Valuation of Drought Information: Understanding the value of the U.S. Drought Monitor in land management

May 2019

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EXECUTIVE SUMMARY

This study presents the first-ever comprehensive estimate of the economic valuation of the information provided by the U.S. Drought Monitor. In the report, we focused on the Bureau of Land Management.

Our estimate of the total cost of labor saved using the information provided by the U.S. Drought Monitor for the state and field/district offices within the Bureau of Land Management alone varies from $0.2 million to $19 million, with an average of $3.1 million. The average minimum willingness to pay for the information provided by the U.S. Drought Monitor in all the state and district/field offices is $14,400 and $32,040 per year, respectively. These estimates, which are based on limited information from survey respondents, include the avoided cost identified by users from different organizations and institutions. These estimates are based on the time and labor saved by using the U.S. Drought Monitor rather than compiling drought-related information from other sources, or using other sources for tracking/monitoring droughts, communicating drought conditions, and dealing with drought-related issues. These estimates can be used to estimate the societal benefits in different sectors and help policy makers understand whether the investment in the U.S. Drought Monitor is cost-effective.

Our results are derived from two independent surveys following interviews of people from the Bureau of Land Management. Web surveys were distributed internally through the Bureau of Land Management. Survey participants were asked how many hours they spend on compiling information provided by the U.S. Drought Monitor, with and without the U.S. Drought Monitor. In addition, we asked survey respondents whether they would be willing to pay for similar information if the U.S. Drought Monitor were not available. A follow-up question asked survey respondents how much they would be willing to pay for similar information if the U.S. Drought Monitor were not available and their agency had a budget. These two methods are consistent with methods and techniques employed by other organizations and institutions for economic valuation of climatic or meteorological information. The results reflect rational behavior—the more time needed to compile or collect drought information provided by the U.S. Drought Monitor, the higher the dollar value in avoided cost, and the higher the dollar amount respondents were willing to pay. This dollar amount also varies by institution and organization, which indicates respondents from different organizations value the information from the U.S. Drought Monitor differently. For example, compared to the state offices, the field offices in the BLM were willing to pay more for the information provided by the U.S. Drought Monitor.

Overall, a majority of survey respondents indicated that the U.S. Drought Monitor provided useful information compared to other sources. None of the survey respondents said that the information provided by the U.S. Drought Monitor is less useful compared to other sources. The features that respondents use include the current and/or archived maps; the spreadsheets, data, and/or shapefiles; the text of the drought summary; and the links to other tools representing current conditions and outlooks. Most agreed or strongly agreed that "the information from the USDM is easy to understand," "the USDM is clear in its message" and "the USDM is accurate in describing drought conditions," "the USDM is a trustworthy source of information," "the USDM provides a relevant source of accepted information," "the USDM is timely," "the USDM is respected by other key stakeholders," and "the USDM provides enough evidence for a decision maker to act upon." Two respondents somewhat disagreed that the U.S. Drought Monitor was accurate and only one person somewhat disagreed that it was timely.

This report describes our methodology in detail, including interviews, survey development and implementation, and our statistical analysis. The report also considers the policy implications of this first-ever analysis of the value of information provided by the U.S. Drought Monitor. The methodologies can be applicable to other sectors that involve tracking/monitoring droughts, communicating drought conditions, and dealing with drought-related issues.

INTRODUCTION

The National Drought Mitigation Center (NDMC) hosts and maintains the U.S. Drought Monitor (USDM), a weekly map of drought conditions throughout the United States, showing which parts of the United States are experiencing various degrees of drought. The U.S. Drought Monitor has been used by many enterprises, such as producers, commodity brokers, congressional committees, media, farm programs, and federal, state, and local government agencies, to track the status of droughts (Svoboda et al. 2002). For example, the U.S. Farm Bill has used the USDM as a trigger for various farm and ranch programs in the U.S. to the tune of nearly $7 billion in relief since 2012 alone. In this study, we only focus on the use of the U.S. Drought Monitor in the Bureau of Land Management. To understand how the USDM is used and its potential value, this study evaluated the uses of the USDM by the Bureau of Land Management through interviews and surveys. It provides an overview of the use of information provided by the U.S. Drought Monitor in tracking/monitoring droughts, communicating drought conditions, and dealing with drought-related issues.

This paper presents the first-ever estimate of the economic value of the information provided by the U.S. Drought Monitor, including both avoided costs and stated preference methods. The avoided costs include labor costs saved and other associated costs saved, whereas the values estimated by stated preference method were noted by survey respondents. The willingness-to-pay estimates are independent of the values estimated using the avoided cost method. In the first case, we asked survey respondents to estimate the numbers of hours spent tracking or monitoring drought, with and without the U.S. Drought Monitor, and the hourly wage rate of the person who tracks/monitors drought. In the second case, we asked survey respondents to state willingness to pay—how much people would pay if the U.S. Drought Monitor were not available and their agency had a budget. We also explored the possibility of using a benefit transfer method to understand the potential damage avoided to the environment by utilizing the information, but because of the lack of original research on the topic, these benefits are very hard to estimate.

Over the past 30 years, a number of studies have looked at the amount the public would pay for specific benefits provided by climatic or meteorological information in different sectors. The majority of studies focus on private users such as residents, farmers, individual organizations or institutions. Very few studies focus on the economic impact of the information provided by the U.S. Drought Monitor. None of the studies have focused on the value of the information provided by the U.S. Drought Monitor, let alone the value in two specific contexts, the Bureau of Land Management.

Our study began with a literature review that summarized all the methods for valuing public goods, focusing on climatic and meteorological information, including the market approach, the avoided costs approach, the non-market approach, and the benefit transfer method.

The present study is the first to look at the value of the information provided by the U.S. Drought Monitor. It addresses the broader question of the overall economic value to the Bureau of Land Management.

It is impossible to fully capture the value of information provided by the U.S. Drought Monitor because it is widely used in many sectors, and the potential for damage avoided is vast and complex. Because of lack of information, we cannot estimate market expenditures that would have been incurred to prevent or mitigate the impacts of drought. Some disasters and damages to BLM-managed lands can be avoided, ecosystems can be protected from overgrazing and wildfires, and cases of drought-related diseases may be reduced (through lives saved and reduced hospital visits). If more data were available, we could use the benefit transfer approach to measure avoided costs to ecosystem services.

Additionally, we made conservative assumptions in estimating respondents' values of the information provided by the U.S. Drought Monitor and interpolating the survey results to the sector. For example, we assume there is only one person tracking or monitoring drought for a district/field office that has less than 10 people; between 2 and 10 people tracking or monitoring drought for district/field offices that have more than 10 people and all the state offices. We focused on BLM using avoided costs of labor and other associated costs, so this study only provides rough estimates, substantially less than the total value that the U.S. Drought Monitor provides.

The respondents provided insight into two types of costs that the USDM helps them avoid. The first set of avoided costs is the effort and resources they would need to commit to generate data and maps comparable to the USDM. The second set of avoided costs is potentially larger but harder to measure: costs avoided by using early warning information to mitigate the effects of drought.

We devised surveys for BLM employees based on what we learned in interviews. We used questions about employees' salary ranges and time spent gathering information on drought to estimate how much it would cost the BLM to come up with similar information in the absence of the U.S. Drought Monitor: the total avoided cost per year for all BLM state offices and district/field offices alone varies from $0.2 million to $19 million, with an average of $3.1 million.

INTERVIEWS

1.1 INTRODUCTION

The study is designed to address two questions:

- Are the targeted stakeholders using the U.S. Drought Monitor in ways that improve their decision-making?
- What is the economic value to the decision makers of the information provided by the U.S. Drought Monitor?

To begin to develop estimates of measures of the value of the USDM based on how it is used in decision-making, NDMC, supported by Cadmus, conducted one-on-one interviews. Interview subjects were from the Bureau of Land Management, and, as a test of the interview protocol, the Central Nebraska Public Power and Irrigation District.

We used information from the interviews to develop survey instruments to learn more about how Bureau of Land Management personnel use the U.S. Drought Monitor, and what the avoided cost value is for those groups of users.

1.2 PARTICIPANT SELECTION

Using NDMC's contacts from workshops and other interactions with stakeholders, NDMC developed a list of the organizations and individuals that use the data.

The National Integrated Drought Information System (NIDIS) reviewed the list. NDMC contacted potential participants, sending email invitations in April and scheduling phone interviews in May and early June. We also used snowball sampling, which means the potential interview participants can refer others for potential interviews. Each interview was conducted using Zoom, which let NDMC share screens with the interview participants. Three people from NDMC and Cadmus interviewed each participant, including a note taker. The interviews lasted up to one hour and followed a set interview protocol. The protocol, which is in Appendix C, provided the information that was required and the questions to be addressed. The interviews followed the protocol, but were not scripted. Instead, the interviews were open and flexible, based on the experience of the interview subject and the information they provided.

To fine-tune the interview questionnaire, the NDMC conducted a trial run with participants from the Central Nebraska Public Power District, which operates a reservoir, generates hydropower and delivers water for irrigation. Although CNPPD does not fit within BLM, results are included here because the interviewees articulated their use of the USDM in decision-making in a way that is relevant beyond their sector.

1.3 SUMMARY OF INTERVIEWS

The interviews focused on how the individuals and their organizations use the USDM, its value to their organization, and their overall view of the USDM. The interviews provide information about

- The types of decisions and communication the USDM supports
- Potential complements and alternatives to the USDM that are available and are being used
- What resources—levels of effort and dollars—they would use to replace the USDM

USES OF THE USDM

Most of the individuals interviewed were familiar with the USDM and use it to support their work. In some cases, it is used, together with other information, to trigger actions or decisions. For example, BLM uses the USDM to determine industrial fire management response, grazing allotment, and when to turn cows out. Central Nebraska Public Power and Irrigation District uses the USDM, as well as data on snowpack, lake levels, and other information, to manage their reservoirs.

OTHER SOURCES OF INFORMATION

The people interviewed do not rely solely on the USDM, but use it in concert with other data. Central Nebraska uses several sources to monitor drought conditions, including data on river flow, snowpack, precipitation, and the USDM. They rely on the USDM for historical data and comparisons to current conditions. In some cases, additional information about the method used to describe drought conditions is needed to support the use of the USDM.

MEASURES OF THE USDM'S VALUE

Overall, the interview subjects were familiar with the USDM and found it very valuable. They trust it, find it easy to use, and have a great deal of confidence it the information it provides. It is a critical source of information that supports research, communication, and policy decisions. A recurring theme in the interviews was that the USDM increases the efficiency and confidence with which agency personnel make drought-related decisions and communicate about drought.

The respondents could not place a dollar value on what they would be willing to pay for this type of information for several reasons: The subjects interviewed were in public agencies and do not directly control spending. They rely on publicly available data that they get through the federal government or other sources. Many, if not all, face tight budgets, and would not be able to pay for the data. Many of the alternatives to the USDM also are available with no charge.

The respondents provided insight into two types of costs that the USDM helps them avoid. The first set of avoided costs is the effort and resources they would need to commit to generate data

and maps comparable to the USDM. These are administrative costs avoided by the USDM. The Corps of Engineers would need to get climate data from other sources and analyze and massage them to make them presentable. BLM would look for alternative sources, but recognizes they may not be as reliable.

2. LITERATURE REVIEW

2.1 INTRODUCTION

Need for timely information to cope with extreme weather

Evidence has shown that extreme weather events, such as hurricanes and droughts, have increased in the past five decades, and people are experiencing more frequent heat waves, heavy storms, and severe floods (National Climate Assessment, 2014). Long-term strategies for mitigating impacts of extreme weather include sustainable land use and land planning, land management practices, sustainable infrastructure and education at the state and local levels. In the short run, climatic and meteorological information can provide communities with real-time notification and/or forecasts of these extreme events, which help people respond in time to protect property and save lives. Timely and accurate climatic and meteorological information is critical for people's decision making. This information is typically provided by government for free. This public information can be of great of value to households, sectors, regions, states, and countries in terms of making decisions on household activities, land use management, crop and livestock planning, disaster preparation, and relief. Private providers lack sufficient incentives to deliver comparably timely weather and climate information because of its public good characteristic. Because the information is available to users at no additional cost, governments, who are most often the providers of such information, may not know the potential benefit of the taxpayers' money. Finding a way to assign a value to the information, in the absence of a price, would help decision-makers conduct cost-benefit analyses to decide whether to continue to allocate resources to providing weather and climate information.

Assigning value to climate and weather information

Because climatic and meteorological information is widely used to support local, regional, tribal, state and national agencies' decision making, efforts have been made to value the information. The valuation of the climatic and meteorological information can be used to estimate the societal benefits from government investment and understand societal benefits of disaster prevention and management. Research has been conducted in both developed and developing countries, including Vietnam, China, Australia, Korea, Switzerland, and the United States (Kenkel and Norris,1995; Anaman and Lellyett, 1996; Labao Wang et al., 2007; Lazo et al., 2009; Frei, 2010; Park et al., 2016). Although many efforts have been made, efforts in some sectors have been more focused than others. For example, many of the studies have focused on farmers and local decision-makers utilizing the climatic and meteorological information. land management sector has been less examined. Additionally, better understanding of the literature on valuation of climatic and meteorological information can provide some useful methods and tools to guide future research on those less examined sectors.

Past approaches

This section reviews a range of previous efforts, from valuation of public information on drought, climate, early warning systems, and other metrological products such as weather forecasts, to satellite images. Existing literature tends to fall into three categories: applied economic studies,

agent-based models (ABMs), and literature reviews. Methods and tools that have been explored to examine benefits of climatic and meteorological information include avoided cost, contingent valuation, choice experiments, benefit transfer, and descriptive approaches using surveys to understand use of this information.

