim Block – Meteorologix	MITRE, Eric Miller	May 21, 2002	Aviation

Appendix B

GOES Product List

The GOES Products and Services Catalog describes the current product and services available from NESDIS and derived from GOES. Table B-1 lists those products. This list can also be found at: http://orbit-net.nesdis.noaa.gov/arad/fpdt/goescat/html/introduction.html

Table B-1. GOES Products Listing

GOES Products	
ABBA (fire information)	Precipitation Histograms
Aircraft Icing	Radiance
ASADA (aerosol information)	RAMSDIS
AutoEstimator (rainfall)	Real-time Imagery Products
Channel Brightness Temperature	Reflectivity
Cloud (includes Cloud Effective Amount and Cloud Top Height)	Sea Surface Temperature
Density Visible Winds	Site-Specific Cloud Product
Effective Cloud Amount	Sounder-based Winds
Fog	SST-Imager
Geopotential Heights	SST-Sounder
High Density Winds	Thermal Wind Profiles
Hot Spot	Top Pressure
IFFA (rainfall)	TPW-Imager
Layer Precipitable Water	TPW-Sounder
LI-Imager	Tropical Cyclones
LI-Sounder	Vertical Temperature and Moisture Profiles
Low-Level High	Volcano Ash Advisory Statements
Low-Level Winds (includes Cloud Drift Winds and Water Vapor Winds)	Volcano Ash Product
Multichannel Precipitation	WEFAX
NH Snow and Ice Chart	WINDEX
Ozone	

Appendix C

Acronym List

ABBA	Automated Biomass Burning Algorithm
ABI	Advanced Baseline Imager
ABS	Advanced Baseline Sounder
ASOS	Automated Surface Observation System
ASADA	Automated Smoke/Aerosol Detection Algorithm
AWC	Aviation Weather Center
CBA	Cost Benefit Analysis
CCFP	Collaborative Convective Forecast Product
CER	Cost Estimating Relationship
CIMSS	Cooperative Meteorological Satellite Studies
CINH	Convective Inhibition
CONUS	Continental United States
CPI	Consumer Price Index
CY	Calendar Year
DOC	Department of Commerce
DoE	Department of Energy
EIA	Energy Information Administration
ENUM	Expected Number of Aircraft Losses
EO	Electro-optical
ESA	European Space Agency
FAA	Federal Aviation Administration
FPA	Focal Plane Array
GDP	Gross Domestic Product
GFE	Government Furnished Equipment
GOES	Geostationary Operational Environmental Satellite
IA&T	Integration, Assembly and Test
IMU	Inertial Measurement Unit
IR	Infrared
ITWS	Integrated Terminal Weather System
LFEI	Local Forecast Error Improvement

M/SEC	Meters per second
MWH	Megawatt Hours
MW	Megawatts
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Radar
NPAR	Net Proportion of Annual Repair
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPWD	Net Proportion of Weather-Related Days
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OMB	Office of Management and Budget
OPSNET	Operations Network
ORA	Office of Research and Applications
POES	Polar Operational Environmental Satellite
RMS	Root Mean Square
ROM	Rough Order of Magnitude
TVA	Tennessee Valley Authority
USDA	U.S. Department of Agriculture
WBS	Work Breakdown Structure
WEFAX	Weather Facsimile
WINDEX	Wind Index