Learning from Oregon's 2015 Drought: A Review of Documented Conditions, Impacts, and Response Strategies

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June 23, 2017

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Executive Summary

In 2015, Oregon experienced one of its most severe droughts on record, with emergency drought declarations in 25 of the state's 36 counties (State of Oregon, 2016). Although winter precipitation levels were relatively average, it was Oregon's warmest winter on record, and snowpack was at a historic low. Snow melted earlier than normal, and there was less continuous runoff available during the summer months. Severe conditions continued in to the year, as the state also faced its warmest and driest summer on record.

The primary purpose of this report is to provide a high-level summary of what Oregon experienced during the 2015 drought and the current status of drought monitoring and impacts reporting in the state. Comprised of five main components, the report includes:

1) a review of extant literature on monitoring and reporting the ecological, social, and economic impacts of drought in the United States;
2) a description of the hydrometeorological conditions of the 2015 drought (i.e., precipitation, temperature, snowpack, and streamflow), and a comparison of these conditions to the historic record and to those of other years of significant drought;
3) a summary of the effects of the 2015 drought, as well as examples of response strategies implemented by water providers and users to alleviate the impacts of drought;
4) a discussion of this research process and the insights gained regarding the current status of drought impacts monitoring and reporting in Oregon; and
5) a set of conclusions and recommendations based on the findings of this report.

This summary provides a general, statewide overview of the 2015 drought, which had varying impacts over time and across Oregon's regions, sectors, and economies. For example, limited water supply and high temperatures damaged certain crops and reduced yields, and ranchers in multiple counties struggled with dry pasturelands and limited stock water. In response to water level declines, several municipalities imposed some form of water conservation, be it by requesting voluntary cutbacks from customers or mandating enforceable restrictions. The drought also impacted Oregon's popular recreational activities, such as skiing, boating, fishing, and hunting, as well as the local economies that depend on visitors. In addition, Oregon's fish and wildlife were also affected by an increase in fire, insect, and disease outbreaks.

Information for this summary was collected by reviewing pre-existing written or logged information in: databases; publicly available documents and websites from government agencies and other reliable organizations; government press releases; written media coverage; and existing drought reporters. Based on the findings of this report, the following recommendations, presented in no particular order, have been developed for the consideration of relevant state agencies and advisory committees.

Recommendation #1. Secure funding and work in partnership to conduct drought risk, vulnerability, and impact assessments on geographic and sectoral scales. Consider incorporating interviews with water resource managers, providers, and users into this research.

Recommendation #2. On a statewide level, determine: a) priorities and a preferred format for summarizing the effects of drought and response strategies; and b) methods for coordinating and

minimizing duplicative efforts around collecting, documenting, sharing, and compiling relevant information (e.g., water supply conditions, effects on sectors and local economies, emergency grant and loan programs).

Recommendation #3. Review and discuss the appropriateness and effectiveness of Oregon's county drought declaration process, drought emergency tools, and water law stipulations that may help or inhibit drought management and response options.

Recommendation #4. Investigate how water conservation and storage efforts have impacted water consumption and modify or develop policies, policy tools, and programs as appropriate.

Recommendation #5. Increase government capacity for groundwater monitoring and develop a long-term plan for sustainable groundwater management with clear objectives and metrics.

I. Introduction

In 2015, Oregon experienced one of its most severe droughts on record. Despite relatively average precipitation in the winter, Oregon had a record warm winter and summer, as well as an unusually dry summer. Documenting and reviewing drought conditions, impacts, and responses is an important component of understanding and preparing for the potential implications of future drought years. Doing so is critical, especially as climate projections indicate that the Pacific Northwest will more regularly experience warmer and wetter winters and warmer summers (Dalton, Mote, & Snover, 2013).

The primary purpose of this report is to provide a high-level summary of what Oregon experienced during the 2015 drought and the current status of drought monitoring and impacts reporting in the state. Comprised of five main components, the report includes:
a review of extant literature on monitoring and reporting the ecological, social, and economic impacts of drought in the United States; a description of the hydrometeorological conditions of the 2015 drought (i.e., precipitation, temperature, snowpack, and streamflow), and a comparison of these conditions to the historic record and to those of other years of significant drought;
a summary of the effects of the 2015 drought, as well as examples of response strategies implemented by water providers and users to alleviate the impacts of drought;
a discussion of this research process and the insights gained regarding the current status of drought impacts monitoring and reporting in Oregon; and a set of conclusions and recommendations based on the findings of this report.

It is important to note that the impacts of drought vary spatially and temporally, especially in Oregon, which has diverse landscapes, eco-regions, and economies. While this summary does not go into detail about the 2015 drought on a monthly or basin-specific basis, it provides a general, statewide overview of the drought, with occasional reference to the seasonal and regional variations. Information for this summary was collected by reviewing pre-existing written or logged information in: databases; publicly available documents and websites from government agencies and other reliable organizations; government press releases; written media coverage; and existing drought reporters.

As was experienced in this data collection process, it is challenging to identify the impacts of and responses to drought for multiple reasons. For example, there is not a sole entity at the state or federal level responsible for tracking or compiling information about the impacts of a drought. Instead, numerous agencies in Oregon (e.g., Oregon Water Resources Department, Oregon Department of Fish and Wildlife, Natural Resources Conservation Service) are involved in monitoring and responding to drought such that data and knowledge are decentralized. Another reason it is challenging to determine the effects of drought is that many impacts and responses are difficult to measure, be it due to complexity (e.g., economic impacts) or sparse data (e.g., change in groundwater usage). In addition, it is often impossible to fully attribute conditions and management decisions, such as soil erosion and a farmer switching to a new crop, to drought. Thus, this summary is a reflection of the information that was readily available online or was shared by Oregon Water Resources Department (OWRD) (e.g., memoranda to the Governor regarding the drought, e-mails from other state agencies about drought conditions and impacts).

A preliminary version of this report was developed between April and July 2016 to help OWRD compile information about the conditions and impacts of the 2015 drought, and how they may have differed from previous years of significant drought. In addition, the report was intended to help provide a foundation for a chapter dedicated to drought in Oregon, which, as mandated by the Governor, will be added to the state's award-winning Integrated Water Resources Strategy (IWRS) during its 2017 revision. The original report was submitted as a draft to OWRD's Director's Office on July 23, 2016. Further research and writing was completed after the first submission as a master's research project through Oregon State University's Water Resources Policy and Management program. The primary additions to the report include: a methods section; a literature review; a finalized section on Oregon's streamflow and reservoir levels in 2015; new sections reflecting the information found on the drought impacts experienced and response strategies used with regard to tribal matters, public health, hydropower, and industry; and expansions to the discussion and conclusions and recommendations sections based on these additions.

II. Methods

Before explaining the methods completed in this research, it is important provide the definitions that will be used for the following terms, for the purposes of this report:

- ***Drought***- insufficient water supply to meet the demands of human and natural systems, due to warm or dry conditions (relative to historic averages) that lead to: low mountain snowpack, early mountain snowmelt, diminished soil moisture, and/or low streamflow, springflow, groundwater, or surface reservoir levels. (influenced by Bumbaco & Mote 2010)
- ***Drought impacts***- the effects of the drought conditions on society, the environment, or the economy
- ***Hydrometeorological conditions***- physical and hydrologic variables, including temperature, precipitation, snowpack, streamflow, and surface reservoir levels.
- ***Response strategies***- actions taken, or plans developed for future action, to help mitigate or adapt to the impacts of drought.

As mentioned in the introduction, there are five main sections of this report. The first is a review of extant literature that discusses monitoring the ecological, social, and economic impacts of drought in the United States, with a more targeted concentration on literature about drought impacts reporting, specifically. The key messages from the sources reviewed are summarized in the Literature Review section and were considered in developing the final Conclusions and Recommendations section of this report.

The second main section, Drought Conditions, provides a description of the hydrometeorological conditions of the 2015 drought and a comparison of these conditions to the historic record and to those of other years of significant drought. Statewide data from existing datasets on precipitation, temperature, snowpack, and streamflow were imported and analyzed in editable spreadsheets, focusing on specific time periods of interest (e.g., the two halves or four quarters of the 2015 water year). Several sources of data were used. For temperature and precipitation, data from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for

Environmental Information were plotted to show which seasons of each year were normal, warm/wet, warm/dry, cold/wet, or cold/dry, relative to the historic average (see Figure 1).

For snowpack, data from snow course measurements and the Natural Resources Conservation Service's (NRCS) Snow Telemetry (SNOTEL) sites were used to graph the statewide average and overall trend line of the Snow Water Equivalent (SWE) as of April 1 for the historic record (see Figure 4). In addition, the ten lowest April 1 SWE years in Oregon were ranked (see Figure 4). For streamflow, discharge data were used from seven U.S. Geological Survey (USGS) stream gauges from different regions across the state (north coast, south coast, north central, central cascades, south central, and southeast). Seven stream gauges were selected based on the following criteria: 1) there were at least 45 contiguous years of data available for each gauge, 2) there is minimal human regulation or diversion of the flow upstream from the gauge station, and 3) when contacted, NRCS staff recommended the stream gauge as among the most appropriate for capturing what is as close to the natural flow of a river as possible. The data were used to compare the average monthly streamflow for the 2015 water year to that of the historic record (see Figures 6a-6d and, in Appendix A, Figures A-2 through A-4).

The third main section of the report, Impacts and Response Strategies, summarizes the ecological, social, and economic effects of the 2015 drought, as well as examples of response strategies implemented by water providers and users to alleviate the impacts of drought. Information for this summary was collected by reviewing documented information, which was considered to be pre-existing written or logged information in: databases; publicly available documents and websites from government agencies and other reliable organizations; government press releases; written media coverage; and existing drought reporters (i.e., the National Drought Mitigation Center's Drought Impact Reporter). Unwritten, verbal accounts were not considered "documented" for the purposes of this research. Thus, the summary reflects the information that was readily available online or was shared by relevant agencies, particularly the Oregon Water Resources Department (e.g., memoranda to the Governor regarding the drought, e-mails sent from other state agencies about drought conditions and impacts).

In addition, if the initial online search yielded significant geographical or topical information gaps (e.g., the drought's impacts on public health), phone calls were made and emails were sent to agencies and service providers asking whether there was existing documented information that could be shared. An information gap was considered as missing or very little information about the drought impacts on any of the main geographic regions or topical sectors considered in this report, relative to what was found for other regions/sectors. The main geographic regions include: the Oregon coast and western, central, and eastern Oregon. The main topical sectors include: municipal, business/industry, agriculture and ranching, fish and wildlife, recreation, tribal matters, and public health. These sectors were chosen based on the areas of drought impacts primarily discussed in the literature reviewed. In addition, the findings on Oregon's 2015 drought impacts and response strategies easily fit into these categories, as presented and organized in the Impacts and Responses section of this report. "Government" is another topical sector that could be considered but is not included in this report. Further research could be conducted on how agency operations (e.g., procedures, cooperative efforts, funding) were impacted by the drought and how agencies responded.

Again, this report is intended to reflect information about the impacts of and responses to the 2015 drought, only as already documented. For this reason, if information was not found during the in-depth online search and by contacting the major, sectoral players in water resource management and drought monitoring (e.g., OWRD, Oregon Department of Fish and Wildlife, Bonneville Power Administration), it is not considered to be "feasibly accessible" for the purposes of this research.

The fourth main section of this report, Discussion, reflects on the research process of this project and the insights gained regarding the current status of drought impacts monitoring and reporting in Oregon. Finally, the fifth main section, Conclusions and Recommendations, provides a set of conclusions and recommendations related to: a) Oregon's existing water management and drought planning, and b) the collection, compilation, and application of information about drought impacts and responses to help inform water management and policy. These conclusions and recommendations were based on the findings from each of the three preceding sections.

III. Literature Review

This literature review is focused on extant literature that discusses monitoring the ecological, social, and economic impacts of drought in the United States, with a more targeted concentration on literature about drought impacts reporting, specifically. Five themes emerged from the literature, including: the difficulty of defining "drought" and "drought impacts;" the challenges of drought monitoring and impacts reporting; the current status and evaluations of existing drought impacts reporting efforts; and recommendations for improved drought monitoring and impacts reporting. The key messages from the sources reviewed are summarized below and are considered in the final Conclusions and Recommendations section of this full report.

Defining Drought and Drought Impacts

As is noted in nearly every publication focused on the topic of drought, "drought" and "drought impacts" are difficult terms to define, and there is not a universal definition of drought (Wilhite, 1993; p. 3). A couple of examples of suggested definitions of drought include: when water "supply does not meet demand" (Redmond, 2002; p. 144); and "lower than expected or lower than normal precipitation that, when extended over a season or longer period of time, is insufficient to meet the demands of human activities and the environment" (World Meteorological Organization, 2006; p. 4). Drought is difficult to define for many reasons, including the fact that it is a "slow-moving" disaster (Vins, Bell, Saha, & Hess, 2015; p. 13252-13253), and it is challenging to pin-point the beginning and end of a drought. The effects of drought can emerge subtly, potentially have a long lag time, and interact with other stressors (Dow, 2010; p. 499).

Drought is commonly classified into the following four types: meteorological drought (based on a precipitation deficiency compared to a particular period of time); hydrological drought (based on the average surface and subsurface supplies); agricultural drought (based on precipitation and supply shortages that affect crops and forage growth); and socio-economic drought (based on deficient water supply interrupting the supply of economic goods) (Wilhite, 1993; p. 4; World Meteorological Organization, 2006; p. 8; Vins et al., 2015; p. 13253).

The consequences—or impacts—of drought are typically discussed as "direct" and "indirect" impacts, or as an order of propagation, with "first-order impacts" mostly considered as biophysical, like low reservoir levels, and higher-order impacts (second- and third-order) "associated with socioeconomic valuation, adjustment responses, and long-term 'change'" (e.g., less boating recreation) (Wilhite, 1993; p. 9). Drought impacts can also be classified as economic (e.g., loss from crop production), environmental (e.g., air quality effects from increased dust and pollutants), and social (e.g., conflicts between water users) (Wilhite, 1993; pp. 11-12; Wilhite, Svoboda, & Hayes, 2007; p. 773). The impact of drought depends on its duration, severity, geographical range, and societal vulnerability (Wilhite, 1993; p. 4).

The Need for Drought Impacts Reporting

State drought managers in the Western Governors' Association region "are highly concerned about droughts, and expect them to become more frequent and severe" (Steinemann, 2014; p. 843). As explained by the State of Oregon's Task Force on Drought Emergency Response, there are five key components of drought preparedness: 1) data collection for monitoring, early warning, and prediction; 2) assessing risk, vulnerability, and impacts; 3) preparing and implementing response strategies; 4) building awareness; and 5) developing and carrying out mitigation actions (State of Oregon, 2016; p. 9).

Each component cannot be accomplished without those that come before it. In order to thoroughly assess risk, vulnerability, and impacts, then, an understanding of the previous and potential impacts of drought on a system is critical (Lackstrom et al., 2013; p. 12). Common drought indicators used in monitoring and predicting drought are often based on hydrometeorological data and focus on direct impacts (Lackstrom et al., 2013; p 6), such as: percentage of normal precipitation; temperature; soil moisture; reservoir levels; stream-flow; groundwater levels; numerous drought; precipitation; water supply; crop moisture indexes (e.g., the Palmer Drought Severity Index); and various tools that combine multiple data sets and indexes (e.g., the U.S. Drought Monitor). Both Oregon and Utah, for example, significantly depend on the Surface Water Supply Index (SWSI) when assessing drought conditions (Fontaine et al., 2014; p. 96-97). Other drought-related data in Oregon includes snowpack, instream flow needs, and water use. Much of the drought impacts reporting work has been focused around these types of metrics, which are often based on below-average precipitation. (State of Oregon, 2016; p. 11)

However, these hydrometeorological indicators do not fully capture the complexity of actual drought conditions. Other types of drought conditions, such as second-order or more distant impacts (e.g., water quality degradation, public health problems), often go unconsidered when assessing drought conditions. (Lackstrom et al., 2013; pp. 10-11; Vins et al., 2015; p. 13253) For example, "the implications of drought for mental health via pathways such as loss of livelihood, diminished social support, and rupture of place bonds have not been extensively studied" (Vins et al., 2015; p. 13251). This is also true for economic impacts of drought, which include direct impacts (e.g., soil degradation) and indirect impacts (e.g., temporary unemployment) (Travis & Klein, 2012; p. 3). In 1993, Wilhite wrote that few studies had been conducted in a consistent or systematic way and that economic analyses were mostly focused on agricultural losses (p. 2). For example, little research has been done to measure the regional and national economic costs of drought beyond agricultural effects (Dow, 2010; p. 498; Travis & Johnson, 2013; p. 9; Travis &

Klein, 2013; pp. 4-5). This is a critical research gap, as drought managers across the West estimate a range of drought damages from millions of dollars to billions of dollars per year per state. In fact, of the 19 state drought managers interviewed in Steinemann's 2014 study on Western Governors' Association states, it was found that all managers believed that improved "early warning information could help reduce drought costs, with an average reduction of 33%." (2014; p. 843)

Research is also lacking on short- and long-term ecological drought impacts and how those affect connections among ecosystems and their species (Lackstrom et al., 2013; p. 12), as well as how ecological impacts carry over to socio-economic impacts (Travis & Johnson, 2013; p. 9). With regard to drought planning and response, the literature calls for a better understanding of direct drought impacts (Wood et al., 2015; p 1636), indirect drought impacts (Lackstrom et al., 2013; p. 10), objective measures of drought (e.g., improved hydrometeorological assessment tools) (Wood et al., 2015; p. 1650-1651), and subjective measures of drought (e.g., self-reported effects via surveys) (Hunter et al., 2013; p. 419, 431). In order to make progress in assessing the socioeconomic impacts of drought, new indicators must be developed and data must be collected, visualized, and disseminated (Travis & Johnson, 2013; p. 9). Such "drought impacts reporting" will help provide information that can be used to better understand and evaluate vulnerability, cost-effective preparedness, response needs, early warning of other impacts, and build mitigation and resiliency efforts to reduce the severity of impacts (Dow, 2010; p. 499; Mariotti et al., 2013; p. ES186; State of Oregon, 2016; p. 12; Travis & Johnson, 2013; p. 9; Travis & Klein, 2012; p. 1).

