University of Nevada, Reno

Water Managers’ Perceptions of the Utility of Seasonal Forecasts in Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geography

by

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Abstract

Nevada is the driest state in the United States and is subject to recurrent drought even without the influence of climate change. As a result, careful water management is critical in meeting the needs of the three million people who live in Nevada. Seasonal climate forecasts, such as Seasonal Outlooks produced by the Climate Prediction Center that predict average temperature and precipitation for three-month seasons with lead times of two weeks to 12 months. These outlooks could be a valuable resource for water managers in the state, providing the potential to improve streamflow forecasts and the understanding of drought progression. However, it is not known whether water managers in Nevada find these seasonal climate forecasts useful, how they use seasonal climate forecasts, or they even use the forecasts at all. To answer this question, we sent an online survey out to water managers – defined as people who "plan, develop, distribute, and manage the optimum use of water resources" (AWRA, 2022) – to determine their perceptions of seasonal forecasts. Survey results yielded 23 respondents. Three-fourths (74%, n = 17) of respondents were familiar with seasonal forecasts. More than 95% (n = 22) of the respondents indicated that they use seasonal precipitation forecasts, and 61% of respondents use seasonal temperature forecasts. Roughly 40% (n = 9) of water managers indicated that they viewed seasonal temperature forecasts as accurate or very accurate, whereas 30% (n = 7) of respondents considered precipitation outlooks as accurate or very accurate. Water managers considered temperature and precipitation outlooks generally useful, but there were some documented barriers to their use. Spatial and temporal scales are at a mismatch between water managers and seasonal forecasts, which was confirmed by a set of questions gaining water managers' forecast time horizons and water management decisions. These questions revealed that water managers considered short-term forecasts, monthly being the most prominent, to be the most useful to them. Top management decisions included those dealing with water supply, outreach, and education. Future work should focus on further defining use and accessibility of seasonal forecasts, along with finding climate products that better align with water managers' spatial and temporal scale needs.

Key words: seasonal forecasts, Nevada, water managers, water management, water management decision-making, seasonal forecast perceptions

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Acronym List

NOAA	National Oceanic and Atmospheric Administration
CPC	Climate Prediction Center
ECMWF	European Centre for Medium-Range Weather Forecasts
SSTs	Sea surface temperatures
ENSO	El Niño Southern Oscillation
MJO	Madden Julian Oscillation
CFS	Climate Forecast System
NMME	North American Multi-Model Ensemble
CCA	Canonical Correction Analysis
SLMR	Screening Multiple Linear Regression
HSS	Heidke Skill Score
RFC	River Forecast Center
NRCS	Natural Resources Conservation Service
AWRA	American Water Resources Association
SWNA	Southern Nevada Water Authority
USDOI	U.S. Department of the Interior
NCICS	North Carolina Institute for Climate Studies
WRCC	Western Regional Climate Center
NDEP	Nevada Division of Environmental Protection
BLM	Bureau of Land Management
USGS	United States Geological Survey
NWRA	Nevada Water Resources Association

Perceptions of Seasonal Forecast Utility by Water Managers in Nevada

Chapter 1

1. Introduction

Over the course of the year, water managers make many decisions. Seasonal forecasts provide information about anticipated climate, typically temperature and precipitation anomalies, for the next season to the next year (Gawthrop, 2015). In many regions across the United States, water resource planning decisions are made outside of the weather forecast window, defined as minutes to two weeks out (Raff et al. 2013). It seems like this kind of long-lead information would be very useful for water management decisions. However, seasonal forecasts appear to be an unused resource among water managers. Studies such as Rayner et al. (2005), Bolson et al. (2013), and Crimmins and McClaran (2015) suggest that water managers do not use seasonal forecasts in their decision-making processes for a variety of reasons. These include issues concerning forecast accuracy, accessibility, and/or timing (i.e., temporal scale mismatch).

In much of the western United States, most precipitation falls as rain or snow during the cool season, defined as October-April of each year (Wise et al., 2015). Throughout the year, but especially during the warm season (May-September), water is used in municipal settings, such as homes and businesses, and for agricultural irrigation, recreation, and environmental flows. Thus, overall water demand reaches its maximum during the warm season (Raff et al., 2013), yet there is a timing mismatch between when precipitation falls and when water needs are greatest. To compensate for this temporal scale mismatch, dammed rivers and reservoirs are common across the West. Reservoir operations consist of storing and releasing of river surface flows as needed for various purposes (e.g., to support irrigated agriculture, downstream fisheries and aquatic ecosystems, and reserving empty storage space that could be used to reduce downstream flood risk by storing significant storm or snowmelt runoff during the cold season) (Raff et al., 2013). Thus, a critical set of water management decisions in the West involve reservoir operations. Reservoir management could potentially be improved using skillful climate forecasts, but they are not in regular use.

Two primary forecast tools are widely used among water resource managers in the western United States: River Forecast Center (RFC) streamflow forecasts and NRCS (Natural Resources Conservation Service) water supply forecasts. Streamflow forecasts released by the RFC consist of flow forecasted in percentages of normal observed streamflow with respect to various climatologies and water years (NWS CNRFC, 2022). The NRCS water supply forecasts provide water managers with streamflow forecasts in a table format with five probabilities depicting flow exceedance; these forecasts/probabilities are compared to the 30-year median (NRCS, 2022). These forecasts are largely based on current and historical climate data, although they sometimes include atmospheric or oceanic teleconnections (Harpold et al., 2017a; Pagano et al., 2004).

Management of the Colorado River includes crucial water decisions involving reservoir operations across this river system (Lukas and Payton, 2020). Each month for the Colorado River system, a 24-month study is released depicting hydrological conditions and projected reservoir operations for the next two years given existing reservoir conditions and operational guidelines. Streamflow forecasts used in the 24-

month study are based not on forecasted climate but on 35 years of past climate (Lukas and Payton, 2020).

Although seasonal forecasts are intended to aid and improve seasonal-scale decisions about water resources management, their use and utility in Nevada is not known. Because of the potential for these forecasts to inform water management decision-making, this study asks: **Do water managers in Nevada use seasonal forecasts, and if they do not, why?** To assess the role of seasonal forecasts in informing water management decisions in Nevada, I conducted a statewide online survey of various water managers, which were defined broadly as individuals who make decisions on water supply, distribution, and planning.

Chapter 2

2. Background

2.1. Seasonal Forecasts

Seasonal forecasts are developed using models of the atmosphere, oceans, and land surface (Arribas et al., 2011), sometimes combined with statistical models and forecaster judgement (CPC, 2020). Seasonal forecasts were first created and released in the late 1980s into the 1990s, although research had been conducted on their potential in the 1970s (Davis, 1976). There are multiple entities that release seasonal forecasts, such as the Climate Prediction Center (CPC) and the European Centre for Medium-Range Weather Forecasts (ECMWF). The most common seasonal forecasts feature temperature and precipitation. Temperature and precipitation are also important variables in water resource management, as they are both commonly used in projecting future water supply, which most water resource decisions are reliant on (Raff et al. 2013).

Seasonal forecasts are developed with numerous different tools and resources. One such tool are statistical atmospheric relationships called teleconnections, which relate global circulation and climate patterns to local weather. Sea surface temperatures (SSTs) are critical in driving convection that directly impacts global circulation patterns, which can have a strong control on regional climate (Crimmins and McClaran, 2015). Two of the teleconnection patterns frequently used to predict climate in the western United States are the El Niño-Southern Oscillation (ENSO) and the Madden Julian Oscillation (MJO) (Barnston et al., 1994; Crimmins and McClaran, 2015).

The El Niño-Southern Oscillation is a coupling between atmosphere and ocean in the tropical Pacific Ocean (Troccoli et al., 2010). This coupling has the potential to influence worldwide climate on seasonal time scales, making it the largest climate signal to affect global climate after the seasonal cycles (Livezey and Timofeyeva, 2008). Since the 1980s, ENSO has been used when forecasting further out than weather predictions, which is around two weeks in advance (Gawthrop, 2015); this continued in the 1990s when seasonal forecasts were first released, and ESNO is still heavily used in seasonal forecasting (Livezey and Timofeyeva, 2008).

There are pros and cons associated with using teleconnections such as ENSO. The El Niño-Southern Oscillation does have a strong signal on climate and can produce skillful forecasts. (e.g., An and Wang, 2000; Livezey and Timofeyeva, 2008; Crimmins and McCarran, 2015; Lenssen et al. 2020). However, ENSO teleconnections can vary over time (e.g., Cole and Cook, 1998, McAfee and Wise, 2015) due to changes in background conditions (e.g., Gershunov and Barnett, 1998, Wise, 2010) or in the pattern and position of SST anomalies (e.g., Capotondi et al., 2015). Because ENSO has been so extensively studied (An and Wang, 2000, Livezey and Timofeyeva, 2008, Troccoli et al. 2010, Crimmins and McClaran, 2015, Lenssen et al. 2020) and is relatively simple it remains important for seasonal climate forecasting.

The Madden-Julian Oscillation (MJO) is another teleconnection used in developing seasonal forecasts. The MJO is a tropical intraseasonal oscillation that, through convective heating, can influence an extratropical weather response (Madden and Julian, 1971). This mode of variability impacts mid-latitude circulation on sub-seasonal timescales, which can in turn impact the tracks and frequency of atmospheric rivers (Henderson et al., 2016). The MJO teleconnection is strongest in the western United States when the majority of precipitation falls, which is during the winter months (December, January, February) (WRCC, 2020). Therefore, its inclusion into the list of tools used in seasonal forecast development is important. Similar to ENSO, the weather during a specific MJO phase may not reflect the usual or expected conditions, but extensive studies have shown that it is a fairly reliable tool to use (Li and Robertson, 2015, Mayer and Barnes, 2019).

Other statistical tools are also used in the formation of seasonal forecasts. The CPC Outlooks incorporate Canonical Correlation Analysis (CCA) and Screening Multiple Linear Regression (SMLR), statistical approaches that use data on current and past temperature and precipitation – and soil moisture for SMLR – SSTs and pressure patterns to predict future climate. (CPC, 2022; Barnston et al. 1994; Mo, 2003).

Numerical weather models are another tool used in developing seasonal forecasts. Numerical weather models are computer models that solve physical and statistical equations to simulate atmospheric processes (CPC, 2020). One model used as a seasonal forecast tool by the CPC is the Climate Forecast System (CFS). Another tool used is the North American Multi-Model Ensemble (NMME), which combines multiple models, including the CFS (CPC, 2022).

The CFS is a fully coupled ocean-atmosphere dynamic model that produces an ensemble mean forecast (Saha et al. 2010). Specific CFS output used in seasonal forecasts are seasonal climate anomalies of temperature and precipitation (CPC, 2022).

The NMME is a combination of multiple meteorological models originating from centers across North America (Kirtman et al., 2014). The products that are used in seasonal forecast development are global SSTs, global precipitation rate, global 2-meter temperature, precipitation rate, and 2-meter temperature (CPC, 2020). These tools and products are either derived directly from the NMME's output or included as tools for forecasters (Kirtman et al., 2014).

Forecaster expertise is also a key component of seasonal forecasts. Forecaster expertise is when meteorological forecasters use intuition to make their decisions alongside direct analysis (Stuart et al., 2007). This intuition is important, as forecasters often have overwhelming amounts of data to look through and time constraints for events or product releases (Stuart et al., 2007). In particular, forecasters use their knowledge of concepts to recognize patterns or past events and base their decision-making on that (Hoffman et. al, 2002). This is combined with the model output mentioned above and incorporated into the seasonal forecasts before their release.

These tools and resources, from ENSO to complex numerical models like CFS and NMME, to forecaster expertise, are incorporated in one of the most commonly used seasonal forecasts in the United States: the CPC seasonal forecasts and the accompanying CPC Prognostic Discussion. A Prognostic Discussion is when a forecaster combines everything mentioned above into a document detailing the reasoning behind recently released forecasts. Prognostic Discussions are released for every forecast the CPC releases, including seasonal forecasts, and are written by various forecasters, allowing different perspectives of forecaster expertise.

2.2. CPC Seasonal Outlooks

These seasonal forecasts can easily be accessed, as they are an official NOAA product and therefore available for public use online. These forecasts depict average temperature and precipitation over three-month seasons (Vitart et al., 2017), have lead times – the time between the forecast issue date and the beginning of the forecast validity period (AMS, 2022) – between 0.5 and 13.5 months, and have been issued by the CPC since mid-December 1994 (CPC, 2020). They are released in the middle of each month for the next thirteen three-month combinations (i.e., in mid-December forecasts are issued January-February-March, February-March-April, and so on).

CPC seasonal forecasts are defined as tercile forecasts, which means that there are three equal categories the forecasts fall into (Crimmins and McClaran, 2015). The three categories are defined as: above normal, below normal, and near normal, or equal chances (Figures 1 and 2). These seasonal forecasts depict average temperature in terms of above normal temperatures/precipitation, near normal temperature/precipitation, and below normal temperatures/precipitation (Livezey and Timofeyeva, 2008). Equal chances forecasts can also be issued. Equal chances means that there are 33.3% chances of below, near, or above normal precipitation or temperatures. To define equal chances, it means that there is a possibility for either below normal or above normal to occur. These categories are with respect to 30-year climatologies. There have been three climatologies released by the CPC: 1971-2000, 1981-2010, and 1991-2020. These categories are shown on a map as different colors over the contiguous United States: the temperature colors are orange and blue, the precipitation colors are green and yellow, and equal chances colors are white (Figures 1 and 2). The forecasts are released in two formats: in a map format representing climate divisions, and in a 2° x 2° degree grid format – Figures 1 and 2 represent the grid format.

The newly updated maps have an expanded legend to help users understand what categories their targeted area falls into (Figures 1 and 2). The lighter shades of above and below normal temperature and precipitation indicate that the forecast is leaning above/below. The darker shades of temperature and precipitation indicate that the forecast is likely going to be above/below, and equal chances is depicted in white.