The keywords we used for our literature search were "valuation", "cost-benefit", "drought information", "climate information", "meteorology information", and "Early Warning System". We conducted the literature search through Web of Science and Google Scholar. We found 17 peer-reviewed papers and two reports. Different types of information have been valued in the literature, including Landsat Satellite imagery, an early warning system for tropical cyclones, a heat watch/warning system, forecasted drought information, meteorological information, and weather (forecast) information worldwide (Table 1). We found that that there have been significant efforts to understand the value of the information. Five studies summarized the literature, including case studies, methods of valuation on hydro-meteorological systems and meteorological information (Malik et al., 2014; Leviäkangas, 2009). In addition, a number of empirical studies focused on different sectors (agriculture, residential, energy, health, multiple sectors and all sectors). For a complete list of these papers, please see Table 1.

2.2 METHOD

We reviewed the methods that have been used in the valuation of climatic and meteorological information. We found four basic types of methods: direct and indirect valuation methods, and market and non-market approaches. For example, for information traded on the market, the value can be easily calculated based on the price reflected in people's purchase behaviors. However, for public information, it is important to note that there is no standard approach, and the valuation of information may vary by sector. For such information with non-market values, both contingent valuation and choice experiments can be used to examine the value of the information.

2.2.1 Direct market approach:

The direct market approach uses market prices and quantities to estimate the extractive direct use of the information or services, such as crop or livestock revenues. For example, in addition to weather forecast and visualization such as the radar that free weather apps offer, a paid weather app provides additional services and customization, such as an alarm if the heat index is forecast to hit 100 degrees Fahrenheit (IFAI, 2017). This can help decision-makers and vulnerable individuals prepare for extreme events and, if necessary, evacuate ahead of time. The Climate Corporation, a subsidiary of Monsanto Company, has developed a tool called FieldView, incorporating field data, advanced agronomic modeling and local weather monitoring into a simple mobile and web software platform. They said the tool can be used to help farmers understand their fields better and make more informed decisions to optimize yields, maximize efficiency and reduce risk (Monsanto.com, 2018). In 2017 they had more than 120 million platform acres and paid offerings on 35 million acres. They offer advanced seed prescription and nitrogen monitoring by zone bundled together for $4 per acre, or farmers can purchase either advanced seed prescriptions or nitrogen monitoring by zone for $3 per acre for the crop season (Monsanto.com, 2018). Using the direct market approach, the estimated value of the FieldView Pro ranges from $105 to $140

million. If we account for other related products (including FieldView prime and plus) in the estimation, the value of the tool is much higher.[1]

2.2.2 Indirect market approach:

Because of the public nature of the climatic and meteorological information, market prices do not exist most of time. Another commonly used indirect method is avoided cost. This method refers to the costs that people avoid by using the climatic and meteorological information, such as estimating market expenditures that would have been incurred to prevent or mitigate the impacts of drought. Some disasters and damages can be avoided or reduced in agriculture, transportation, health, power generation, and recreation, and the benefits of these prevention and mitigation actions can be translated into monetary terms. For example, Ebi et al. (2004) did benefit-cost analysis of Philadelphia Hot Weather-Health Watch/Warning System (PWWS) and found that issuing an individual warning lowered daily mortality by about 2.6 lives on average. They chose to use a $4 million value of life in the benefit estimate. They conclude that the net benefits of the issued heat wave warning were around $468 million over 1995-98. Kite-Powell (2005) examined the NOAA PORTS information in navigation of Houston/Galveston, and found that $11.9 million in direct annual benefits can be attributed to PORTS data with a reasonable degree of confidence. Von Gruenigen et al. (2014) examined the economic benefit of meteorological services to Switzerland's domestic airlines by analyzing the use of terminal aerodrome forecasts at Zurich Airport. By extrapolating the results based on the number of flights, the total economic benefits of TAF to Switzerland's domestic airlines add up to 13-21 million Swiss francs per year. Sharda and Srivastava (2016) used scenario analysis to estimate avoided cost (both in volumetric and economic savings) if water management adjustments are made based on the ENSO drought forecast information. They estimated that the forecast information could have saved $1,183,308 and $491,783 during winter to summer seasons for 1999-2000 and 2007-2008, respectively. Table 1 summarizes the literature that has examined the values of climatic and meteorological information using avoided cost method.

2.2.3 Stated Preference Methods:

The stated preference method has been widely used for estimating the economic value of public goods or services. It has also been used in valuation of climatic and meteorological information, using both contingent valuation (Kenkel and Norris, 1995; Anaman and Lellyett, 1996; Rollins and Shaykewich, 2003; Lazo et al., 2009; Loomis et al., 2015; Park et al., 2016) and choice experiments (Nguyen et al., 2015). The contingent valuation method attempts to measure the value that people place on a particular public good or service taken as a specific bundle of attributes (National Research Council, 2005). The choice experiments method builds on the idea that the value of a good is a reflection of its characteristics, and it requires the respondents to compare and select (rank or rate) alternative combinations of goods and policy characteristics. Contingent valuation generally poses a written or verbal description of the change to be valued, while choice experiments pose the changes in terms of changes in the attributes of the item to be valued (National Research Council, 2005). Contingent valuation typically asks respondents to state their value directly or indicate a range in which the value resides in an open-ended or closed-ended

[1] FieldView prime is free product and FieldView plus has an annual prescription fee of $999.

question, while in choice experiments, survey respondents would be given alternatives to consider and asked to choose the preferred alternatives or rank the alternatives (National Research Council, 2005). The contingent valuation method is often criticized because of the problem of protest bids. Several types of protest bids may occur: some survey respondents may not answer, some may give positive but invalid bids (outliers), and others may state zero value for a good or service that they actually value (Halstead, 1992). These bids may potentially bias the willingness to pay (WTP) results, and thus special attention and treatments are needed.

Kenkel and Norris (1995) investigated real-time mesoscale weather information using the contingent valuation method among agricultural producers in Oklahoma. Their findings show that agricultural producers in Oklahoma do not appear to be willing to pay significant fees to access improved weather information, despite the perceived usefulness of weather information and impact of weather on farm income and profitability. Results show that on average producers are willing to pay $5.83 per month for raw mesoscale data and $6.55 per month for the raw data plus value-added weather-related products. The anticipated income from user fees could cover as much as half of those costs using the conservative estimates of aggregate WTP for the raw weather data. Rollins and Shaykewich (2003) used the contingent valuation method to examine the weather forecast Automated Telephone Answering Device in multiple sectors (institutes, hotel/catering, construction, landscape/snow, recreation/sport, TV/film, agriculture, and others). They found the average value per call varied by commercial sectors, from $2.17 for agricultural users to $0.60 per call for institutional users, with an overall mean of $1.2 per call. This would result in an estimate of benefits to commercial users of $16,500,000 per year based on roughly 13,750,000 commercial calls annually. Park et al. (2016) conducted a contingent valuation survey of 1,000 randomly selected households in Korea in 2014. They used a one and one half bound dichotomous choice question to derive the WTP responses and applied a spike model to deal with WTP responses of zero. The median additional WTP per household was $0.75 per month and the monthly expenditure was $1.26 per household as of 2013. The economic value thus was $2.01 per household per month, which aggregates to $445 million per year. Lazo et al. (2009) focused on people's attitudes and behaviors about specific weather forecast information. The paper examined the sources, perceptions, uses and values of weather forecast information using the contingent valuation method. The results showed a net benefit of $26.4 billion a year ($31.5 billion in benefits minus $5.1 billion in costs) to households. In a similar study, Loomis et al. (2015) surveyed users worldwide in 2012 by asking about WTP for one scene covering the area equivalent to a Landsat Scene. Responses ranged from $10 to $20,000 (one out of 20 different dollar amounts randomly).

The use of choice experiments is relatively new for nonmarket valuation of climatic and meteorological information, and very few choice-experiment studies have been undertaken. Nguyen et al. (2015) is the only study that we found using a choice experiment to examine climatic and meteorological information. They estimated the benefits of an improved cyclone warning service to households in Vietnam. They did choice experiments surveys and found the benefit estimates of the maximal improvements in a number of attributes of cyclone warning services (i.e., forecasting accuracy, frequency of update, and mobile phone based warnings) are approximately $7.1 – $8.1 per household, which would be an upper-bound estimate.

2.2.4 Benefit transfer

The benefit transfer method, which is always referred to as the second-best approach, is often criticized because people's willingness to pay for the particular climatic and meteorological information may vary across sites and even time (Liu, 2014). Errors may occur if researchers rely on prior studies and transfer others' estimates directly into their own analyses. Despite this caveat, the benefit transfer method serves as a low-cost screening technique for further valuation studies (Liu, 2014). Frei (2010) used the benefit transfer method to value the information of meteorology and climatology. In this pilot study, the author calculated the economic benefit of meteorological services in Switzerland by extrapolating the values of meteorological services in households, agriculture, and energy sectors from previous literature worldwide (e.g., Anaman and Lellyett, 1996). The study shows that it is hardly possible to estimate one single figure representing the total benefit of weather services in Switzerland. However, it is possible to work out specific answers concerning particular benefits within specific sectors.

Table 1: Summary of the papers/reports examining the values of climatic and meteorological information

Authors	Types of information	Sector	Study Area	Methods
Bernknopf et al. (2017)	Remoted sensed information: the case of GRACE Drought Severity Index	Agriculture	All U.S. counties with corn production information (USDA ARS, BEA)	Bayesian decision framework
Sharda and Srivastava (2016)	El Niño Southern Oscillation (ENSO) forecasted drought information	Residential	Auburn, AL (with 55,000 people)	Avoided cost
Loomis et al. (2015)	Landsat Satellite Imagery	All sectors	All users worldwide	Contingent Valuation
Nguyen et al. (2015)	Early Warning System for tropical cyclones	Residential	Vietnam	Choice Experiments
Malik et al. (2014)	Hydro-meteorological systems	Multiple users/sectors	Worldwide	Literature review
Leviäkangas (2009)	Meteorological information	N/A		Literature review
Frei (2010)	Meteorology and climatology information	Household, Ag, and Energy	Switzerland	A case study using benefit transfer
Anaman and Lellyett (1996)	Weather information	Household	Sydney, Australia	Contingent Valuation
Rollins and Shaykewich (2003)	Weather Forecast Automated Telephone Answering Device	Multiple sectors (institutes, hotel/catering, construction, landscape/snow, recreation/sport, TV/film, agriculture, and others)	Toronto, Canada	Contingent Valuation
Ebi et al. (2004)	Heat Watch/Warning System	Health	Philadelphia, PA	Avoided cost
Freebairn and Zillman (2002)	Meteorological services	N/A	Worldwide	Literature review
Park et al. (2016)	Meteorological services	Household	Korea	Contingent Valuation
Kenkel and Norris (1995)	Real-time mesoscale weather information	Agriculture	Oklahoma	Contingent Valuation
Frei et al. (2014)	Meteorological services	Transportation	Switzerland	Surveys
Perrels et al. (2013)	Weather and climate services	N/A	Europe	Literature review
Von Gruenigen et al. (2014)	Meteorological services	Transportation/aviation	Switzerland	Avoided cost
Rogers and Tsirkunov (2011)	Early Warning System	N/A	worldwide	Literature review paper
Lazo et al. (2009)	Weather forecasts	Household	U.S.	Contingent Valuation

Kite-Powell (2005)	NOAA PORTS information	navigation	Houston/ Galveston, U.S.	Avoided cost

2.3 DROUGHT AND LAND MANAGEMENT

The Bureau of Land Management's mission is to sustain the health, diversity, and productivity of public lands for the use and enjoyment of present and future generations (BLM, 2019). The Bureau of Land Management manages public lands to maximize opportunities for commercial, recreational, and conservation activities including energy development, timber harvesting, grazing, and recreation, including hunting and fishing (BLM, 2019). Drought affects land management and ecosystem services, including the supply and quality of water resources for municipal, industrial and agricultural use (Chang and Bonnette, 2016; Covich, 2009; Rosegrant, 1997). Drought can also have important indirect effects for the ecosystems and species that rely on water.

2.3.1 Recreation

The public lands managed by the BLM offer more recreational opportunities than lands managed by any other federal agency, with more than 99% available for recreation with no fee – a public good, provided without a market. In 2016, BLM lands received more than 64.6 million recreation-related visits (BLM, 2017b). Climate indirectly affects nature-based tourism by impacting the physical resources that define the nature and quality of natural environments on which mountain tourism depends (i.e., climate-induced biophysical change). Any changes in the natural characteristics of mountain environments could negatively influence tourism by reducing the perceived attractiveness of the region's mountain parks (Elsasser and Burki, 2002; Scott, 2003). Although access to public lands is free, there is an economic benefit to local economies surrounding lands used for recreational activities. Ward et al. (1996) examined the economic value of water in recreation using visitors' data before and during the 1985-1991 California drought. They found that annual recreational value per acre-foot (1,234 m^3) of water varied from $6 to $600. As another example, drought conditions during the summer of 1988 contributed to widespread forest fires in Yellowstone National Park, which resulted in evacuations of campgrounds and seasonal visitor accommodations being closed four weeks earlier than normal (Franke, 2000). Total annual visits to Yellowstone in 1988 were reduced 15 percent (compared to 1987) and park officials estimated that the forest fires resulted in a loss of tourism-related economic benefits of $60 million (Franke, 2000). Schneckenburger and Aukerman (2002) analyzed the economic effects of the 2002 drought on Colorado's recreation and tourism industry. The estimated revenue decline due to the 2002 drought was around 20 percent, about $1.7 billion, both directly and indirectly in Colorado's tourism and recreation sectors. Enormous and severe drought impacts were found for state and county parks, the boating industry, the rafting industry, the fishing industry, the ski industry, and regional small business such as hotels and motels. Hart (2002) found that the drought of 1977 in Colorado caused a 40 percent reduction in lift ticket sales and a 15 percent drop in employment. In another study, Leones et al. (1997) examined the impacts of streamflow depletion on rafting businesses in northern New Mexico counties. They found that the lower water levels generally had negative effects on daily visitor numbers and rafting-related expenditures, but the magnitude of the impacts depended on the characteristics of the river courses.