In addition, drought impact reporting helps create analogs that can be used to conduct historic comparisons of drought events and their impacts. This type of comparison can help those involved in drought management anticipate the potential impacts of a current drought event, based on the impacts that occurred during previous droughts with similar conditions (Steinemann, 2014; p. 845). All the information and actions mentioned above can help reduce the severity of future drought events, as well as help request and leverage funding (State of Oregon, 2016; p. 12; Travis & Klein, 2012; p. 1). The benefits of drought impacts reporting are clear; however, it remains unclear whether those benefits are sufficiently strong incentives for implementing consistent reporting efforts (Lackstrom et al., 2013; p. 12).

Challenges of Drought Impacts Reporting

Due to the difficulties of defining "drought" and "drought impacts," monitoring drought is inherently challenging. Of course, accurately measuring drought indicators and effects can also be a challenge, especially for indirect impacts that may not be able to be numerically quantified. Below is a list of the challenges in drought monitoring and impacts reporting, as identified by the literature, several of which are interconnected:

- **Difficulty in collecting data and measuring impacts.** Drought impacts can be considered "visible," "invisible," or somewhere in between. Losses due to drought usually do not result in injuries, fatalities, or obvious property damage (Travis & Klein, 2012; p. 5), and "impacts can only be reported when they are observed" (Lackstrom et al., 2013; p. 12). Although some losses cannot be quantified, even those that can are often difficult to measure. Methodologies for assessing certain types of losses, especially nonmarket losses like loss of recreational opportunities, are difficult, expensive, and require expertise (Travis & Klein, 2012; pp. 3-4). Furthermore, the ambiguous, nonstructural characteristics of drought, including its difficult-to-define temporal and geographic extent, make it challenging to quantify drought impacts on the economy and ecological services (Travis & Johnson, 2013; p. 9; Travis & Klein, 2012; p. 1, 5). Qualitative data can help address these types of ill-defined boundaries of drought. Newspaper articles, for example, from which the U.S. National Drought Mitigation Center's web-based Drought Impact Reporter heavily draws, is a form of drought impacts reporting that can help document quantitative and qualitative information. While media can help address the lack of information about drought impacts, especially with regard to qualitative data, it is not a systematic monitoring method and can include editorial and institutional bias (e.g., judgment of "newsworthiness" and the significance of the actors involved, profit motivations). (Dow, 2010; pp. 499-500, 507)

- **Attribution of effects.** Further compounding the difficulty of collecting data on and measuring drought impacts, attributing what might be an impact of drought directly to drought, rather than to a different stressor or a combination of stressors, is another challenge in drought impacts reporting (Lackstrom et al., 2013; p. 10, 12). This is especially true because interactions of drought with other stressors (e.g., unrelated disease in fish) might exacerbate the drought impacts (e.g., fish die-offs) (Dow, 2010; p. 499). In addition, the slow onset of drought, which can last for many years, and the unclear beginning and end of a drought (temporally) can make attribution even more difficult (Dow, 2010; p. 499; Travis & Klein, 2012; p.1). Not only can certain impacts (e.g., fire susceptibility) continue after a drought has ended, but there can be a time lag between when a drought ends and when deficiencies become apparent (World Meteorological Organization, 2006; p. 4). The following example provided by Lackstrom et al. (2013) illustrates the challenge of attribution when multiple stressors are at play as well as the issue of lag time: does urban subsidence in Arizona occur as a result of drought, overdraft of groundwater (which may or may not have been a response to a lack of precipitation), or both (p. 12)?

- **Fragmented information and lack of coordination.** Information about the effects of drought is fragmented temporally, spatially, across sectors, and across institutions, which causes numerous challenges in drought impacts reporting. For example, if observed impacts are to be compared with a drought index, a homogenous time series of impact information is needed in order to determine relationships between multiple factors (Redmond, 2002; p 1145). In addition, because of the potentially large geographic range of a drought's impact, institutions across the affected area would need comparable data to assess a certain metric (Wood et al., 2015; p. 1641). This is not to say, however, that measuring drought effects on a smaller scale is better positioned for success. Drought effects on smaller spatial scales, "where almost all impacts are ultimately felt, are not sampled or reported adequately, and in some cases, at all" (Redmond, 2002; p. 1145). Regardless of the geographic scale, there is a lack of standards and consistent methodology for collecting information about drought impacts (Dow, 2010; p. 499), such that information can vary in quality, format, and availability (Wood et al., 2015; p. 1641). This is in part due to the lack of a single institution responsible for collecting and managing a drought impacts database, or even integrated and regularly collected information about drought impacts at the national, regional, or state levels (Dow, 2010; p. 499). In fact, a national roster of drought events has yet to be developed (Travis & Klein, 2012; p. 5). On the state level, for example, there may be several agencies responsible for drought planning and response, such as water resources, hazards mitigation, fish and wildlife, and agriculture departments (Lackstrom et al., 2013; p. 15). Federal and state agencies, and their distinct drought impacts reporting efforts, work to fulfill their own mission, target different audiences, define and characterize drought impacts differently, and accept varying formats of impact reports (Dow, 2010; p. 499; Lackstrom et al., 2013; p. 8).

- **Dependence on volunteers.** Currently, drought impacts reporting systems in the U.S. heavily depend on volunteers (e.g., citizen observers) to report impacts (Lackstrom et al., 2013; p. 12; Meadow, Crimmins, & Ferguson, 2013; p. 1510). In an evaluative study on Arizona DroughtWatch (AZDW), Arizona's drought impacts reporting system, Meadow et al. (2013) suggest that without direct incentives or a clear understanding of how data would be used in decision making processes, volunteers may be less likely to engage in drought impacts reporting (p. 1515). Furthermore, volunteers have shown a lack of understanding about the role of qualitative drought impacts observations in drought monitoring, which can also take more time to record through written descriptions, such that there may be more constraints on qualitative data compared to quantitative data in volunteer-dependent drought impacts reporting systems. In addition, as stated by Lackstrom et al. (2013), "volunteers often have differing motivations and interests, diverse technical capacities, and differing needs for regular communication and outreach, factors which challenge sustained impacts reporting efforts" (p. 12). Another challenge found in AZDW's reliance on volunteers is that participants tend to disengage when they are not directly affected by drought impacts or they do not perceive drought impacts, leading to reports with spotty data and lacking information on stable or improving drought conditions (Meadow et al., 2013; p. 1515).

- **Imbalance of information across sectors.** The type and severity of drought impacts vary across economic sectors, "ranging from none to extreme" (Redmond, 2002; p. 1145). As previously mentioned, much of the research on drought impacts is focused on the agriculture sector, which is often a high priority in policy and public support. Drought impact studies on other sectors, such as recreation and tourism, are mostly based on qualitative information (Ding, Hayes, & Widhalm, 2011; p. 441), and there is a lack of data on insurance or impacts on insurance outside of agriculture (Travis & Klein, 2012; p. 5). In addition, with current drought impacts reporting so heavily dependent on volunteers, who tend to be more engaged in data collection when the value of the data is most clearly demonstrated, reporting is most reliable and systematic in sectors like agriculture and wildlife management. Conversely, there is less data collected in sectors that experience significant impacts but are not well represented in drought monitoring and management plans, such as ecosystems and public health. (Lackstrom et al., 2013; p. 12) Sectoral dominance in drought impacts reporting can carry over to media, as well. In a study that examined regional newspaper coverage on drought from 1998 to 2007 in the Carolinas, it was found that while most of the coverage focused on broadly recognized sectors (e.g., agriculture, livestock, and water supplies), at the height of the two droughts experienced, coverage extended to recreation and tourism, business, manufacturing, and households (Dow, 2010; p. 497).

- **Lack of incentives and resources.** An issue that ties all of the above issues together is that of a lack of incentives and resources in drought monitoring and impacts reporting. For instance, with the fragmented system of drought impact data collection, and because there is not a formal mechanism or institutional support for data collection, it is unclear what the value of data collection would be to those who provide and use the data. This is especially true "if a state, county, or city does not have an effective drought management plan," as there "may be no potential application for drought impacts reports…and governments are unlikely to provide incentives or mandates to collect drought impact data" (Lackstrom et al., 2013; p. 15). The issue of resources also relates to existing drought impacts reporting systems' dependency on volunteers. Without available resources, it is difficult to support staff who can collect drought impacts data in a more consistent way, as is especially needed from engaged field personnel who understand the value of and have expertise in monitoring (Lackstrom et al., 2013; p. 12). Also, due to the close connection between the field of climate and the field of drought impacts, coordination among the expertise within the fields is important. However, while such coordination occurs in the state climate office in some states, "many states lack the resources to support such expertise" (Redmond, 2002; p. 1145).

Despite the many challenges included in drought impacts monitoring and reporting, several types of drought monitoring systems have been developed across varying scales. The next section lists these systems and discusses the current status of drought impacts monitoring and reporting.

Current Status of Drought Monitoring

There has been increased attention toward the need for more reliable drought impacts information, a national database of such information, and improved drought management at the state and national level (Travis & Klein, 2012; p. 4; Wilhite et al., 2007; p. 773). However, as mentioned above, the current indicators and indices of drought impacts mostly focus on short-term rainfall deficits, and the indicators used (e.g., soil moisture and surface water supply) may not reflect the same degree of a drought's severity (Dow, 2010; pp. 498-499). Again, the majority of existing drought monitoring and reporting efforts and research is on agriculture and economic impacts (Dow, 2010; p. 499; Travis & Klein, pp. 4-5). There are still great limitations in the current ability to comprehensively monitor drought impacts in these areas, however (Dow, 2010; p. 499), largely due to the challenges previously discussed. Socioeconomic drought impacts are monitored less than those of other natural disasters (e.g., floods and hurricanes), and without a central database of drought losses, damages from drought events cannot be compared across years (Travis & Klein, 2012; pp. 4-5, 9).

There are various drought monitoring efforts taking place on the national, regional, and state levels. On a national level, there are six primary drought monitoring systems, including the following:

- **National Drought Mitigation Center's (NDMC) Drought Impact Reporter (DIR) at the University of Nebraska-Lincoln**- a web-based mapping tool that collects broad information from media, government agencies, and citizen volunteers about "observable loss[es] or change[es] that occurred at a specific time and place because of drought" (Lackstrom et al., 2013; p. 9). Launched in 2005, the DIR is considered the "nation's first comprehensive database of drought impacts," (Travis & Klein, 2012; p. 4) and has been used by scientists, policymakers, natural resource managers, academic researchers, the public, and media (Lackstrom et al., 2013; p. 14; Wilhite et al., 2007; p. 773). However, it is not clear to what extent the data can be compared temporally and spatially, and the majority of the economic losses reported are in the agriculture sector (Travis & Klein, 2012; p.4).

- **U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) and Farm Service Agency (FSA)**- gathers information about agricultural and crop impacts (Lackstrom et al., 2013; p. 9).

- **National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC)**- as part of the National Weather Service, "delivers real-time products and information that predict and describe climate variations on timescales from weeks to years" with the goal of "promoting effective management of climate risk" ("Who We Are," 2013).

- **National Weather Service (NWS) Weather Forecast Offices**- issue "Drought Information Statements" when an area is considered to be in severe or worse drought on the U.S. Drought Monitor, which is further explained below; the Drought Information Statements are used in the DIR. (Lackstrom et al., 2013; p.9)

- **National Integrated Drought Information System's (NIDIS) Drought Early Warning System (DEWS)**- as part of NOAA, consists of a network of federal, state, regional, local, and private partners that "explore[s] and demonstrate[s] a variety of early warning and drought risk reduction strategies that incorporate drought monitoring and prediction information" ("What is NIDIS?," n.d.; "Regions," n.d.). Currently, the DEWS efforts are taking place on regional scales (e.g., Pacific Northwest, Missouri River Basin, California-Nevada) ("Regions," n.d.).

- **Community Collaborative Rain, Hail and Snow Network (CoCoRaHS)**- gathers precipitation data measured by a national network of volunteers, which is incorporated into the NDMC (Lackstrom et al., 2013; p. 9; Travis & Klein, 2012; p. 4).

The four groups listed above in bold are alternatingly responsible for producing the U.S. Drought Monitor, (USDM) which is housed by the NDMC and summarizes and maps "drought conditions across the U.S and Puerto Rico on a daily basis" (Lackstrom et al., 2013; p. 5; Wood et al., 2015; p. 1641). The USDM ranks areas by their severity of drought on a six-point scale, ranging from D0 (abnormally dry) to D4 (exceptional drought), upon which areas can base requests for or be designated emergency funding (Lackstrom et al., 2013; p. 6; State of Oregon, 2016; p. 13; U.S. Drought Monitor; 2017). The U.S. Secretary of Agriculture designates federal declarations of drought (State of Oregon, 2016; p. 13). One critique of the USDM is the lack of objective consistency in its data due to the interpretive information that feeds into it (e.g., media reports, qualitative data) (Wood et al., 2015; p. 1651).

On the state and local level, the degree to which drought monitoring and impacts reporting efforts are incorporated into drought planning, monitoring, and mitigation initiatives "appears extremely limited." While most western states are active in drought monitoring and response, only some have conducted or commissioned what are typically one-off or ad hoc studies on the *impacts* of specific drought events. (Lackstrom et al., 2013; p. 15) Furthermore, few states have completed post-drought assessments, impact and risk assessments, or mitigation, and resources were focused on drought response rather than drought mitigation and assessment (Fontaine, Steinemann, & Hayes, 2014; p. 99; Lackstrom et al., 2013; p. 15). According to Fontaine et al. (2014), results from formal postdrought assessments that states have conducted have been used to "prioritize mitigation activities" (p. 99).

While Maryland, Alaska, and California are recognized for being the "most proactive states in climate change adaptation," (Averyt et al., 2011; p. 81) the literature pointed to Colorado and Arizona as states with advanced drought monitoring and impacts reporting activities. For example, Colorado implemented a project called the Colorado Climate Preparedness Project (CCPP), which "through a series of 22 structured interviews,…provides a catalog of climate impacts and adaptation activities and options in five climate-sensitive sectors in the state of Colorado: water; wildlife, ecosystems and forests; electricity; agriculture; and outdoor recreation" (Averyt et al., 2011; p. 1). The interviews were conducted with representatives of key agencies, cooperating non-profit organizations, and one private utility (Xcel Energy) from the following sectors: agriculture; electricity; wildlife, ecosystems, and forests; outdoor recreation; and water (Averyt et al., 2011; pp. 8-9). The final report produced from the CCPP summarizes key findings for each of the sectors, as well as sector-specific and overarching recommendations for reducing drought vulnerability. The CCPP helps state agencies and other entities identify what type of information could be useful when planning for climate variability and change (Klein & Travis, 2012; p. 1).

Colorado also has a Colorado Drought Mitigation and Response Plan (DMRP), most recently updated in 2013, which "provides a blueprint for how the state will monitor, mitigate, and respond to drought" (State Drought Planning, 2017). As outlined in the plan, drought monitoring is ongoing, and Water Availability Task Force meetings are held regularly. The DMRP is "one of the most comprehensive examples of how vulnerability and impacts can inform response and mitigation efforts" (State of Oregon, 2016; p. 12). In order to assess the effectiveness of drought planning and gain a better understanding of drought and drought impacts, the state completed a Drought and Water Supply Assessment in 2004 and updated the assessment in 2007 ("State Drought Planning," 2017).

Arizona has a drought impacts reporting system, called the AZDW, which is a web-based data collection center "designed to gather drought impact reports from across the state to inform decisions about drought status and response options" (Meadow et al., 2013; p. 1507). Led by the Arizona Department of Water Resources, the AZDW stemmed from a monitoring and reporting framework in the state's 2003 drought preparedness plan. The AZDW is comprised of three types of groups to help identify the impact of drought, define the sources of drought vulnerability and outline a monitoring program, and prepare drought response and mitigation options. The Local Drought Impact Groups consist of county-level volunteer groups that are led by Arizona Cooperative Extension and county emergency management. The Monitoring Technical Committee (MTC) includes experts from across that state who monitor drought conditions and produce the state's drought status maps, using "qualitative drought impact observations and quantitative drought monitoring metrics" (Meadow et al., 2013; p. 1508). Finally, the Interagency Coordinating Group, composed of state, federal, and nongovernmental resource management agencies and organizations, "meets twice a year to evaluate drought conditions presented by the [MTC]" and provide recommendations to the governor about drought emergency statuses (Meadow et al., 2013; p. 1509). In addition, Arizona has multiple committees that coordinate drought monitoring and response efforts (Meadow et al., 2013; p. 1508).

In Oregon, the state of focus in this report, drought monitoring and impacts reporting efforts are not nearly as advanced or well-coordinated. Currently, drought data collected is limited to first-order impacts, including the: "number of historic drought declarations, reduced snowpack, lower reservoir levels, groundwater-level declines, reduced streamflow, reduced soil moisture, increased vegetation stress, depreciated water quality, and increased wildfire risk" (State of Oregon, 2016; p. 12). This type of data is not sufficient to inform risk and vulnerability assessments (State of Oregon, 2016; p. 12). As is the case in Utah, counties in Oregon must formally declare drought emergencies before the governor grants the county declaration. According to Fontaine et al. (2014), this type of local-level empowerment in the drought declaration process gives officials a sense of shared responsibility around drought (p. 97). This also allows for input on locally-specific conditions (State of Oregon, 2016; p. 14). However, drought and drought declaration affects sectors differently (e.g., perhaps assistance is given to the agriculture sector but not to fish and wildlife), and county-level consideration could be given to only some sectors and not others (State of Oregon, 2016; pp. 14-15).