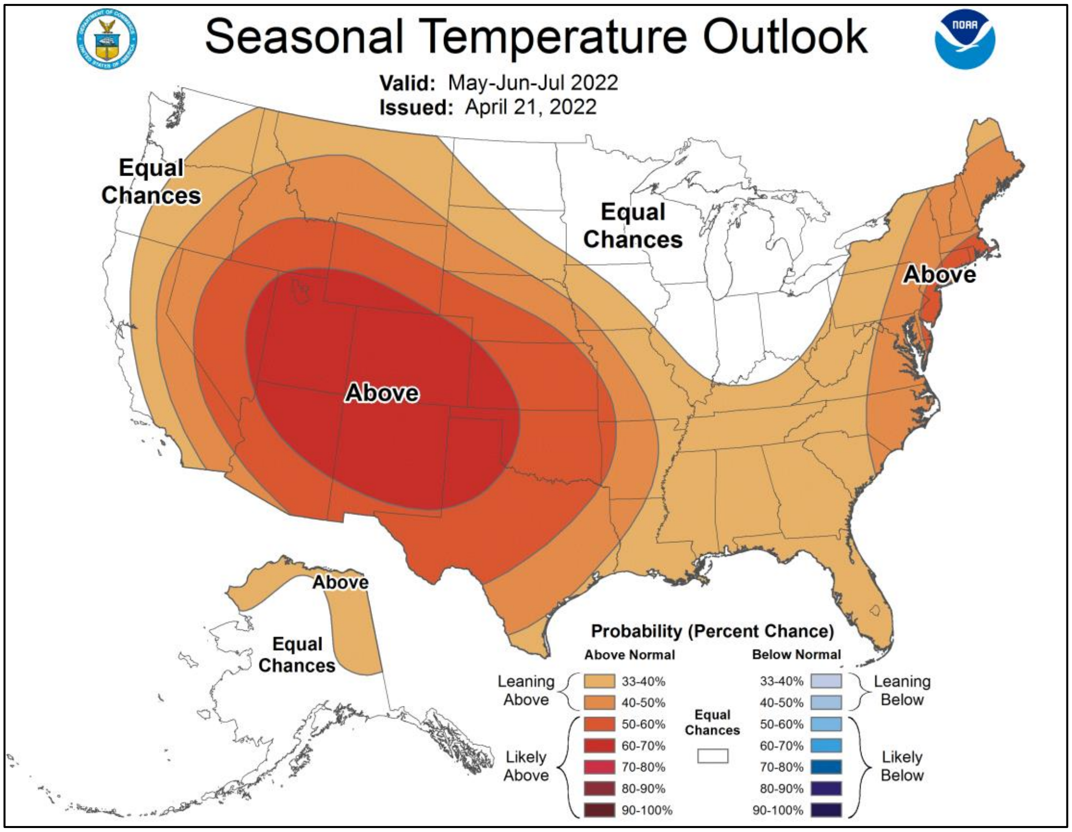

Figure 1: A map depicting the CPC's seasonal temperature forecast. This forecast was issued on April 21, 2022, and valid for the months of May, June, and July of 2022. The three categories these forecasts fall into are: Above Normal (Red/Orange), Below Normal (Blue), and Equal Chances (White). Image taken from: https://www.cpc.ncep.noaa.gov/products/predictions/long_range/lead01/off01_temp.gif.

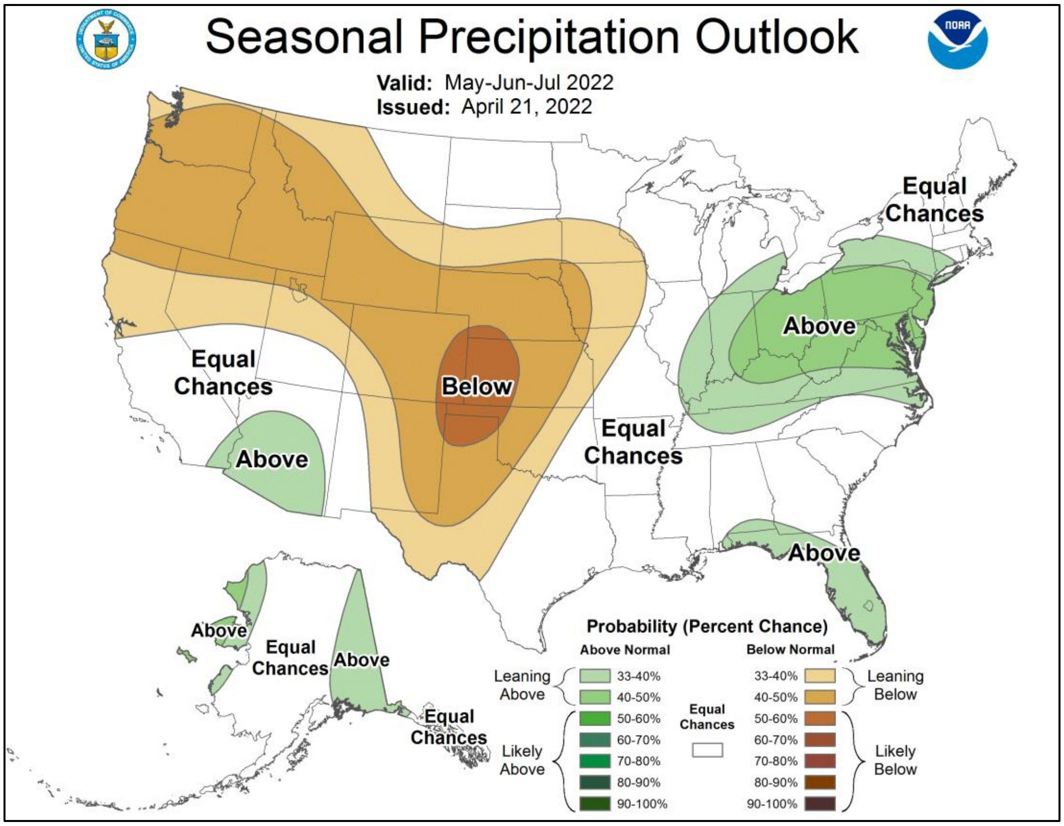

Figure 2: A map depicting the CPC's seasonal precipitation forecast. This forecast was issued on April 21, 2022, and valid for the months of May, June, and July of 2022. The three categories these forecasts fall into are: Above Normal (Green), Below Normal (Yellow/Brown), and Equal Chances (White). Image taken from: https://www.cpc.ncep.noaa.gov/products/predictions/long_range/lead01/off01_prcp.gif.

Seasonal forecast skill, a measure of the forecast performance, is evaluated by using the Heidke Skill Score (Figures 3 and 4). The Heidke Skill Score (HSS), which follows the form of the generic skill score defined by Wilks (2006) and measures accuracy by calculating the proportion of correct forecasts, is defined as an equitable score by Wilks (2006). The HSS is used because it takes into account tercile forecasts. Tercile-based probabilities fall into three equal forecast categories: above normal, below normal, and equal chances (Crimmins and McClaran, 2015). The HSS equation is as follows: $HSS = 100 * \ (H - E)/(T - E)$, where H is defined as the number of correct forecasts, E is defined as one-third of the expected number of correct forecasts, and T is defined as the total number of forecasts (CPC, 2022). Forecast verification depends on what climatology the agency is currently using. At the time of the publication of this thesis, the climatology being used is 1991-2020.

The Heidke Skill Score ranges from -50 to 100, with -50 being the worst possible skill, 0 being as good as climatology (or essentially, as good as a random forecast), and 100 being the best possible score (Figures 3 and 4). For temperature, the average score is 15.3, but it is higher in some parts of Nevada, indicating that seasonal temperature forecasts are slightly better than climatology (Figure 3). For precipitation, the average score is 4.9, with Nevada having a 0 score for all but a small area, indicating that seasonal precipitation forecasts hover near zero, or are as good as climatology (Figure 4).

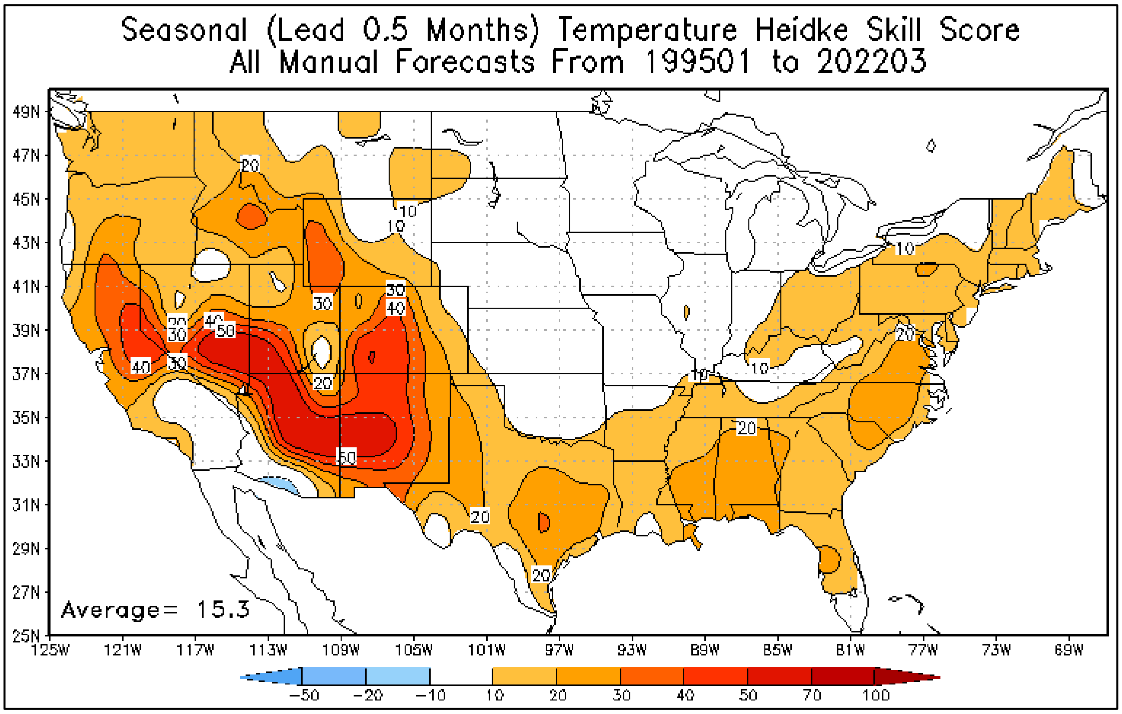

Figure 3: The Heidke Skill Score for all CPC seasonal temperature forecasts with a half month lead. The Heidke Skill Score ranges from -50 to 100, with blue representing the scores -50 to -10, white representing the scores -10 to 10, and red/orange representing the scores 10 to 100. Image taken from: https://www.cpc.ncep.noaa.gov/products/verification/summary/index.php?page=map.

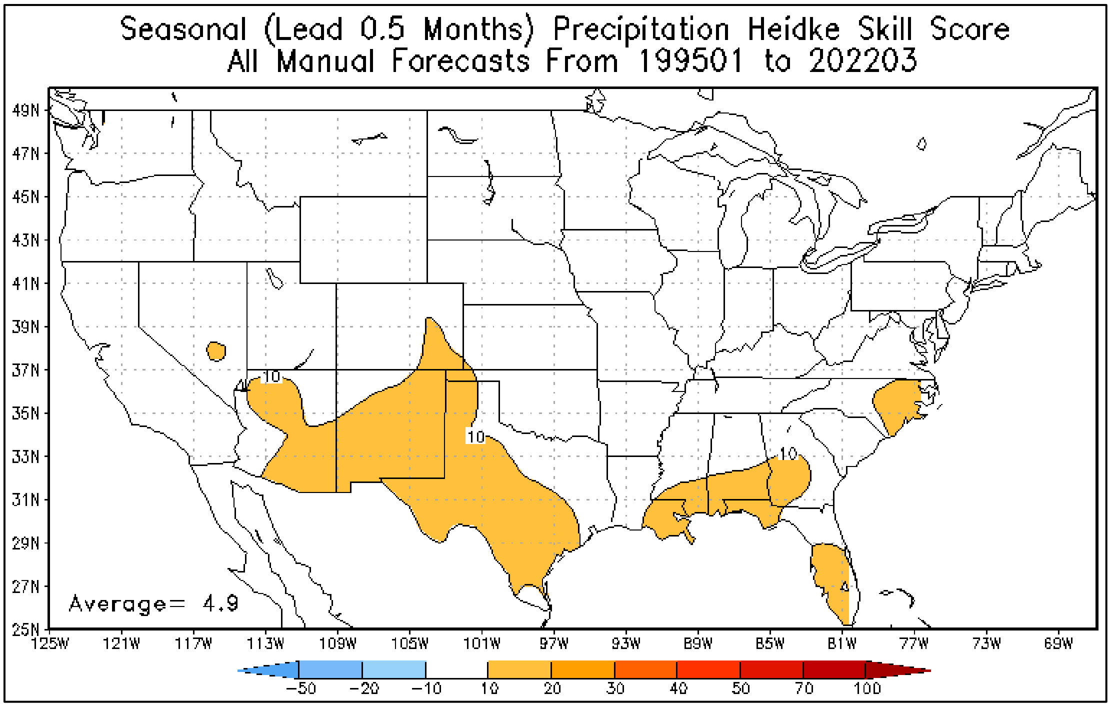

Figure 4: The Heidke Skill Score for all CPC seasonal precipitation forecasts with a half month lead. The Heidke Skill Score ranges from -50 to 100, with blue representing the scores -50 to -10, white representing the scores -10 to 10, and red/orange representing the scores 10 to 100. Image taken from: https://www.cpc.ncep.noaa.gov/products/verification/summary/index.php?page=map.

The main question regarding these seasonal forecasts remains: why don't more water managers use them? They are official NOAA forecasts, so they are originating from a credible source, and ostensibly having one more resource to look at is better than having resources be limited. The published literature indicates seasonal forecasts aren't being used widely by water managers, including several reasons related to their functional utility.

2.3. Usage Barriers

While seasonal forecasts are not extensively used by the water resources management community (Bolson et al., 2013, Rayner et al., 2005, Dilling and Lemos, 2011, 2014, Baker et al., 2019), there are specific communities that use seasonal forecasts in their decision-making. For example, farmers in South Africa report benefits to commercial agriculture when seasonal forecasts were continuously utilized over the long term (Klopper et al., 2006). Studies of the use of seasonal forecast in agriculture focusing on maize yield found that they did not improve yield predictions in Europe and New Zealand, but did within the United States (Semenov and Doblas-Reyes, 2007; Peng et al., 2018). The marine fisheries and aquaculture sciences use seasonal forecasts in their decision-making; for example, one study found that seasonal forecasting was used in marine farming and fishing operations in Australia to diminish uncertainties and manage business risks (Hobday et al., 2016). In addition, various seasonal forecasts are used to predict weather issues faced during ecological restoration projects in Australia (Hagger et al., 2018).

Despite the CPC's seasonal forecasts being publicly available, studies have identified several usage barriers that water managers face when attempting to use them for decision-making. One of the most important barriers is perceived seasonal forecast accuracy (Callahan et al. 1999, Hartmann et al., 2002, Rayner et al. 2005, Feldman and Ingram, 2009, Bolson et al. 2013, Dilling and Lemos, 2011, Dilling and Berggren 2015). Most of these research findings report that water managers do not perceive seasonal forecasts as sufficiently accurate to regularly use for their decision-making.

Developing skillful seasonal forecasts remains challenging. Meteorological forecasts have accuracy out to about two weeks. After that, accuracy declines (Gawthrop, 2015). With the lead times for seasonal forecasts varying between 0.5 and 12 months, seasonal forecasts can demonstrate low forecast skills for certain areas and seasons, particularly as the lead time increases.

Seasonal forecasts and predictability depend on many different factors: the stratosphere, teleconnection instability, ocean and land surface connections, sea ice prediction, midlatitude atmospheric variability, and extremes (Lang et al., 2020). Because so many variables go into seasonal prediction, forecasts are particularly hard to get right, especially with climate change complicating things (Lang et al., 2020).