Many researchers have documented the effects of drought on tourism and recreation. Closing recreation sites is one potential BLM response to drought, and in-depth research could reveal the cost to local economies. However, the question of whether drought monitoring tools were used in the decision – as opposed to an on-site assessment of local conditions – is a separate one, as would be the value of those tools in making the decision. In that case, closing a recreation site would probably be a negative for the local economy, balanced against a public good such as protecting the long-term capacity of the site to provide ecosystem services.

2.3.2 Grazing

In 2016, the BLM permitted 12 million animal unit months (AUMs) for ranchers who graze their livestock, mostly cattle and sheep, on public lands. An AUM is the amount of forage needed to feed a cow and calf or the equivalent for one month (BLM, 2017b). In 2016, the grazing fee was $2.11 per AUM (BLM, 2017b). While the number of AUMs sold each year remains relatively steady, annual variations in use occur because of factors such as drought, wildfire, market conditions, and restoration projects (BLM, 2017b). Figure 1 shows the total number of grazing permits and leases from 2001 to 2017. The severe droughts in 2002 and 2012 may have influenced the total number of grazing permits and leases. Despite the fact that BLM and the Forest Service spend more managing the grazing programs than they collect in grazing fees, drought and wildfires may have an impact on the acreage available for grazing (Congressional Research Service, 2016). The droughts in 2002 and 2012 have contributed to $190,006 and $516,989 losses in terms of grazing fees correspondingly when compared with the number of AUMs in 2001, based on grazing fees of $1.43 per AUM in 2002 and $1.35 per AUM in 2012 (Congressional Research Service, 2016).

A close look at what tools play a role in decisions to reduce grazing permits and leases in drought years will help shed light on which if any climatological drought monitoring tools were used. Parsing the contribution of each indicator would be an additional challenge.

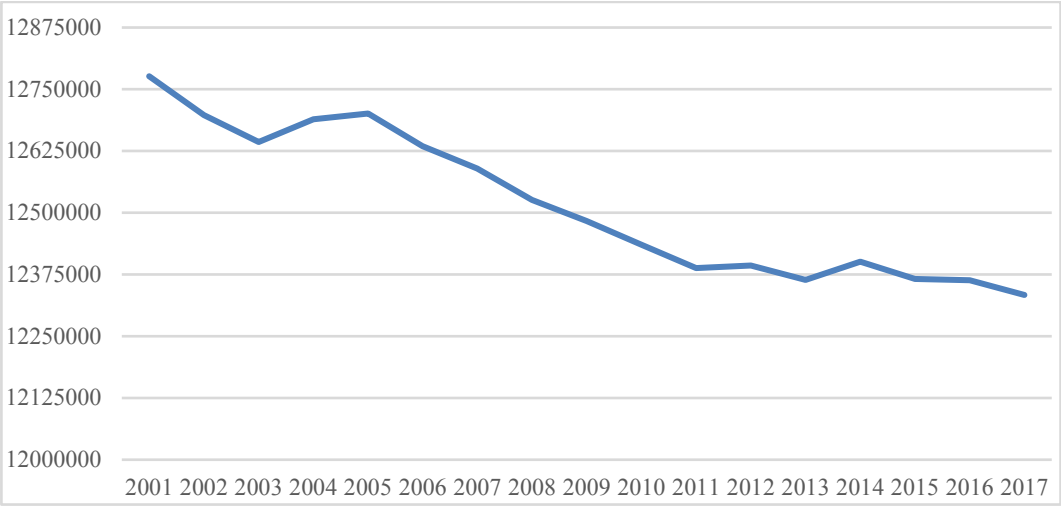


Figure 1: The total number of grazing permits and leases: animal unit months (AUMs) from 2001-2017. Source: BLM Public Land Statistics (BLM, 2001-2017a)

2.3.3 Forest and Timber

Forest ecosystems cover approximately 30 percent of Earth's land surface and provide numerous ecological, economic and aesthetic benefits across many spatial scales (Anderegg et al., 2012). One-fourth of the 245 million acres of lands managed by the BLM are forest ecosystems, spread across 13 western states, including Alaska (BLM, 2017b). Through responsible management of these lands, the BLM ensures the health and resilience of the nation's public forest lands as well as the availability of traditional forest products, such as timber (BLM, 2017b). In 2016, the BLM offered 233.2 million board feet of timber for sale. This number has remained relatively steady over the past decade (BLM, 2017b). Forests are very vulnerable to drought and temperature extremes. Anderegg et al. (2012) reviewed more than 150 studies documenting the global trend of forest mortality, and identified 41 studies around the world on drought- and heat-induced forest mortality. Anderegg et al. (2012) also found extreme drought events can directly alter fungal, microbial and animal communities, which have an indirect impact on the forest mortality. Drought may have an impact on the timber production. Klos et al. (2009) found some tree species are sensitive to drought, while others are tolerant of drought. The observed differential growth and mortality rates among species groups may alter the species composition of southeastern U.S. forests if drought episodes become more frequent and/or intense. Drought-related forest mortality may further influence other ecosystem services that rely on forests. Forest mortality can in some cases increase the overall yield of the watershed, and increase flood risks because of tree canopy loss. Forest mortality could also decrease water turbidity and quality and increase runoff, erosion and stream siltation in steep terrain (Anderegg et al., 2012). Forest die-off may increase the risk of wildfires and respiratory health-related issues. Forest mortality can also decrease cultural and esthetic values. For example, economics studies show that significant decreases in property values followed forest mortality in California and New England (Anderegg et al., 2012). Price et al. (2010) studied the impact of forest die-off on property values in Colorado. They found that property values declined by $648, $43, and $17 for every tree killed within a 0.1, 0.5, and 1.0 km buffer, respectively.

Further research may determine whether BLM alters the amount of timber for sale based on drought, and if so, what information goes into the decision.

2.3.4 Other Ecosystem Services

Droughts can diminish water flow, thereby concentrating organisms and chemicals, and may reduce water for basic hygiene and decrease water quality in pools and lakes (Rose et al., 2001; Yoder et al., 2004). Other ecosystem services can also be greatly influence by drought. We adapted the table of Compton et al. (2011) and summarized ecosystem services and human benefits affected by drought.

Table 2: Ecosystem services and human benefits affected by drought (adapted from Compton et al. 2011)

Ecosystem Services	Drought impacts on human benefits	Mechanism of impact
Production of food and materials	-	Reduced crop production and nutritional quality of food crops
	+/-	Increased livestock production in the short term due to the water shortage; reduced livestock production in the long run during drought
	-	Reduced production of building materials and fiber for clothing or paper
	-	Reduced agricultural and wood production due to the lack of water
	-	Soil erosion, nutrient imbalances, altered species composition and diversity and other natural ecosystems, which ultimately impact stability and resistance to disease, invasive species and wildfires
Energy production	-	Reduced hydro-related power production; power plants may need to be shut down; a switch from coal to natural gas for utility providers; increased demand for air conditioning during heat wave/drought
	-	Increased demand for energy for pumping groundwater or surface water during drought
Clean air	-	Increased poor air quality due to dust or particles, dust bowl and wildfires
	-	Increased water demand from consumers

Drinking water	-	Increased airborne and dust-related disease such as Valley fever
	-	Increased contaminate levels in source waters can lead to diminished source water and can affect treatment costs and the ability to meet drinking water standards
	-	Increased outbreaks of waterborne diseases including E. coli and other viruses
Swimming	-	Increased outbreaks of waterborne diseases including E. coli and leptospirosis
	-	Harmful algal blooms that make the water unsafe for swimming
Fishing	-	Increased hypoxia and harmful algal blooms in coastal zones, closing fish and shellfish harvests
	-	Increased hypoxia and harmful algal blooms in lakes and ponds
	-	Reduced number and species of recreational fisheries
Hiking	-	Altered biodiversity, health and stability of natural ecosystems
Aesthetics	-	Reduced scenery aesthetics due to altered biodiversity, unhealthy and unbalanced natural ecosystems
Visibility	-	Increased dust in air stimulates formation of particulates, smog and regional haze
Cultural and spiritual values	-	Altered biodiversity, food webs, habitat and species composition of natural ecosystems
	-	Damage to buildings and structures due to drought; people may abandon their houses and migrate
	-	

Greater impact on poor communities compared to more prosperous communities

3.
Valuation of the U.S. Drought Monitor–Bureau of Land Management Survey Data Analysis

3.1 INTRODUCTION

To begin to develop estimates of measures of the value of the USDM, NDMC conducted detailed studies in the Bureau of Land Management through one-on-one interviews. These studies provided information about how the USDM is used and initial assessments of how to measure the value of the USDM to its users. The information collected through the interviews was used to develop a survey instrument targeted to specific USDM users, including employees of the Bureau of Land Management, who manage public lands primarily in the more-arid western states. The survey to assess the value of the USDM to the Bureau of Land Management was conducted in the fall of 2018. The survey included questions about whether the USDM is used, how it is used, qualitative measures of its value, and questions about its potential monetary value. The BLM questionnaire was distributed via Scott Davis, BLM National Operations Center, Denver, who introduced the survey on one of the regular BLM Resources and Minerals Committee phone calls and then distributed it along with post-call materials to about 330 field-level managers and state office deputy-level managers through emails. We received 43 responses to the BLM survey, and 35 people have completed the survey, which is an effective 11 percent response rate. The geographic locations of our survey responses represented all the BLM's western state offices. The questionnaire is shown in Appendix B.

We added multiple filters throughout the survey questionnaire so the respondents irrelevant to the questions were filtered out gradually. More specifically, the first filter was "Does your agency address any of the following issues that are potentially affected by drought or lack of precipitation"? If the answer was "No, we don't address any of these issues or any other drought-related issue", then we asked the respondent to stop the survey and provide a reference to someone with responsibility in these areas to take the survey. Among the 35 people who completed the survey, none of them answered "No, we don't address any of these issues or any other drought-related issue". Thus nobody was filtered out for the question. We asked respondents "Do you work in a role or position related to the issue(s) that you checked above (that is / are affected by drought or lack of precipitation?)" If the answer was "No", we asked the respondent to stop the questionnaire and provide a referral. Among the 35 respondents who completed the survey, nobody chose "No". Thus we kept all the 35 respondents. We asked respondents "Does your agency track or monitor the location or severity of drought for any purpose"? If the answer was "No" or "I don't know", we asked them to stop the survey and provide us a referral. Four respondents were filtered out for the question, and we had 31 respondents left. Next we asked the respondent "Are you or staff that you supervise specifically responsible for gathering drought monitoring information"? If the answer was "No, neither I nor my staff are responsible for this task", the respondent skipped all the valuation questions, to the last four questions of the survey. After that question, only 15 respondents remained to answer the following questions related to valuation of the information provided by the U.S. Drought Monitor. We also asked respondents "What sources of information

does your agency use to track or monitor drought"? If their answers were "None", we asked them to stop the survey. If their answers were "I don't know", we asked them to answer the next question about the frequency of tracking or monitoring drought and then stop and provide a referral. One person indicated "I don't know," which meant that the respondent was required to answer the next question before stopping the survey. Next, we asked the respondents "On average, how often does your agency seek information to track or monitor drought"? We listed multiple choices. If the respondent chose "Never", we asked them to stop the survey. If the answer was "I don't know", we thanked the respondent for participation and asked them to provide a referral. Based on responses to this question, our survey respondents for the following valuation questions dropped from 15 to 14.

This document provides an overview of how the data from the survey are used to answer the research questions. The analysis involves three steps. First, we provide a general summary of the survey results, including frequency of responses to each question. Second, we conduct a deeper dive into the data, creating summary statistics based on the survey results. Finally, we develop lessons learned about how the data can be used to evaluate and value the USDM. The surveys were conducted and recorded using Qualtrics. The basic summaries of the survey results are from Qualtrics.

3.2 SUMMARY STATISTICS

The responses to each question are summarized in a series of tables that show the number and percentage of respondents that chose each answer to each question. In this section, we summarize statistics about the survey respondents, the respondent's organization (including BLM offices represented), and drought tracking and monitoring.

3.2.1 Summary statistics about the survey respondents

Of the 30[2] survey respondents who answered this question, 27 have a primary disciplinary background of environmental science, GIS, biological science, natural resources science, ecology, or forestry. Two persons have a primary disciplinary background of social science such as economics and political science. Among the same 30 respondents, 12 have more than 20 years' experience; 12 people have 11-20 years' experience; 2 persons have 6-10 years' experience; and 4 people have 2-5 years' experience.

3.2.2 Summary statistics about the respondent's organization

Of the 35 survey respondents, five indicated they worked in national offices, nine worked in administrative state offices and 21 worked in district or field offices. Six of the twelve BLM administrative state offices were represented in this survey (i.e., Alaska, California, Colorado, Idaho, Montana-Dakotas, and New Mexico, Table 1), and 17 district/field offices out of 63 were represented in Arizona/Utah, California, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming (Table 2).

[2] The number of respondents who answered the question is 31 because some respondents are filtered out from the survey. Please see Appendix B for the survey questionnaire and the filters.