In a 2016 State of Oregon report, called, "Report of the Task Force on Drought Emergency Response," the process for county-level drought declarations is described as follows:

> *"Due to the challenges associated with defining drought, the Drought Readiness Council reviews the information provided by the county and data about conditions from the Water Supply Availability Committee to ensure that a declaration is warranted. In addition to hydrologic and meteorological indicators, the Drought Readiness Council also considers impacts on the ground that may require a response. The county's ability to describe impacts is an important factor in the Council's decision. As a result, it is important to note that a drought declaration makes State drought tools available [e.g., temporary emergency water use permits, water right transfers, instream leases]; however, there are likely to be areas of the state experiencing drought conditions that do not request or receive State-level assistance. The Drought Readiness Council provides recommendations to the Governor's Office; ultimately, it is up to the Governor to decide whether to issue a drought declaration."* (State of Oregon, 2016; p. 14, pp. 17-18)

In addition to the federal agencies engaged in state-level and regional drought impacts reporting (e.g., those listed above), there are at least eleven state-level government agencies and four groups involved in drought management and planning in Oregon. For example, using data from OWRD, USGS, NWS, and other cooperators, the NRCS produces a monthly "Water Supply Outlook" report that includes "current and forecasted streamflow information, snowpack, precipitation, and reservoir data for each major river basin in Oregon" ("Basin Outlook Report, April," 2015). The Oregon Department of Fish and Wildlife (ODFW), Oregon Department of State Lands, and Oregon Office of Emergency Management are other examples of state agencies involved in drought management. As for multi-agency and/or multi-sectoral groups, the Water Resources Commission, Water Supply Availability Committee, Drought Readiness Council, and a temporary Drought Task Force all focus on drought monitoring and preparedness. (State of Oregon, 2016; pp. 9-10, 13-16)

In the U.S. in general, there has been little effort to coordinate efforts and share information across drought impacts reporting systems. Furthermore, the literature has identified the AZDW as the only drought impacts reporting system that has been formally evaluated (Lackstrom et al., 2013; p, 8). The evaluation, which was completed by Meadow et al. (2013) of the University of Arizona, reflects on and provides recommendations specific to the AZDW, but also to the broader field of drought impacts monitoring and reporting. The findings of this report, most of which are summarized in the above section on challenges and the following section on recommendations, can be used to help inform future systems. (Meadow et al., 2013; p. 1515)

Conclusions and Potential for Improved Drought Impacts Reporting

Within the literature reviewed, several conclusions and recommendations were identified on how to improve drought monitoring and impacts reporting at various scales. First, Lackstrom et al. (2013) strongly emphasized the need for integrating, coordinating, institutionalizing, and professionalizing drought impacts reporting. For example, although they recognize the lack of available resources, the authors are proponents of integrating disparate drought monitoring efforts into a national system, like the DIR, so that information could "support local decisions and national policy and resource allocation decisions" (Lackstrom et al., 2013; p. 15). An important component of a more integrated system would be translating the information in a way that could be used to inform decision making, which would require diverse groups of decision makers and researchers, including "impact translating." In order to help sustain coordination and long-term operation of an integrated system, which is also important at the local level, it is suggested that training be provided to all groups involved in drought reporting processes, as well as opportunities for ongoing interactions and communications (Lackstrom., et al., 2013; p. 16; pp. 20-21).

A second theme in the conclusions and recommendations identified in the literature is the need for new research surrounding drought monitoring and impacts reporting. In contrast to Lackstrom et al.'s call for comprehensive and integrated monitoring systems, for example, Travis and Klein (2012) suggest carefully selecting factors and early warning indicators for specific regions, as was done for the Western Water Assessment region by Travis, Gangwer, and Klein (2011). Focusing on a certain region yielded a longer list of potential indicators than what is typically involved in drought impact studies (e.g., water use restrictions, river traffic, hunting and fishing licenses or gear sales). In the same vein of steering away from further initiatives around empirical drought impact measurements across larger scales, Travis and Klein (2012) also suggest that it might be more beneficial to conduct "more routine modeling of drought impacts with regional economic input-output models, other types of economic impacts models, and risk and decisions tools" (p. 5).

Also emphasizing the importance of understanding socioeconomic impacts of drought, in their study conducted in Australia, Hunter et al. (2013) suggest that social surveys can be used to help advance research on the social and economic impacts of drought and on drought monitoring. The authors argue that there is evidence that a survey-based self-report measure of drought (e.g., asking people whether they are experiencing or have recently experienced drought) can be "internally consistent and highly correlated with meteorological measures of drought." (Hunter et al., 2013; p. 421, 430) Media coverage, which is used among other forms of impact reports in the

DIR, can also help address the lack of information on socioeconomic drought impacts. However, newspaper coverage is "not a systematic monitoring system." (Dow, 2010; pp. 499-500)

In addition, Travis and Klein (2012) argue that there should be an increased focus on conducting geographical and sectoral vulnerability studies, like Colorado's previously mentioned Drought and Water Supply Assessment (p. 5). The need to better understand sectoral vulnerabilities is critical, considering most drought impacts research is focused on agriculture, as was previously discussed. Other sectors that could especially "benefit from improved drought impacts reporting include energy, public health, tourism, natural ecosystems, and small businesses and communities dependent on natural resources" (Lackstrom et al., 2013; p 19). Of course, further and more in-depth research would require funding, and it is unlikely that there will be significant new funding for drought monitoring. Thus, Lackstrom et al. (2013) suggest that *existing* data sources should be identified and evaluated to explore how they can be incorporated `into drought impacts reporting (pp. 18-19).

The lack of resources available for drought monitoring is the primary reason that many systems rely so heavily on volunteers. Meadow et al. (2013) and Lackstrom et al. (2013) strongly focus on lessons learned from volunteer-based monitoring approaches, largely because Meadow et al. conducted an evaluation of the AZDW, which heavily depends on volunteers. Lackstrom et al. incorporated much of the findings from Meadow et al. into their report, which is on the opportunities and barriers to drought impacts reporting, as the AZDW evaluation is the only known formal evaluation of such a system. One of the main challenges in relying on volunteers in drought data collection, as previously described, is that the lack of volunteer's continued engagement can lead to "spotty" data that do not capture how conditions change over time. It is suggested, then, that volunteers should be directly shown how their efforts are valued and how they inform decision making. This could serve as an incentive and could motivate continued participation in data collection. (Lackstrom et al., 2013; p. 12; Meadow et al., 2013; p. 1515)

Another recommendation is that volunteers be shown examples of impact reports and how volunteers' observations are linked to hydroclimatic data; doing so could also help volunteers understand the difference between quantitative and qualitative data, which has proved to be difficult in the AZDW system despite numerous training and development sessions (Meadow et al., 2013; p. 1515). Although these challenges exist, volunteers do add value by expanding the capacity for drought data collection. Thus, it is recommended that a combination of trained staff and volunteers engage in local-level data collection on drought impacts. This approach would help keep citizen observers involved in collecting data that would complement core data, which could be more consistently, and expertly, collected by field staff. (Lackstrom et al., 2013; p. 12; Meadow et al., 2013; pp. 1515- 1516) The need for well-trained staff is supported by a study (Steinemann, 2014) in which state drought managers in nineteen of the Western Governors' Association states were interviewed. It was found that managers "stressed the value of 'field intelligence' and talking with local experts and stakeholders across the state" (Steinemann, 2014; p. 845).

The findings and recommendations yielded from the AZDW evaluation by Meadow et al. (2013) are a reflection of the valuable insights that could be gained from a formal evaluation of other drought monitoring and impacts reporting systems, including those at the national level. Specific to Oregon, many of these concluding themes found in the literature closely relate to the recommendations included in the State of Oregon's *Report of the Task Force on Drought Emergency Response.* Aside from stating that the state's Drought Readiness Council and Water Supply Availability Committee "should continue to meet and coordinate on drought preparedness, response tools, and data" and "agencies should…work with local communities and partners to identify and prioritize data needs" (State of Oregon, 2016; p. 12, 14), increased coordination in drought data collection and impacts reporting was not highlighted as a primary need in the Task Force's report. That said, recommendations surrounding the need for more data collection and new studies on drought vulnerability, impact, and risk assessments were strong, and the need for funding to achieve these recommendations was repeatedly recognized. Of the eighteen recommendations included in the report, which are directed to various parties (e.g., agencies, OWRD, Oregon Legislature), the following three are directly focused on drought monitoring.

- ***Recommendation A***- "The State should continue to increase and enrich water-related data collection to inform water use decisions, conservation, and management, as well as better anticipate and respond to drought." This recommendation is mostly focused on collecting data that would help determine first-order impacts, such as measurements of streamflow, groundwater, precipitation, and snowpack, as there is currently inadequate data in some areas of the state. (State of Oregon, 2016; p. 11)

- ***Recommendation B***- "Provide resources for assessments of drought impacts, risks, and vulnerabilities on instream and out-of-stream sectors in order to better prepare for, respond to, and recover from drought." The report acknowledges that data collection in the state is currently limited to first-order drought impact data and that this type of data is not sufficient for vulnerability assessments. Due to limited resources, the Task Force recommends prioritizing vulnerability assessments for "agriculture, instream, and municipal water systems, taking into account the cumulative impacts of drought." (State of Oregon, 2016; p. 12)

- ***Recommendation C***- "The State should review the drought declaration process and tools to ensure drought declarations are effective to assist with emerging drought response." Building on this recommendation, the Task Force suggests that more information be provided "to help the public, elected officials, and others to understand when an area is likely to experience drought, and what a drought declaration means." It is also suggested that drought conditions should be identified as early as possible and that the timing of drought declarations be reviewed, and possibly reconsidered. (State of Oregon, 2014; p. 14)

It seems that conducting interviews with selected players in drought management, similar to what was done in Colorado's CCPP, could be of great benefit to Oregon in identifying drought impact data gaps, targeted drought indicators, and potential areas and methods for improved geographical and sectoral coordination in drought monitoring and impacts reporting. Doing so would require funding and time, which are already quite constrained; however, perhaps such an effort could be taken on by multiple partners, including academic researchers. This type of research would help to address each of the three recommendations above.

IV. Drought Conditions

This section describes the statewide conditions experienced during the 2015 drought, specifically precipitation, temperature, snowpack, and streamflow, and how those conditions compare to: a) historic Oregon conditions; and b) the conditions of previous years of significant drought. For the purposes of this report, "significant drought" refers to drought years in which most of the state experienced moderate to severe drought. Based on these criteria, the following were selected by OWRD staff as previous years of significant drought as points of reference: 1934, 1977, 1992, 1994, 2001, 2002, and 2005.

Some areas of the state faced severe drought in other years, including in the past decade. For example, drought emergency was declared in ten Oregon counties in 2014, and the impacts of the drought in those areas should not be overlooked (Governor's Office, 2015). The drought of 2015 is of key focus in this summary, however, because it had statewide effects with emergency drought declarations in 25 of Oregon's 36 counties. Although not discussed in this report, the 1980s was a very dry period for the state, as well, with years of national drought in 1987 and 1988 (Andreadis, Clark, Wood, Hamlet, & Lettenmaier, 2005). During these years, Oregon faced a warm and dry summer and a warm and dry winter, respectively, as shown in Figure 1.

Physical and meteorological conditions are presented in this summary in terms of water years rather than calendar years, as is typical when discussing drought. The water year starts on October 1 of any given year and ends on September 30 of the following year. The first half of the water year is from October through March (e.g., October 2014 through March 2015 for the 2015 water year) and the second half is from April through September.

Introduction to Drought Conditions

Precipitation and temperature are the main drivers of the hydrologic cycle, and therefore the main drivers of drought. Precipitation and temperature largely determine snowpack and streamflow levels, which are commonly used as indicators of drought. In Oregon, many watersheds depend heavily on snowpack for annual water supply, and the timing of peak runoff from snowmelt is critical. During years with warm winters, early runoff can increase streamflow and reservoir levels during wet seasons, which can contribute to flooding. In addition, early runoff means there is less continuous runoff available during the summer months when water is needed most. (Bumbaco & Mote, 2010) There are three main types of watersheds in Oregon: snowmelt dominant, rain dominant, or mixed snow-rain (Dalton et al., 2013). This means that precipitation and temperature conditions affect watersheds differently, which is one of the reasons impacts of drought vary both spatially and temporally.

Precipitation and Temperature

Drought events can occur in the Pacific Northwest if one or more of the following occur:

- a dry winter, with low precipitation limiting snowpack accumulation;
- a warm winter, with more precipitation falling as rain rather than being stored as snow; or
- a dry summer, with little precipitation available during the driest months. (Bumbaco & Mote, 2010)

In addition, high temperatures in the summer can exacerbate drought conditions, as increased temperature can reduce soil moisture and increase rates of evaporation and evapotranspiration. Oregon has experienced multiple types of drought, as shown in Figure 1. For example, the winters of 1977 and 2001 were average in temperature but abnormally dry. Moving forward in the water year, the summer of 1977 was relatively warm but wet, whereas the summer of 2001 was both warm and dry. In another scenario, 2002 saw an average winter with no early signs of drought, however the summer was abnormally warm and dry. In contrast, concern over drought began to develop in January of 2015, with clear signs of drought present about two months earlier than usual. Although winter precipitation was relatively average, Oregon experienced its warmest winter on record and snowpack was at a historic low. Severe conditions continued in to the year, as the state faced its warmest and driest summer on record (1896-2015).

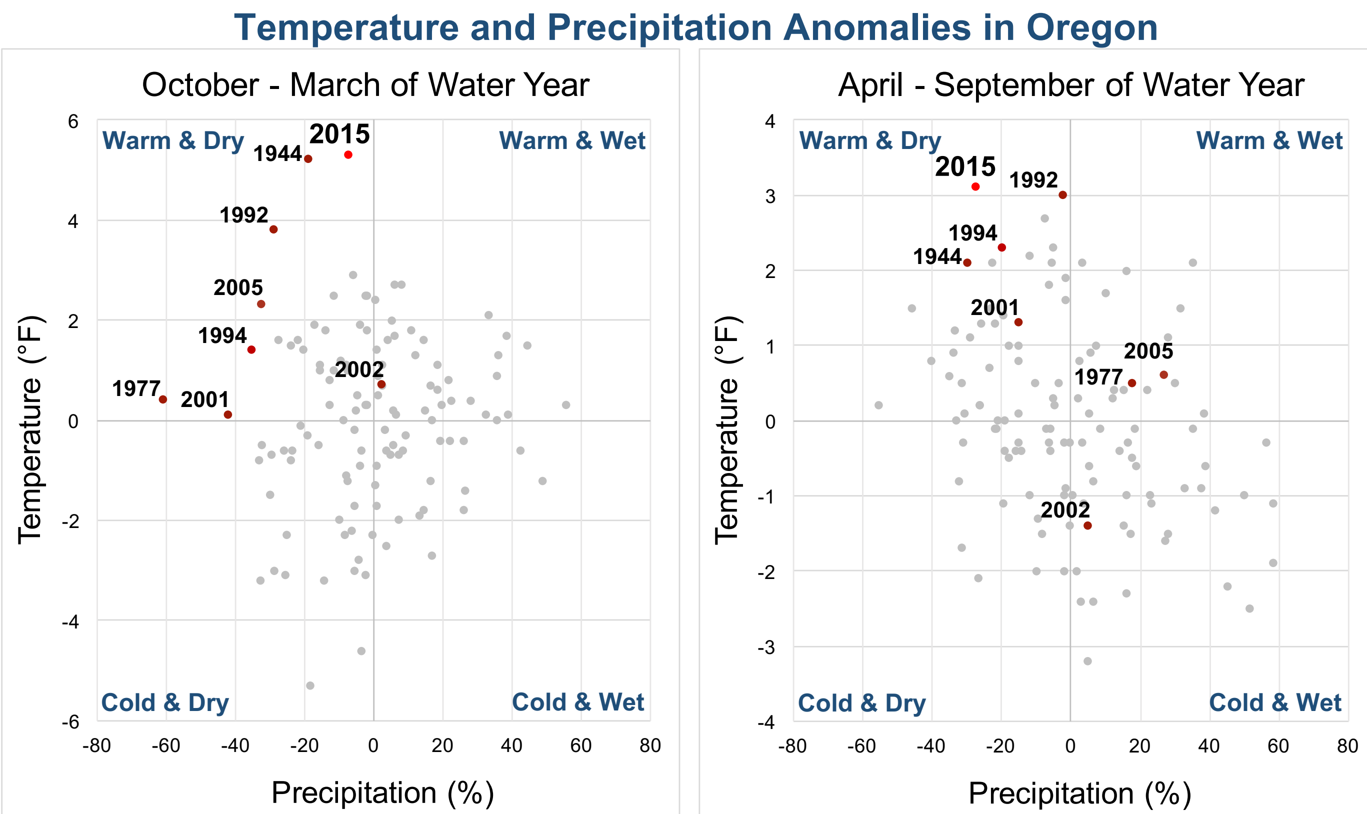

Figure 1. These plots show past climate in Oregon, with each year represented by a dot whose position indicates, on the horizontal axis, the percent above or below the historic annual precipitation average and, on the vertical axis, the annual temperature (°F) above or below the historic average. The baseline period is 1896-2015 (water years). The plot on the left shows the cool/wet half of the water year (October to March) and on the right, the dry/warm half of the water year (April to September). Select drought years are labeled. Data are from NOAA's National Centers for Environmental Information (https://www.ncdc.noaa.gov/cag/).

In order to better capture the variance in temperature and precipitation anomalies for the 2015 water year, monthly anomalies are provided in Table 1 below and a scatterplot (Figure A-1) showing anomalies for each quarter of the 2015 water year, rather than halves, can be found in Appendix A. As shown in Table 1, January, February, March and June were the most unusually warm months for Oregon in 2015. Oregon's statewide average temperature for the entire water year was 50.8°F (4.2°F warmer than the historic average), which was a significant increase compared to that of the average national temperature (1.6°F warmer than the historic average for the contiguous U.S.). There was also great variance in the relative precipitation throughout the 2015 water year. While October, December, and July were much wetter than the historic monthly averages, January and June were extremely dry. Average precipitation was at least 62% or higher for the other seven months of the water year. Oregon's statewide average precipitation was only 42% of its historic average in January, a critical month for snowpack accumulation, compared to the nationwide precipitation, which was 80% of its historic average ("Climate at a Glance," n.d.). In addition, showers and thunderstorms provided relief from very dry summer conditions, especially for south-central and southeast Oregon and, in August and early September, to the northwest ("Drought Information Statement, Sep," 2015a). January and June were especially harsh months as they had both particularly warm and dry conditions.

Monthly Temperature and Precipitation Anomalies in Oregon						
	Temperature Averages (°F)			Precipitation Averages (inches)		
	Historic	2015 WY	Anomaly	Historic	2015 WY	Anomaly (% avg.)
October	54.3	60.5	**6.2**	2.4	3.5	**143.4**
November	35.9	34.1	-1.8	4.6	4.1	91.0
December	31.9	32.4	0.5	4.9	6.2	**125.9**
January	30.7	38.1	**7.4**	4.6	2.0	**42.7**
February	34.3	41.7	**7.4**	3.7	3.6	96.8
March	38.5	45.7	**7.2**	3.5	2.6	74.4
April	44.7	45.6	0.9	2.4	1.6	63.8
May	50.6	53.5	2.9	2.1	2.2	101.9
June	57.3	65.6	**8.3**	1.5	0.4	**28.3**
July	65	67.5	2.5	0.5	0.8	**155.1**
August	67	69.9	2.9	0.6	0.4	62.3
September	57.4	58.2	0.8	1.2	0.8	68.6
Annual	**46.6**	**50.7**	**4.1**	**32.08**	**28.12**	**87.7**

Table 1. This table shows which months were above, near, or below the historic average for temperature and precipitation during the 2015 water year. The cells highlighted in orange show for which months both the temperature was abnormally high and precipitation was abnormally low. Data are from NOAA's National Centers for Environmental Information (https://www.ncdc.noaa.gov/cag/).