Another obstacle faced by water managers is spatial resolution. Water managers, through surveys, have reported that the spatial resolution used in seasonal forecasts is far too large and regional to be useful in decision-making, suggesting that local forecasts are more helpful (Rayner et al. 2005, Dilling and Lemos, 2011, Bolson et al. 2013, Baker et al. 2019). In a study where seasonal forecasts were postprocessed to watershed scales, water managers were able to view these forecasts for their specific basins and considered these postprocessed forecasts more useful (Baker et al. 2019).

An additional obstacle faced by water managers is that of a timescale match or mismatch as indicated in several studies where water managers were surveyed to gage their perceptions of climate information. Bolson et al. (2013), for example, found that nearly one-fourth of respondents who answered survey questions regarding barriers to forecast usage noted that the timescales of seasonal forecasts did not match with their decision-making processes. This was also highlighted in Rayner et al. (2005), which also examined barriers water managers face when attempting to use climate forecast information. A study reviewing seasonal forecast use by water managers suggests that the timing of seasonal climate forecast information is critical for whether or not it is used (Dilling and Lemos, 2011).

Additional studies found that some water managers did not use seasonal forecasts as a matter of protocol. In a study of water managers in the southeastern US, one-third reported that they did not use seasonal forecasts because they were not on their list of approved decision support tools (Bolson et al., 2013). Many water managers have an informal or formal institutional set of decision rules, some of which can be inflexible (Dilling and Lemos, 2011). An example of this was highlighted in a study of water allocation practices in the United States Pacific Northwest. That study found that managers faced inflexible institutional decision rules when managing for flood risk (Callahan et al., 1999).

Another barrier could be that seasonal forecasts are expressed in tercile probabilities for temperature and precipitation, and are therefore distinct from most of the other forecasts released by NOAA. The forecast maps can be difficult to read if water managers do not understand how these forecasts are visually represented or if they understand tercile forecasts incompletely (Hartmann et al., 2002).

2.4. Study Area and Relevance

The goal of this research is to gain insight into the functional utility of seasonal forecasts for water managers in Nevada, following the American Water Resources Association (AWRA) definition of water management, which is “the activity of planning, developing, distributing, and managing the optimum use of water resources” (AWRA, 2019). An example of a water manager in Nevada is a person working for a water utility agency and who makes decisions on the distribution of water. Currently, research shows that water managers use many tools to accomplish this, such as RFC streamflow forecasts, NRCS water supply forecasts, and US Bureau of Reclamation's 24-month studies, and others (Raff et al., 2013). It is unknown to what degree water managers in Nevada use seasonal forecasts; this is an important question to ask because seasonal forecasts could be an additional helpful tool they can use in their decision-making.

Nevada is the driest state in the nation, mainly due to the orographic barrier created by the Sierra Nevada Range. This topographic feature means that the majority of Nevada's water supply originates as snowpack in the Sierra Nevada Range and the Rocky Mountains (Kapnick et al., 2018; WRCC, 2020, SWNA, 2020). These serve both major metropolitan areas in Nevada. Precipitation in the Sierra Nevada range largely falls as winter snowpack that becomes spring snowmelt runoff, which is a large part of northern Nevada's water budget, serving the Truckee, Carson, Walker river basins (Kapnick et al., 2018; WRCC, 2020).

The Southern Nevada Water Authority (SWNA) reports that nearly 90% of the water used in southern Nevada, home to the majority of the state's population, comes from the Colorado River (SWNA, 2020). The Colorado River is composed mostly of snowmelt that occurs in the Rocky Mountains (SWNA, 2020). Since 2000, the Colorado River Basin has experienced extended drought and the water levels of Lake Mead, located in southern Nevada, continue to decline (U.S. Department of the Interior (USDOI), 2020).

Agricultural and rural areas in Nevada are served by a mix of snowfed rivers and groundwater (NDEP, 2021). Snowmelt from the Jarbridge, Independence, and Ruby Mountain ranges in eastern Nevada feeds the Humboldt River Basin in northeastern Nevada (Hare et al., 2013). If there is less snowpack accumulation in the winter, there is less water in Nevada's water budget for the spring and summer seasons. Multiple years of diminished snowpack combined with general drought conditions can lead to snow drought that presents challenges for water resource managers (Harpold et al., 2017b).

With an average precipitation rate of less than 10 inches per year (Runkle et al., 2022), water use and management are important to Nevada (Foresta, 2018). Questions remain about whether water managers use seasonal forecasts, and if not, why. This study addresses four key research questions that inform the overarching research goal of understanding seasonal climate forecast use by Nevada's water managers: 1) Are Nevada's water managers familiar with seasonal forecasts? 2) Do water managers use seasonal forecasts in their decision-making? 3) How do water managers rate the accuracy of seasonal forecasts? 4) How useful are seasonal forecasts for water managers? These research questions will be answered through the use of a survey of Nevada's water managers.

Chapter 3

3. Methods

3.1. Research Design

Water managers are knowledgeable in the field of water supply and distribution, and they make decisions based on these as part of their daily job duties (Raff et al., 2013), but previous research suggests that they do not use seasonal forecasts extensively in their management decisions (Bolson et al., 2013, Dilling and Lemos, 2011, Rayner et al., 2005, Crimmins and McClaran, 2015, Feldman and Ingram, 2009). This study evaluates water managers' perceptions and use of seasonal forecasts in Nevada. Assessing the role of seasonal forecasts in water management may help climate scientists to see decision-making through the perspectives of water managers so that seasonal forecasts can be as applicable, tailored, and therefore useful, as possible.

3.2. Target Population

This study population is water managers in Nevada, defined as people responsible for "planning, development, distribution, and management of the optimum use of water resources," (AWRA, 2019). Participants could work in a range of settings in Nevada. These include but are not limited to the Conservation Districts, Irrigation Districts, Subconservancies, Water System/Utilities, state agencies, federal agencies such as the Bureau of Land Management (BLM) and United States Geological Survey (USGS), tribal nations/governments, local farms and ranches, local hospitality businesses, private consultants and companies, and non-profit organizations (Raff et al., 2013, Bolson et al., 2013, Rayner et al., 2005, Dilling and Lemos, 2011). Presumably the majority of these participants are already engaged or interested in climate information and data. Therefore, the survey respondents are also assumed to have occupational awareness, knowledge, and understanding of the complexities of climate science related to hydrology and water supply and management.

3.3. Survey Instrument

The survey instrument assesses the utility of seasonal forecasts in informing water management decisions. The questions developed for this survey were based in part on literature describing water managers' use of climate forecast information (Dilling and Lemos, 2011, Bolson et al., 2013, Rayner et al., 2005). The topics cited most frequently throughout these studies were knowledge gaps in climate information, which we narrowed down further to seasonal forecasts (Dilling and Lemos, 2011), an understanding of water managers’ decision-making time scales (Bolson et al., 2013), how often they used seasonal forecasts (Bolson et al., 2013), and the perceived accuracy of seasonal forecasts (Rayner et al., 2005). These research results helped to clarify the types of questions necessary to gage water managers’ perceptions of forecasts and their information needs. Based on the literature review, early drafts of survey question items focused on assessing information needs and perceptions relating to seasonal forecast quality – specifically question items that allowed the participants to demonstrate their knowledge and perceptions of forecast accuracy and utility to decision-making.

A panel of University of Nevada, Reno faculty, with expertise in climatology, water resources, and survey design, reviewed each draft of the survey instrument. These reviews ensured the survey instrument was legible, concise, and contained all the necessary research topics. The final survey instrument was pre-tested with a sample of University of Nevada, Reno Geography faculty with expertise in survey design, climate scientists from other states, and staff with the Nevada Division of Water Resources. The pre-test responses were excluded from the formal results section.

The survey was developed online and administered via Qualtrics. Survey questions featured 13 close-ended questions (i.e., forced choice, rating scales, Likert scales) and three open-ended follow-up questions (see Appendix A). To encourage participation, respondents were not required to answer every question to page forward through the survey or to submit the survey.

Survey questions were designed to assess the information needs, accessibility, perceptions, and decision-making practices of water managers concerning seasonal forecasts. While water managers may access hydrological, climatological, and environmental information from many sources, this study focused specifically on seasonal forecasts issued by the CPC, which are available for public use and could provide key pieces of information in water managers' decision-making methods. Therefore, seasonal forecasts are a key resource when conducting climate information assessments and informing water management decision-making.

Responses from the survey will allow us to better understand if, how, and why Nevada water managers use seasonal forecasts and what the barriers to use are. For example, Feldman and Ingram (2009) stress the importance of water managers needing information at key decision-making times. Therefore, if the timelines of water managers' needs and the release of seasonal forecasts do not overlap, water managers likely will not find them useful. The survey is included as Appendix A.

3.3.1. Survey Instrument Part I: Employment Characteristics

Questions 1-3 ask water managers to identify their employment sector and provide details about their job duties. These questions allow us to verify that participants work in water resources management in Nevada. Although we targeted organizations with water-management responsibilities, some employees in these organizations hold purely administrative roles that do not directly rely on knowing the state of water supply or any forecasts of water supply. These questions also provide information that is pertinent in assessing who uses seasonal forecasts. Previous studies (Dilling and Lemos, 2011, Bolson et al., 2013, Rayner et al., 2005) have found that water managers who work for federal or state agencies have more experience and knowledge of seasonal forecasts than those who work at smaller, private, or rural companies and that that use and can differ between rural and urban water managers (Bolson et al., 2013). Water management in Nevada occurs within federal, tribal, state, and county organizations and includes both large and small water utilities and purveyors (Drozdoff et al., 2015). Nevada also exhibits a clear divide between urban and rural counties, so it would be informative if participants from every county completed the survey.

3.3.2. Survey Instrument Part II: Accessibility and Use

This section of the survey defines seasonal forecasts and asks about participants' familiarity with, access to, and use of seasonal forecasts. Familiarity with and ease of access were evaluated for seasonal forecasts generally, in part because the CPC outlooks here are provided together. Use of seasonal temperature and precipitation forecasts were assessed separately to determine if there are any differences in the use and perceptions of the two variables.

3.3.3. Survey Instrument Part III: Perceived Accuracy and Utility

Questions 8-12 ask participants to rate the accuracy and utility of seasonal forecasts and describe barriers they face that, if corrected, would allow them to use seasonal forecasts more. These survey questions are some of the most important as they evaluate the key question of how useful seasonal forecasts are to water managers and their decision-making. Responses to these questions helped determine if water managers used one type of seasonal forecast (temperature or precipitation) more frequently than the other. This question allows climate scientists to determine if there is a knowledge gap in water managers' perceptions of these seasonal forecasts, or if their perceptions lead them to use one over the other.

3.3.4. Survey Instrument Part IV: Decision-Context

This portion of the survey asks water managers about the time horizons of seasonal forecasts needed for their water management decisions, their top three water management decisions, and how far in advance forecasts are needed to make each of those decisions. These questions provide information about the compatibility between water managers' timelines and seasonal forecast windows. It is imperative that water managers use tools that are compatible with their decision-making (Bolson et al., 2013; Dilling et al., 2011, 2015; Rayner et al., 2005; Feldman and Ingram, 2009; and Stuart et al., 2007). Determining the barriers water managers face when attempting to use seasonal forecasts is imperative when considering whether seasonal forecasts are a useful tool for water management decision-making (Dilling and Lemos, 2011). Specifically, determining the forecast needs of water managers can help climate scientists to better understand the water management community's information needs.

3.3.5. Survey Instrument Parts V and VI: Final Thoughts and Suggestions

The final questions on the survey asked water managers to provide the names of other water managers who might be interested in responding and for their thoughts about seasonal forecasts or the survey. Asking respondents their survey perceptions allows their responses to be implemented into future studies (Dillman et al., 2009). Responses to these questions were coded and cross-referenced with identified trends in responses and perceptions.

3.4. Survey Sample

Accessing the target population for this survey required two methods of sampling done in succession: purposeful judgement sampling followed by snowball sampling. Judgement sampling entailed identifying those individuals in Nevada that met AWRA's definition of water management. Specifically, I used this definition to determine the job duties of survey participants we would define as water managers and recruited all individuals that met that criteria. This sampling process consisted of reviewing federal, state, tribal, private, and utility industry online directories to identify individuals with job titles that implied that their duties matched AWRA's definition of water management.

This was followed by snowball sampling. That is, as part of the survey administration, I asked participants to share the email addresses of water managers they think should take the survey, referring us to new participants. This second method of sampling helped to ensure that any potential survey participants initially missed could be captured. Incidental exclusion could occur due to a variety of reasons such as website inaccuracies, lack of regular website updates, lack of complete representation of rural areas through websites, and contact methods being altogether unavailable.

Before creating the survey participant list, we observed that the most available form of contact for these potential participants was via email; therefore, an electronic survey (e-survey), administered via email, is the most suitable tool. Survey literature also indicates that e-surveys achieve the highest response rate if the entire survey population has access to internet (Dillman et al. 2009).

3.4.1. Survey Recruitment and Administration

The e-survey was administered online using Qualtrics from January 13 to February 25, 2022. To ensure confidentiality, an anonymous link to the e-survey was emailed to the survey sample. All potential participants received an email that provided a brief overview of the study. This overview requested their voluntary survey participation, an explanation of the purpose of the study, the estimated time it would take to complete the survey (10-15 minutes), and an informed consent agreement. Participants received assurances that their responses were confidential, and that the data collected would be reported only in summary form with no individual identifiers. This study protocol was reviewed and approved by the University of Nevada, Reno Office of Human Research Integrity and Internal Review Board (Reference # 1809386-1).

In total, the list was 46 people long. The survey was initially sent out to these 46 people, and there were two emails provided via direct snowball sampling from the survey. In addition to this snowball sampling, an administrator for the Nevada Water Resources Association (NWRA) forwarded the email with the link to the survey to its listserv of 413 people. Because of this snowball sampling, it is nearly impossible to calculate a response rate, so I did not include that statistic in the results.

3.5. Survey Data Analysis

3.5.1. Close-ended Questions

In total, 23 surveys were completed and supplied the data for analysis. Responses to close-ended items were tabulated for statistical analysis. Because the survey was focused on assessing information needs, it is important to look for any relationships between accessibility, information needs, and perspectives. This was done by calculating basic descriptive statistics for each question and a thorough cross-examination of responses from different questions.

3.5.2. Open-ended Questions

The open-ended questions provide supplemental qualitative data. Responses to the question about water managers’ most important decisions were subject to word frequency content analysis. For this type of analysis, I create a word cloud featuring open-ended answers from Question 15, where the most frequently mentioned words appear in larger sized text and less frequently mentioned words appear in smaller sized text.

Chapter 4

4. Results

4.1. Employment Characteristics

Twenty-three respondents answered the question “In which county(ies) do you work?” (Figure 5). Statewide was the most common response (n = 10, 43%); about one-third (n = 7, 30%) of respondents identified a specific county. A breakdown of county-specific responses is included in Appendix B.