District/field office regions represented in the survey range from 2,500 to over 5 million people served. Administrative state regions represented range from 100,000 to over 5 million people.

According to respondents, the most common BLM-related issues that are potentially affected by drought or lack of precipitation include wildfire protection, grazing allotment and number of permits, protecting terrestrial habitats, wildlife, recreation and tourism (such as rafting, kayaks, fishing, aquatic habitats, and hiking), and agriculture-forage-grazing industries and wild horses, as shown in Table 3. All of the respondents said they work in a role or position that related to the drought issues that they checked.

Table 1: Responses from administrative state offices

State Offices	Count	Percentage
Alaska	1	11%
California	1	11%
California/Nevada	1	11%
Colorado	1	11%
Idaho	1	11%
Montana & Dakotas	3	34%
New Mexico	1	11%
Total	9	100%

Table 2: Responses from district/field offices

District/field offices	State location	Count	Percentage
Albuquerque	New Mexico	1	5%
Arizona Strip	Arizona	1	5%
Baker City	Oregon	1	5%
Burns	Oregon	1	5%
Canyon Country	Utah	1	5%
Central California	California	1	5%
Elko	Nevada	2	10%
High Desert	Wyoming	1	5%
Lakeview	Oregon	2	10%
Northern California	California	1	5%
Pecos	New Mexico	2	10%
Prineville	Oregon	2	10%
Roseburg	Oregon	1	5%
Southern Nevada	Nevada	1	5%
Spokane	Washington	1	5%
Vale	Oregon	1	5%
Winnemucca	Nevada	1	5%
Total		21	100%

Table 3: Does your agency address any of the following issues that are potentially affected by drought or lack of precipitation? (Select all that apply)

Responses	Count	%
Municipal water protection	11	31%
Wildfire protection	35	100%
Grazing allotment and number of permits	32	91%
Recreation and tourism, such as rafting, kayaks, fishing, aquatic habitats, hiking	30	86%
Agriculture-forage-grazing industries, wild horses	30	86%
Protecting terrestrial habitats, wildlife	32	91%
Economic impacts	18	51%
Energy loss--utilities, transmission	14	40%
Health	7	20%
Other (please describe)	5	14%
No, we don't address any of these issues or any other drought-related issue	0	0%

Monitoring Drought

About 91 percent of respondents reported that their agency tracks or monitors the location or severity of drought for any purpose (see Table 4). Of those, half were not responsible for monitoring drought and were excluded from further analysis. Four of the five respondents who worked at the national level said that they were not at all responsible for monitoring drought; thus, only one national-level respondent was included in the subsequent analysis (Table 5). Of the 20 individuals included in the rest of the analysis, about half were themselves responsible for drought monitoring, and about half supervised staff who were responsible for drought monitoring. These individuals held a range of positions including field management, state leadership, research staff, and program leadership (with two write-in entries as "preparedness/predictive services" and "fuels").

Table 4: Does your agency track or monitor the location or severity of drought for any purpose?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**

Yes	4	80%	7	78%	20	95%	31	89%
No	1	20%	0	0%	0	0%	1	3%
I don't know	0	0%	2	22%	1	5%	3	8%
Total	5	100%	9	100%	21	100%	35	100%

Table 5: Are you or staff that you supervise specifically responsible for gathering drought monitoring information?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
Yes, I myself am responsible for this task.	0	0%	2	29%	6	30%	8	26%
Yes, staff whom I supervise are specifically responsible for this task.	1	25%	4	57%	2	10%	7	22%
No, neither I nor my staff are responsible for this task.	3	75%	1	14%	12	60%	16	52%
Total	4	100%	7	100%	20	100%	31	100%

3.3 DROUGHT INFORMATION AND THE U.S. DROUGHT MONITOR

3.3.1 Drought Information and Drought Tracking

3.3.1.1 Purpose of tracking drought

In order to understand the motivation behind the agency's drought tracking and monitoring behavior, we asked a multiple-choice question about the purposes for which the respondent's agency tracks or monitors drought. As shown in Table 6, the largest percent of respondents representing national, state, and district/field offices said they monitor drought for "risk communication with the public such as sending out newsletters or warnings to the public on fire risks and conditions," to "support decisions or actions to respond to drought conditions," for "internal communications," and to "support research (trend analyses, etc.). One district/field

office respondent wrote in that his/her agency tracks or monitors drought for land use planning under the National Environmental Policy Act (NEPA).

Table 6: For what purposes do your agency track or monitor drought? (Select all that apply)

	National		State		District/Field		Total	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
Risk communication with the public (e.g., sending out newsletters or warning to the public on fire risks and conditions)	0	0%	4	67%	5	63%	9	60%
Internal communications (brief governing boards, management, etc.)	1	100%	3	50%	6	75%	10	67%
Support research (trend analyses, etc.)	1	100%	3	50%	3	38%	7	47%
Support decisions or actions to respond to drought conditions (e.g., grazing, recreation, firefighting)	1	100%	6	100%	7	88%	14	93%
Support legislative policy decisions and other actions	1	100%	0	0%	2	25%	3	20%
Other (please describe)	0	0%	0	0%	1	13%	1	7%
I don't know	0	0%	0	0%	1	13%	1	7%
Total Respondents	1	100%	6	100%	8	100%	15	100%

3.3.1.2 Sources of information about drought

The U.S. Drought Monitor, numeric indices (Palmer Drought Severity Index, Standardized Precipitation Index, and Standardized Precipitation Evapotranspiration Index), and data on snowpack were the most commonly used sources of information used to monitor drought. Other sources include the Climate Engine, field data collected by staff, The Great Basin Geographic Area Coordination Center (GBCC) Predictive Services, Fire Remote Automated Weather Stations (RAWS) and Parameter elevation Regression on Independent Slopes Model (PRISM), National Oceanic and Atmospheric Administration (NOAA), and Western Water Assessment.

Table 7: Sources of information used to monitor emerging drought or to assess the extent and severity of past drought? (Select all that apply)

	National		State		District/Field		Total	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
U.S. Drought Monitor	1	100%	8	100%	10	91%	19	95%
Numeric indices*	1	100%	7	88%	8	73%	16	80%
Evaporative Demand Drought Index	1	100%	7	88%	8	73%	6	30%
Energy Release Component Index	0	0%	3	38%	3	27%	5	25%
Data on lake/reservoir levels	0	0%	3	38%	4	36%	8	40%
Data on snowpack	1	100%	3	38%	2	18%	16	80%
General sources like the media	1	100%	0	0%	4	36%	6	30%
Other (please describe)	1	100%	2	25%	5	45%	7	35%
None	0	0%	0	0%	1	9%	0	0%
I don't know	0	0%	0	0%	0	0%	1	5%
Total Respondents	1	100.00 %	8	100%	11	100%	20	100

* Numeric indices include the Palmer Drought Severity Index, Standardized Precipitation Index, and Standardized Precipitation Evapotranspiration Index

3.3.2 Drought Information Tracking/Monitoring Behavior

Most respondents seek information to track or monitor drought on a regular basis: more than half sought information at least a couple of times per month, year-round. Others seek the information only during critical seasons or only when there is drought. State and district/field office representatives were fairly similar in their answers, while the one national office representative said they monitored at least once a week, year round (Table 8).

The majority of respondents reported that they consult the U.S. Drought Monitor every month. Of those who said they consult the U.S. Drought Monitor only during critical seasons, spring and summer were indicated as critical more frequently than fall and winter. Notably, all of those who said they consult the U.S. Drought Monitor only when there is drought worked in district/field offices. Of those who only consult the U.S. Drought Monitor during drought, they ranged from once-a-week usage during drought to a-couple-of-times-per-year usage during drought, displaying wide variance in dependence upon the tool.

Table 8: On average, how often does your agency seek information to track or monitor drought? (Select one)

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
At least once a week, year round	1	100%	2	33%	2	25%	5	33%
A couple of times per month, year round	0	0%	2	33%	3	38%	5	33%
Only during critical season(s)	0	0%	1	17%	1	13%	2	13%
A couple of times per year	0	0%	0	0%	0	0%	0	0%
Only when there is drought	0	0%	1	17%	1	13%	2	13%
Never	0	0%	0	0%	0	0%	0	0%
I don't know	0	0%	0	0%	1	13%	1	7%
Total	1	100.00 %	6	100%	8	100	15	100%

Table 9: On average, how often does your agency specifically consult the U.S. Drought Monitor? (Select one)

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**

At least once a week, year round	1	100%	3	50%	1	14%	5	36%
A couple of times per month, year round	0	0%	2	33%	4	57%	6	43%
Only during critical season(s)	0	0%	1	17%	0	0%	1	7%
A couple of times per year	0	0%	0	0%	0	0%	0	0%
Only when there is drought	0	0%	0	0%	2	29%	2	14%
Never	0	0%	0	0%	0	0%	0	0%
I don't know	0	0%	0	0%	0	0%	0	0%
Total	1	100%	6	100%	7	100%	14	100%

3.3.3 Views of the U.S. Drought Monitor

When we asked about the information provided by the U.S. Drought Monitor compared to other sources of drought monitoring information, 13 out of 14 people chose "the U.S. Drought Monitor provides useful information that I do not get from other sources," while only one person chose "the U.S. Drought Monitor provides the same information that I get from other sources." None of the respondents said that the U.S. Drought Monitor provides less useful information than they get from other sources.

The features that our respondents use include the current and/ or archived maps (93%), the text of the drought summary (86%), the links to other tools representing current conditions and outlooks (64%), and the spreadsheets, data, and/or shapefiles (36%).

The majority of survey respondents agree or strongly agree that "The information from the USDM is easy to understand," "The USDM is clear in its message," "The USDM is accurate in describing drought conditions," "The USDM is a trustworthy source of information," "The USDM provides a relevant source of information," "The USDM is timely," "The USDM is accepted or respected by other key stakeholders," and "The USDM provides enough evidence for a decision maker to act upon."

Table 10: Responses on the quality of information provided by the U.S. Drought Monitor

Question	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
The information from the USDM is easy to understand.	7% (2)	7% (2)	7% (2)	43% (13)	37% (11)
The USDM is clear in its message.	3% (1)	6% (2)	13% (4)	33% (10)	43% (13)
The USDM is accurate in describing drought conditions.	3% (1)	10% (3)	13% (4)	43% (13)	30% (9)
The USDM is a trustworthy source of information.	3% (1)	7% (2)	10% (3)	40% (12)	40% (12)
The USDM provides a relevant source of information.	7% (2)	0% (0)	17% (5)	33% (10)	43% (13)
The USDM is timely.	3% (1)	0% (0)	17% (5)	37% (11)	43% (13)
The USDM is accepted or respected by other key stakeholders.	3% (1)	0% (0)	23% (7)	37% (11)	37% (11)
The USDM provides enough evidence for a decision maker to act upon.	3% (1)	13% (4)	20% (6)	47% (14)	17% (5)

3.4 VALUES OF THE INFORMATION PROVIDED BY THE U.S. DROUGHT MONITOR

3.4.1 Costs Associated with Drought Tracking

3.4.1.1 Cost for climate or drought information

The majority of the 14 people that regularly use the U.S. Drought Monitor reported that their agency does not pay for drought information, as shown in Table 11. Of those whose agencies pay for climate or drought information, all indicated that "their agency spends $3000 or above for this information in an average year."

Table 11: Does your agency currently pay for any climate or drought information?

	National		State		District/Field		Total	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
Yes	0	0%	2	33%	1	14%	3	21%
No	1	100%	4	67%	6	86%	11	79%
Total	1	100%	6	100%	7	100%	14	100%

3.4.1.2 Cost of labor when tracking drought

Ten people (four state, six district/field) reported that they spend less than one hour per week gathering drought-related information; three respondents (one national, two state) reported that they spend between one and two hours per week; and one respondent (district/field) reported spending three to five hours per week gathering drought-related information (Table 12).

Table 12: On average, how many hours per week do you spend gathering drought-related information currently?

	National		State		District/Field		Total	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
0 hours per week	0	0%	0	0%	0	0%	0	0%
Less than 1 hour per week	0	0%	4	67%	6	86%	10	71%
1-2 hours per week	1	100%	2	33%	0	0%	3	21%
3-5 hours per week	0	0%	0	0%	1	14%	1	7%
Total	1	100%	6	100%	7	100%	14	100%

3.4.2 Avoided Costs of Using the U.S. Drought Monitor

3.4.2.1 Increased cost of labor if the U.S. Drought Monitor were not available

In 4.1.2, we show the labor hours spent tracking drought per week. However, if the U.S. Drought Monitor were not available, the hours per week spent gathering and analyzing or mapping drought-related information would increase. Ten respondents stated that they currently spend less than one hour per week or no time gathering drought-related information. If the U.S. Drought Monitor were not available, five of those ten respondents would spend more than one hour per week gathering this information (see Table 13).

While national office respondents did not indicate any change in the amount of time they would spend tracking drought without the U.S. Drought Monitor, some national and state office respondents were likely to increase the amount of time spent by an additional 1-4 hours per week. Based on the six observations, state employees were likely to increase the time spent per week from a low of 1 hour to a high of 2.5 hours per person, with an average increase of 1.75 hours if they did not have the U.S. Drought Monitor. Some district/field office respondents said they would increase amount of time they spend tracking drought by less than 2 hours, and others said greater 5 hours per week. Based on the seven observations, district/field employees were likely to increase the time spent per week tracking drought by a minimum of 0.72 hours to a maximum of 5.86 hours per person, with an average increase of 3.29 hours per week if they did not have the U.S. Drought Monitor. The respondent from the national office was likely to increase the time spent per week tracking drought by a minimum of 1 hour to a maximum of 4 hours, with an average increase of 2.5 hours per week, if the US. Drought Monitor were not available.