Certain areas of Oregon experienced drought earlier than others and to more extreme degrees. For example, as shown in Figure 2, southeastern Oregon was the first to experience drought in 2015 and remained in severe drought conditions for the majority of the water year.

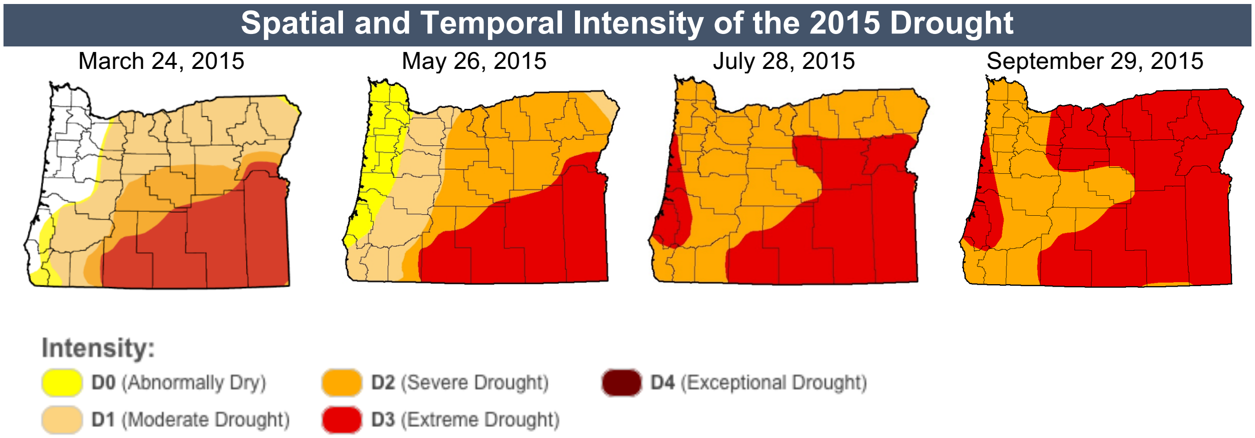

Figure 2. Drought conditions were experienced across Oregon at different times of the year and to varying degrees. Dates for the above were selected based on available maps, with similar dates in the months that best showed variation across time. *Source (Maps and Legend):* U.S. Drought Monitor

Snowpack

Oregon experienced a historically low seasonal snowpack in the winter of 2015, as shown in Figures 3 and 4. Most winter storms did not produce mountain snow because the precipitation fell irregularly, with extended dry periods broken up by several days of heavier rain ("Drought Information Statement, Sep," 2015a). Some mountain areas in western Oregon had snow on the ground for only a few weeks. Throughout the state, 60% of the snow measurement sites measured the lowest snowpack on record or were measured as snow-free for the first time on record during the middle of winter. In western Oregon, the snowpack peaked 60-90% below normal, while the snowpack in the eastern part of the state peaked 30-80% below normal. The snow melted significantly earlier than normal in all regions of the state. In a normal year, mountains accumulate several feet of stored water until March or April, and then slowly melt away the snowpack, providing a continuous source of water to streams and reservoirs during the dry summer season. ("Basin Outlook Report, April," 2015) However, in 2015, the flow in most rivers was already approaching their summer baseflow levels (i.e., dry weather flow levels) by April and May ("Drought Information Statement, Sep," 2015a).

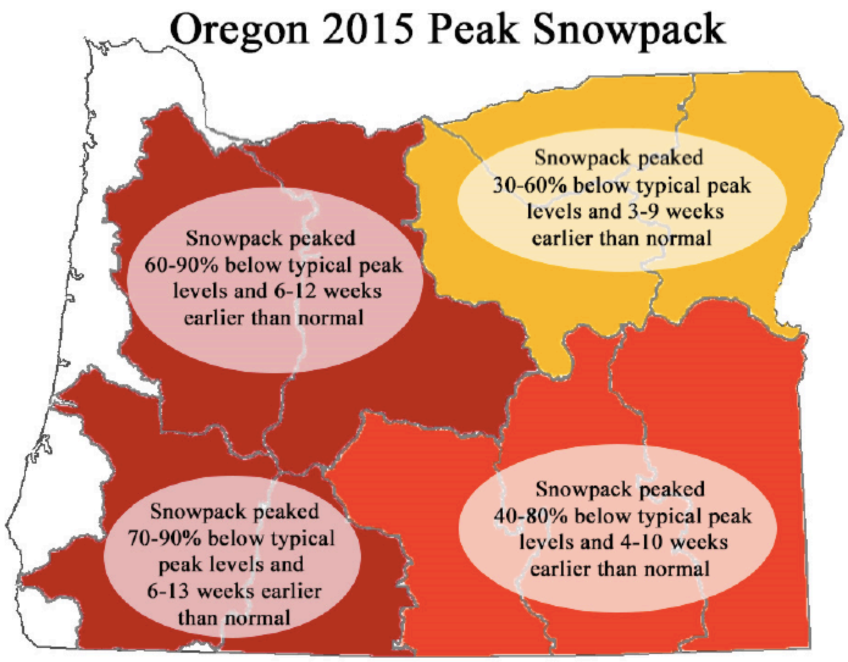

Figure 3. Throughout Oregon, 60% of the snow measurement sites measured the lowest snowpack on record or were snow-free for the first time during the middle of winter. Source: NRCS Oregon Basin Outlook Report: May 1, 2015 ("Basin Outlook Report, May," 2015)

Snow Water Equivalent (SWE) is a common snowpack measurement, which represents the amount of water contained within the snowpack. In other words, SWE is the depth of water that could result if the entire snowpack melted instantaneously. The April 1 measurement of SWE is often referenced when discussing snowpack levels for a particular water year. The first plot in Figure 4 shows the statewide April 1 SWE average since1938, with a declining trendline. Based on these data, the second plot in Figure 4 ranks the ten lowest SWE years in Oregon, with 2015 ranking as the lowest SWE year on record. Almost all of the other years of significant drought discussed above also ranked as one of the ten lowest SWE years, including 1977, 1992, 2001, and 2005. The other three years of significant drought discussed were 1934, 1994, and 2002. There is not sufficient SWE data for 1934, and of the 77 years included in the data, 1994 and 2002 ranked as the 57th and 65th lowest SWE year, respectively. However, as previously explained, abnormally warm and dry conditions in the second half of the 1994 and 2002 water years ultimately led to drought conditions in those years (see Figure 1).

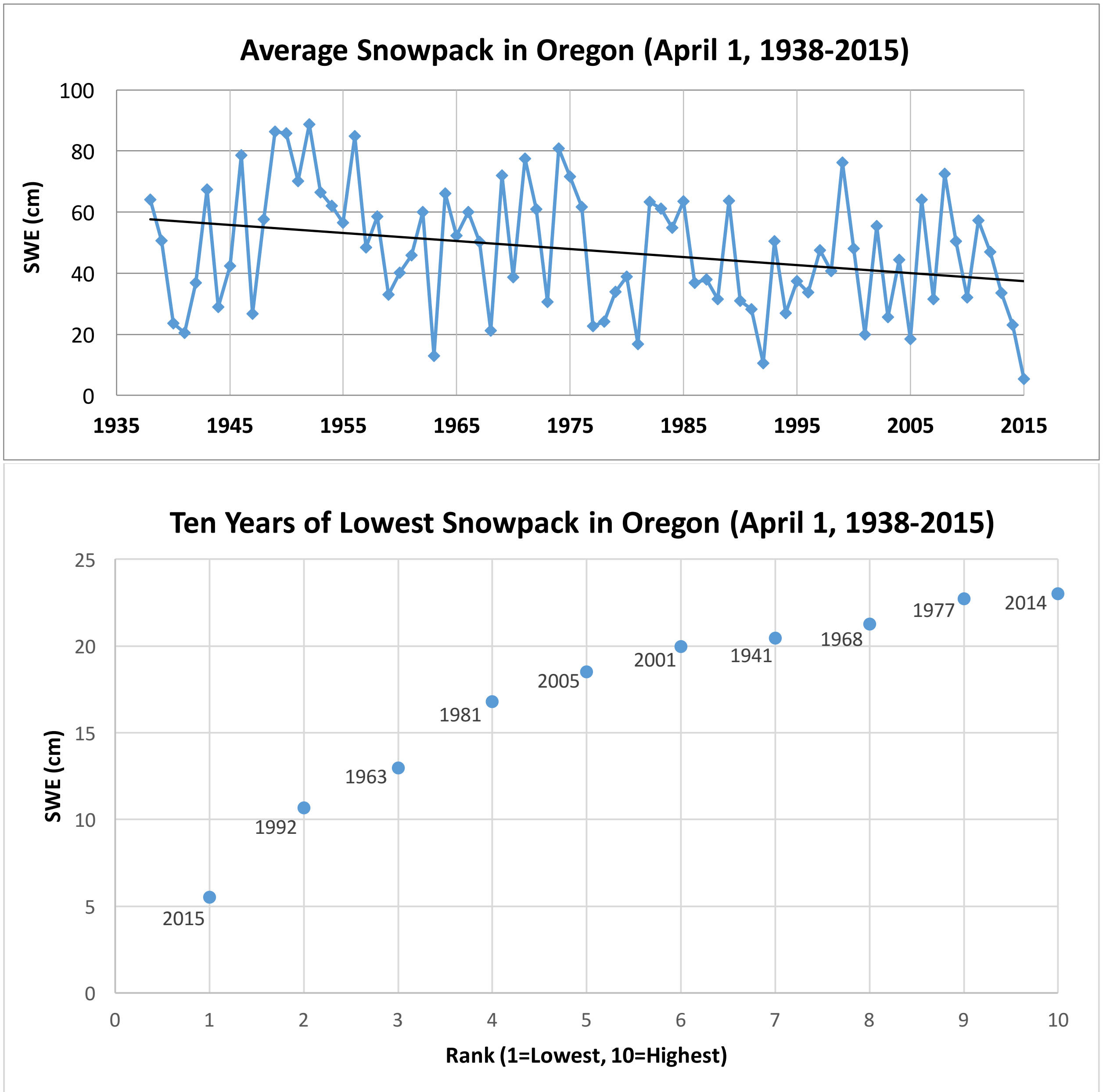

Figure 4. The first plot provides the statewide average SWE as of April 1 for each year since 1938 and shows a declining trendline. Based on this data, the second plot ranks the ten lowest April 1 SWE years in Oregon, with 2015 ranking as the lowest SWE year on record. Data reflect the average SWE measurement taken from NRCS snow course measurements and SNOTEL sites (with a range of 33 to 59 total sites for each year). These raw data were provided by Dr. Philip Mote (Oregon Climate Change Research Institute).

Streamflow and Reservoir Levels

As explained above, below- average snowpack in 2015 provided less continuous spring runoff, which affected streamflow and reservoir levels. Typically, melting snow would lead to a significant increase in Oregon streamflow in May and June. During those months in 2015, however, streamflow was well below average, especially for western and coastal Oregon rivers (see Figure 5) ("Drought Information Statement, Jul," 2015). Looking at a longer time range, from April through September of 2015, water supply volumes were approximately 20-60% of average in locations across the state and only 10-20% of average in some eastern Oregon basins. For many rivers, such as the Siletz, Clackamas, Donner und Blitzen Rivers (see Figure 6d for Donner und Blitzen), these 2015 volumes were at or near their record low.

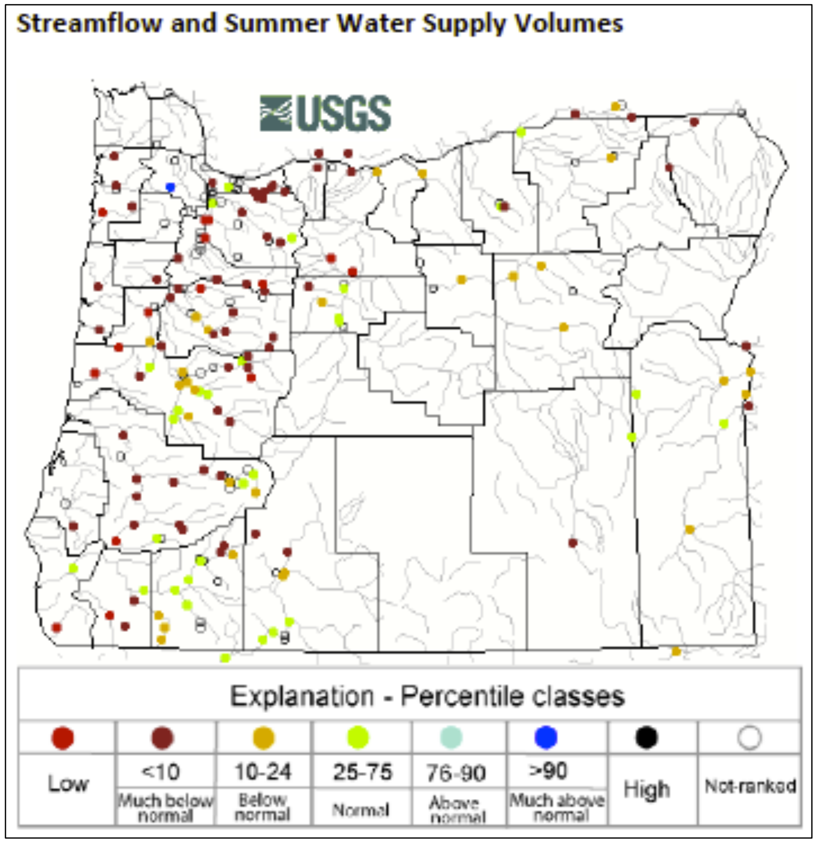

Figure 5. Monthly streamflow for June 2015 compared to historic averages. *Source: "Drought Information Statement, July 17, 2015," National Weather Service*

Fortunately, the summer showers and thunderstorms previously mentioned led to gradual increases in streamflow, which improved conditions in many eastern Oregon streams to what was still a low but raised flow of 50-80% of average ("Drought Information Statement, Sep," 2015a).

For reservoirs in Oregon, *total* storage by September of 2015 was at approximately 25% capacity, compared to the historic average of nearly 50% capacity. In addition, "several reservoirs in south-central and southeast Oregon [had] little or no remaining storage." For instance, reservoir storage for the Warm Springs Reservoir and Owyhee Reservoir were at 0% and 1% capacity, respectively, and was generally 10% to 50% of average in other areas. What storage remained "needed to be managed for recreation and a variety of downstream needs, including irrigation, instream fisheries habitat, and hydro-electric power." ("Drought Information Statement, Sep," 2015a)

It is important to note that other factors besides drought conditions influence streamflows and reservoir levels, both temporally and spatially, such as irrigation and municipal withdrawals, dam and hydropower management, and environmental flow targets set by biological opinions. Furthermore, when comparing flows and reservoir levels to previous years, it is important to recognize that changes in the surrounding human and natural systems may have occurred such that the data are not completely comparable. For example, there may have been changes in neighboring forest composition and structure, flow regimes, human population size and geographic extent, consumption patterns, land use, and policy.

With this said, value can be attained by comparing streamflows and reservoir levels across time. Figures 6a-6d below show the monthly average discharge of streams in four different Oregon regions (north coast, north central, northeast, and southeast) during the 2015 water year compared to the historic average. These general regions were selected to help capture the geographic diversity of the state. The data were collected from USGS stream gauges based on the following criteria: 1) there were at least 45 contiguous years of data available, 2) there is minimal human regulation or diversion of the flow measured upstream from the gauge station, and 3) when contacted, NRCS staff recommended the stream gauge as among the most appropriate for capturing what is as close to the natural flow of a river as possible. The figures below help show the variance in how streamflow was affected in different regions across the state and visually reflect the precipitation and snowpack conditions described above (e.g., low snowmelt to feed flows throughout the spring and beyond). See Appendix A for three other comparative hydrographs for rivers in the south coast, central Cascades, and south central regions (Figures A-2 through A-4).

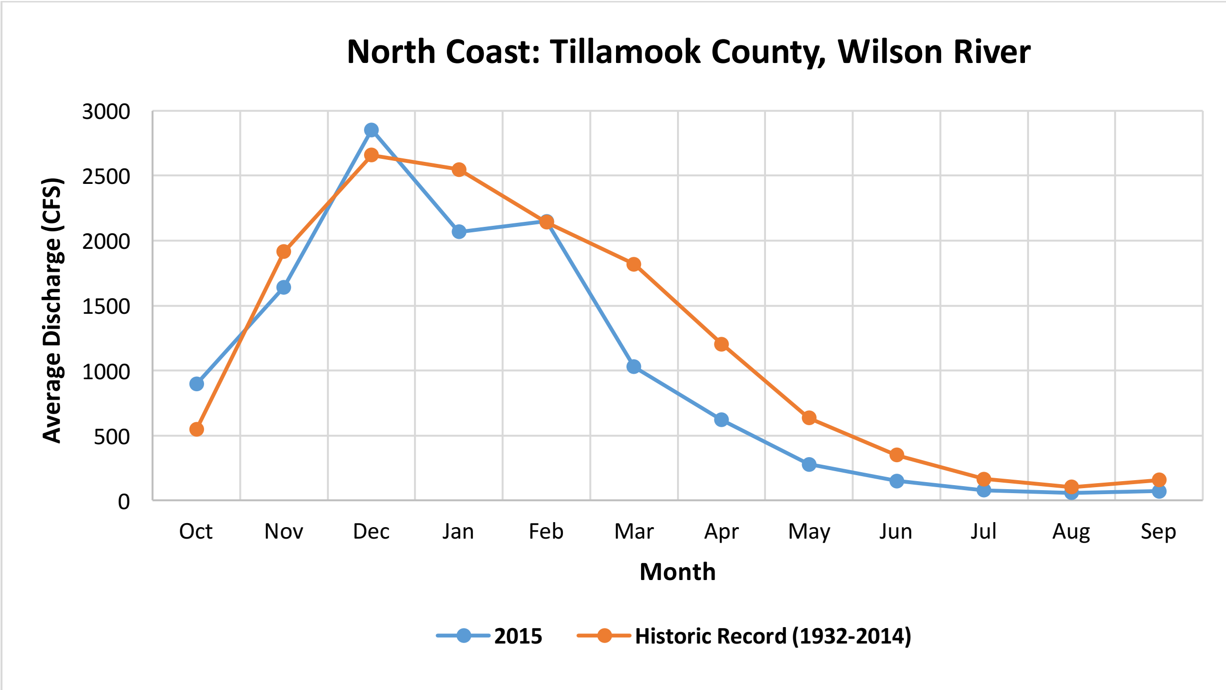

Figure 6a. The monthly average discharge at a station along Wilson River during the 2015 water year compared to the historic average. Discharge peaked in December as usual, however discharge was approximately half of the historic average from March through June There are no flow regulations upstream from this gauge, although there are small upstream diversions. (USGS Site Number: 14301500).