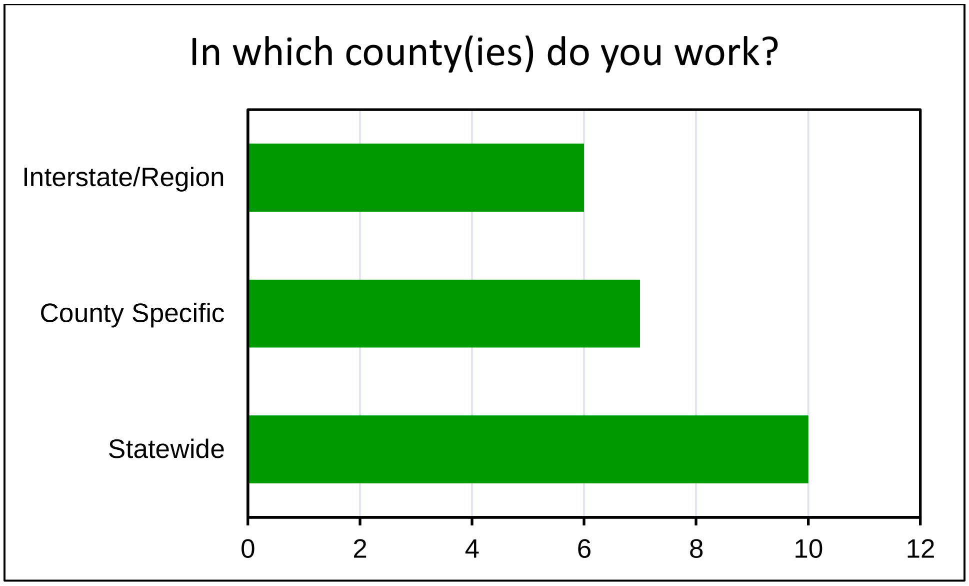

Figure 5: Water managers’ geographic responsibilities. “In what county(ies) do you work? (n = 23)”

Figure 6 depicts employment types. When asked where they worked, the most common response was for a state agency (n = 7, 30%). Among those reporting other, two worked in consulting (n = 2, or 9%), and two reported as managers (n = 2, or 9%), with the rest of the open-ended answers having one response each. 22% (n = 5) worked in the private sector, and 9% (n = 2) worked for a federal agency.

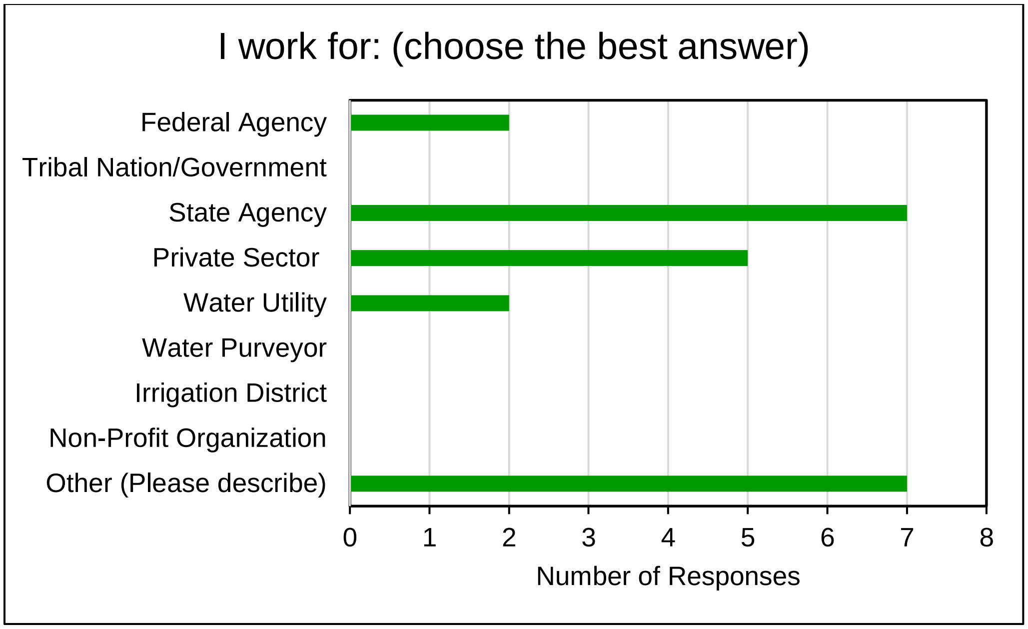

Figure 6: Type of employment among surveyed water managers (n = 23).

4.2. Familiarity With and Use of Seasonal Forecasts

Twenty-three respondents answered the question, “I am familiar with seasonal forecasts.” Most respondents (74%, n = 17) agreed or strongly agreed that they were familiar with these resources (Figure 7). Just over half of the respondents (57%, n = 13) felt that this information was easy to find (Figure 8).

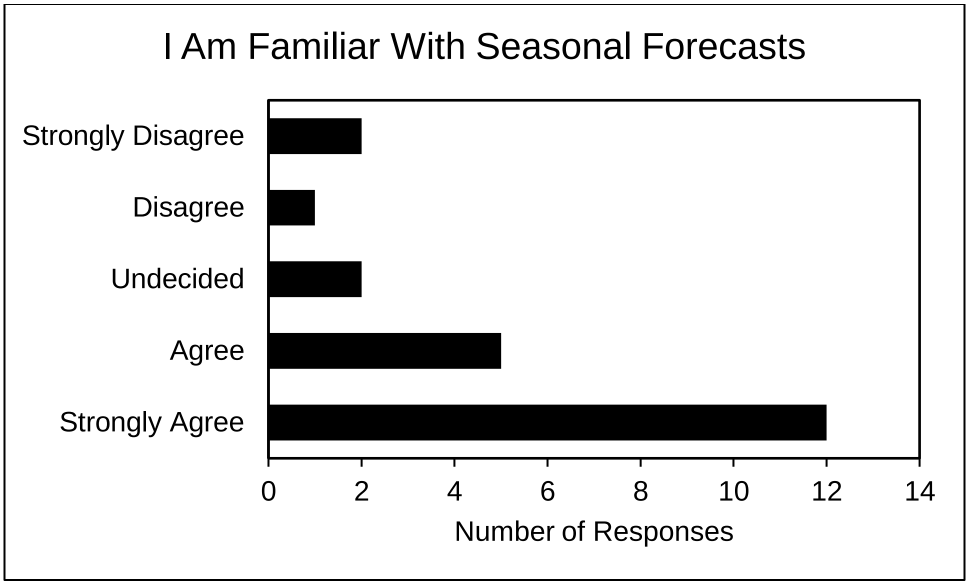

Figure 7: Water managers' familiarity with seasonal forecasts (n = 23).

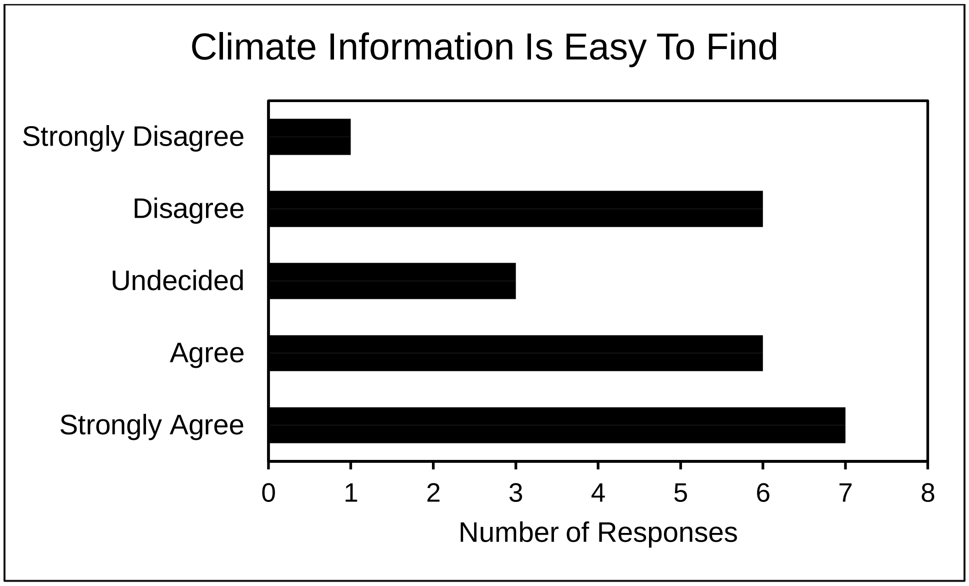

Figure 8: Ease of access to seasonal climate forecast information (n = 23).

Similarly, 23 respondents answered questions about their use of precipitation and temperature forecasts (Figure 9). More than 95% (n = 22) of the respondents indicated that they used seasonal precipitation forecasts, with 74% (n = 17) using them at least every few months (Figure 9). Only one water manager surveyed did not use precipitation outlooks. Fewer water managers used seasonal temperature forecasts, with n = 4 (17%) not using them at all. However, the majority of respondents (n = 14 or 61%) did use seasonal temperature forecasts, consulting them monthly or every few months (Figure 9). Interestingly, more water managers said that they use seasonal forecasts than said they are familiar with them.

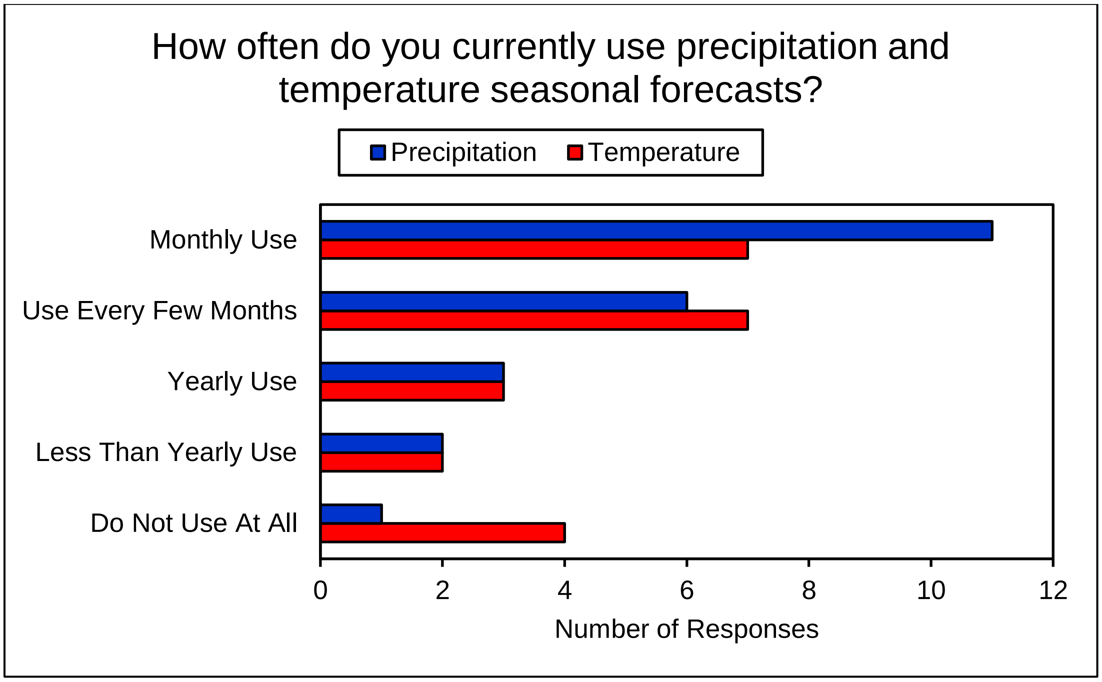

Figure 9: How often Nevada water managers use seasonal temperature and precipitation forecasts (n = 23).

4.3. Perceived Accuracy of Seasonal Forecasts

Despite widespread use of seasonal forecasts, Nevada water managers expressed some concern about their accuracy. Seasonal temperature outlooks were judged to be more accurate than precipitation outlooks (Figure 10). About 40% (n = 9) of respondents indicated that temperature outlooks were accurate or very accurate, in comparison to about 30% (n = 7) who considered precipitation outlooks accurate or very accurate. Almost one-half (for temperature: n = 11, or 48%; for precipitation, n = 10, or 43%) of surveyed water managers were undecided about the accuracy of seasonal forecasts.

Far more respondents doubted the accuracy of precipitation than temperature outlooks. Six (26%) respondents indicated that precipitation outlooks were inaccurate, but only three water managers rated temperature outlooks to be inaccurate (Figure 10).

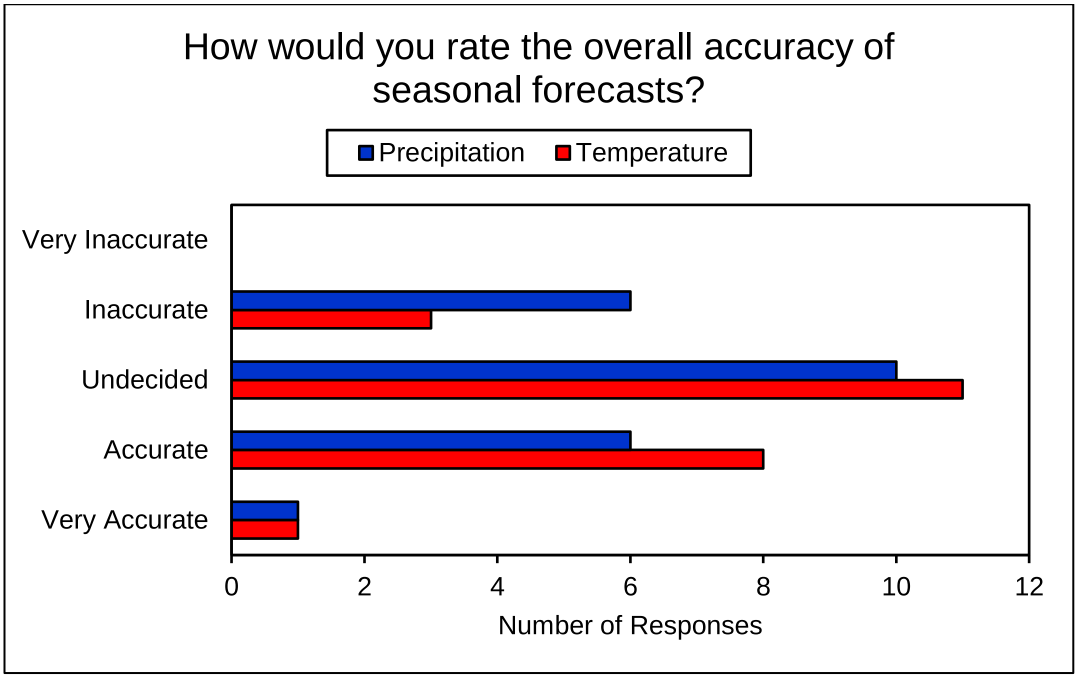

Figure 10: Perceived accuracy of seasonal temperature and precipitation forecasts (n = 23).