We do not know the exact wage rate of the staff that would increase their hours spent on gathering drought-related information, but we can estimate the potential labor costs based on the hourly wage data provided through the survey. The hourly wage for the individuals who access or work with the U.S. Drought Monitor varies from $25 to $100, as shown in Table 14. Based on the limited observations, the average wage rate for state employees who are doing drought-related work is $42, with a lower bound of $25 and an upper bound of $75. The average wage rate for district/field employees who are using the U.S. Drought Monitor is $44, with a lower bound of $25 and an upper bound of $100. Multiplied by the increased hours of labor needed if the U.S. Drought Monitor were not available, the increased cost of labor for a state office employee who is doing drought-related work ranged from $25 to $250 per week, with an average of $73.5. For a district/field office employee who is doing drought-related work, the increase ranged from $18 to $586 per week, with an average of $145. For the respondent from national office who is doing drought-related work, the increased cost ranged from $35 to $200 per week, with an average of $106.

Based on the input from BLM, we made the following assumptions about the number of people per office tracking drought information.

- For a district/field office that has less than 10 people, we assume there is only one person tracking or monitoring drought.

- For district/field offices that have more than 10 people and all the state offices, we assume there are between 2 and 10 people tracking or monitoring drought.

- We assume there are 52 working weeks per year.

Appendix Tables 1 and 2 show the offices and number of employees per office based on the survey questionnaire. The number of employees at all 63 district/field offices who track or monitor drought is between 124 and 612, with an average of 368, based on our assumptions. The number of employees at all 12 state offices who track or monitor drought is between 24 and 120, with an average of 72. Multiplying this number of employees by the cost per employee derived above, we estimate that the total cost of labor saved for all 12 state offices is between $31,200 and $1,560,000 per year, with an average of $275,184 per year. The total cost of labor saved for all district/field offices is between $116,064 and $18,648,864 per year, with an average of $2,774,720 per year. (The ranges are large because of the uncertainty regarding the number of people tracking drought in each office.) We only have one observation from the national offices and we also do not have information about the number of people who are tracking drought in national offices; therefore, we did not estimate the total cost of labor saved at national offices.

Table 13: On average, if the U.S. Drought Monitor was not available to you, how many hours per week would you spend gathering and analyzing or mapping drought-related information?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
0 hours per week	0	0%	0	0%	0	0%	0	0%
Less than 1 hour per week	0	0%	1	17%	4	57%	5	36%
1-2 hours per week	0	0%	2	33%	2	29%	4	29%
3-5 hours per week	1	100%	3	50%	0	0%	4	29%
6-10 hours per week	0	0%	0	0%	0	0%	0	0%
More than 10 hours per week	0	0%	0	0%	1	14%	1	7%
Total	1	100%	6	100%	7	100%	14	100%

Table 14: What is the hourly wage (or annual salary) of the individual(s) who access or work with the U.S. Drought Monitor map and/or data?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**

Below $15 per hour	0	0%	0	0%	0	0%	0	0%
$15 – $24.99 per hour	0	0%	0	0%	0	0%	0	0%
$25 – $34.99 per hour	0	0%	2	33%	3	43%	5	36%
$35 – $49.99 per hour	1	100%	3	50%	3	43%	7	50%
$50 – $74.99 per hour	0	0%	1	17%	0	0%	1	7%
$75 – $99.99 per hour	0	0%	0	0%	1	14%	1	7%
$100 or over per hour	0	0%	0	0%	0	0%	0	0%
Total	1	100%	6	100%	7	100%	14	100%

3.4.2.2 Other costs if the U.S. Drought Monitor were not available

Seven respondents indicated that there would be other costs if the USDM were not available (Table 15). These costs include items such as purchasing software and hardware and other maintenance costs. Some respondents mentioned additional labor costs including collecting data and data quality control/improvement, costs associated with land management decisions, and additional costs such as expanding the current range of products. Table 16 shows the estimated cost of these items. Based on the limited observations, the potential other costs saved by using the U.S. Drought Monitor varies from $50 or less to $3,000 or more in state offices per year, with a weighted average of $2,333. In district and field offices, the potential other costs saved by using U.S. Drought Monitor varies from $100 to $3,000 or more per year, with a weighted average of $1,367. The minimum total potential other costs for the 12 state offices are $28,000 and the minimum total potential other costs for 63 district/field offices, $86,100 per year.

Table 15: What other costs would your agency incur if the U.S. Drought Monitor were not available?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**

Purchase software and hardware such as printer, ArcGIS etc.	0	0%	0	0%	2	29%	2	14%
Purchase printing papers, inks	0	0%	0	0%	0	0%	0	0%
Other maintenance cost	0	0%	0	0%	0	0%	0	0%
Other	0	0%	4	67%	1	14%	5	36%
None	1	100%	2	33%	4	57%	7	50%
Total	1	100%	6	100%	7	100%	14	100%

Table 16: What is the estimated annual cost, including maintenance, associated with the items you identified above?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
None	0	0%	0	0%	0	0%	0	0%
Under $50	0	0%	1	25%	0	0%	1	14%
$50 – $99.99	0	0%	0	0%	0	0%	0	0%
$100 – $499.99	0	0%	0	0%	1	33%	1	14%
$500 – $999.99	0	0%	0	0%	0	0%	0	0%
$1,000 – $2,999.99	0	0%	1	25%	1	33%	2	29%
$3,000 or above	0	0%	2	50%	1	33%	3	43%
Total	0	0%	4	100%	3	100%	7	100%

3.4.3 Willingness to pay for drought information provided by the U.S. Drought Monitor

3.4.3.1 Whether the agencies are willing to pay for drought-related information if the U.S. Drought Monitor were not available

Another approach to measuring the value of the U.S. Drought Monitor is willingness to pay. We received 16 responses about the BLM user's willingness to pay for drought information if the U.S. Drought Monitor were not available (Table 17). Only six (4 state and 2 district/field) out of 14 respondents indicated that their agency would be willing to pay for drought-related

information if the U.S. Drought Monitor were not available. State offices were more likely to indicate that they would be willing to pay than district/field offices or the national office. Of those that responded that they would not be willing to pay for the U.S. Drought Monitor, 70 percent reported that it was because another source of information such as data on lake/reservoir levels, data on snowpack, general sources like the media, Evaporative Demand Drought Index, Energy Release Component Index, Desert Research Institute (DRI) Climate Engine, RAWS, or NOAA would provide their agency's needs. The other 30 percent of the respondents indicated that their agency could not pay for this type of information. No respondents said that they would not pay because the USDM was not useful to the organization.

Table 17: Would your agency be willing to pay for drought-related information if the U.S. Drought Monitor were not available?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**
Yes	0	0%	4	67%	2	29%	6	43%
No	1	100%	2	33%	5	71%	8	57%
Total	1	100%	6	100%	7	100%	14	100%

Table 18: How much would your agency be willing to pay annually for similar information per year if the U.S. Drought Monitor were not free and your agency had a budget?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**

My agency has no ability to pay for this type of information.	1	50%	1	33%	1	20%	3	30%
Another source of information is available that provides what my agency needs.	1	50%	2	67%	4	80%	7	70%
The U.S. Drought Monitor is not useful to my organization.	0	0%	0	0%	0	0%	0	0%
I don't know.	0	0%	0	0%	0	0%	0	0%
Other	0	0%	0	0%	0	0%	0	0%
Total	2	100%	3	100%	5	100%	10	100%

3.4.3.2 Willingness to pay for similar information per year if the U.S. Drought Monitor were not free and your agency had a budget

Because not all agencies have funding to pay for data sources like the U.S. Drought Monitor, a follow-up question asked the respondents how much their agency would be willing to pay annually for similar information if the U.S. Drought Monitor were not free and their agency had a budget for this type of data. This hypothetical question allowed those who answered "No" in the previous question to put a dollar value on the information provided by the U.S. Drought Monitor. The responses from the 14 people are shown in Table 19. In general, state and national offices were more willing to pay more per year than district offices. Based on the limited observations, the willingness to pay for the U.S. Drought Monitor information varied from less than $50 per year to $3,000 or above per year per agency (office), with a minimum average of $3,000 per national office, $1,200 per state office, and $480 per district/field office. The total minimum average willingness to pay is $14,400 for all 12 state offices and $32,040 for all 63 district/field offices per year.

Table 19: How much would your agency be willing to pay annually for similar information per year if the U.S. Drought Monitor were not free and your agency had a budget?

	National		**State**		**District/Field**		**Total**	
Responses	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**	**Count**	**Percent of Total**

Under $50	0	0%	3	50%	2	29%	5	36%
$50 – $99.99	0	0%	0	0%	1	14%	1	7%
$100 – $499.99	0	0%	0	0%	3	43%	3	21%
$500 – $999.99	0	0%	0	0%	0	0%	0	0%
$1,000 – $2,999.99	0	0%	1	17%	0	0%	1	7%
$3,000 or above	1	100%	2	33%	1	14%	4	29%
Total	1	100%	6	100%	7	100%	14	100%

3.5 SUMMARY

Because of the public nature of climatic and meteorological information, market prices do not exist most of the time. We used two economic methods – avoided cost and stated preference – to value the information provided by the U.S. Drought Monitor to the BLM. The avoided cost approach is an indirect approach to estimate the potential costs avoided by using the U.S. Drought Monitor. Based on the limited observations from staff and field managers at national, state, and district/field offices in the BLM, we estimate that the weekly avoided cost of labor per person who tracks or monitors drought is:

- From $22 to $250 with an average of $74 for state offices
- From $18 to $586 with an average of $145 for district/field offices
- From $35 to $200 with an average of $106 for national offices

The total cost of labor saved for all state offices is between $31,200 and $1,560,000 per year, with an average of $275,184 per year. The total cost of labor saved for all district/field offices is between $116,064 and $18,648,864 per year, with an average of $2,774,720 per year. (We did not estimate the total cost of labor saved at national offices because of limited information.) The avoided cost of labor per year for all BLM state offices and district/field offices alone varies from $0.2 million to $19 million with an average of $3.1 million.

Other associated avoided costs include purchasing software and hardware, additional labor costs including collecting data and data quality control/improvement, costs associated with land management decisions, and additional costs such as expanding the current range of products as identified from our respondents. Based on the limited number of observations, the minimum total potential other costs for all BLM state offices are $28,000 and the minimum total potential other costs for all district/field offices, $86,100 per year. Compared to the total avoided cost of labor, the other costs avoided by using the U.S. Drought Monitor are trivial, which means that the total avoided cost per year for all BLM state offices and district/field offices alone varies from $0.2 million to $19 million with an average of $3.1 million.

The total average minimum willingness to pay is $14,400 for the 12 state offices and $32,040 for the 63 district/field offices per year. Although this study provides substantial evidence of the

values of the information provided by the U.S. Drought Monitor, several caveats must be kept in mind.

- First, we do not account for other indirect avoided costs using the U.S. Drought Monitor. For example, our estimates exclude the cost of relocating resources to control wildfires and the potential savings from preventing wildfires, and the savings from avoiding overgrazing and related environmental damage by using drought information provided by the U.S. Drought Monitor. We have listed some of the potential benefits/avoided damages in the literature review section. Despite all the caveats, our approach approximates the partial avoided cost from using the U.S. Drought Monitor.

- Second, our sample size is relatively small. We reached out to 330 staff and field managers based on our BLM connection, and 35 people completed the survey, with an effective 11 percent response rate. While the sample size was small, respondents represented a range of BLM offices, including national offices (including headquarters and predictive services) as well as state offices and district/field offices. Seven of the 12 (58 percent) BLM administrative state offices and 18 out of the 63 (29 percent) BLM district/field offices were represented in the survey.

- Third, for some of the key questions in our survey, such as avoided costs and willingness to pay, we have very limited observations, with only 14 respondents having the relevant job responsibilities or knowledge to provide answers

- Some of the other data needed to estimate the value of the U.S. Drought Monitor are uncertain. For example, we estimate the number of people tracking drought information in each office, and the range of people doing this work across offices is relatively large.

We provide rough estimates that should only serve as a starting point. Future studies could take a more general approach to exploring the indirect avoided cost or a more rigorous approach to examine the willingness to pay for the information provided by the U.S. Drought Monitor. Estimates of the number of BLM staff tracking drought information would help to improve the precision of the estimated value of the U.S. Drought Monitor to the BLM. A follow-up survey to the BLM could collect this information, but other sources may be available.

Information about drought helps to manage grazing land and herds. Additional information about how drought data are used and the economic risks avoided by timely information about drought is needed to estimate the costs avoided by the U.S. Drought Monitor. Case studies that evaluate the BLM's management of grazing land, its use of drought information as part of their land management, and ranchers' use of the information, could help to develop estimates of the potential role and value of the Drought Monitor.

4. SUMMARY AND CONCLUSIONS

Decision makers in many sectors and contexts benefit from drought monitoring and early warning: households, land management, crop and livestock planning, disaster preparation and relief, hydropower, fisheries management, and more. Drought monitoring and early warning is typically provided as a public good, along with information such as weather forecasts. Valuing public goods is an inherent challenge, because by definition, they are services that the private sector lacks incentive – a market – to provide. In the private sector, market-based revenue provides a ready gauge for whether to continue an activity. In the absence of a market, determining value requires looking at the effect of a given product – how are people using it? Does it help? What is the avoided cost by using the product or what people would be willing to pay if the product were not available?

This summary reviews the three different approaches to understand the value of the information provided by the U.S. Drought Monitor: avoided cost method, stated preference method, and benefit transfer method. Drawing on the analysis from the three valuation methods, it then reviews some of the challenges faced when valuing public information such as the U.S. Drought Monitor. It concludes with suggestions for additional research.