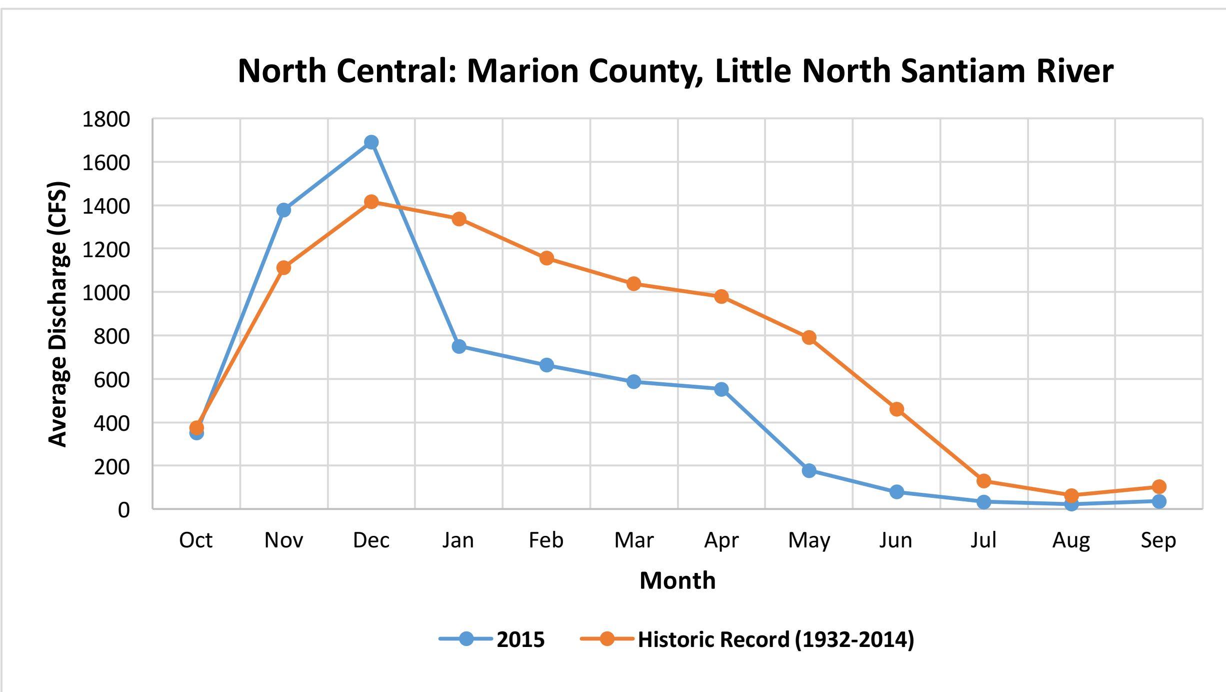

Figure 6b. The monthly average discharge at a station along Little North Santiam River during the 2015 water year compared to the historic average. Discharge peaked in December as usual, however discharge was approximately half of the historic average from January through September, with especially low flow in May. There are no flow regulations or diversions upstream from this gauge. (USGS Site Number: 14182500)

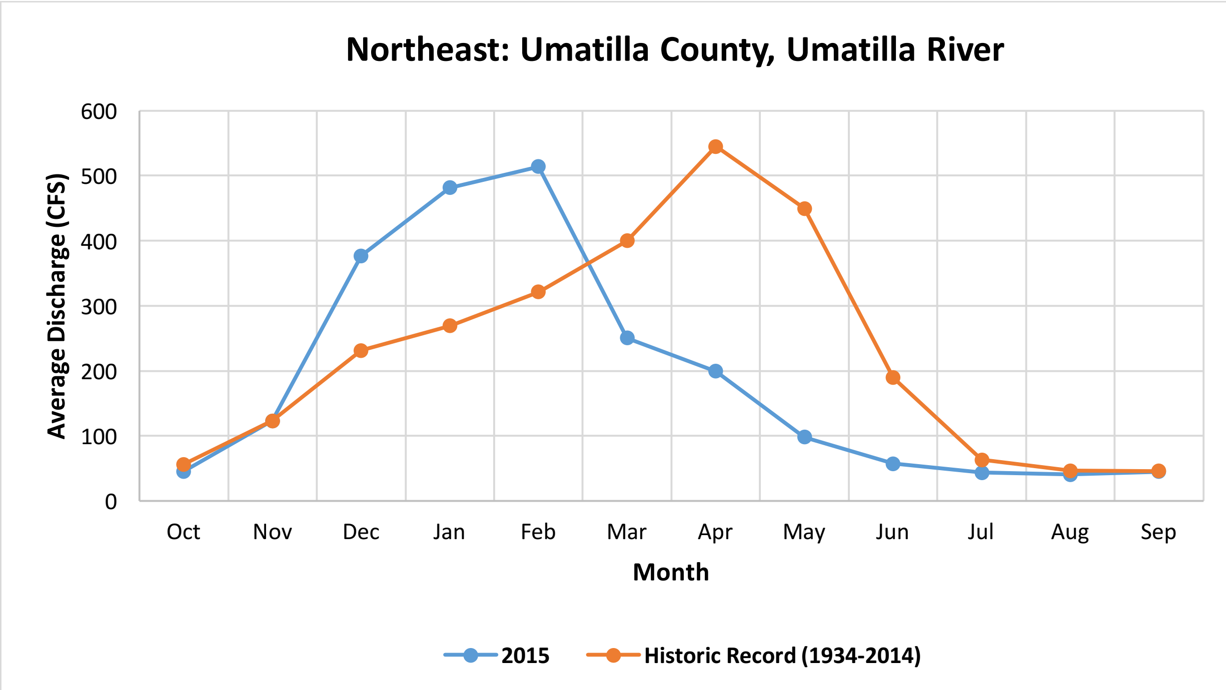

Figure 6c. The monthly average discharge at a station along Umatilla River during the 2015 water year compared to the historic average. Discharge peaked in February rather than April, and flows approximately half of the historic average, or less, from March through June. There are no flow regulations or diversions upstream from this gauge. (USGS Site Number: 14020000)

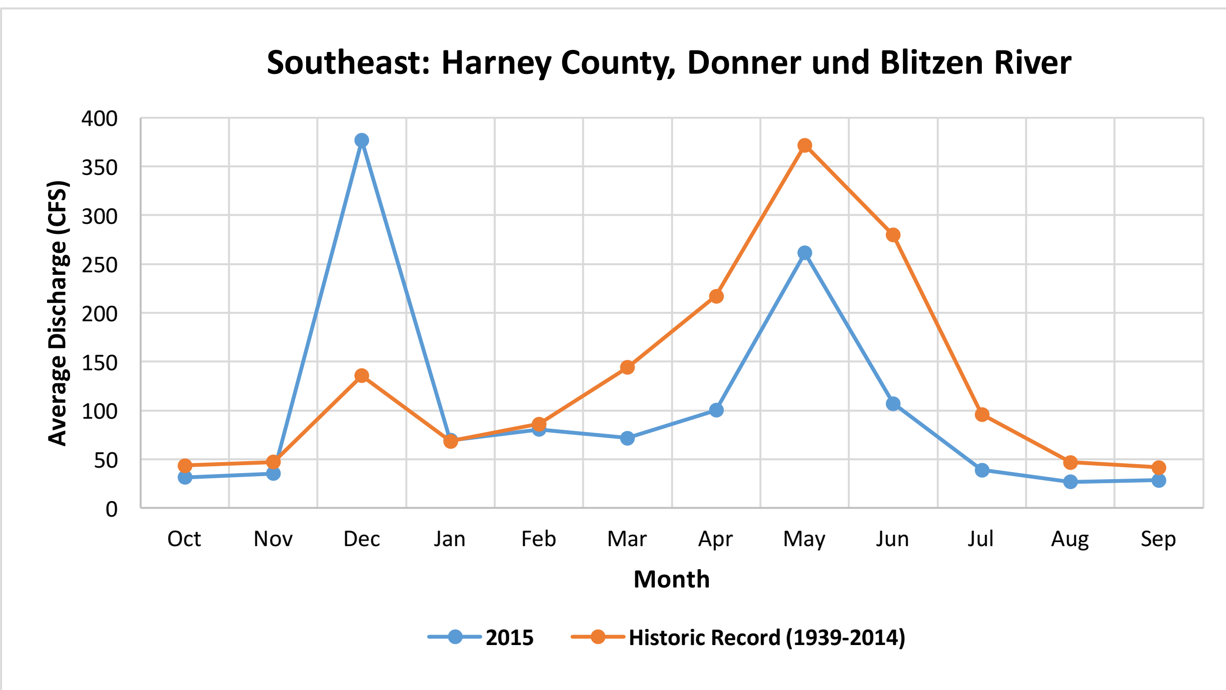

Figure 6d. The monthly average discharge at a station along Donner und Blitzen River during the 2015 water year compared to the historic average. Discharge peaked in December as usual, however at approximately 2.5 times the historic average discharge. The shape of the 2015 hydrograph mostly follows that of the historic average for the remained of the year, however at consistently lower flow. There are no flow regulations or diversions upstream from this gauge. (USGS Site Number: 10396000)

V. Impacts and Response Strategies

The 2015 drought affected Oregon statewide, with impacts varying over time and across regions, sectors, and local economies. This section provides an overview and examples of how the drought impacted agriculture and ranching; municipalities; recreation; and fish and wildlife. This section also discusses response strategies that have been implemented within each sector to alleviate the impacts of drought in Oregon. It is important to note that it is often difficult or impossible to attribute certain drought impacts solely to drought. A rancher's loss of livestock, for instance, could be due to a combination of factors, including dry conditions and unrelated health issues. Another important point is that some impacts were not a result of 2015 conditions specifically; rather, they were the cumulative result of multiple years of drought. For example, 2015 was the third consecutive drought year for some parts of Oregon, including areas in southeastern Oregon, which did not allow some reservoirs to refill. Furthermore, it may be too soon to observe some of the long-term impacts of the drought. Low streamflow and reservoir levels in 2016 or beyond could partially be due to the 2015 drought, for instance. The content below is a summary of readily available information from existing datasets, agency reports, and media coverage, as well as from interviews with water providers and water users.

Agriculture and Ranching

Due to the numerous inputs, outputs, management decisions, and external factors that influence farming and ranching – such as landscape, crop type, and water source – drought has different impacts not only across Oregon counties but also among neighboring irrigators. For these reasons, the specific impacts of the 2015 drought on irrigators should not be generalized on a spatial scale.

Drought Impacts

There are a range of impacts that irrigators can encounter during times of drought, such as:

- Limited water supply, which can shorten irrigation seasons and reduce yields.
- Changes in the timing of water supply (e.g., rainfall, snowmelt), which can affect and cause uncertainty around when crops can be planted.
- Declines in soil moisture, which can cause soil erosion, or the removal of topsoil; degraded soil quality, such as in soil structure and texture; loss of fertile land; and degraded air quality due to an increase in airborne dust.
- Increased plant stress, which can affect crop quality (e.g., coloring, taste, size) and reduce yields, including reduced feed for livestock.
- Increased animal stress, which can lead to loss of livestock and reduced conception and weaning rates.
- Increased fire risk, which can lead to the loss of livestock, feed, and structures, such as animal cover and fences. ("Drought Assistance," n.d.)

These impacts were experienced across Oregon during the 2015 drought. For example, depending on the region, a limited water supply and high temperatures led to increased stress for several types of crops, such as perennial grasses, potatoes, berry crops, varieties of cherries, and dry-farm grapes. Other crops did well in the heat, including onions and, in some regions, hay. While fruit crops struggled and were damaged by sun-scalding in Linn and Benton counties, they generally did well along the coast. In addition, dry conditions progressed the growing season for many crops by anywhere from two to six weeks compared to recent years. Different regions experienced season progression for crops, meaning plants grew and matured earlier in the season than usual, including crops of strawberries and most other berries; cherries; wheat and barley; apples and pears; and grass seed. Often times these crops needed to be harvested quickly in order to avoid damage from the heat or lack of water. In some areas, there were reports that the continued heat caused high evapotranspiration stress in crops and topsoil moisture was extremely dry, raising concerns about soil quality for the fall planting season. ("Oregon Crop Progress and Condition," n.d.)

Response Strategies

In response to water shortages in 2015, many irrigators planted fewer crops and left land idle, enabling them to use more of their water allotments on other plots. It has been estimated that 20% of farm acreage in Treasure Valley, which is located across the border between Oregon and Idaho, were taken out of production in the 2015 season. Some farmers switched to different crops, possibly planting higher value crops, such as onions and beets, or moved to lower value crops that require less irrigation, such as grain and seed crops. These management decisions are heavily dependent on both expected water supply and market prices. (Stevenson, 2015) In addition, crops need to be ready for harvest by the time a farmer has used his/her full water allocation, which can be more challenging during a shorter irrigation season. To help address issues of timing, some farmers choose to plant early-maturing varieties and hybrids of plants, such as wheat and corn. As for livestock, heat-stressed cattle were fed supplemental rations to help provide necessary nutrients. It was reported that ranchers in the northeast region shipped cattle to feedlots earlier than normal due to a lack of feed and water, or weaned cattle early due to dry conditions and lack of pasture. ("Oregon Crop Progress and Condition," n.d.)

Eligible irrigators can apply to grant, shared-cost, and emergency loan programs to help with expenses associated with water conservation practices, supplementing water shortages, fire damages, and crop or livestock loss. Soil and water conservation districts, the NRCS, Farm Service Agency (FSA), and other organizations have such financial assistance programs. For example, the Agricultural Act of 2014 (2014 Farm Bill) makes FSA's Livestock Forage Disaster Program (LFP) a permanent program, which provides compensation to eligible livestock producers that have suffered grazing losses for covered livestock due to a qualifying drought condition. The LFP also provides compensation in particular instances of grazing losses due to fire. ("LFP Fact Sheet," 2015) In 2015, irrigators from 21 out of Oregon's 36 counties received aid through the LFP, with the most aid going to Malheur and Harney Counties at over $21 million and nearly $12 million, respectively ("FSA 2015 Disaster Payments," 2016).

Water suppliers also had a variety of responses to the drought, some of which were running low on water for delivery in late summer. In some areas, water regulators shut off irrigation for junior water right holders weeks ahead of normal, conserving water for those with more senior water rights. Also, irrigators in the Northwest corner of Oregon were shut off, such as users of Rickreall Creek and Luckiamute River, which is unusual. In several areas, water calls applied to those with earlier priority dates than is typical. For instance, irrigators with a water priority date from 1876 or later were shut off, and Fifteenmile Creek in Hood River County was regulated back to 1861. (Perkowski, 2015) In addition, growers were allocated much less water than normal. Strict water rights requirements like these prevented some small farming operations from planting their scheduled annual crops ("Oregon Crop Progress and Condition," n.d.).

There are successful examples of drought response strategies implemented in Treasure Valley, where the Owyhee and Vale Irrigation Districts have made efforts to conserve and extend summer water supply. The valley has seen a short snowpack season and reduced runoff in recent years, and for the first time in history, farmers in the Owyhee Irrigation District were allocated one-third of their full irrigation allotment for three consecutive years (2012-2015). The Owyhee Irrigation District has invested in automating delivery devices such that the headgates along their supply system no longer need to be manually opened and closed. This automated system constantly monitors and adjusts the flow of water to meet the operating targets of that particular day, and it has been estimated that these efficiencies have extended the irrigation season by two to three weeks.

As another example, Vale Irrigation District has replaced open-ditch canal systems with gravity-fed, pressurized water via buried pipes. This closed system reduces water loss and rids the need for farmers to pressurize their water electronically, thereby saving energy for the grower. (Oregon Sea Grant, 2016b) Using a similar system, Three Sisters Irrigation District estimates that farmers received 20-40% of their expected water in 2015. In contrast, farmers received only 10% of expected water in 1977, when the area experienced similar drought conditions to 2015. In addition, farmers saved $200,000 on energy bills due to pressurized water delivery. ("1977 and 2015 Drought Comparison," n.d.)

Municipal

The ways in which drought impacts a municipality depend on a variety of factors, such as the municipality's water source (e.g., rainwater, snowmelt, groundwater), local weather events and climate, the number and type of customers (e.g., domestic, industrial), and availability of supplemental storage.

Drought Impacts

With precipitation affecting the availability of a municipality's water supply, precipitation and temperature conditions can impact water demand. In times of low rainfall and warm temperatures, people often increase their water use, especially outdoors. For example, with the exception of September and November, monthly temperatures in Portland ranged from 0.50°F to 6.7°F above average in 2015, and demand for water during the hot months of June and July far exceeded that of the previous five years (see Figure 7) ("2015 Summer Water Supply Season," 2016). In addition to Portland, many other Oregon cities, including Salem, Eugene, Medford, and Klamath Falls, experienced their hottest summer on record in 2015 ("Drought Information Statement, Sep," 2015b).