4.4. Seasonal Forecast Utility

The majority of water managers who responded found seasonal forecasts somewhat useful (Figure 11). Many respondents felt that seasonal precipitation forecasts were moderately useful (n = 11 or 48%), with nine (39%) finding them very useful and only three (13%) indicating that they were not useful (Figure 11). Seasonal temperature forecasts were also generally useful. More than 80% (n = 19) of water managers considered seasonal temperature outlooks moderately or very useful (Figure 11).

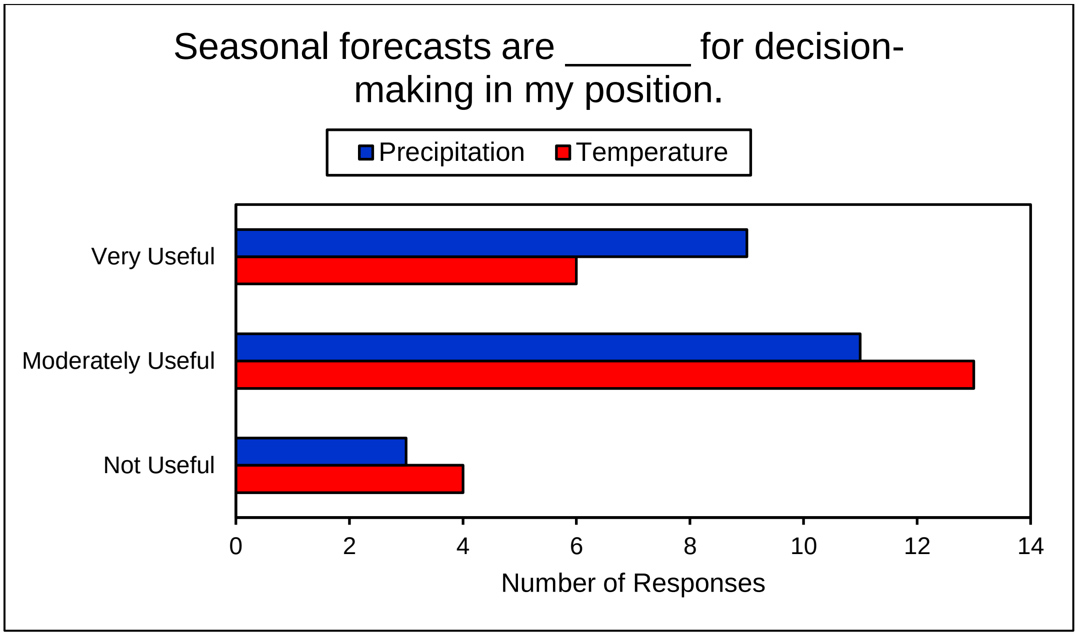

Figure 11: Utility of seasonal temperature and precipitation forecasts (n = 23).

The spatial and temporal scale of forecasts appeared to be significant barriers to use (Figure 12). Water managers who responded indicated that the forecasts would be more useful if they provided more detailed information (n = 6, or 26%), were more representative of the region (n = 6, or 26%), and were issued for less than a three-month season (n = 8, or 35%). A related hurdle to use was the perceived accuracy of forecasts, with seven respondents indicating that they would make more use of more accurate forecasts.

There appear to be other limitations in terms of the perceived value of forecasts in improving decisions. Six (26%) indicated that, at present, using these forecasts does not improve their decisions (Figure 12). Although water managers who responded indicated that finding forecasts was an obstacle to using them (n = 8, or 35%), interpreting them was not. Finally, five respondents indicated that seasonal forecasts are not approved for use in their decision process.

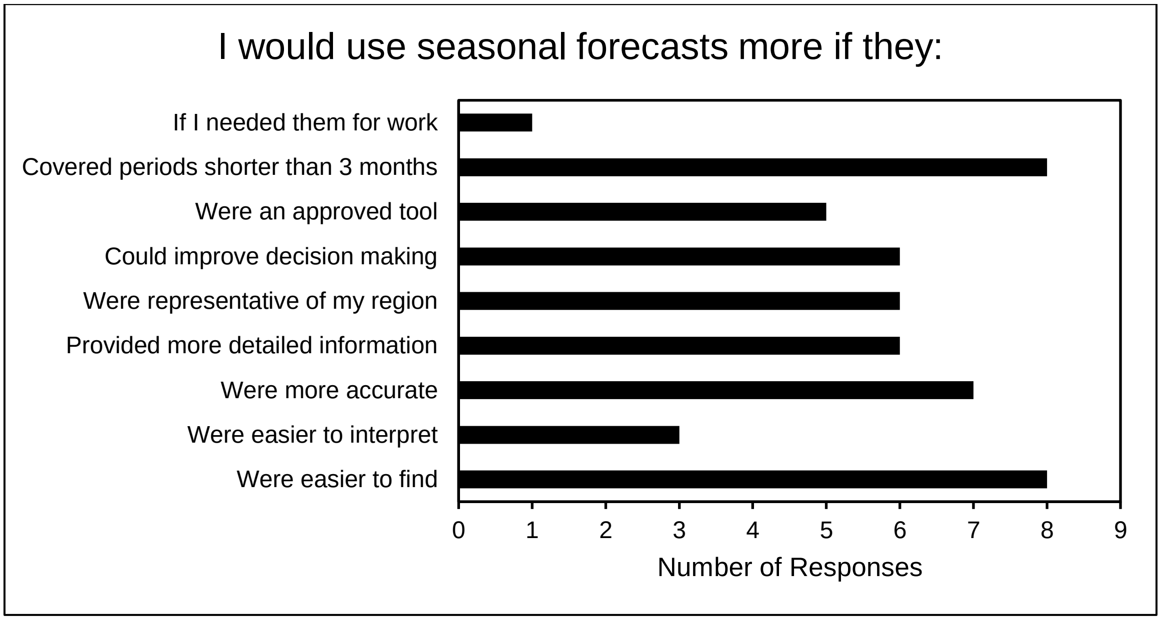

Figure 12: Barriers to the use of seasonal forecasts in decision-making (n = 23).

4.5. Water Management Decision Time Horizons

In general, water managers who responded used short-to-medium-term forecast time horizons. Monthly (n = 11, or 48%), 10-day (n = 9, or 39%) and three-month (n = 8, or 35%) forecasts were the most commonly used (Figure 9). In contrast, two-week forecasts were not readily used (n = 6, or 26%); as many water managers use two-week forecasts as use yearly forecasts (n = 6, or 26%) (Figure 13).

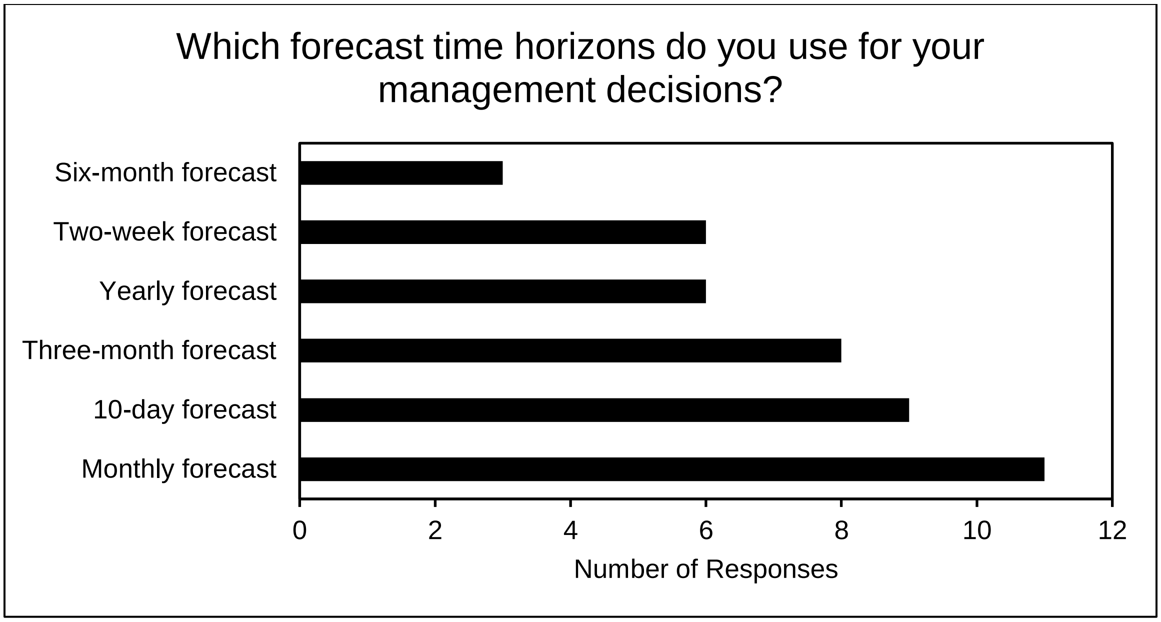

Figure 13: Commonly used forecast time horizons for water management decisions (n = 23).

Respondents' use of short-term forecasts appears consistent with an approximately monthly lead-time for many major water management decisions. Respondents made their three most important water management decisions typically between one week and three months out, with a monthly timeframe most common across all decisions (Figure 14). Water managers who responded most often indicated a 10-day or monthly lead time for Decision 1 (n = 4, or 17%), and a monthly (n = 3, or 13%) or three-month (n = 4, or 17%) lead time on Decision 2. Responses concerning Decision 3 were more diverse, with (n = 2, or 9%) equal numbers of respondents indicating weekly, monthly, three-month and six-month lead times. Decision 3 comprised the single decision described as being made a year in advance. Slightly fewer respondents answered this question comparatively, with n = 12 (or 52%) for Decision 1, n = 11 (or 48%) for Decision 2, and n = 10 (or 43%) for Decision 3.

For each timeline question, an open-ended response option allowed respondents to indicate their top three water management decisions. When compared with the close-ended timeline choices, fewer respondents completed this question. That is, for Decision 1 n = 10 (or 43%), for Decision 2 n = 9 (or 39%), and for Decision 3 n = 8 (or 35%).

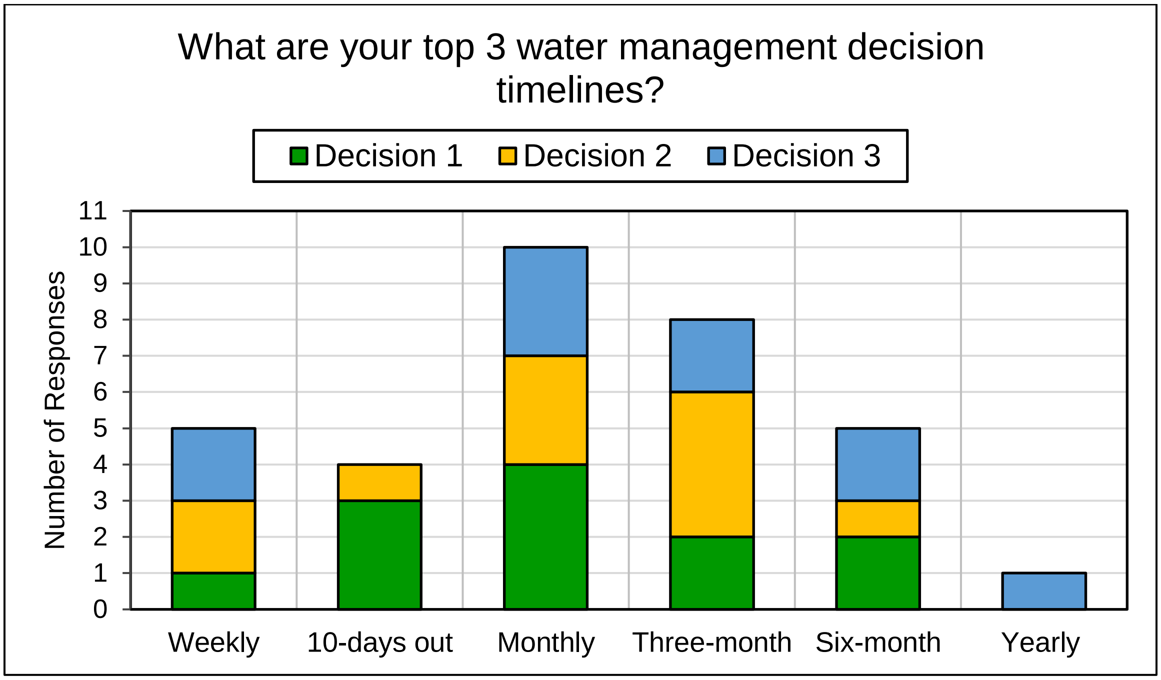

Figure 14: Timelines for Nevada managers' most important management decisions. Decisions 1 (n = 12, or 52%), Decision 2 (n = 11, or 48%), Decision 3 (n = 10, or 43%). Top decisions are made most often a month in advance (n = 10, or 43%), followed by three months in advance (n = 8, or 35%), and weekly/six-months in advance (n = 5, or 22%).

For the top three decisions themes that emerge included water supply, water quality, flood safety, outreach and engagement, and climate change response (Table 1). Water supply decisions under Decision 1 included water supply, permitting water rights, potential groundwater curtailment (restrictions), snowpack, and snowfall; Decision 2 themes included lake levels and water supply management, and Decision 3 themes included groundwater and irrigation. Water quality is demonstrated by one response for each Decisions 1-3. That is, for Decisions 1-3 respectively, predicting when harmful algae blooms appear in water bodies, determining when to fly over certain waterbodies to check for algal blooms, and turbidity levels. Engagement and outreach related decisions are evident in Decision 3 and include outreach and education for drought and stakeholder engagement.

Decision Lead Time	**Decision (Free-response)**
10 days out	– Water supply – Reservoir Flood Control – Determining when to fly over certain waterbodies to check for algal blooms.
Weekly	– Snowfall – Streamflow – Turbidity – Well drilling regulation
Monthly	– Permitting water rights – Snowpack – Collection of drought impacts – Water supply management – Groundwater – Irrigation
Three-month	– Potential groundwater curtailment – Range conditions – Hay buying – Irrigation classes to be served – Lake Levels – Stakeholder Engagement
Six-month	– Distribution of drought status reports – Predicting when harmful algae blooms may begin in certain waterbodies. – Dam safety inspections – Outreach and education for drought
One-year	– Long-term climate predictions
No Answer	– Long term averages – What is climate change doing to average? – What is max and min of predictions?

Table 1: Timelines for Nevada water professionals' top three management decisions. Decision 1 (n = 10, or 43%), Decision 2 (n = 9, or 39%), Decision 3 (n = 8, or 35%). Time horizon, when indicated, is underlined and in parentheses next to the decision.

Figure 15 illustrates the frequency of words that appeared in open-ended answers concerning timelines for Nevada water managers' top three water management decisions. Words mentioned most often appear in larger-sized text. The two words mentioned most were water and drought, followed in frequency by: irrigation, groundwater, climate, certain, waterbodies, predictions, supply, and blooms.