4.1 VALUATION METHODS

4.1.1 Avoided Cost Method

Because of the public nature of climate and meteorological information, market prices do not exist most of time. Avoided cost is one of the most commonly used methods for assigning value in these circumstances, and it is an indirect method to assess the costs that people avoid because of the availability of climatic and meteorological information. Some disasters and damages can be avoided or reduced in sectors such as agriculture, transportation, health, power generation, and recreation, and these prevention and mitigation actions can be translated into monetary terms. These avoided disaster-related losses are too complicated to calculate in these sectors through our survey methodology. In our study, we focused on the Bureau of Land Management.

In order to understand the avoided cost by using the information provided by the U.S. Drought Monitor, we asked questions on the avoided cost of labor because of the availability of the U.S. Drought Monitor. More specifically, we have asked respondents questions such as "On average, how many hours per week do you spend gathering drought-related information currently?" and "On average, if the U.S. Drought Monitor was not available to you, how many hours per week would you spend gathering and analyzing or mapping drought-related information such as precipitation, numeric drought indices, streamflow, snowpack, etc.?" Through the comparison and subtraction of the amount of time spent with and without the U.S. Drought Monitor, we can estimate the number of hours avoided (or saved) by using the information provided by the U.S. Drought Monitor. We also asked respondents to choose their hourly wage range by selecting from multiple hourly wage rate range choices. In this way, we can identify the minimum wage and maximum wage rate for respondents who work in different organizations/institutions, and at different scales of the government agencies such as federal, state, and local. We also asked questions about other costs that would be incurred if the U.S. Drought Monitor were not available, as well as the estimated annual costs.

In the analysis of the Bureau of Land Management, based on the limited observations from staff and field managers at national, state, and district/field offices within BLM, we estimate that the weekly avoided cost of labor per person who tracks or monitors drought is:

- From $22 to $250 with an average of $74 for state offices
- From $18 to $586 with an average of $145 for district/field offices
- From $35 to $200 with an average of $106 for national offices

The total cost of labor saved for all state offices is between $31,200 and $1,560,000 per year, with an average of $275,184 per year. The total cost of labor saved for all district/field offices is between $116,064 and $18,648,864 per year, with an average of $2,774,720 per year. We did not estimate the total cost of labor saved at national offices because of lack of information. The avoided cost of labor per year for all BLM state offices and district/field offices alone varies from $0.2 million to $19 million with an average of $3.1 million.

Other associated avoided costs include purchasing software and hardware, additional labor costs including collecting data and data quality control/improvement, costs associated with land management decisions, and additional costs such as expanding the current range of products as identified from our respondents. Based on the limited number of observations, the minimum total potential other costs for all BLM state offices are $28,000 and the minimum total potential other costs for all district/field offices, $86,100 per year. Compared to the total avoided cost of labor, the other costs avoided by using the U.S. Drought Monitor are trivial, which means that the total avoided cost per year for all BLM state offices and district/field offices alone varies from $0.2 million to $19 million with an average of $3.1 million.

Stated Preference Method

Stated preference methods such as contingent valuation and choice experiments have been widely used in the literature for estimating the economic value of public goods or services. Researchers have used both methods in the valuation of climatic and meteorological information. The contingent valuation method attempts to measure the value that people place on a particular public good or service taken as a specific bundle of attributes, while the choice experiments method builds on the idea that the value of a good is a reflection of its characteristics and requires the respondents to compare and select (rank or rate) alternative combinations of goods and policy characteristics (National Research Council, 2005). In Phase One of this study, we interviewed people on the usefulness of the information provided by the U.S. Drought Monitor and whether they would be willing to pay for the information provided by the U.S. Drought Monitor. In Phase Two of the study, we designed two separate questionnaires on people's willingness to pay for drought-related information if the U.S. Drought Monitor were not available. We asked, "Would your agency be willing to pay for drought-related information if the U.S. Drought Monitor were not available?" Because not all agencies have funding to pay for data sources like the U.S. Drought Monitor, a follow-up question asked the respondents how much their agency would be willing to pay annually for similar information if the U.S. Drought Monitor were not free and their agency had a budget for this type of data. This hypothetical question allowed those who answered "No" in the previous question to put a dollar value on the information provided by the U.S. Drought Monitor. More

specially, we asked survey respondents to state their value of the information provided by the U.S. Drought Monitor directly through multiple choices: "Under $50", "$50 – $99.99", "$100 – $499.99", "$500 – $999.99", "$1,000 – $2,999.99", and "$3,000 or above".

In the analysis of the Bureau of Land Management, we find that, in general, national and state offices were willing to pay more per year than district/field offices based on the limited observations. The willingness to pay for the U.S. Drought Monitor information varied from less than $50 per year to $3,000 or above per year per agency (office), with a minimum average of $3,000 per national office, $1,200 per state office, and $480 per district/field office. The total minimum average willingness to pay for all 12 state offices is $14,400, and for the 63 district/field offices, $32,040 per year.

4.1.2 Benefit Transfer Method

The benefit transfer method is often criticized since people's willingness to pay for particular climatic and meteorological information may vary across sites and times (Liu, 2014). Errors may occur if researchers rely on prior studies and transfer others' estimates directly into their own analysis. Despite its caveat, the benefit transfer method serves as a low-cost screening technique for further valuation studies (Liu, 2014). In order to understand the other potential costs that can be saved by using the information provided by the U.S. Drought Monitor, we reviewed the literature on economic impact of droughts in both the Bureau of Land Management. Although specific dollar amounts associated with potential avoided cost in BLM do not exist, we have listed effects of drought on range, forest conditions, and recreation. For example, BLM lands received more than 64.6 million recreation-related visits (BLM, 2017b). Closing recreation sites because of drought can have a huge impact on recreation and tourism industries and also further damage the local economy. But if the environmental benefits were included, the benefits to ecosystem services and the environment may outweigh the temporary loss in profits generated in recreation and tourism in the long run. As another example, droughts in 2002 and 2012 contributed to $190,006 and $516,989 losses, respectively, in terms of grazing fees when compared with the number of AUMs in 2001, based on grazing fees of $1.43 per AUM in 2002 and $1.35 per AUM in 2012. The potential costs on ecosystem services and the environment may outweigh the loss in grazing fees if they were considered. More original research is needed before we can examine how drought information from the U.S. Drought Monitor and the Early Warning System benefit the Bureau of Land Management using the benefit transfer method.

4.2 AREAS FOR FUTURE RESEARCH

This study identified gaps in available information, policy approaches, and challenges facing the valuation of the information provided by the U.S. Drought Monitor. The value of the benefits of the information provided by the U.S. Drought Monitor is hard to measure. Because effective use of the information can potentially help agencies and institutions avoid higher costs due to drought, these avoided costs could provide a useful measure of the values of the information and can be used as a proxy for benefits in a cost-benefit analysis. More tangible avoided costs include saved labor costs such as tracking and monitoring drought information, documenting drought

information, communicating drought risks to stakeholders, and making decisions on drought-related issues. We also used contingent valuation by surveying people who work on drought-related issues in both the Bureau of Land Management. Our case studies examined the value of the U.S. Drought Monitor within the BLM. A suggestion that arose during our BLM research was to survey all of the federal agencies involved in coordinated fire response efforts on their use of the USDM.

This study used different approaches to value the information provided by the U.S. Drought Monitor: avoided cost, contingent valuation, and benefit transfer. It explored the value and limitations of surveys to elicit necessary data in both the BLM. Subsequent research can build on the study and develop a more rigorous estimate of the value of information provided by the U.S. Drought Monitor in specific contexts, and compare the short-term and long-term benefit by using the information provided by the U.S. Drought Monitor. More detailed understanding of the value of the U.S. Drought Monitor can be helpful for policy makers in decision making related to investing in public goods and services in the face of droughts.

APPENDIX A
District/Field and State Office Information

Appendix Table 1: District/field offices and number of employees based on questionnaire

District/field offices	State location	Number of Employees
Albuquerque	New Mexico	35
Arizona Strip	Arizona	100
Baker City	Oregon	6
Burns	Oregon	200
Canyon Country	Utah	50
Central California	California	75
Elko	Nevada	20
Elko	Nevada	75
High Desert	Wyoming	50
Lakeview	Oregon	40
Lakeview	Oregon	20
Las Cruces	New Mexico	2
Northern California	California	55
Pecos	New Mexico	20

Pecos	New Mexico	120
Prineville	Oregon	63
Prineville	Oregon	100
Roseburg	Oregon	120
Southern Nevada	Nevada	100+
Spokane	Washington	35
Vale	Oregon	200
Winnemucca	Nevada	25

Appendix Table 2: State offices and number of employees based on questionnaire

State offices	State location	Number of Employees
California	California/Nevada	160
Alaska	Alaska	250
Eastern Montana/Dakotas	Montana & Dakotas	150
Eastern Montana/Dakotas	Montana & Dakotas	600-800
New Mexico	New Mexico	100
Idaho	Idaho	600
Colorado	Colorado	150

APPENDIX B
VALUATION OF THE USDM – BLM QUESTIONNAIRE

Q1 What is your organization? (Select all that apply)

☐ State government agency (1)

☐ Tribal government agency (2)

☐ Local government agency (3)

☐ Federal government agency (4)

☐ Consultant or contractor (9)

☐ Other organization not listed above (please describe) (5)
_____

Q33 What is your role at the BLM? (Select one)

○ Field management (2)

○ State leadership (1)

○ Headquarters (3)

○ Research Staff (4)

○ Program leadership (5)

○ Others (6) _____

Q2 Approximately how many people work for your agency or organization (selected above)?

_____

Q3 What is the approximate population of the region that your agency serves?

- ○ 0 - 2,499 (1)
- ○ 2,500 - 9,999 (2)
- ○ 10,000 - 49,999 (3)
- ○ 50,000 - 99,999 (4)
- ○ 100,000 - 249,000 (5)
- ○ 250,000 - 499,000 (6)
- ○ 500,000 - 999,999 (7)
- ○ 1,000,000 - 1,999,999 (8)
- ○ 2,000,000 - 4,999,999 (9)
- ○ 5,000,000 or greater (10)

Q4 Please list the geographic community, state, or region which your organization serves.

_____

Page Break

Q5 Does your agency address any of the following issues that are potentially affected by drought or lack of precipitation? (Check any or all issues that your agency addresses, and also please describe any other drought-related issue that we have failed to include in this list.)

- ☐ Municipal water protection (2)
- ☐ Wildfire protection (3)
- ☐ Grazing allotment and number of permits (4)
- ☐ Recreation and tourism, such as rafting, kayaks, fishing, aquatic habitats, hiking (5)
- ☐ Agriculture-forage-grazing industries, wild horses (6)
- ☐ Protecting terrestrial habitats, wildlife (7)
- ☐ Economic impacts (8)
- ☐ Energy loss--utilities, transmission (11)
- ☐ Health (12)
- ☐ Other (please describe) (10) _____
- ☐ No, we don't address any of these issues or any other drought-related issue (1)

Skip To: Q32 If Does your agency address any of the following issues that are potentially affected by drought or... = No, we don't address any of these issues or any other drought-related issue

Q6 Do you work in a role or position related to the issue(s) that you checked above?

○ Yes (1)

○ No (2)

Skip To: Q32 If Do you work in a role or position related to the issue(s) that you checked above? = No

---

Q7 Does your agency track or monitor the location or severity of drought for any purpose?

○ Yes (1)

○ No (2)

○ I don't know (3)

Skip To: Q32 If Does your agency track or monitor the location or severity of drought for any purpose? = No

Skip To: Q32 If Does your agency track or monitor the location or severity of drought for any purpose? = I don't know

---

Q8 Are you or staff that you supervise specifically responsible for gathering drought monitoring information?

○ Yes, I myself am responsible for this task. (2)

○ Yes, staff whom I supervise are specifically responsible for this task. (3)

○ No, neither I nor my staff are responsible for this task. (1)

Skip To: Q27 If Are you or staff that you supervise specifically responsible for gathering drought monitoring inf... = No, neither I nor my staff are responsible for this task.

Display This Question:

If Are you or staff that you supervise specifically responsible for gathering drought monitoring inf... = Yes, I myself am responsible for this task.

Or Are you or staff that you supervise specifically responsible for gathering drought monitoring inf... = Yes, staff whom I supervise are specifically responsible for this task.

Q9 For what purpose(s) does your agency track or monitor drought? (Select all that apply, and also please describe any additional purpose that we have failed to include in this list.)