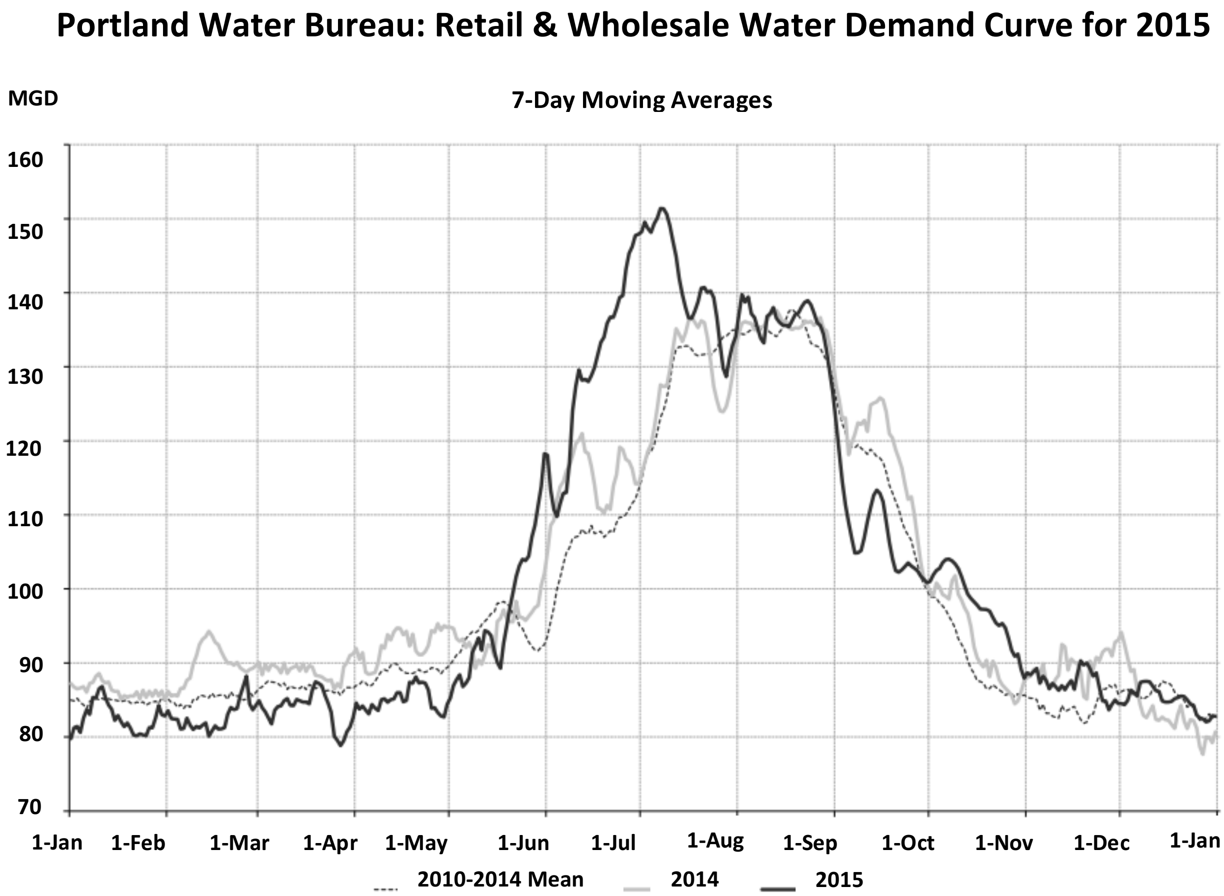

Figure 7. The water demand curve for 2015 and the preceding five-year period, based on 7-day moving averages, in Portland. Note: demand numbers are reflective of the total amount of water supplied to serve Portland retail and wholesale customers (e.g., other cities, water districts, and private water companies), not the total amount of metered and billed water. *Source:* "2015 Summer Water Supply Season," Portland Water Bureau, 2016

Response Strategies

Several of Oregon's municipalities across the state imposed some form of water conservation in 2015, be it by requesting voluntary cutbacks from customers or mandating enforceable restrictions. Some cities have adopted curtailment plans, such as Banks, Bend, and Lafayette, through which there are typically multiple stages of curtailment, with triggers and conservation actions for each. In Oregon, the majority of enforced curtailment regulations are for commercial, manufacturing, and outdoor uses, with mandatory restrictions on residential customers as a last resort. For example, the City of Banks issued water use restrictions in the late summer of 2015, requiring its major commercial water customers to reduce their water use by 50-60% for two weeks at the end of the summer. (Pilorget, 2015) Examples of voluntary actions requested from residential users to help stretch limited water supply include: installing a rain sensor to regulate automatic sprinkler systems; cleaning outdoor spaces with a broom rather than a hose; reusing water for outdoor purposes; and installing water efficient appliances. Some cities, like the City of Ashland, provide financial rebates for residents who replace their toilets, dishwashers, and washing machines with more efficient ones. ("Water Conservation Programs," n.d.)

In addition to conservation, municipalities across Oregon turned to supplemental water sources to meet demand during the 2015 drought. For example, in response to reservoir drawdown levels, increased summer demand, and long-range weather forecasts, the Portland Water Bureau used additional groundwater to augment the Bull Run supply in July, August, and September. Groundwater use varied during this period, starting at approximately 25% and increasing to approximately 70% of supply. ("2015 Summer Water Supply Season," 2016) However, not every city has sufficient supplemental water supply available. The City of Sodaville, for instance, provides its 325 residents with drinking water from five groundwater wells, which – in part due to mechanical difficulties – have struggled in recent years to produce enough water for the city's consumption needs. In 2015, well production began to slow in July as a result of the drought and dropping aquifer water levels in the area. Despite resting the pumps for longer periods and allowing the water levels in the wells to recover, production was low enough by August that levels in the City's 150,000-gallon reservoir tank began to drop, and the City adopted water use restrictions. To meet demand and maintain pressure levels, Sodaville began purchasing and trucking in water from the neighboring town of Lebanon. In response to its water challenges, the City applied for and was awarded a USDA Rural Development grant of approximately $130,000 through the Emergency Community Water Assistance Grant Program. With these funds, Sodaville will make improvements to all five of its wells and will install a dedicated water level sounding tube to help monitor water availability. Overall, this project will increase production and enable the city to meet its residents' needs in future years. ("USDA Grant," 2016)

Recreation

Oregon is known for its variety of recreational opportunities, such as skiing, fishing, boating, river rafting, hunting, hiking, and camping. The 2015 drought affected these and other activities enjoyed by Oregonians and visitors. Due to increased stress on wildlife from severely dry conditions or wildfires, public access was closed to many hunting areas, trails, and roads, which reduced available recreational area and led to more crowds in areas that remained open. For instance, with watering holes fewer and farther between, there was greater competition among wildlife for water sources and therefore among hunters for placement of hunting blinds. Hunters were encouraged to avoid deterring animals from accessing water by camping out of sight and sound of important watering sources. There were numerous impacts like these on a range of recreationists. The sections below provide more detail on the effects of and responses to drought in three of the main water-dependent recreation sectors in Oregon: skiing, boating, and angling (Dalton et al., 2013). These popular activities were impacted by dry conditions, reduced snowpack, lower summer flows, and reduced reservoir storage. Angling was also impacted by reduced water quality.

Snowfall and Ski Industry

With abnormally warm conditions during the winter of 2014-2015, Oregon received historically low levels of what the ski industry relies on most—snowfall. If a ski resort receives low snowfall, it may need to open or close early, or suspend operations until conditions improve. Fewer operation days can increase costs to skiers and decrease revenue for ski resorts and the surrounding economy. In the 2014-2015 season, Mt. Bachelor saw its lowest seasonal snowfall in the last 10 years and, with 167 operation days, had its shortest season since 2008-2009. Its shortest season on record (1973-2015) was in 1976-1977, with 108 days of operation. (Darling, 2015)

Resorts at lower elevations experience relatively mild temperatures, making them more sensitive to slight warming that can cause decreased snow, increased rain, and earlier spring snowmelt. (Dalton et al., 2013) During the 2014-2015 season, smaller ski resorts suspended operations, including Hoodoo Ski Area and Willamette Pass, which are located at lower elevations, and Mt. Ashland, which is located in southern Oregon and a warmer climate. After poor ski conditions prevented Mt. Ashland from opening during the 2013-2014 season, the business responded to sparse snowfall the following year by relocating and concentrating snow from some places on the mountain to others. Doing so allowed Mt. Ashland to remain open for 38 days. To supplement ski-season income and reduce its dependency on snowfall, the business will increase existing summer services, such as hosting weddings, and will venture into offering new summer recreation activities, including ziplining, a bungee trampoline, disc golf, and concerts. (Oregon Sea Grant, 2016a)

Reservoir Levels and Boating

Lakes and reservoirs are popular destinations for numerous recreation activities that depend on sufficient water levels. As previously discussed, by September of 2015, Oregon's *total* reservoir storage was at approximately 25% capacity, compared to the historic average of nearly 50% capacity, (NRCS, n.d.) and "several reservoirs in south-central and southeast Oregon [had] little or no remaining storage" ("Drought Information Statement, Sep," 2015a). The remaining storage "needed to be managed for recreation and a variety of downstream needs, including irrigation, instream fisheries habitat, and hydro-electric power" ("Drought Information Statement, Sep," 2015a). For recreation, one issue with low water levels is that there is an increased risk of boaters, paddlers, and swimmers encountering stumps and dry banks. Because of these obstacles, the Oregon Marine Board reminded recreationists to wear life jackets and be cautious about potentially hidden objects just below the water surface. (Richard, 2015b)

In several reservoirs, water levels dropped below the end of boat ramps, making it difficult or impossible to back trailers up close enough to the water to launch boats (Burns, Schick, & Bernert, 2015). For example, in May of 2015, eight of the nine boat ramps at Detroit Lake were unusable due to low water levels. The only usable ramp was concrete and had been specially built by state parks and the Oregon Marine Board for low water levels during winter or periods of drought. (Richard, 2015a) Other examples of reservoirs that lacked boat access were Blue River and Cougar in the Willamette Valley and Prineville in central Oregon. Poor conditions can hinder recreational opportunities and lead to a reduced number of visitors, which can hurt the local economy. Jackson County, for instance, was unable to rent out boats at Howard Prairie Lake due to low water levels, which equates to a $50,000 loss in revenue. (Burns et al., 2015) Despite the inability to launch motorized boats in some reservoirs, many were still accessible by watercrafts that could be manually launched from the beach, including kayaks, canoes, paddle boards, and small portable motorized boats (Richard, 2015a).

Freshwater and Angling

Drought can cause a number of environmental conditions that affect fish, such as reduced lake and reservoir pools, low stream flows, and elevated water temperatures. These changes in habitat can increase stress on fish and make them more susceptible to disease outbreaks. In 2015, half of Oregon's hatcheries were impacted by drought conditions. Despite best management practices, several hundred thousand fish were lost due to diseases, and several million juveniles were under increased stress. Coastal hatcheries were predominantly impacted, with Rock Creek Hatchery being the most severely affected. ("Memo to Governor," 2015) Shallow and warm waters from the North Umpqua River fed Rock Creek, which led to disease and the loss of nearly all of the hatchery's summer steelhead (House, 2015b). Another example of an impacted system is the lower Willamette, where two different daily ODFW surveys found 175 fish carcasses, including Chinook salmon and steelhead. Over the past decade, the previously highest survey count of fish carcasses on a single day was only around 15 fish. ("Memo to Governor," 2015)

In order to help avoid mortality of hatchery fish and assure the greatest survival and accessibility of those fish to fisheries, ODFW adjusted the timing and location of hatchery fish stocking. According to an ODFW drought briefing memorandum to the governor, "over 30% of coastal hatchery production was released early or transferred to a new hatchery due to drought," and "several scheduled rainbow trout releases were cancelled and numerous release groups were reallocated to other sites." ("Memo to Governor," 2015) Even when stocking is possible, managers might need to adjust the type and number of fish they add to a fishery with declined water levels. The actual process of releasing fish becomes more difficult during drought, as well, because fish need to be transported further when water levels are low (e.g., through additional piping). (Burns et al., 2015)

Although early fish releases and transfers prevented severe losses in 2015, drought conditions can increase the stress of hatchery fish and negatively affect post-release survival. To help relieve stress that native fish species were facing from record high water temperatures, "fisheries managers closed fishing for trout, salmon, steelhead, and sturgeon in the lower Willamette River below the Willamette Falls and in the lower portion of the Clackamas River." ("Memo to Governor," 2015) While these types of restrictions help reduce the stress of angling on fish, there can be associates costs, such as lost fisheries opportunities, reduced angling participation, and economic loss for local communities. However, numerous waterbodies, especially streams that were less prone to high water temperatures (e.g., tidal, spring-fed, high elevation streams and ones that received cold water releases from dams), remained open. Some of these streams included the McKenzie River, Hood River, Malheur River, and Deschutes River. ("Memo to Governor," 2015)

Throughout the season, ODFW provided information about risks, voluntary actions, management changes, and impacts related to the drought in order to "educate the public, reduce impacts on native fish, and improve the effectiveness of management actions" ("Memo to Governor," 2015). Outreach was conducted through "numerous news releases, advisories, and information to the media, other entities, and the public" ("Memo to Governor," 2015). For example, anglers were encouraged to follow the usual precautions when catch-and-release fishing in warm weather, such as fishing early in the day when water temperatures are cooler and to stop fishing when temperatures reach 70°F ("ODFW takes action," 2015).

Fish and Wildlife

During periods of drought, high heat and limited water supply can increase stress on plants and animals, hindering growth and overall health, as well as promote fire, insect, and disease outbreaks. As discussed below, wildlife across Oregon experienced these impacts during the 2015 drought.

Drought Impacts

Drought can cause a number of environmental conditions that affect fish and fish habitat, such as:

- reduced lake and reservoir pools;
- low streamflows;
- elevated water temperatures;
- depleted oxygen levels;
- blue-green algae blooms; and
- wildfire. ("Memo to Governor," 2015)

Some of the negative effects these conditions have on wild and hatchery fish of all life stages include: stress; disease; pre-spawning mortality; inaccessible habitat; lack of forage; and excessive vulnerability to angling, predation, and poaching/snagging. In addition, the habitat range for invasive species can expand if they can better tolerate drought conditions (e.g., warmer water) than native species. There were several significant fish kills in 2015, including in the Willamette, Clackamas, John Day, and Deschutes Rivers and some ODFW hatcheries, where high water temperatures amplified the effects of a naturally occurring parasite called *Ichthyophthirius* (Ich) and a bacterial fish disease known as *columnaris*. Mortality caused by drought not only affects those immediate fish, but also may result in lower numbers of fish in future generations. As another example, nearly half (approximately 250,000) of the adult sockeye salmon population that passed through Bonneville Dam died before reaching spawning grounds because of record high water temperatures and low flows. Some of these mortalities included Snake River sockeye salmon, which are listed under the Endangered Species Act. ("Memo to Governor," 2015)

Overall flow and water level declines in streams, ponds, and wetlands occurred earlier than normal in 2015. In some areas, vegetation that the ODFW typically irrigate to sustain wildlife (i.e., wildlife crops) suffered under drought stress, which reduced forage for waterfowl, upland game birds, and big game. ("Memo to Governor," 2015) Also, by June, land managers were experiencing wildfire conditions that do not usually occur until late July or early August (Eastman, 2015). As of mid-October, the Oregon Department of Forestry (ODF) had recorded 1,001 fires (73 more than their 10-year average) and 91,487 burned acres of ODF-protected land (63,948 acres more than the 10-year average) (Ducote, 2015). Several wildlife areas, especially in northeast Oregon, experienced fires ("Memo to Governor," 2015).

In addition, drought affects plants differently depending upon species and location. For example, pines, oaks, and madrones are more resistant to drought than Douglas firs. After facing drought conditions for three consecutive years (2013-2015), there has been significant tree die-off in Southern Oregon. From the Applegate Valley and into the Willamette Valley, forests have experienced tree mortality due to lack of water or insects. Most of the impacted trees are Douglas firs, and, in denser stands, some of the more drought-tolerant trees, such as Ponderosa pines, have struggled with increased competition for water. Weakened by limited water conditions, trees become more vulnerable to harmful pests, such as the flat-headed fir borer and several species of pine bark beetles (Freeman, 2016).

Response Strategies

One example of responding to, and proactively preparing for, drought impacts on wildlife is ecological restoration. In Curry County, for instance, the Oregon State University Extension Service worked with the South Coast Watershed Council to implement two riparian restoration projects. The objective of these projects was to help create optimal habitat for spawning salmon. One of the projects, which dates back to 1995, took place along Pea Creek, where there was a large spike in temperature along the lower part of the creek. When water temperatures increase, salmon will try to spend more time in refugia in cool pools instead of more time feeding, which stunts growth and impacts their health. In order to help reduce temperatures in the warmer section of Pea Creek, wetland species were planted to provide shade. According to water-temperature data recorders that were installed, temperatures dropped by 6°F to 7°F between the upper and lower parts of the creek, and by 2004, temperatures matched almost perfectly. The purpose of the second Curry County project was to help augment reduced water levels in Gallacher Creek. To do so, a new water channel was dug through what had been a nearby grassland pasture, directing more water in to the creek, and trees were planted alongside the channel to help keep the water cool. Based on water table monitors, the water levels have increased in Gallacher Creek and water now flows for three to four additional weeks compared to historic levels. (Oregon Sea Grant, 2016b)

Managing fire to protect wildlands is another example of a drought response strategy. In 2015, 11 state and federal agencies were involved in wildland fire suppression in Oregon, including the National Guard. The Forestry Department estimates that its large-fire costs for this season amounted to $76.7 million, compared to the 10-year average of $22.3 million. About $19.5 million of that was reimbursed by grants from the Federal Emergency Management Agency (FEMA). (Ducote, 2015) After wildfire occurs on state and private lands, restoration and management opportunities include "rangeland seeding for wildlife foraging, weed control, and timber salvage opportunities to provide wildlife habitat enhancement" ("Memo to Governor," 2015).

Topical Gaps: Tribal Matters, Public Health, Hydropower, and Industry

After conducting the initial online search for this report, it was found that there were clear information gaps for the following topical sectors: tribal matters, public health, hydropower, and business/industry. Although hydropower was not explored as a distinct topical sector in this research, it is critical in Oregon's energy consumption and is dependent on water supply. For these reasons and because no information was found on Oregon's 2015 drought and hydropower, it was considered to be an information gap.

To address these topical information gaps, emails were sent and phone calls were made to relevant government agencies and other organizations. Pre-existing, written information was requested to better understand how the 2015 drought impacted their associated sector and/or community, or what response strategies were taken in response to the drought. The following sections summarize the results of this effort.

Tribal Matters

In the initial online search, very little information was found on how the 2015 drought impacted indigenous peoples and the nine federally recognized tribes in Oregon. Two news articles were found that discussed the competing demands for water in the Klamath Basin, one of which from March 27, explained that: "[Groundwater] pumping has increased in the Klamath Basin, where tribes, irrigation project members, private landowners and a national wildlife refuge compete for increasingly limited water" (House, 2015a). In an article from the *The Washington Post*, the chair of the Columbia River Inter-Tribal Fish Commission in Portland, Oregon, N. Kathryn Brigham was quoted as saying, "we're very worried," about the potential salmon die-offs due to drought conditions (Fears, n.d.). Salmon are a significant part of Native American heritage in the Pacific Northwest, both culturally and as a food source (Nasser, Petersen, & Mills, 2015). Although there is documentation of fish die-offs, as previously described, no information was found on how tribes and indigenous peoples in Oregon may have been impacted, in particular.