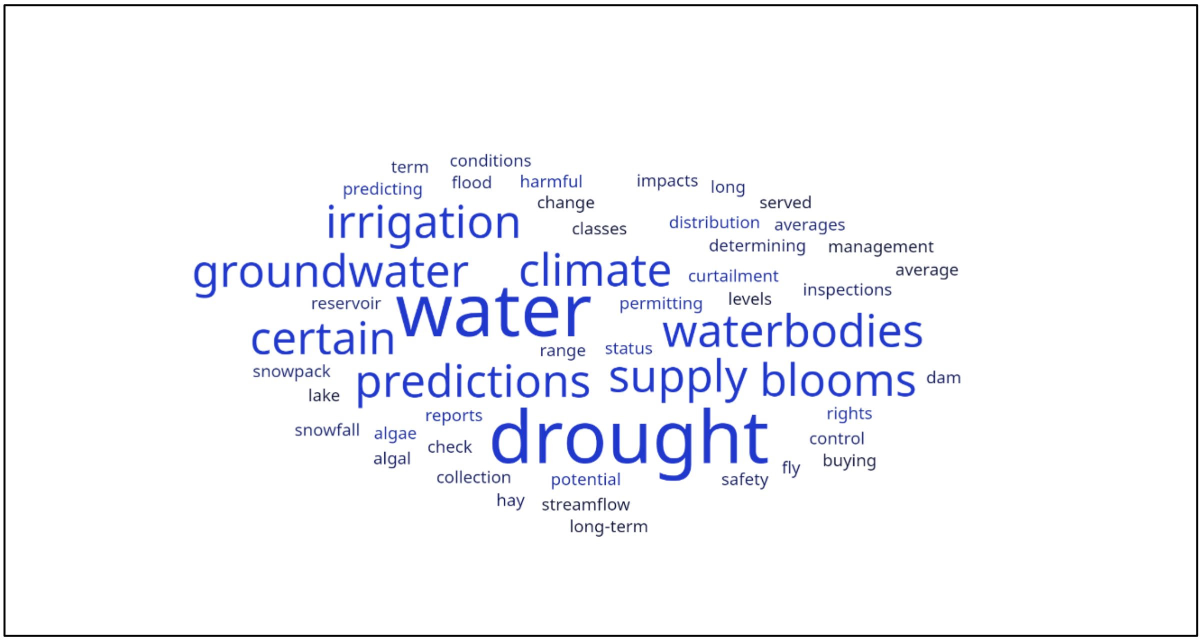

Figure 15: A word cloud illustrating the open-ended answers to timelines for Nevada water managers' top three management decisions. Decision 1 (n = 10, or 43%), Decision 2 (n = 9, or 39%), Decision 3 (n = 8, or 35%).

Chapter 5

5. Discussion

5.1. Employment Characteristics

When respondents were asked in which counties they worked, 10 (43%) respondents indicated statewide, seven cited specific counties, and six worked for a specific interstate/region (Figure 5). The relatively large proportion of respondents working statewide (43%, n = 10) is consistent with the employment results (Figure 6) indicating that many of the water managers who responded worked for state agencies.

The survey data analyzed and reported here feature water managers' responses representative of 15 of the state's 17 counties (Supplemental Figure 1). Additionally, nearly half of respondents (43%, n = 10) indicated that they work in water management statewide. None of the water managers who responded to this survey indicated working for a Tribal Nation/Government, Water Purveyor, Irrigation District, or Non-Profit Organization. Additionally, one of the two counties not directly represented is Clark County, the most populous in the state. These two specific issues will be discussed further in the limitations section of this chapter.

Previous studies have found that it is hard to identify water managers as most lists are handmade by the researcher (Bolson et al., 2013; Feldman and Ingram (2009)). Both studies found that water managers working in rural counties were less familiar with seasonal forecasts, which is something to focus on in future research.

5.2. Familiarity with and Use of Seasonal Forecasts

Three-quarters (n = 17 or 74%) of respondents agreed or strongly agreed that they were familiar with seasonal forecasts (Figure 7), but only 57% (n = 13) of respondents felt that this information was easy to find (Figure 8). This level of familiarity is within the range reported in similar studies. For example, Steinemann (2006) reported that over 80% of water managers interviewed were aware of seasonal forecasts. Bolson et al. (2013), also working in the southeastern United States, reported that only about half of water managers were familiar with the CPC Three-Month Outlook. Among studies published in the late 1990s and early 2000s, there was a consensus that seasonal forecasts were hard to find online (Lowery et al., 2009; Callahan et al., 1999; Lemos et al., 2012, Rayner et al., 2005). Despite a decade of progress, simply finding this information online appears to remain a barrier to use.

Despite some degree of difficulty in finding seasonal forecasts, a majority of water managers surveyed used seasonal precipitation (n = 22, 96%) and temperature (n = 19, 83%) forecasts (Figure 9). An interesting finding is that more water managers said they used seasonal forecasts than said that they were familiar with them. This is in contrast to other studies that found lower levels of use than of awareness (Bolson et al., 2013; Hartmann, 2002; Lowrey et al. 2009; Rayner et al. 2005). There are a number of potential explanations for this finding. Perhaps sharing of resources contributes to more water managers using seasonal forecasts than are familiar with them finding. Another possibility is that water managers responding to this survey interpreted the term “familiar” as implying that they had in-depth knowledge of seasonal forecasts, rather than just acknowledging that forecasts are available.

The finding that respondents rely more on precipitation than temperature forecasts is intuitive given the direct influence of precipitation on water availability in a water scarce state, but also contrasts with perceived lower precipitation forecast accuracy (see Section 4.3). The higher level of use as compared with familiarity also poses interesting questions about how managers are using seasonal forecasts. Previous studies have documented a number of ways in which water managers use seasonal forecasts. Many times, managers use seasonal forecasts as background information only, or do not use them at all due to perceived poor forecast skill and/or a mismatch of temporal and spatial scales (Rayner et al., 2005; Callahan et al., 2009; Lowrey et al., 2009; Baker et al., 2019).

5.3. Perceived Accuracy of Seasonal Forecasts

Despite greater use of precipitation than temperature forecasts, water managers who responded to this survey considered temperature forecasts to be more accurate than precipitation (Figure 10). Nine of 23 (39%) respondents indicated that temperature forecasts were accurate or very accurate, as opposed to only seven of 23 (30%) respondents indicating that for precipitation forecasts. Six respondents (26%) indicated that precipitation forecasts were inaccurate. Perceived differences in accuracy between temperature and precipitation forecasts reflect measured forecast skill.

Water managers’ perceptions of seasonal forecast accuracy align with CPC’s calculated verifications of these forecasts. It is generally observed in verifications that temperature forecasts are more accurate than precipitation forecasts (CPC, 2022). Crimmins and McClaran (2015) mention that apart from some very localized areas in Arizona, summer precipitation has low forecast skill. Livezey and Timofeyeva (2008) found that temperature skill was decent in the southern United States and precipitation skill was low apart from very strong ENSO episodes, which are a bit more predictable.

This finding might suggest that water managers do not require seasonal forecasts to be perceived as highly accurate to be useful in some way to management decisions. This contrasts directly with Crimmins and McClaran (2015) whose results suggest that users' satisfaction with seasonal forecasts was low, with only 25% of ranchers being satisfied with forecast skill levels – suggesting that ranchers disregard seasonal forecasts altogether. Instead, it may be more likely that ranchers do not weigh seasonal forecasts heavily into their overall or final decision-making because of perceptions concerning their accuracy, but that they are still useful as background information. This lies in the middle of our results and Crimmins and Mclaran's (2015) responses. More survey research is needed to assess precisely how Nevada's water managers use seasonal forecasts. Therefore, the small sample of survey results reported here could change, supporting those found in previous literature.

5.4. Seasonal Forecast Utility

The majority of water managers indicated that seasonal forecasts are somewhat useful, as detailed in Figure 11. Only 13% (n = 3) of water managers felt that precipitation forecasts were not useful. This aligns with the findings and discussions reported in the previous section, where even though there is uncertainty expressed over the accuracy of these forecasts, they are still accurate enough to be considered useful and regularly used on some scale. Aligning with other previous literature, over 80% (n = 19) of water managers considered temperature forecasts moderately or very useful (Figure

11), even though they used them less in their overall decision-making (Bolson et al., 2013).

Overall, water managers indicated that finding these forecasts online was an obstacle to using them but interpreting them was not (Figure 12). This, too, would be an interesting area of research to explore further, as previous studies have indicated that seasonal forecasts are challenging to understand. Pulwarty and Redmond (2007), Changnon et al. (1995), and Nicholls (1999), for example, mention that the lack of supplementary background information could be a significant barrier to use, indicating that this lack of information can lead to water managers not understanding these forecasts. Despite these studies taking place over a decade ago, it still seems that there is a barrier to seasonal forecast use because forecasts are hard to find and somewhat understand.

Although water managers who responded to this survey found seasonal forecasts useful, there were some barriers that water managers face when attempting to use seasonal forecasts in their decision-making (Figure 12). The coarse spatial and temporal scale of forecasts appeared to be a significant barrier to use, which is also reflected in water managers believing that forecasts would be more useful if they were more representative of the region. Seasonal forecasts are released on a 2x2° grid spread across the United States (Livezey and Timofeyeva, 2008) as well as for climate divisions (CPC, 2022). This barrier could be due to the resolution not being what water managers are used to, as many of the products they use are on watershed scales or other similar hydrological scales. An area for future research may lie in educating water managers about this resolution and how it can still be helpful despite its relative unfamiliarity.

Another important point of discussion is a mismatch of temporal time scales. That is, when asking water managers about barriers to the use of seasonal forecasts they indicated that they would be more useful if they covered periods shorter than three months. Because Raff et al. (2013) mention that water management decisions happen on scales of days to weeks to months, three-month windows may be too broad for the kinds of decisions that water managers make. An area for future investigation might assess which forecast products might have improved temporal matches. To further explore potential temporal scale mismatches between seasonal forecasts and water management decisions (e.g., Baker et al., 2019, Bolson et al., 2013, Rayner et al., 2005), we asked Nevada water managers about the forecasts they use and how far in advance they make decisions.

5.5. Water Management Decision Time Horizons

In general, water managers who responded to this survey reported using short-to-medium-term forecasts. That is, monthly, 10-day, and three-month forecasts were used most often. Two-week forecasts were not used as readily, but they are also not as widely available as weekly or 10-day forecasts. The National Weather Service issues a 7-day forecast, along with 6-10 day and 8-14 day outlooks. Many commercial outlets and apps offer 10-day forecasts.

The use of short-term forecasts is consistent with the monthly lead-time for major water management decisions, as visualized in Figure 10. Respondents’ three major water management decisions are typically made between one-week and three-months out, with a monthly time-frame most common across all three management decisions (Figure 14). Many of the short-term water decisions (five years or less) mentioned by Raff et al. (2013) are in these same timelines: daily, to weekly, to months. (Raff et al., 2013; Bolson et al., 2013).

Word-frequency content analysis for the open-ended data reveal that most top management decisions appear related to short-term water supply (Table 1). There were seven answers that contributed to this conclusion: water supply (1), permitting water rights (1), potential groundwater curtailment (restrictions) (1), reservoir flood control (1), range conditions (1), snowpack (1), and snowfall (1). Permitting water rights, groundwater restrictions, and flood control, snowpack, and snowfall all describe actions taken to manage the distribution and use of water. Snowpack and snowfall can add to or take away from current water supply, and range conditions rely on precipitation and snowfall.

Decisions made further in advance included dam safety inspections (1), when to fly over waterbodies (1), hay buying (1), lake levels (1), and streamflow (1). Other than decisions made on a different timescale, there were no apparent themes detected in these responses.

A third theme was outreach and communication, which half of all respondents mentioned. Four responses that point to outreach and communication are: outreach and education about drought (1), stakeholder engagement (1), and well-drilling regulations (1). Communication is one of the most important aspects of water management (Raff et al., 2013; Dilling and Lemos, 2011; Dilling and Berggren 2014; and Rayner 2005). This may be especially the case in water scarce states where water allocation and use may be characterized by conflict; so, seeing communication reflected in these responses is an important result.

Content analysis on the answers to this open-ended question resulted in a word cloud (Figure 15). This word cloud reaffirms the themes reported above as the top two (largest-sized text) words were water and drought, and the second-most mentioned words were: groundwater, irrigation, climate, certain, predictions, waterbodies, supply, and blooms. These words suggest that water supply forecasts (irrigation and groundwater, as well as municipal supply) and outreach (dealing with drought conditions and predictions being relayed to the public) are key topics of concern to Nevada's water managers.

Overall, the top management decisions respondents reported match those reported in earlier studies. Bolson et al. (2013) had participants answer a similar question with similar results, focusing on water supply, water use planning, and outreach. Raff et al. (2013) also mention that water supply and outreach are two of the more critical decisions managers make using forecast information.

5.6. Future Research Directions and Study Limitations

Twenty-three participants completed most of the survey, but response numbers fell for the two-part timeline question (Question 14). Fewer than half of respondents answered questions about how far in advance they made their top three decisions; 12 responded to Decision 1, 11 to Decision 2, and 10 to Decision 3. Even fewer respondents completed the open-ended part of the question as opposed to the close-ended part. For open-ended responses, there were 10 responses for Decision 1 (43%), nine responses for Decision 2 (39%), and eight responses for Decision 3 (35%). According to Dillman (2009), the more complicated a question, the more likely it is that respondents will skip it. As this was the most intricate question of the survey suggests that those respondents who did not complete the question may have considered it too complex or confusing. In forthcoming surveys, revising this question by subdividing it into as many components as possible may yield higher response rates. Another solution to improving our knowledge about water managers' decision timelines might involve interviewing water managers in person to explain the question more thoroughly and allow for any follow-up questions for clarification.

Further research should also look into water managers' definitions of use. In a particularly interesting result, more water managers said they used seasonal forecasts than said that they were familiar with them. Future surveys could focus on clearly defining use to avoid miscommunication and include more specific questions about types of uses. Interviews might also be a solution for better understanding water managers' level of familiarity with seasonal forecasts and for getting more detailed information about how they are using these tools.

A major limitation of this study relates to the small number of respondents. That is, while our sampling was purposeful, it produced a relatively small number of respondents which may not represent adequately the entire population of water managers. Because contact information pertaining to water managers is difficult to locate and can change frequently, creating and maintaining a directory of water managers in Nevada could facilitate future survey efforts to sample the entire population of water managers more effectively in the state. Despite their role as water managers, there is a lack of representation from Tribal Governments and Irrigation Districts in this study. Further research should focus on getting responses from these two areas of water management.

One option for expanding the use of seasonal forecasts is to hold workshops to show water managers where to find seasonal forecasts, improving accessibility. These workshops would improve user awareness and forecast accessibility while also improving forecast usage.