- ☐ Risk communication with the public (e.g., sending out newsletters or warning to the public on fire risks and conditions) (1)
- ☐ Internal communications (brief governing boards, management, etc.) (2)
- ☐ Support research (trend analyses, etc.) (3)
- ☐ Support decisions or actions to respond to drought conditions (eg. grazing, recreation, firefighting) (4)
- ☐ Support legislative policy decisions and other actions (5)
- ☐ Other (please describe) (6) _____
- ☐ I don't know (7)

Page Break

Q10 What sources of information does your agency use to monitor emerging drought or to assess the extent and severity of past drought? (Select all that apply)

- ☐ U.S. Drought Monitor (1)
- ☐ Numeric indices, such as Palmer Drought Severity Index, Standardized Precipitation Index, and Standardized Precipitation Evapotranspiration Index (2)
- ☐ Evaporative Demand Drought Index (9)
- ☐ Energy Release Component Index (10)
- ☐ Data on Lake/reservoir levels (3)
- ☐ Data on snowpack (4)
- ☐ General sources like the media (5)
- ☐ Other (please describe) (6) _____
- ☐ None (7)
- ☐ I don't know (8)

Skip To: Q32 If What sources of information does your agency use to monitor emerging drought or to assess the ext... = None

Q11 On average, how often does your agency seek information to track or monitor drought? (Select one)

- ○ At least once a week, year round (1)
- ○ A couple of times per month, year round (2)
- ○ Only during critical season(s) (3)
- ○ A couple of times per year (4)
- ○ Only when there is drought (5)
- ○ Never (6)
- ○ I don't know (7)

Skip To: Q32 If On average, how often does your agency seek information to track or monitor drought? (Select one) = Never

Skip To: Q32 If On average, how often does your agency seek information to track or monitor drought? (Select one) = I don't know

---

Display This Question:

If What sources of information does your agency use to monitor emerging drought or to assess the ext... = U.S. Drought Monitor

Q12 On average, how often does your agency specifically consult the U.S. Drought Monitor? (Select one)

- ○ At least once a week, year round (1)
- ○ A couple of times per month, year round (2)
- ○ Only during critical season(s) (3)
- ○ A couple of times per year (4)
- ○ Only when there is drought (5)
- ○ Only if specific impacts have been reported, such as dry wells or air quality (6)
- ○ Never (7)

Display This Question:

If On average, how often does your agency specifically consult the U.S. Drought Monitor? (Select one) = Only during critical season(s)

Q13 During which season(s) are you most likely to consult the U.S. Drought Monitor? (Select all that apply)

- ☐ Spring (1)
- ☐ Summer (2)
- ☐ Fall (3)
- ☐ Winter (4)

Display This Question:

If On average, how often does your agency specifically consult the U.S. Drought Monitor? (Select one) = Only when there is drought

Q14 During drought, how often does your agency consult the U.S. Drought Monitor? (Select one)

- ○ At least once a week (1)
- ○ A couple of times per month (2)
- ○ A couple of times per year (3)

Display This Question:

If What sources of information does your agency use to monitor emerging drought or to assess the ext... = U.S. Drought Monitor

Q15 Compared to the other sources of drought monitoring information that you have used, which of the following statements best describes the U.S. Drought Monitor?

○ The U.S. Drought Monitor provides useful information that I do not get from other sources. (1)

○ The U.S. Drought Monitor provides the same information that I get from other sources. (2)

○ The U.S. Drought Monitor provides less useful information than I get from other sources. (3)

Display This Question:

If What sources of information does your agency use to monitor emerging drought or to assess the ext... = U.S. Drought Monitor

Q16 Which features of the U.S. Drought Monitor does your organization use? (Select all that apply)

☐ The current and/or archived maps (1)

☐ The spreadsheets, data, and/or shapefiles (2)

☐ The text of the drought summary (3)

☐ The links to other tools representing current conditions and outlooks (4)

Q17 Does your agency currently pay for any climate or drought information? (Select one)

○ Yes (1)

○ No (4)

Skip To: Q19 If Does your agency currently pay for any climate or drought information? (Select one) = No

---

Q18 In an average year, how much does your agency spend for this information? (Select one)

- ○ Under $50 (1)
- ○ $50 – $99 (2)
- ○ $100 – $499 (3)
- ○ $500 – $999 (4)
- ○ $1,000 – $2,999 (5)
- ○ $3,000 or above (6)

Page Break

Q19 On average, how many hours per week do you spend gathering drought-related information currently? (Select one)

- ○ 0 hours per week (1)
- ○ Less than 1 hour per week (2)
- ○ 1-2 hours per week (3)
- ○ 3-5 hours per week (4)
- ○ 6-10 hours per week (5)
- ○ More than 10 hours per week (6)

Q20 On average, if the U.S. Drought Monitor was not available to you, how many hours per week would you spend gathering and analyzing or mapping drought-related information such as precipitation, numeric drought indices, streamflow, snowpack, etc.? (Select one)

- ○ 0 hours per week (1)
- ○ Less than 1 hour per week (2)
- ○ 1-2 hours per week (3)
- ○ 3-5 hours per week (4)
- ○ 6-10 hours per week (5)
- ○ More than 10 hours per week (6)

Q21 What is the hourly wage (or annual salary) of the individual(s) who access or work with the U.S. Drought Monitor map and/or data? (Select one)

- ○ Below $15 per hour (less than $31,200 per year) (1)
- ○ $15 – $24.99 per hour ($31,200 –$51,999 per year) (2)
- ○ $25 – $34.99 per hour ($52,000 – $72,799 per year) (3)
- ○ $35 – $49.99 per hour ($72,800 – $103,999per year) (4)
- ○ $50 – $74.99 per hour ($104,000 – $155,999 per year (5)
- ○ $75 – $99.99 per hour ($156,000 – $208,000 per year) (6)
- ○ $100 or over per hour ($208,000 and over per year) (7)

Page Break

Q22 What other costs would your agency incur if the U.S. Drought Monitor were not available? (Select all that apply)

- ☐ Purchase software and hardware such as printer, ArcGIS etc. (1)
- ☐ Purchase printing papers, inks (2)
- ☐ Other maintenance cost (3)
- ☐ Other (please describe) (4) _____
- ☐ None (5)

Skip To: Q24 If What other costs would your agency incur if the U.S. Drought Monitor were not available? (Select... = None

---

Q23 What is the estimated annual cost, including maintenance, associated with the items you identified above? (Select one)

- ○ None (1)
- ○ Under $50 (2)
- ○ $50 – $99.99 (3)
- ○ $100 – $499.99 (4)
- ○ $500 – $999.99 (5)
- ○ $1,000 – $2,999.99 (6)
- ○ $3,000 or above (7)

Page Break

Q24 Would your agency be willing to pay for drought-related information if the U.S. Drought Monitor were not available? (Select one)

○ Yes (1)

○ No (4)

Skip To: Q26 If Would your agency be willing to pay for drought-related information if the U.S. Drought Monitor... = Yes

---

Q25 Which of the following reasons describe why your agency would not pay for drought-related information if the U.S. Drought Monitor were not available? (Check all that apply, and elaborate as necessary.)

☐ My agency has no ability to pay for this type of information. (1)

☐ Another source of information is available that provides what my agency needs. (2)

☐ The US Drought Monitor is not useful to my organization. (3)

☐ I don't know. (4)

☐ Other (please describe) (5) _____

Page Break

Q26 How much would your agency be willing to pay annually for similar information per year if the U.S. Drought Monitor were not free and your agency had a budget? (Select one)

- ○ Under $50 (1)
- ○ $50 – $99.99 (2)
- ○ $100 – $499.99 (3)
- ○ $500 – $999.99 (4)
- ○ $1,000 – $2,999.99 (5)
- ○ $3,000 or above (6)

Page Break

Q27 How strongly do you agree or disagree with the following statements about the U.S. Drought Monitor?

	Strongly disagree (8)	Somewhat disagree (9)	Neither agree nor disagree (10)	Somewhat agree (11)	Strongly agree (12)
The information from the USDM is easy to understand. (1)	○	○	○	○	○
The USDM is clear in its message. (2)	○	○	○	○	○
The USDM is accurate in describing drought conditions. (3)	○	○	○	○	○
The USDM is a trustworthy source of information. (4)	○	○	○	○	○
The USDM provides a relevant source of information. (5)	○	○	○	○	○
The USDM is timely. (6)	○	○	○	○	○
The USDM is accepted or respected by other key stakeholders. (7)	○	○	○	○	○

The USDM provides enough evidence for a decision maker to act upon. (8)	○	○	○	○	○

Page Break

Q28 What is your primary disciplinary background? (Select one)

○ Geology, Cartography, Archaeology (1)

○ Environmental Science, GIS, Biological Science, Natural Resources Science, Ecology, Forestry (2)

○ Engineering (3)

○ Law (4)

○ Social sciences (e.g., economics, political science etc.) (5) _____

○ Other (please describe) (6)

Q29 How long you have worked for your organization? (Select one)

○ 1 year or less (1)

○ 2 - 5 years (2)

○ 6 - 10 years (3)

○ 11 - 20 years (4)

○ More than 20 years (5)

Page Break

Q30 What recommendations do you have for the U.S. Drought Monitor? (Please describe below)

_____

_____

_____

_____

_____

Skip To: End of Survey If What recommendations do you have for the US Drought Monitor? (Please describe below) Is Displayed

Page Break

Q32 Thanks for participating in this survey. The rest of the questions in this survey are likely not relevant to you, so this is the last question that we will ask you to complete. Could you refer us to someone in your agency with responsibility in these areas, to take the survey?

- ○ Name (4) _____
- ○ Position (5) _____
- ○ Email (6) _____

End of Block: Default Question Block

APPENDIX C INTERVIEW QUESTIONS

I. Describe your program and/or organization.

   A. How does drought affect your agency and its mission?

   B. Are you responsible for any decisions or actions in response to droughts?

      1. If not, who else can we talk to at your agency?

      2. If so, what types of decisions or actions?

      3. Are there procedures or requirements for how those decisions are made? As far as the information that informs the decision or action?

II. Are you familiar with the USDM? If yes:

   A. Do you consult it? If yes, how frequently do you use or consult it?

   B. Is it your main source of drought monitoring information, or do you consult other sources?

   C. What is your opinion of the USDM? (Prompts: For your needs, do you consider the USDM to be:

      1. Easy to understand and use?

      2. Clear in its message?

      3. Accurate in depicting drought conditions?

      4. A trustworthy source of information?)

   D. If no, do you rely on other sources?

III. Do you use the USDM in some way?

   A. If no, do you use other sources of information about drought?

   B. If yes, how do you use drought monitoring information? (Do you use the USDM in these ways, or other sources?)

      1. Triggering: what decisions need to be made, what are the triggers?

         i. Do you use the USDM to support decisions, and if so, how?

         ii. What other tools and information do you use?

         iii. If you do not use the USDM, why do you not use it?

            a. Problems with the USDM or other attributes that make it hard to use?

            b. Organizational requirements?

c. Rely on other sources.

2. Risk communication tool:

i. Do you use the USDM as a source of information in any communication, education or outreach?

ii. Who is your audience and how do they use the information you provide?

iii. What other information is used? If not why not?

iv. What would you have used if the USDM was not available?

3. Advocacy:

i. In your position, do you advocate for policy change or actions from anyone other than the public?

ii. Do you use the USDM as a source of information in your communication?

C. Depending on the uses identified above, do you consider the USDM to be useful? (Prompts below:)

1. A relevant source of information?

2. Timely?

3. A tool that is accepted or respected by other key stakeholders?

4. Enough evidence for a decision maker to act upon?

IV. What is the potential value of the USDM to you?

A. What, if anything, do you pay for similar meteorological or climatic data?

B. If the Monitor was not available, would you use a paid service for the information?

C. If a standardized precipitation index was the only information available, what would you pay for the additional information provided by the USDM?

D. What costs does the USDM help avoid, either by triggering policies or as a risk communication tool?

1. Diseases avoided, reduced hospital visits

2. Transportation: reduced down-time

V. What other resources do you need to support your drought-related decisions and efforts?

Show them the following figures to give them examples of the U.S. Drought Monitor (Figure 1) and the Standardized Precipitation Index (Figure 2).