Similarly, although an article was published on a Warm Springs Radio website about the Warm Springs Tribal Council preparing to declare drought on the reservation, (Macy, 2015) which is not done through the state like it is with counties, (Mucken, 2016) information to confirm whether the declaration was indeed eventually made was not found. If so, it would have been the first drought declaration in the tribes' history and would have enabled the tribes to compete for federal relief funds for managing a water shortage. As explained in the article and outlined in the Confederated Tribes of Warm Springs Reservation Natural Hazard Mitigation Plan (NHMP), "the lack of water affects the tribes' drinking water system," which was temporarily down from two to one functioning drinking water pumps in June, as well as "residential wells in rural areas, fish and wildlife, huckleberries and roots, fire response capabilities, etc." (Macy, 2015). The NHMP briefly (in one to three sentences) explains some hydrologic conditions of droughts previously experienced by the tribes and ranks drought as their fourth highest natural hazard risk, behind riverine floods, winter storms, and wildfire (see UO, CSC, & OPDR, 2016). It is worth noting that although it does not document drought impacts experienced by the tribes thus far, the Confederated Tribes of the Umatilla Indian Reservation has a Climate Change Vulnerability Assessment (see Nasser et al., 2015). The assessment was released in September 2015 and includes some information about projections related to drought and potential impacts.

In search of more information, natural and/or cultural resources departments from the Confederated Tribes of Warm Springs, Confederated Tribes of the Umatilla Indian Reservation, and Confederated Tribes of Siletz Indians of Oregon were contacted. However, no further information was found from these attempts. This was due to a lack of response from some departments and because the contacts that did respond did not have documented information to share about the tribe they represented, nor did they have recommendations for where to find documented information about how tribes may have been impacted.

Public Health

No information was found in the online search about how public health was affected during the drought. Fortunately, after being contacted via e-mail, the Oregon Health Authority's (OHA) Climate and Health Program (CHP) shared a couple of informative documents that were not available online. During the summer of 2015 and prompted by the drought, the CHP "conducted informational interviews with public health leaders representing six local jurisdictions around

Oregon to learn more about potential health risks related to drought" ("Drought and Health," n.d.). The CHP shared its brief, bulleted summary of the interview findings, all of which were based on anecdotal observations because Oregon's Local Health Jurisdictions were not monitoring specific drought indicators. Many of the findings reflect concerns of public health leaders or community members, rather than *known* impacts, and a majority of the impacts noted cannot be fully or even partially attributed to drought with confidence. Below is a list of the most relevant interview findings.

- **Vector-borne diseases-** Mosquito populations can increase during times of drought due to more stagnant water available for their habitat (rather than flowing water). There was an increase in Lyme disease reports in Hood River and Wasco counties. ("Drought and Health," n.d.)

- **Air quality-** People in Klamath County were stressed by the air quality issues and smoke carried by the wind from fires in neighboring counties. ("Drought and Health," n.d.)

- **Recreational waters and harmful algal blooms-** There were large harmful algal blooms, ("Drought and Health," n.d.) which can cause toxins associated with lung irritation to become airborne, on Klamath Lake and many lakes and rivers across the state ("FAQ About Drought and Public Health," n.d.). There were also concerns about possible drownings because of changes in recreational waters ("Drought and Health," n.d.).

- **Mental health** - In Deschutes County, there was concern about future access to water, which can cause psychological stress; it was noted that "the mental health impact is more anecdotal" and could be difficult to monitor ("Drought and Health," n.d.). According to Vins et al. (2015), "the implications of drought for mental health via pathways such as loss of livelihood, diminished social support, and rupture of place bonds have not been extensively studied" (p. 13251).

- **Wildlife encounters**- More wildlife was drawn to water sources near residential areas.

- **Other health issues-** There was an increase in cases of the plague in counties neighboring Klamath County. Also, there was concern around there being more agricultural chemical spraying than normal in response to drought conditions. The importance of understanding safe and appropriate uses for reclaimed and recycled water was also noted. ("Drought and Health," n.d.)

The other document shared by the CHP was written by OHA's Public Health Division Drought Response Work Group. After the 2015 drought, the Work Group updated the language about its roles and responsibilities in drought response. A description of each agency's responsibilities for drought response is included in the "Drought Annex: State of Oregon Emergency Operations Plan" (see OEM and OWRD, 2016). The proposed revisions outline in more detail the following OHA programs' specific roles in drought response: the Drinking Water Protection Program; the Preparedness, Surveillance and Epidemiology Team; the Climate and Health Program; the Domestic Wells Protection Program; and the Healthy Waters Program. The updated language was not approved at the time this document was received (February 13, 2017). The new roles and responsibilities added to the proposed language include:

- "The Preparedness, Surveillance and Epidemiology team and Climate and Health Program:
    - In conjunction with the [Centers for Disease Control and Prevention], may provide analysis of the impact of drought on public health and vulnerable populations.
    - Will work with partners to integrate public health considerations and social vulnerability indicators into drought response planning.
- The Domestic Wells Protection Program and Healthy Waters Programs:
    - May work with partners to inform community members of health risks associated with the use of private wells and recreational waters." ("Update Suggested by OHA Drought Work Group," 2016)

Hydropower

From 2012-2014, nearly 43% of Oregon's electricity generation was produced from hydropower, ("Electricity Mix in Oregon," n.d.) and there are 34 consumer-owned utilities in the state "that rely on [the Bonneville Power Administration's hydropower] for all or the majority of their power" ("Hydropower," n.d.). The Bonneville Power Administration (BPA) is a nonprofit federal power marketing administration. According to its 2015 Annual Report, after recognizing that winter precipitation was falling as rain rather than snow, BPA prepared to implement its dry-year operations in conjunction with its federal and Canadian partners to "stretch the benefits of the system for power production and fish and wildlife protection under conditions of scarce snowpack" (Bonneville Power Administration, 2015). Fortunately, snowpack from the Canadian Rockies recharged the Columbia River, and with 86% of the average total volume of water passing the Dalles Dam in 2015, the federal hydropower system was able to produce more than enough energy for its regional customers. As stated in the Annual Report, "timely measures to manage both resources and costs helped BPA maintain net revenues and meet its financial targets." (Bonneville Power Administration, 2015)

This was the extent of the information found during the initial online search. Thus, a phone call was made to an energy analyst at the Northwest Power Conservation Council, who recommended reviewing BPA's surplus energy sales. It was suggested that even if customers' power needs were met, BPA likely generated less power due to drought conditions such that there was less available to sell. After downloading BPA's Surplus Power Sales Transaction Quarterly reports from the Federal Energy Regulatory Commission's online Report Viewer ("Report Viewer," n.d.) and analyzing the data, it was found that BPA's surplus power sales for the 2015 water year was approximately 52% of that for the 2014 water year (see Table 2).

BPA's Surplus Power Sales, 2014 and 2015		
	2014 WY (USD)	**2015 WY (USD)**
Oct-Dec	84,195,087	55,890,978
Jan-Mar	44,952,166	79,068,696
Apr-Jun	78,281,923	60,726,848
Jul-Sep	156,307,536	50,460,357
Total	**363,736,711**	**190,255,901**

Table 2. BPA's quarterly surplus power sales for the 2014 and 2015 water years. Each of BPA's Surplus Power Sales Transaction Quarterly reports was downloaded from the Federal Energy Regulatory Commission's online Report Viewer. Only the sales for "Energy Transactions" were totaled for each quarter.

Industry

Outside of the information found on the ski and recreation industry that was previously discussed, the online search did not yield any findings on how Oregon's industry (e.g., businesses, commercial fishing, manufacturing, food processing) was impacted by the drought or how industry actors responded to the drought. Phone calls were made and emails were sent to the Oregon Manufacturing Extension Partnership, Portland Development Commission, Northeast Oregon Water Association, and the Northwest Food Processors Association. Due to the lack of responses received and the lack of pre-existing written information, these attempts did not yield any information.

VI. Discussion

The data collection process for developing this summary demonstrated the challenges entailed with identifying the effects of a drought at the state level. There are numerous entities with programs focused on tracking or compiling information about water supply, underscoring that data and knowledge management around drought is disaggregated. Much of this information is not feasibly accessible because it is stored within internal databases and systems. Although there is substantial information on the conditions and projected impacts of a drought, very little information is readily available on the actual effects of drought and the management responses that were implemented. During research for this summary, it was especially difficult to find information on the impacts of the 2015 drought on municipalities, tribal matters, public health, hydropower, industry, and wildlife beyond fish. Most of the information on these matters was found in newspaper articles, which may be less accurate than formal reports or agency press releases. In addition, despite talking with OSU Extension Service staff, no documented information was found about the drought impacts experienced by or response strategies implemented around marine systems. This could be because no significant impacts on marine systems were observed, however it could also be due to a lack of awareness about the type of impacts that should be of concern or monitored.

Documented information about the impacts of the drought on groundwater was also missing, and OWRD hydrogeology staff did not have any pre-existing information to share. This is in part due to the limited groundwater monitoring information available in Oregon. The monitoring efforts that are in place tend to be more concentrated in some parts of the state, with no groundwater monitoring in other areas. Furthermore, even when groundwater data are available, it is difficult to attribute changes in groundwater levels to a particular cause. For example, would observed groundwater declines be due to limited recharge from the lack of precipitation or overpumping? Or, what is the lag time between low precipitation and declining groundwater levels? Although understanding the impacts of drought on groundwater is challenging, it is critical to know whether (and where) there is increased groundwater pumping, perhaps as a response to a shortage of surface water during times of drought. It is especially important to gain a better understanding of how increased pumping may be affecting human and natural systems, especially in vulnerable areas. This issue of limited groundwater monitoring in Oregon has recently become more publicly visible, especially after the publication of a four-part OregonLive news article series, called, "Draining Oregon." One of the articles states:

> *"As drought and economic opportunity prompt growers to look underground for new water to sustain their crops, it's exposing a fatal flaw in Oregon's water management. Across much of the state, the agency charged with rationing Oregon's water supply lacks solid numbers on the natural reservoirs beneath Earth's surface."* (House, 2016)

Conducting research was difficult even on topics for which more data was available, such as impacts on agriculture and ranching. However, there are existing resources that could be improved upon for the purposes of documenting drought impacts and responses. For instance, as previously discussed, the U.S. Drought Monitor summarizes and maps "drought conditions across the U.S and Puerto Rico on a daily basis" (Wood et al., 2015; p. 1641). However, the tool yielded little help in this research process. The drought impact reports found for Oregon in 2015 were scarce, and some included very little information or detail, making it difficult to confidently attribute the reported incidents even partially to drought. Part of the reason the U.S. Drought Monitor was found to be mostly unhelpful in developing this report was because the small amount of information included in the tool had already been found through a general web search (e.g., through Google and the Oregon State University library). In addition, most of the reports were sourced from newspaper articles, and several discussed potential and anticipated impacts of the drought rather than describing impacts that were actually observed.

As another example of an existing tool that could be improved upon, the Oregon Field Office of USDA's National Agricultural Statistics Service posts weekly Crop Progress and Condition Reports from April through November. Although these reports are not exclusively focused on drought, they were very useful for collecting specific information on how crops and livestock faired in 2015. However, because there is not an overarching summary for the year, 26 separate weekly reports from April through September were reviewed to identify general trends in how crops and livestock were affected by the 2015 drought (e.g., which crops did well and which struggled). In addition, it was often unclear whether the information provided in the weekly reports pertained to a particular region or county of Oregon, or to Oregon statewide. With such detailed information, an annual summary of these reports would serve as an incredibly valuable and reader-friendly resource. As another example, the NRCS releases Oregon Water Supply Outlook Reports on a monthly basis from January through June each year. These reports provide substantial information about predictions for water supply conditions, statewide and by basin, as well as information about current conditions. An "end-of-the-year" summary based on these six reports, highlighting the most important information about conditions for the state and its basins, would be immensely beneficial. If possible, it would also be helpful to incorporate more information about the specific impacts of these conditions.

One of the most important insights gained from this research is the value interviews can play in understanding the impacts of drought in certain areas and sectors, and what types of response strategies were used. The initial version of this report, which was submitted to OWRD for internal use, includes four case studies that were based on interviews conducted about the 2015 drought impacts and response strategies implemented. A city manager, rancher, farmer, and an owner of an angling shop and guide business were interviewed. The summaries of and findings from these interviews are not provided in this version of the report due to administrative restrictions through the Oregon State University Research Office's Institutional Review Board. Most of the information provided during these interviews was qualitative and anecdotal, however learning about how individuals were impacted by the drought and managed water yielded some of the most detailed information found during this research process. For instance, challenges and opportunities associated with groundwater declines and dry wells, municipal aquifer storage and recovery, managing livestock, adjusting commodity pricing, and continuing the generational tradition of farming and ranching were all discussed in the interviews. Nearly none of these issues were discussed in the documented information found during the online search or through resource inquires to agencies and organizations.

It is this type of "on-the-ground" information that could and should be learned from when developing drought vulnerability assessments and drought adaptation, mitigation, and response plans. The challenge with conducting interviews is that they require time and resources, and that they need to be conducted relatively soon after a drought event while memories are most intact. Assistance from researchers and students from academic institutions and from associations, such as the Western Governors' Association, may help overcome these barriers. An example interview guide for water managers, providers, and users is provided in Appendix B. The interview guide is an amended version of the one used for the four interviews conducted for the original draft of this report.

To help consolidate drought impacts and response strategy information that *is* available, relevant agencies, tribes, and organizations could develop their own report on impacts and responses after a drought year in Oregon. Information from these individual reports could then be compiled into one cohesive document. For example, in March 2016, Washington State's Department of Ecology developed a summary after the 2015 drought, which included succinct information on the timeline of drought responses; drought funding; emergency drought permits; curtailment orders; water leases; drought response strategies implemented by multiple agencies and coordination among agencies; and a list of challenges and considerations for future water and drought management. A comprehensive report like this would help provide Oregon with a full picture of what a drought year can mean for the state as well as help assess what information, programs, and resources may be needed to effectively mitigate and adapt to drought. However, it should be noted that Oregon's water management is structured differently than that of Washington's, and a tailored approach to documenting and summarizing drought conditions, impacts, and responses may be more beneficial.

VII. Conclusions and Recommendations

It is important to gain a comprehensive understanding about how drought affects Oregon communities, economies, and ecosystems in order to develop appropriate adaptation and response plans. In times of drought, concerns and predictions about drought impacts and associated regulations are shared through a variety of sources, such as agency news releases, newspaper articles, and radio and television broadcasting. Once drought conditions cease, however, less information is made available about what actually happened during the drought—about the local and state level effects, how different sectors were impacted and how water managers and users responded. This summary is a reflection of information that was readily available online or shared by the Oregon Water Resources Department (e.g., memoranda to the Governor regarding the drought; e-mails from other state agencies about drought conditions and impacts). Based on the findings of this report, the following recommendations, presented in no particular order, have been developed for the consideration of relevant state agencies and advisory committees.

Recommendation #1. Secure funding and work in partnership to conduct drought risk, vulnerability, and impact assessments on geographic and sectoral scales. Consider incorporating interviews with water resource managers, providers, and users into this research.

As discussed in the literature review, the State of Oregon's "Report of the Task Force on Drought Emergency Response" acknowledges that the first-order drought impacts data currently collected is not sufficient for such assessments. Accordingly, the Task Force recommends that resources be provided to assess drought impacts, risks, and vulnerabilities on instream and out-of-stream sectors. This recommendation is supported here, especially as the literature reviewed recognized the following initiatives as helping to strategically guide Colorado's drought impact monitoring, drought mitigation, and drought response efforts: a) Colorado's Climate Preparedness Project (CCPP), b) Drought Mitigation and Response Plan, and c) Drought and Water Supply Assessment. These plans and studies should be referenced by Oregon agency staff and officials whose work intersects with drought, especially those in water resources. Doing so could help gain insight about what advanced, state-level drought monitoring plans entail and about potential drought indicators that may be appropriate for Oregon's geographic regions and sectors. Recommendation #3 and #4 below should also be considered in conjunction with the vulnerability assessment.

Furthermore, conducting interviews with water resource managers and users can help produce rich, and sometimes new, information about drought impacts, management tools, and response strategies, as was done in the CCPP, Oregon's Climate and Health Program, and the initial version of this report. As previously discussed, the need for well-trained staff is supported by a study (Steinemann, 2014) in which state drought managers in nineteen of the Western Governors' Association states were interviewed. It was found that managers "stressed the value of 'field intelligence' and talking with local experts and stakeholders across the state" (Steinemann, 2014; p. 845).

During Oregon's 2015 drought, OWRD's regional Watermasters held weekly meetings with staff of the Director's office to discuss updates on drought conditions and impacts (Mucken, 2016).

High-level notes were taken for internal discussion purposes only. Upon reviewing the notes, it is unclear how frequently stakeholders reached out to their regional Watermasters. Based on the four interviews conducted with water providers and users, as well as personal communications with NRCS and OSU Extension Service staff, it seems that who stakeholders (e.g., farmers/ranchers, municipalities, well owners) contact about drought impacts varies by location and sector. It is likely that the calls and emails received by Watermasters are not representative of the correspondence between stakeholders and field experts statewide, and thus does not accurately capture the concerns of and impacts faced by stakeholders. For example, in a weekly meeting a Watermaster may say that they have not received any calls about water level declines in wells. Of course this does not mean that community members are not experiencing water declines; perhaps well owners do not report them, or they reach out to a different entity for guidance.

Conducting interviews with water resource managers and users would help illuminate answers to questions about who stakeholders contact about drought impacts and would help inform drought risk assessments more accurately and comprehensively about "on-the-ground" impacts. Oregon's drought planning should extend beyond state- and regional-level agency staff and include input from those who experience direct and indirect drought impacts first hand. Thus, funding and staff time should be secured for an agency like OWRD or an institution like the Oregon Climate Change Research Institute (OCCRI) to conduct such interviews.

An example interview guide for interviewing water resource managers and users about drought impacts and impacts reporting is provided in Appendix B. Oregon's Drought Task Force has already identified the priority sectors for vulnerability assessments as agriculture, instream, and municipal water systems, however other sectors should not be overlooked, especially considering the significant information gaps found in this report (i.e., tribal matters, industry, hydropower, marine systems).