Another barrier to use that can be addressed is the temporal scale mismatch. Future research into the details of Nevada water managers' decision-making time scales might allow for identification of existing forecast tools that better meet their needs (e.g., sub-seasonal outlooks). There might even be simple solutions related to increasing communication about seasonal forecasts at critical times of year when water managers might most need the information.

Spatial resolution is also a barrier faced by water managers. Baker et al.'s (2019) study on post-processing seasonal forecasts to watershed scales found that these post-processed seasonal products were perceived as informative and useful. Perhaps addressing these spatial resolution barriers can include education on the spatial resolutions the CPC uses with seasonal forecasts, so that water managers are familiar with both the 2° by 2° resolution as well as watershed or equally important hydrological scales.

Overall, this research presents a preliminary understanding of water managers' perceptions of the utility of season forecasts and potential opportunities for greater use of seasonal forecasts. We found that the water managers who responded to this survey use seasonal forecasts and find them useful. Further research will help to better understand managers' perceptions and usage of seasonal forecasts, and if certain steps need to be taken to improve the use of seasonal forecasts in water management decision-making processes.

Chapter 6

6. Conclusion

As stated in Chapter 1 of this study, Nevada water managers' perceptions and use of the CPC's seasonal forecasts were unknown. This research sought to address four research questions about accessibility, perceived skill, and use of seasonal forecasts by the state's water managers, as well as inquire into the aspects of water management decision-making in Nevada. Through a survey of Nevada's water managers, I answered these questions.

The survey revealed that the majority of water managers in Nevada who responded to the survey were both aware of and used seasonal forecasts in their decision-making (Figures 3 and 5). Despite widespread use of seasonal forecasts, respondents expressed some concerns about their accuracy. Seasonal temperature forecasts were judged to be more accurate than precipitation outlooks (Figure 6). With regards to seasonal forecast utility, the majority of respondents considered the forecasts to be somewhat useful (Figure 7).

However, further questions about utility revealed an important barrier to seasonal forecast use: accessibility. When asked if it was easy to find seasonal forecasts (Figure 4), just over 40% (n = 10) were undecided, disagreed, or strongly disagreed with the statement that seasonal forecast information is easy to find. When asked about usage barriers, over one-third (n = 8, 35%) of participants indicated that they would use seasonal forecasts more if they were easy to find.

Temporal scale mismatch was also a barrier to use reflected in survey responses. Most water managers used short-to-medium-term forecast time horizons (Figure 9), and when asked what their three top management decisions timelines were, responses also reflected that, with only one person stating that they made a top three management decision one year out.

Further research can focus on addressing accessibility uses, further understanding of what use means to different science fields, and focusing on forecast products that might better represent the timelines water managers consider most important. Accessibility issues can be improved in a variety of ways including through workshops led by climate scientists that target water managers. Outreach publications detail seasonal forecasts for Nevada, with specific focus on where and how to find these forecasts would also be useful. Utility mismatches can be explored through future surveys by asking water managers specific questions about how they use seasonal forecasts in their decision-making. As for the temporal mismatch, while seasonal forecasts are an important tool in medium-to-long-term decision-making and can be utilized by water managers, perhaps informing water managers of products between weather forecasts and seasonal forecasts, defined as sub-seasonal-to-seasonal, might help to close the temporal gap. It is important for dialogue to continue between water managers and climate scientists, as even without the complications of climate change, strategic water management is crucial to an arid state such as Nevada and its three-million citizens.

References

American Water Resources Association. (2019). The American Water Resources Association 1964-2014: Fifty years dedicated to water resources management, research, and education https://www.awra.org/Members/About/Mission_and_Vision.aspx

American Meteorological Society Glossary of Meteorology. (2022). Forecast lead time. https://glossary.ametsoc.org/wiki/Forecast_lead_time

An, S. Il, & Wang, B. (2000). Interdecadal change of the structure of the ENSO mode and its impact on the ENSO frequency. *Journal of Climate*, *13*(12), 2044–2055. https://doi.org/10.1175/1520-0442(2000)013<2044:ICOTSO>2.0.CO;2

Arribas, A., Glover, M., Maidens, A., Peterson, K., Gordon, M., MacLachlan, C., … Cusack, S. (2011). The GloSea4 ensemble prediction system for seasonal forecasting. *Monthly Weather Review*, *139*(6), 1891–1910. https://doi.org/10.1175/2010MWR3615.1

Baker, S. A., Wood, A. W., & Rajagopalan, B. (2019). Developing Subseasonal to Seasonal Climate Forecast Products for Hydrology and Water Management. *Journal of the American Water Resources Association*, *55*(4), 1024–1037. https://doi.org/10.1111/1752-1688.12746

Barnston, A. G., van den Dool, H. M., Zebiak, S. E., Barnett, T. P., Ji, M., Rodenhuis, D. R., Cane, M. A., Leetmaa, A., Graham, N. E., Ropelewski, C. R., Kousky, V. E., O'Lenic, E. A., & Livezey, R. E. (1994). Long-Lead Seasonal Forecasts—Where

Do We Stand?, *Bulletin of the American Meteorological Society*, *75*(11), 2097-2114. Retrieved from https://journals.ametsoc.org/view/journals/bams/75/11/1520-0477_1994_075_2097_llsfdw_2_0_co_2.xml

Bolson, J., Martinez, C., Breuer, N., Srivastava, P., & Knox, P. (2013). Climate information use among southeast US water managers: Beyond barriers and toward opportunities. *Regional Environmental Change*, *13*(SUPPL.1), 141–151. https://doi.org/10.1007/s10113-013-0463-1

Capotondi, A., Wittenberg, A. T., Newman, M., Di Lorenzo, E., Yu, J., Braconnot, P., Cole, J., Dewitte, B., Giese, B., Guilyardi, E., Jin, F., Karnauskas, K., Kirtman, B., Lee, T., Schneider, N., Xue, Y., & Yeh, S. (2015). Understanding ENSO Diversity, *Bulletin of the American Meteorological Society*, *96*(6), 921-938. https://journals.ametsoc.org/view/journals/bams/96/6/bams-d-13-00117.1.xml

Callahan, B., Miles, E., & Fluharty, D. (1999). Policy implications of climate forecasts for water resources management in the Pacific Northwest. *Policy Sciences*, *32*(3), 269–293. https://doi.org/10.1023/A:1004604805647

Changnon, S. A., Changnon, J. M., & Changnon, D. (1995). Uses and Applications of Climate Forecasts for Power Utilities, *Bulletin of the American Meteorological Society*, *76*(5), 711-720. https://journals.ametsoc.org/view/journals/bams/76/5/1520-0477_1995_076_0711_uaaocf_2_0_co_2.xml

Cole J.E.,. & Cook E.R. (1998.) The changing relationship between ENSO variability and moisture balance in the continental United States. *Geophysical Research Letters*. 25: 4529–4532. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/1998GL900145

Crimmins, M. A., & McClaran, M. P. (2015). Where Do Seasonal Climate Predictions Belong in the Drought Management Toolbox? *Rangelands*, *38*(4), 169–176. https://doi.org/10.1016/j.rala.2016.06.004

Climate Prediction Center. (2020). *Climate Prediction Center - Seasonal Outlook*. Long Range Tools. https://www.cpc.ncep.noaa.gov/products/predictions/long_range/tools.html

Climate Prediction Center. (2022). *Climate Prediction Center - NMME Forecasts of Monthly Climate Anomalies: 3-Month Mean Spatial Anomalies*. https://www.cpc.ncep.noaa.gov/products/NMME/monanom.shtml

Climate Prediction Center. (2022). Climate Prediction Center - Seasonal Verifications. https://www.cpc.ncep.noaa.gov/products/predictions/long_range/tools/briefing/seas_veri.grid.php

Davis, R. E. (1976). Predictability of Sea Surface Temperature and Sea Level Pressure Anomalies over the North Pacific Ocean, *Journal of Physical Oceanography,* *6*(3), 249-266. Retrieved from https://journals.ametsoc.org/view/journals/phoc/6/3/1520-0485_1976_006_0249_possta_2_0_co_2.xml

Dilling, L., & Lemos, M. C. (2011). Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change*, *21*(2), 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006

Dilling, L., & Berggren, J. (2015). What do stakeholders need to manage for climate change and variability? A document-based analysis from three mountain states in the Western USA. *Regional Environmental Change*, *15*(4), 657–667. https://doi.org/10.1007/s10113-014-0668-y

Dillman, D. A., Smyth, J. D., Christian, L. M., & Dillman, D. A. (2009). Internet, mail, and mixed-mode surveys: The tailored design method. Hoboken, N.J: Wiley & Sons.

Drozdoff, L., Entsminger, J., Barbee, J., King, J., Boyle, D., Walker, M., Huntington, J., & Cage, C. (2015). Nevada Drought Forum: Recommendations Report. http://dcnr.nv.gov/uploads/documents/DroughtForum-sm.pdf

Feldman, D. L., & Ingram, H. M. (2009). Making science useful to decision makers: Climate forecasts, water management, and knowledge networks. *Weather, Climate, and Society*, *1*(1), 9–21. https://doi.org/10.1175/2009WCAS1007.1

Foresta, T. S. (2018). How Does Nevada Use its Scarce Water Resources? Retrieved from https://guinncenter.org/how-does-nevada-use-its-scarce-water-resources/

Gawthrop, E. (2015). *Subseasonal Prediction Project*. International Research Institute for Climate and Society. https://iri.columbia.edu/news/qa-subseasonal-prediction-project/

Gershunov, A., & Barnett, T. P. (1998). Interdecadal modulation of ENSO teleconnections. Bulletin of the American Meteorological Society, 79(12), 2715-2726.

Hagger, V., Dwyer, J., Shoo, L., & Wilson, K. (2018). Use of seasonal forecasting to manage weather risk in ecological restoration. Ecological Applications, 28(7), 1797–1807. https://doi.org/10.1002/eap.1769

Hare, L., Heggem, D., Hall, R., Husby, P. (2013). An Ecological Characterization and Landscape Assessment of the Humboldt River Basin. Environmental Protection Agency. https://www.usgs.gov/centers/nv-water/science/science-humboldt-river-basin

Hartmann, H. C., Pagano, T. C., Sorooshian, S., & Bales, R. (2002). Confidence Builders. Bulletin of the American Meteorological Society. https://doi.org/10.1175/1520-0477(2002)0832.3.CO;2

Harpold, A. A., Sutcliffe, K., Clayton, J., Goodbody, A., & Vazquez, S. (2017a). Does including soil moisture observations improve operational streamflow forecasts in snow-dominated watersheds? *JAWRA Journal of the American Water Resources Association*, *53*(1), 179-196. https://doi.org/10.1111/1752-1688.12490

Harpold, A. A., & Dettinger, M. (2017b). Defining Snow Drought and Why It Matters. Retrieved from https://eos.org/opinions/defining-snow-drought-and-why-it-matters

Henderson, S. A., Maloney, E. D., & Barnes, E. A. (2016). The Influence of the Madden–Julian Oscillation on Northern Hemisphere Winter Blocking, *Journal of Climate, 29*(12), 4597-4616. Retrieved from https://journals.ametsoc.org/view/journals/clim/29/12/jcli-d-15-0502.1.xml

Hobday, A. J., Spillman, C. M., Paige Eveson, J., & Hartog, J. R. (2016). Seasonal forecasting for decision support in marine fisheries and aquaculture. *Fisheries Oceanography*, 25, 45–56. https://doi.org/10.1111/fog.12083

Hoffman, R. R., Coffey, J. W., Carnot, M. J., & Novak, J. D. (2002). An Empirical Comparison of Methods for Eliciting and Modeling Expert Knowledge. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 46*(3), 482–486. https://doi.org/10.1177/154193120204600356

Kapnick, S. B., Yang, X., Vecchi, G. A., Delworth, T. L., Gudgel, R., Malyshev, S., … Margulis, S. A. (2018). Potential for western US seasonal snowpack prediction. *Proceedings of the National Academy of Sciences of the United States of America, 115*(6), 1180–1185. https://doi.org/10.1073/pnas.1716760115

Kirtman, B. P., Min, D., Infanti, J. M., Kinter, J. L., Paolino, D. A., Zhang, Q., … Wood, E. F. (2014). The North American multimodel ensemble: Phase-1 seasonal-to-interannual prediction; phase-2 toward developing intraseasonal prediction.

Bulletin of the American Meteorological Society, *95*(4), 585–601. https://doi.org/10.1175/BAMS-D-12-00050.1

Klopper, E., Vogel, C. H., & Landman, W. A. (2006). Seasonal climate forecasts - Potential agricultural-risk management tools? Climatic Change, 76(1–2), 73–90. https://doi.org/10.1007/s10584-005-9019-9

Lang, A. L., Pegion, K., & Barnes, E. A. (2020). Introduction to special collection: “Bridging weather and climate: Subseasonal-to-seasonal (S2S) prediction”. Journal of Geophysical Research: Atmospheres, 125, e2019JD031833. https://doi.org/10.1029/2019JD031833

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. Nature Climate Change, 2(11), 789–794. https://doi.org/10.1038/nclimate1614

Lenssen, N. J. L., Goddard, L., & Mason, S. (2020). Seasonal forecast skill of enso teleconnection maps. *Weather and Forecasting*, *35*(6), 2387–2406. https://doi.org/10.1175/WAF-D-19-0235.1

Li, S., & Robertson, A. W. (2015). Evaluation of submonthly precipitation forecast skill from global ensemble prediction systems. *Monthly Weather Review*, *143*(7), 2871–2889. https://doi.org/10.1175/MWR-D-14-00277.1

Livezey, R. E., & Timofeyeva, M. M. (2008). The first decade of long-Lead U.S. seasonal forecasts. *Bulletin of the American Meteorological Society*, *89*(6), 843–854. https://doi.org/10.1175/2008BAMS2488.1

Lowrey, J., Ray, A., & Webb, R. (2009). Factors influencing the use of climate information by Colorado municipal water managers. Climate Research, 40(October 2009), 103–119. https://doi.org/10.3354/cr00827

Lukas, J., Wolter, K., & Barsugli, J. (2020.) *"Weather and Climate Forecasting."* Chap. 7 in Colorado River Basin Climate and Hydrology: State of the Science, edited by J. Lukas and E. Payton, 254-286. Western Water Assessment, University of Colorado Boulder. https://wwa.colorado.edu/publications/reports/CRBreport/ColoRiver_StateOfScience_WWA_2020_FullReport_hi-res.pdf

Madden, R. A., & Julian, P. R. (1971). Detection of a 40–50 Day Oscillation in the Zonal Wind in the Tropical Pacific, Journal of Atmospheric Sciences, 28(5), 702-708. Retrieved from https://journals.ametsoc.org/view/journals/atsc/28/5/1520-0469_1971_028_0702_doadoi_2_0_co_2.xml

Mayer, K. J., & Barnes, E. A. (2021). Subseasonal forecasts of opportunity identified by an explainable neural network. Geophysical Research Letters, 48, e2020GL092092. https://doi.org/10.1029/2020GL092092