Figure 1. U.S. Drought Monitor

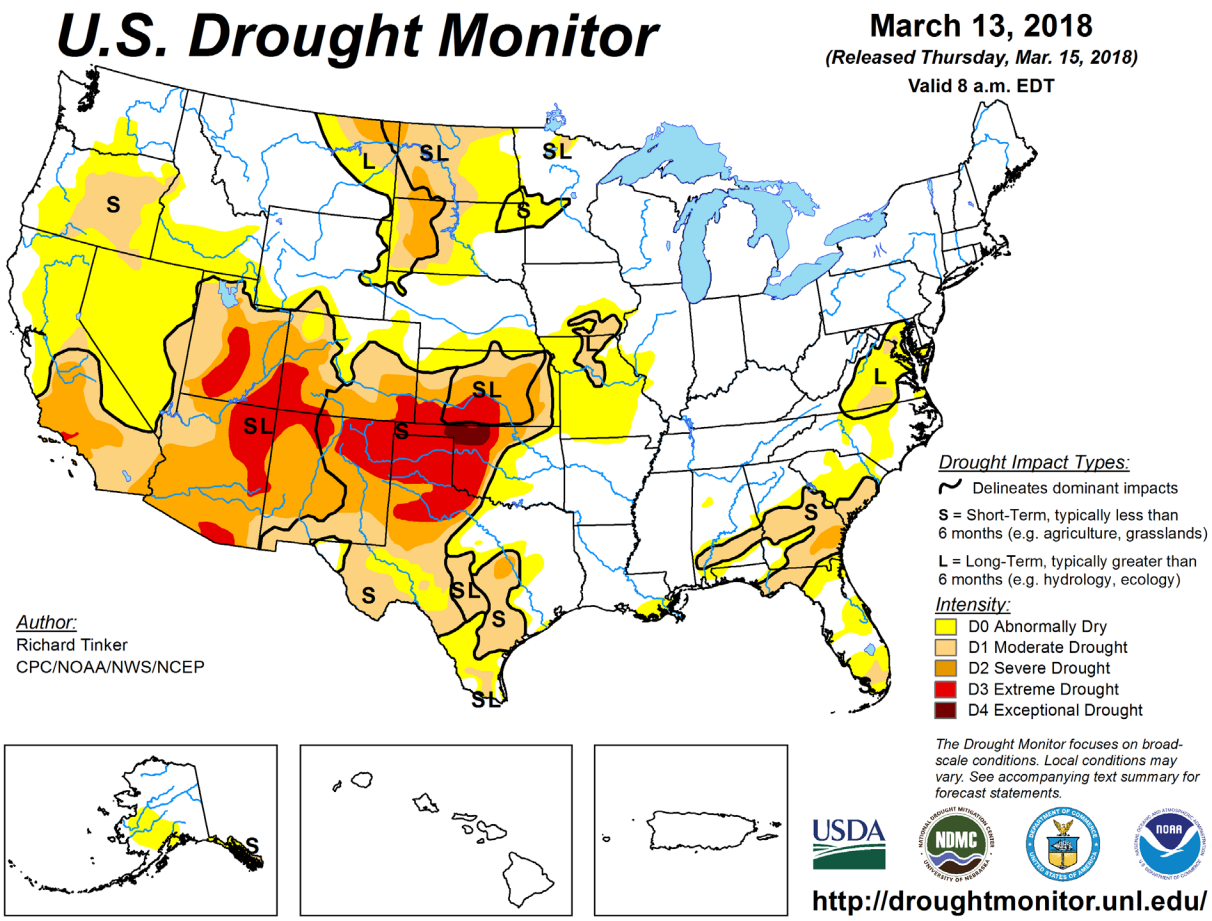
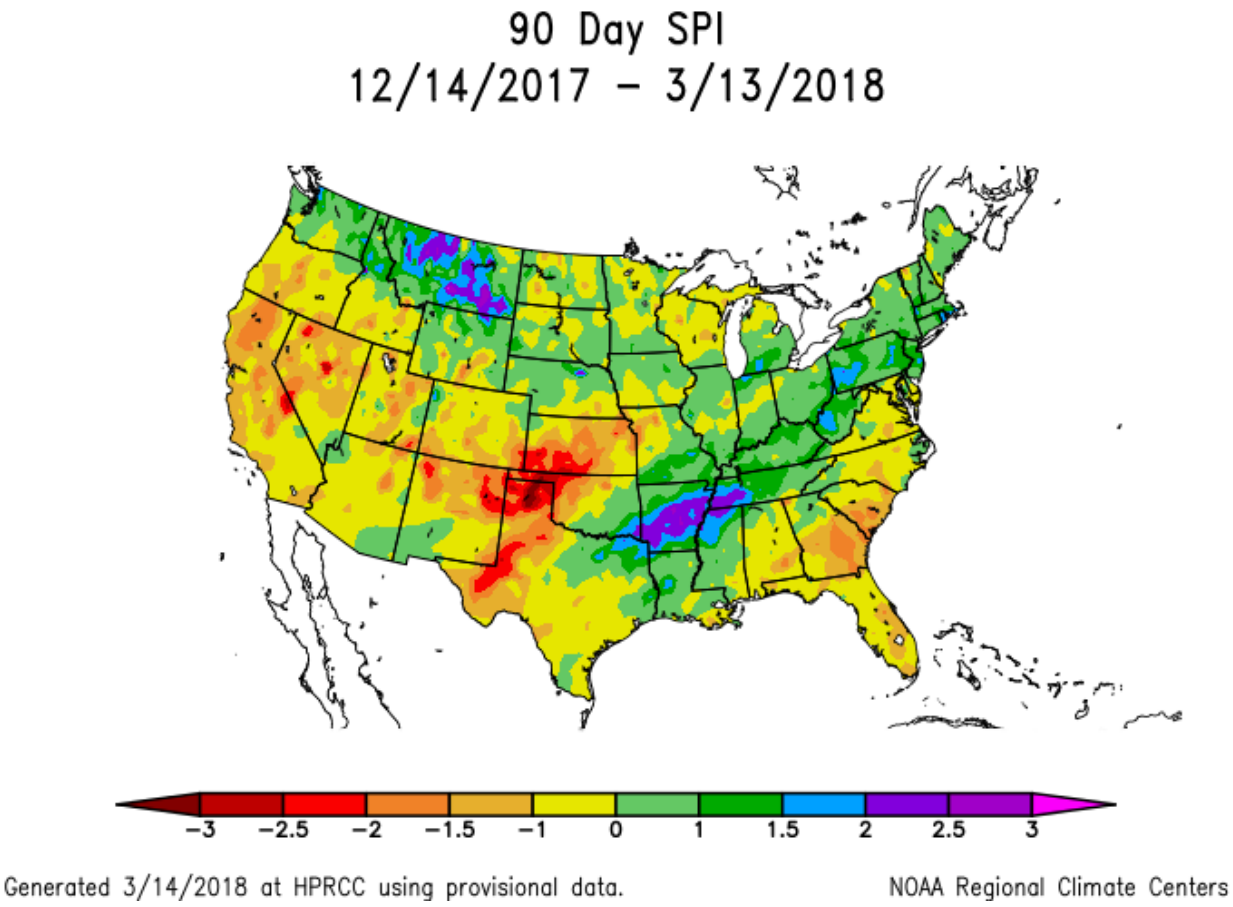


Figure 2. Standardized Precipitation Index



REFERENCES

Anaman, Kwabena A., and Stephen C. Lellyett. "Contingent valuation study of the public weather service in the Sydney metropolitan area." Economic Papers: A journal of applied economics and policy 15, no. 3 (1996): 64-77.

Anderegg, W. R., Berry, J. A., Smith, D. D., Sperry, J. S., Anderegg, L. D., & Field, C. B. (2012). The roles of hydraulic and carbon stress in a widespread climate-induced forest die-off. Proceedings of the National Academy of Sciences, 109(1), 233-237.

Bernknopf, Richard, David Brookshire, Yusuke Kuwayama, Molly Macauley, Matthew Rodell, Alexandra Thompson, Peter Vail, and Benjamin Zaitchik. "The Value of Remotely Sensed Information: The Case of a GRACE-Enhanced Drought Severity Index." Weather, Climate, and Society 2017 (2017).

BLM, 2001-2017a: Public Land Statistics 2001- 2017: For example: https://www.blm.gov/sites/blm.gov/files/PublicLandStatistics2017.pdf accessed on 1/5/2019

BLM, 2017b: The BLM: A Sound Investment for America 2017: https://www.blm.gov/sites/blm.gov/files/The%20BLM%20A%20Sound%20Investment%20America%202017.pdf accessed on 1/5/2019

BLM, 2019: https://www.blm.gov/about/our-mission accessed on 1/5/2019

Cal Fire (2019): http://www.fire.ca.gov/current_incidents/incidentdetails/Index/2277. accessed on 1/5/2019

Chang, H., & Bonnette, M. R. (2016). Climate change and water-related ecosystem services: impacts of drought in California, USA. Ecosystem Health and Sustainability, 2(12).

Compton, J. E., Harrison, J. A., Dennis, R. L., Greaver, T. L., Hill, B. H., Jordan, S. J., ... & Campbell, H. V. (2011). Ecosystem services altered by human changes in the nitrogen cycle: a new perspective for US decision making. Ecology letters, 14(8), 804-815.

Congressional Research Service, 2016: Grazing Fees: Overview and Issues: https://www.everycrsreport.com/files/20160929_RS21232_b52e04ea00b91486680436e52e5795fea1044398.pdf accessed on 1/5/2019 accessed on 1/5/2019

Covich, A. P. (2009). Emerging climate change impacts on freshwater resources. A perspective on transformed watersheds, RFF Report, Resources for the Future, Washington DC, USA.

Ebi, Kristie L., Thomas J. Teisberg, Laurence S. Kalkstein, Lawrence Robinson, and Rodney F. Weiher. "Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995–98." Bulletin of the American Meteorological Society 85, no. 8 (2004): 1067-1073.

Elsasser, H., & Bürki, R. (2002). Climate change as a threat to tourism in the Alps. Climate research, 20(3), 253-257.

Franke, M. A. (2000). Yellowstone in the Afterglow: Lessons from the Fires. Yellowstone Center for Resources, Yellowstone National Park.

Freebairn, John W, and John W Zillman. "Economic Benefits of Meteorological Services." *Meteorological Applications* 9, no. 1 (2002): 33-44.

Frei, Thomas. "Economic and social benefits of meteorology and climatology in Switzerland." *Meteorological Applications*17, no. 1 (2010): 39-44.

Frei, Thomas, Stefan von Grünigen, and Saskia Willemse. "Economic benefit of meteorology in the Swiss road transportation sector." Meteorological Applications 21, no. 2 (2014): 294-300.

Hart, Julie. Senior Economist, Office of State Planning and Budgeting. Memorandum: Economic Impact Task Force Report on the Impact of Drought. Denver, CO: 2002.

Halstead, John M., A. E. Luloff, and Thomas H. Stevens. "Protest bidders in contingent valuation." Northeastern Journal of Agricultural and Resource Economics 21, no. 2 (1992): 160-169.

IFAI, https://intentsmag.com/2017/12/01/paid-weather-apps-offer-service-and-accuracy/ (2017) accessed on 5/25/2018

Kenkel, Phil L., and Patricia E. Norris. "Agricultural producers' willingness to pay for real-time mesoscale weather information." Journal of Agricultural and Resource Economics (1995): 356-372.

Kite-Powell, Hauke. *Estimating Economic Benefits from NOAA PORTS® Installations: A Value of Information Approach*. No. NOAA Technical Report NOS CO-OPS 044. 2005.

Klos, R. J., Wang, G. G., Bauerle, W. L., & Rieck, J. R. (2009). Drought impact on forest growth and mortality in the southeast USA: an analysis using Forest Health and Monitoring data. Ecological Applications, 19(3), 699-708.

Labao Wang, Xinsheng Lu, Dachun Wang, and Wujiu Hu. Benefit Analysis and Assessment of Public Meteorological Service in Anhui Province. Meteorological Science and Technology 6 (2007): 021.

Lawrimore, J., & Stephens, S. (2003). Climate of 2002 Annual Review. NOAA National Climatic Data Center.

Lazo, Jeffrey K., Rebecca E. Morss, and Julie L. Demuth. "300 billion served: Sources, perceptions, uses, and values of weather forecasts." Bulletin of the American Meteorological Society 90, no. 6 (2009): 785-798.

Leones, J., Colby, B., Cory, D., & Ryan, L. (1997). Measuring regional economic impacts of streamflow depletions. Water Resources Research, 33(4), 831-838.

Leviäkangas, Pekka. "Valuing Meteorological Information." *Meteorological Applications* 16, no. 3 (2009): 315-23.

Liu, Tingting. Three essays on the economics of ecosystem services and land use change. University of Rhode Island, 2014.

Loomis, John, Steve Koontz, Holly Miller, and Leslie Richardson. "Valuing geospatial information: Using the contingent valuation method to estimate the economic benefits of Landsat satellite imagery." Photogrammetric Engineering & Remote Sensing 81, no. 8 (2015): 647-656.

Malik, Arun S, Gregory S Amacher, Jason Russ, Enos E Esikuri, and Keiko Ashida Tao. "Framework for Conducting Benefit-Cost Analyses of Investments in Hydro-Meteorological Systems." (2014).

Monsanto.com, https://climate.com/pricing (2018) accessed on 5/25/2018

National Climate Assessment, https://nca2014.globalchange.gov/report (2014) accessed on 5/25/2018

National Research Council. Valuing ecosystem services: toward better environmental decision-making. national academies Press, 2005.

Nguyen, Thanh Cong, and Jackie Robinson. "Analysing motives behind willingness to pay for improving early warning services for tropical cyclones in Vietnam." Meteorological Applications 22, no. 2 (2015): 187-197.

Park, So-Yeon, Seul-Ye Lim, and Seung-Hoon Yoo. "The economic value of the national meteorological service in the Korean household sector: A contingent valuation study." Sustainability 8, no. 9 (2016): 834.

Perrels, A, Th Frei, Francisco Espejo Gil, L Jamin, and A Thomalla. "Socio-Economic Benefits of Weather and Climate Services in Europe." (2013).

Price, J. I., McCollum, D. W., & Berrens, R. P. (2010). Insect infestation and residential property values: A hedonic analysis of the mountain pine beetle epidemic. Forest Policy and Economics, 12(6), 415-422.

Rogers, David, and Vladimir Tsirkunov. "Costs and benefits of early warning systems." Global Assessment Rep (2011).

Rollins, Kimberly S., and Joseph Shaykewich. "Using willingness-to-pay to assess the economic value of weather forecasts for multiple commercial sectors." Meteorological applications 10, no. 1 (2003): 31-38.

Rosegrant, M. W. (1997). Water resources in the twenty-first century: Challenges and implications for action (Vol. 20). Intl Food Policy Res Inst.

Schneckenburger, C., & Aukerman, R. (2002, December). The economic impact of drought on recreation and tourism. In Proceedings from the Colorado drought conference: Managing water supply and demand in the time of drought (pp. 93-97).

Scott, D. (2003, April). Climate change and tourism in the mountain regions of North America. In 1st International Conference on Climate Change and Tourism (pp. 9-11).

Sharda, Vaishali, and Puneet Srivastava. "Value of ENSO-forecasted drought information for the management of water resources of small to mid-size communities." Transactions of the ASABE 59, no. 6 (2016): 1733-1744.

Svoboda, M., LeComte, D., Hayes, M., Heim, R., Gleason, K., Angel, J., ... & Miskus, D. (2002). The drought monitor. Bulletin of the American Meteorological Society, 83(8), 1181-1190

von Gruenigen, Stefan, Saskia Willemse, and Thomas Frei. "Economic value of meteorological services to Switzerland's airlines: The case of TAF at Zurich Airport." Weather, Climate, and Society 6, no. 2 (2014): 264-272.

Ward, F. A., Roach, B. A., & Henderson, J. E. (1996). The economic value of water in recreation: Evidence from the California drought. Water Resources Research, 32(4), 1075-1081.