McAfee, S.A. and Wise, E.K. (2016), Intra-seasonal and inter-decadal variability in ENSO impacts on the Pacific Northwest. Int. J. Climatol., 36: 508-516. https://doi.org/10.1002/joc.4351

Mo, K. C. (2003). Ensemble Canonical Correlation Prediction of Surface Temperature over the United States, *Journal of Climate*, *16*(11), 1665-1683.

https://journals.ametsoc.org/view/journals/clim/16/11/1520-0442_2003_016_1665_eccpos_2.0.co_2.xml

National Weather Service Corporate Image Web Team. (2022). CNRFC - Water Resources - Daily Water Resources Update. NWS CNRFC. https://www.cnrfc.noaa.gov/water_resources_update.php

Natural Resources Conservation Service. (n.d.). Interpreting Water Supply Forecast Charts. USDA. https://www.nrcs.usda.gov/wps/portal/wcc/home/dataAccessHelp/helpCenters/interpretWaterSupplyForecastChart/

Nevada Division of Environmental Protection. (2021). 2021 Annual Capacity Development Report To the US Environmental Protection Agency. https://ndep.nv.gov/uploads/water-financing-srf-drinkingwater-docs/2021_Annual_Capacity_Report_FINAL_9-2-21.pdf

Nicholls, N. (1999). Cognitive Illusions, Heuristics, and Climate Prediction, *Bulletin of the American Meteorological Society*, *80*(7), 1385-1398. https://journals.ametsoc.org/view/journals/bams/80/7/1520-0477_1999_080_1385_cihacp_2_0_co_2.xml

Pagano, T., Garen, D., & Sorooshian, S. (2004). Evaluation of official western US seasonal water supply outlooks, 1922–2002. Journal of Hydrometeorology, 5(5), 896-909. https://journals.ametsoc.org/view/journals/hydr/5/5/1525-7541_2004_005_0896_eoowus_2_0_co_2.xml

Peng, B., Guan, K., Pan, M., & Li, Y. (2018). Benefits of Seasonal Climate Prediction and Satellite Data for Forecasting U.S. Maize Yield. Geophysical Research Letters, 45(18), 9662–9671. https://doi.org/10.1029/2018GL079291

Pulwarty, R. S., & Redmond, K. T. (1997). Climate and Salmon Restoration in the Columbia River Basin: The Role and Usability of Seasonal Forecasts, *Bulletin of the American Meteorological Society*, *78*(3), 381-398. https://journals.ametsoc.org/view/journals/bams/78/3/1520-0477_1997_078_0381_casrit_2_0_co_2.xml

Raff, D., Brekke, L., Werner, K., Wood, A., & White, K. (2013). *Short-Term Water Management Decisions*. 231. https://www.usbr.gov/research/st/roadmaps/WaterSupply.pdf

Rayner, S., Lach, D., & Ingram, H. (2005). Weather forecasts are for wimps: Why water resource managers do not use climate forecasts. Climatic Change, 69(2–3), 197–227. https://doi.org/10.1007/s10584-005-3148-z

National Weather Service Corporate Image Web Team. (2022). *CNRFC - California Nevada River Forecast Center*. NWS CNRFC. Retrieved from https://www.cnrfc.noaa.gov/

Runkle, J., K.E. Kunkel, S.M. Champion, D.R. Easterling, and S.A. McAfee. (2022). Nevada State Climate Summary 2022. NOAA Technical Report NESDIS 150-NV. NOAA/NESDIS, Silver Spring, MD, 5 pp. https://statesummaries.ncics.org/chapter/nv/#:~:text=Nevada%20is%20the%20Nation's%20driest,2020)%20precipitation%20only%2010.2%20inches.

Saha, S., Moorthi, S., Pan, H. L., Wu, X., Wang, J., Nadiga, S., … Goldberg, M. (2010). The NCEP climate forecast system reanalysis. *Bulletin of the American Meteorological Society*, *91*(8), 1015–1057. https://doi.org/10.1175/2010BAMS3001.1

Saha, S., Moorthi, S., Pan, H., Wu, X., Wang, J., Nadiga, S., Tripp, P., Kistler, R., Woollen, J., Behringer, D., Liu, H., Stokes, D., Grumbine, R., Gayno, G., Wang, J., Hou, Y., Chuang, H., Juang, H. H., Sela, J., Iredell, M., Treadon, R., Kleist, D., Van Delst, P., Keyser, D., Derber, J., Ek, M., Meng, J., Wei, H., Yang, R., Lord, S., van den Dool, H., Kumar, A., Wang, W., Long, C., Chelliah, M., Xue, Y., Huang, B., Schemm, J., Ebisuzaki, W., Lin, R., Xie, P., Chen, M., Zhou, S., Higgins, W., Zou, C., Liu, Q., Chen, Y., Han, Y., Cucurull, L., Reynolds, R. W., Rutledge, G., & Goldberg, M. (2010). The NCEP Climate Forecast System Reanalysis, *Bulletin of the American Meteorological Society, 91*(8), 1015-1058. Retrieved from https://journals.ametsoc.org/view/journals/bams/91/8/2010bams3001_1.xml

Semenov, M. A., & Doblas-Reyes, F. J. (2007). Utility of dynamical seasonal forecasts in predicting crop yield. Climate Research, 34(1), 71–81. http://www.jstor.org/stable/24869387

Southern Nevada Water Authority. (2020). Drought and Climate Change. Retrieved from https://www.snwa.com/water-resources/drought-and-shortage/index.html

Steinemann, A. C. (2006). Using Climate Forecasts for Drought Management, Journal of Applied Meteorology and Climatology, 45(10), 1353-1361. Retrieved from https://journals.ametsoc.org/view/journals/apme/45/10/jam2401.1.xml

Stuart, N. A., Schultz, D. M., & Klein, G. (2007). Maintaining the role of humans in the forecast process: Analyzing the psyche of expert forecasters. *Bulletin of the American Meteorological Society*, *88*(12), 1893–1898. https://doi.org/10.1175/BAMS-88-12-1893

Troccoli, A. (2010). Seasonal climate forecasting. Meteorological Applications, 17(3), 251–268. https://doi.org/10.1002/met.184

US Department of the Interior. (2020). OWDI Drought. Retrieved from https://www.usgs.gov/media/images/water-data-viz-owdi-lower-colorado-drought

Vitart, F., Ardilouze, C., Bonet, A., Brookshaw, A., Chen, M., Codorean, C., Déqué, M., Ferranti, L., Fucile, E., Fuentes, M., Hendon, H., Hodgson, J., Kang, H.-S., Kumar, A., Lin, H., Liu, G., Liu, X., Malguzzi, P., Mallas, I., Manoussakis, M., Mastrangelo, D., MacLachlan, C., McLean, P., Minami, A., Mladek, R., Nakazawa, T., Najm, S., Nie, Y., Rixen, M., Robertson, A. W., Ruti, P., Sun, C., Takaya, Y., Tolstykh, M., Venuti, F., Waliser, D., Woolnough, S., Wu, T., Won, D.-J., Xiao, H., Zaripov, R., & Zhang, L. (2017). The Subseasonal to Seasonal (S2S) Prediction Project Database, *Bulletin of the American Meteorological Society, 98*(1), 163-173. Retrieved from https://journals.ametsoc.org/view/journals/bams/98/1/bams-d-16-0017.1.xml

Western Regional Climate Center. (2020). Climate of Nevada. Retrieved from https://wrcc.dri.edu/narratives/NEVADA.htm

Wise, E. K., Wrzesien, M. L., Dannenberg, M. P., & McGinnis, D. L. (2015). Cool-season precipitation patterns associated with teleconnection interactions in the United States. *Journal of Applied Meteorology and Climatology*, *54*(2), 494–505. https://doi.org/10.1175/JAMC-D-14-0040.1

Wise, E. K. (2010). Spatiotemporal variability of the precipitation dipole transition zone in the western United States. *Geophysical Research Letters, 37*(7). DOI:10.1029/2009GL042193.

Wilks, D. S. (2007). Statistical Methods in the Atmospheric Sciences Second Edition. *In Meteorological Applications*. https://doi.org/10.1002/met.16

Appendix A: Survey Instrument

Perceptions of Seasonal Climate Forecasts

1. I work for: (choose the best answer)

- ○ Federal Agency (e.g., US Army Corps of Engineers, NRCS, BLM)
- ○ Tribal nation/government
- ○ State Agency
- ○ Private Sector (farming, ranching, hospitality, etc.)
- ○ Water Utility
- ○ Water Purveyor
- ○ Irrigation District
- ○ Non-Profit Organization
- ○ Other (Please describe)

____

2. Please describe your job title and duties.

____

3. In which county(ies) do you work? Check all that apply.

☐ Statewide

☐ Interstate/region

☐ Carson City

☐ Churchill

☐ Clark

☐ Douglas

☐ Elko

☐ Esmeralda

☐ Eureka

☐ Humboldt

☐ Lander

☐ Lincoln

☐ Lyon

☐ Mineral

☐ Nye

☐ Pershing

☐ Storey

☐ Washoe

☐ White Pine

4. I am familiar with seasonal climate forecasts (i.e., predictions of three-month average seasonal temperature and precipitation).

○ Strongly Disagree

○ Disagree

○ Undecided

○ Agree

○ Strongly Agree

5. Seasonal climate forecast information is easy to find.

○ Strongly Disagree

○ Disagree

○ Undecided

○ Agree

○ Strongly Agree

6. How often do you currently use seasonal **temperature** forecasts?

○ Do Not Use At All

○ Infrequent Use - Less Than Yearly

○ Occasional Use - Yearly

○ Somewhat Frequent Use - Every Few Months

○ Frequent Use - Monthly

7. How often do you currently use seasonal **precipitation** forecasts?

○ Do Not Use At All

○ Infrequent Use - Less Than Yearly

○ Occasional Use - Yearly

○ Somewhat Frequent Use - Every Few Months

○ Frequent Use - Monthly

8. How would you rate the overall accuracy (i.e., forecast skill) of seasonal **temperature** forecasts?

○ Very Inaccurate

○ Inaccurate

○ Undecided

○ Accurate

○ Very Accurate

9. How would you rate the overall accuracy (i.e., forecast skill) of seasonal **precipitation** forecasts?

○ Very Inaccurate

○ Inaccurate

○ Undecided

○ Accurate

○ Very Accurate

10. Seasonal **temperature** forecasts are __________ for decision-making in my position.

○ Not Useful

○ Moderately Useful

○ Very Useful

11. Seasonal **precipitation** forecast are __________ for decision-making in my position.

○ Not Useful

○ Moderately Useful

○ Very Useful

12. I would use seasonal forecasts more if they: (check all that apply)

☐ Were easier to find

☐ Were easier to interpret

☐ Were more accurate

☐ Provided more detailed information

☐ Were representative of my region

☐ Could improve decision making

☐ Were an approved tool for my decision making

☐ Covered periods shorter than three months

☐ Were more useful (please specify)

____

13. Which forecast time horizons do you use for your management decisions? Check all that apply.

☐ 10-day forecast

☐ Two-week forecast

☐ Monthly forecast

☐ Three-month forecast

☐ Six-month forecast

☐ Yearly forecast

14. What are your top three water management decisions and how far in advance do you need to make each decision? Please fill in your answer and select the most appropriate lead time.

	10 days out	Weekly	Monthly	Three-month	Six-month	One-year
Decision 1:	○	○	○	○	○	○
Decision 2:	○	○	○	○	○	○
Decision 3:	○	○	○	○	○	○

15. If there is anybody you think should take the survey, please fill in their emails below.

____

16. Is there anything else you would like to share with us about seasonal climate forecasts or this survey?

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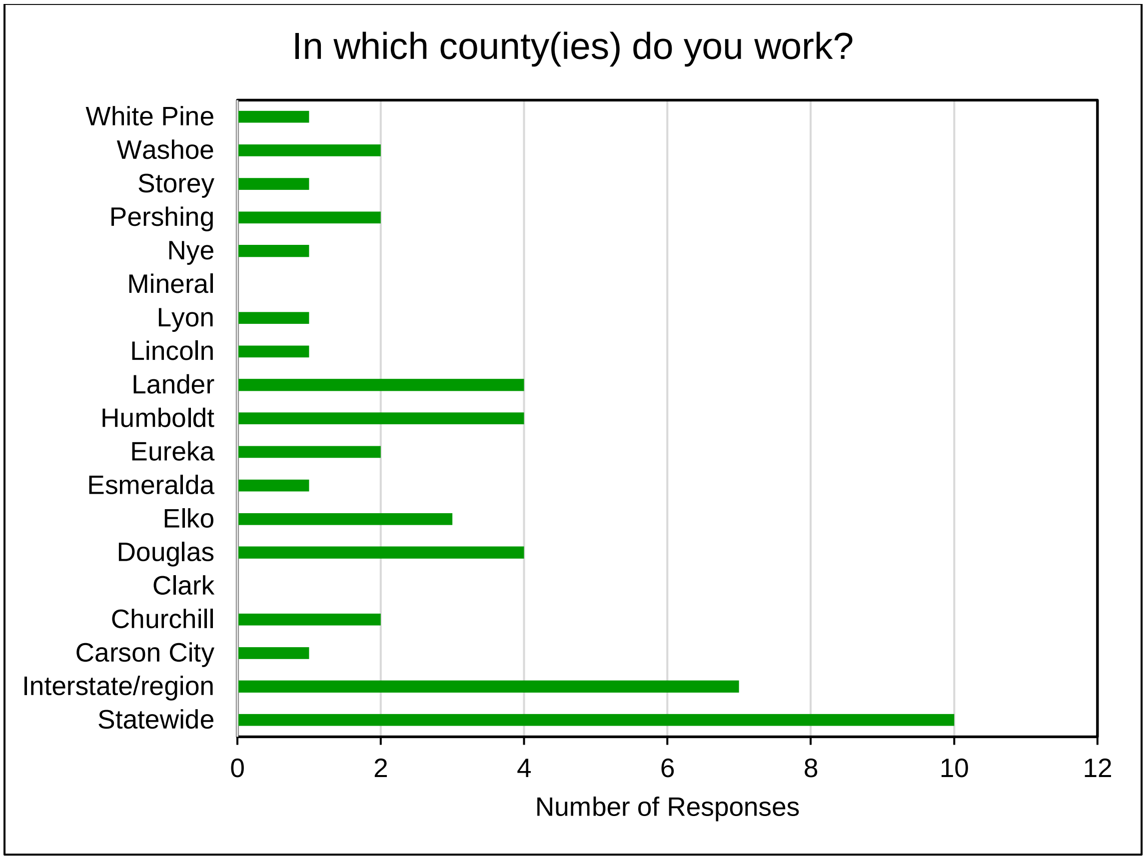
Appendix B: Supplemental Figures and Tables



Supplemental Figure 1: A full breakdown of county specific responses to “In what county(ies) do you work? (n=23, but participants were able to choose all responses that applied to them.)