In order to maximize funding and capacity for vulnerability assessments, state departments should consider working in partnership, both horizontally (across state agencies) and vertically (with local, regional, and federal agencies, such as the Department of the Interior (DOI) Climate Science Centers, DOI Landscape Conservation Cooperatives, and USDA Climate Hubs). Agencies should also consider partnering with nongovernmental organizations (e.g., academic institutions, Western Governors' Association). Again, the CCPP would be another helpful resource for Oregon. Twenty-two interviews were conducted with representatives of key agencies, cooperating non-profit organizations, and a private utility (Xcel Energy) from the following sectors: agriculture; electricity; wildlife, ecosystems, and forests; outdoor recreation; and water (Averyt et al., 2011; pp. 8-9). Appendix A of the CCPP, which Oregon could use as a reference, provides the interview questions used to learn about entities' sensitivities to climate variability and possible long-term climate changes (Averyt et al., 2011; p. 97). Several of these questions are not specific to drought, however. In addition, although the questions are applicable for interviewing state-level representatives, interview questions should be thoughtfully developed for local-level stakeholders and entities, as well.

Recommendation #2. On a statewide level, determine: a) priorities and a preferred format for summarizing the effects of drought and response strategies; and b) methods for coordinating and minimizing duplicative efforts around collecting, documenting, sharing, and compiling relevant information (e.g., water supply conditions, effects on sectors and local economies, emergency grant and loan programs).

In order to improve drought response and adaptation plans, there should be an efficient and organized process for documenting and assessing how drought conditions affect the state. When this information is not logged or written in an organized manner, or even at all, it cannot be used to inform drought planning and preparedness. It is recommended that a strategic process be designed for determining priorities and a clear protocol for coordinated drought impacts reporting, as well as for compiling and sharing information. This process could be designed and led by a professional facilitator, an assigned drought "czar," or an existing or newly formed group. Again, Arizona's and Colorado's drought reporting and planning documents and systems should be referenced as examples, as well as the processes through which these products have been developed and implemented. Furthermore, whether or not Oregon would benefit from a state-level drought impacts reporting tool, like the AZDW, should be considered.

Regardless of who would be responsible for designing and leading the process, it should be a collaborative one. For example, perhaps a series of meetings could be held with representatives from multiple agencies to discuss their current and potential roles in, approach to, and level of capacity for documenting drought impacts and responses. It may be appropriate for an existing multi-organizational committee (including governmental and non-governmental actors) to take on this task; however, it could be more beneficial for representatives from all relevant units to meet directly. These players could include representatives from: Oregon Water Resources Department (e.g., Watermasters and Field Staff); Oregon Department of Environmental Quality; Oregon Department of Agriculture; Oregon Department of Fish and Wildlife; Oregon Department of Forestry; Oregon Parks and Recreation Department; Oregon Department of State Lands; Oregon Health Authority; Natural Resources Conservation Service Centers; Farm Service Agency County Offices; Tribal Councils; Soil and Water Conservation Districts; Oregon State University Extension Service; the League of Oregon Cities; the Association of Oregon Counties; and any other units that may be collecting information or providing support during times of drought.

It should be recognized that there are existing groups and tools related to drought impacts reporting that could be leveraged in both Oregon's efforts to design a drought reporting plan and to improve drought reporting itself. For example, the OWRD Policy Advisory Group, Drought Task Force, Water Resources Commission, and OCCRI are engaged in drought-related discussions, planning, or research. In addition, multiple entities provide data to inform NRCS Water Supply Outlook Reports, such as OWRD, USGS, and NWS (OEM and OWRD, 2016). The same is true for the U.S. Drought Monitor, for which federal, state, regional, local, and private partners contribute information (Lackstrom et al., 2013). Rather than create duplicative processes and tools, these types of existing efforts could be complemented, modified, or incorporated into a broader drought impacts reporting strategy. The State of Oregon Emergency Operation Plan's Drought Annex outlines the current drought-related roles and responsibilities of various state agencies (see OEM and OWRD, 2016).

Recommendation #3. Review and discuss the appropriateness and effectiveness of Oregon's county drought declaration process, drought emergency tools, and water law stipulations that may help or inhibit drought management and response options.
As explained in the State of Oregon's "Report of the Task Force on Drought Emergency Response," there are positive and negative potential outcomes of the current drought declaration process, in which counties declare a drought emergency prior to gubernatorial declarations. According to Fontaine et al. (2014), this type of local-level empowerment in the drought declaration process gives officials a sense of shared responsibility around drought (p. 97). It also allows for input on locally-specific conditions (State of Oregon, 2016; p. 14). However, drought and drought declaration affect sectors differently (e.g., perhaps assistance is given to the agriculture sector but not to fish and wildlife), and county-level consideration could be given to only some sectors and not others (State of Oregon, 2016; pp. 14-15). Because higher-order impacts are difficult to monitor and measure but can still have strong negative consequences in an area or sector, qualitative data can be critical when providing evidence of severe drought conditions during the declaration process.

It is also important to recognize how subjectivity can influence drought impacts reporting and ensure that sectors with the strongest political and public support (e.g., agriculture, municipalities, and the economy) do not inappropriately dominate drought management decisions while overlooking other sectors. Furthermore, Oregon agency staff and officials whose work intersects with drought, especially those in water resources, should thoroughly discuss how execution of the following drought emergency tools can benefit and harm different sectors, especially across different regions of the state. These include: temporary emergency water use permits; temporary transfers; temporary instream leases; temporary substitution; special option agreements; temporary exchange of water; and temporary preference to water rights for human consumption or stock water. To better understand the consequences of these tools, input should be collected from water managers and users in different regions and sectors. The State should then consider how the benefits and disadvantages of these tools align with its water resource management priorities and the findings from any vulnerability assessments that might be completed (see Recommendation #1). An explicit review of these matters, and an associated decision making guide, could help ensure that the decisions made during severe drought conditions remain consistent with the state's overarching water resources management priorities.

Oregon's Drought Task Force also recommends that the "State should review the drought declaration process and tools to ensure drought declarations are effective and assist with emerging drought response" (State of Oregon, 2016; p. 13). Finally, the adaptability of Oregon's Water Code and local-level water policies should be discussed. For instance, according to Brenda Bateman (OWRD Technical Services Division Administrator) "some areas of the Willamette Valley that have their irrigation seasons defined on paper as April 1 through September 30, increasingly experience growing conditions that would benefit from irrigation into the month of October" (Bateman, 2014). This is because of changes in the hydrograph and temperature, (Bateman, 2014) which affects the timing of peak and low flows. Thus, it may be beneficial to explore whether the beginning and end dates of the irrigation season should be adjusted to better align with changing conditions, or if they should be flexible on an annual basis to better fit current conditions. As stated by Bateman, "policymakers may soon have to revisit the body of rules that define irrigation seasons" and "they will need to make adjustments incrementally, to maintain this strong foundation, while keeping up with a changing climate" (Bateman, 2014). Another example question that could be considered is, "what components of Oregon's Water Code help and hinder drought mitigation, adaptation, and response?" Conversations around this type of question might yield new ideas around drought emergency tools and response strategies that could be developed, for example.

Recommendation #4. Investigate how water conservation and storage have impacted water consumption and modify or develop policies, policy tools, and programs as appropriate. Increased irrigation-efficiency, water storage, and water re-use are common approaches to reducing water consumption. For example, in the interviews conducted for the original version of this report, it was found that municipalities in Oregon have developed aquifer storage and recovery systems to supplement their surface water supply. Surface and aquifer reservoirs can help store water that is available during wet months for use during dry months. It was also found through the interviews that some Oregon farmers have implemented more efficient irrigation methods, such as using micro-sprinkler and drip systems, which can apply water to crops more accurately and at a better controlled rate. Also, some farmers use recycle pumps to collect and reuse irrigation runoff, stretching limited supplies for as long as possible.

Whether these conservation and storage techniques actually reduce consumption levels is continuously debated. As an example, incentive-based water conservation programs for irrigated agriculture are often championed as being able to reduce consumptive water use while also increasing farm yields and profits through efficient irrigation technology (Pfeiffer & Lin, 2010; p.1). However, according to Pfeiffer & Lin (2010), "several studies have suggested that more efficient irrigation technology can actually lead to increased water use" for the following reasons: "farmers may adjust their crop mix toward more water intensive crops, expand their irrigated acreage, apply more water to the crops they plant, or their crops may benefit from higher evapotranspiration" (p.1).

The Oregon Water Resources Department, its relevant advisory committees, and research institutions should identify research questions that would help better understand how water conservation and storage affect consumption levels in Oregon. Research that will help directly inform relevant decision making about existing and potential policies, policy tools, and programs should be prioritized. Studies should be aligned with the drought vulnerability assessment called for in Recommendation #1. For example, it would be especially important to gain a clear understanding of how common water conservation and storage techniques affect consumption levels in geographic areas that are at high-risk of and are highly-vulnerable to drought. It could be beneficial to implement experimental or pilot water conservation programs (incentive based and non-incentive based) for research purposes. Possible research partners could include research/academic institutions, OSU Extension Service, USDA Climate Hubs, NRCS, Soil and Water Conservation Districts, Irrigation Districts, and counties.

Enforcement will be key when considering how water conservation policies and programs might be able to benefit Oregon. For irrigation efficiency policies, for instance, Pfeiffer & Lin (2010) suggest that:

> *"…to attain results…policies must be accompanied by corresponding decreases in the total water extraction allowed under the system of water rights, as well as restrictions on the conversion of previously unirrigated cropland. Additionally, the property rights system, reporting requirements, and legal enforcement must be strong enough for these regulations to represent real, enforceable limits on extraction."* (p. 6)

To help develop research priorities for Oregon, extant research and literature should be referenced. Success stories and lessons learned could be drawn from case studies about how water conservation and storage methods, and their associated policies, have affected consumption levels in other states.

Recommendation #5. Increase government capacity for groundwater monitoring and develop a long-term plan for sustainable groundwater management with clear objectives and metrics.

Oregon municipalities and irrigators have relied on increasing their groundwater use to supplement limited water supply during times of drought. If groundwater pumping outpaces aquifer recharge, supplemental and emergency water supplies will become further strained. In order to more carefully manage groundwater resources, statewide infrastructure should be developed for monitoring groundwater levels and sharing data. Data on groundwater supply and use across the state would help inform a long-term plan for sustainable groundwater management, which is critical for ensuring that groundwater sources do not become depleted. California's Sustainable Groundwater Management Act could be referenced as an example policy that has identified basins of concern and required those basins to develop metric-based sustainable groundwater management plans by particular deadlines. Furthermore, existing California basin plans could be used to learn from the type of objectives, metrics, and timelines that have been considered and pursued.

VIII. Acknowledgments

This report was prepared by Rianne BeCraft as an OWRD Drought Intern under the direction of Alyssa Mucken, the Integrated Water Resources Strategy Program Coordinator for the OWRD Director's Office. Continued research for this report was conducted as part of Ms. BeCraft's Water Resources and Policy and Management master's research project for Oregon State University's (OSU) Water Resources Graduate Program. Sincere gratitude is extended to those who served on Ms. BeCraft's project committee– Dr. Michael E. Campana (OSU Professor), who served as primary adviser, Dr. Erika Wolters (Director of the OSU Policy Analysis Laboratory), and John Stevenson (Regional Extension Climate Specialist at the Pacific Northwest Climate Impacts Research Consortium and Oregon Sea Grant). A special thanks is given to Dr. Philip Mote, Director of the Oregon Climate Change Research Institute, for contributing SWE data and providing guidance and examples for aggregating temperature, precipitation, and SWE data.

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Cover page image (Oregon map): www.oregonphotos.com

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Appendix A | Additional Figures

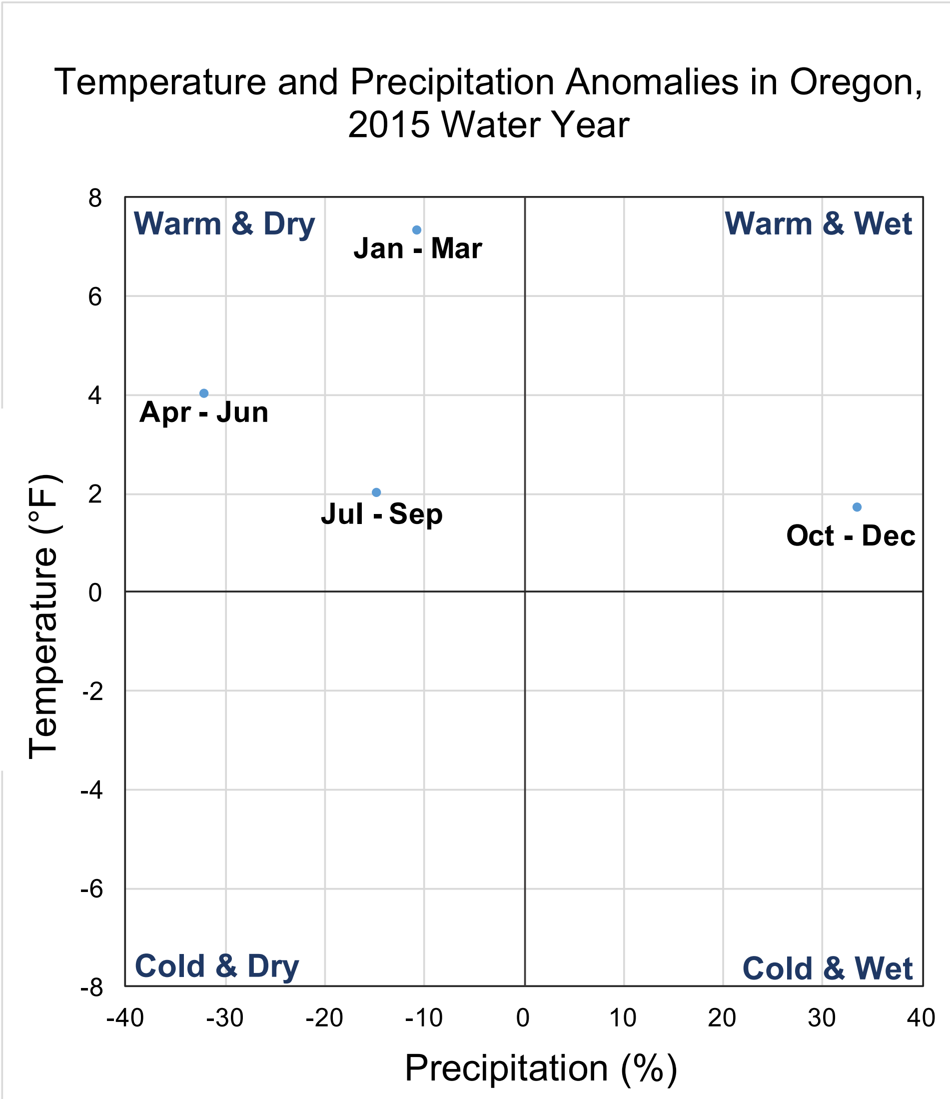

Figure A-1. This plot shows the anomalies for the average precipitation and temperature of each quarter of the 2015 water year, relative to the historic averages for those same quarters. The position of each dot, which represents the labeled quarter of the water year, shows the percent above or below the 20th century precipitation average (on the horizontal axis) and the temperature above or below the 20th century average (on the vertical axis). The plot shows that the final three quarters of the water year were warmer and dryer than the historic average, to varying degrees, while the first quarter of the water year was warmer and wetter. The baseline period is 1896-2015. Data are from NOAA's National Centers for Environmental Information.

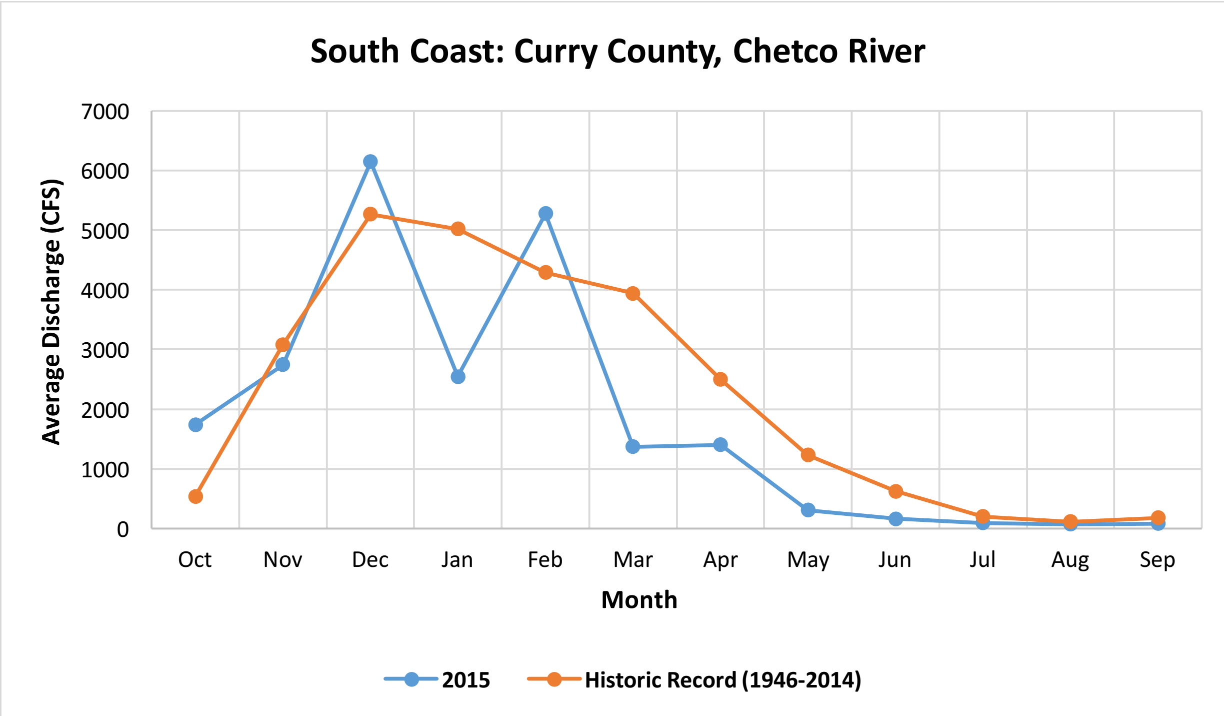

Figure A-2. The monthly average discharge at a station along Chetco River during the 2015 water year compared to the historic average. Discharge peaked in December as usual, however there was a sharp drop in January and March, after which flow was approximately 60% or less of the historic average until July. There are no flow regulations or diversions upstream from this station. (USGS Site Number: 14400000)

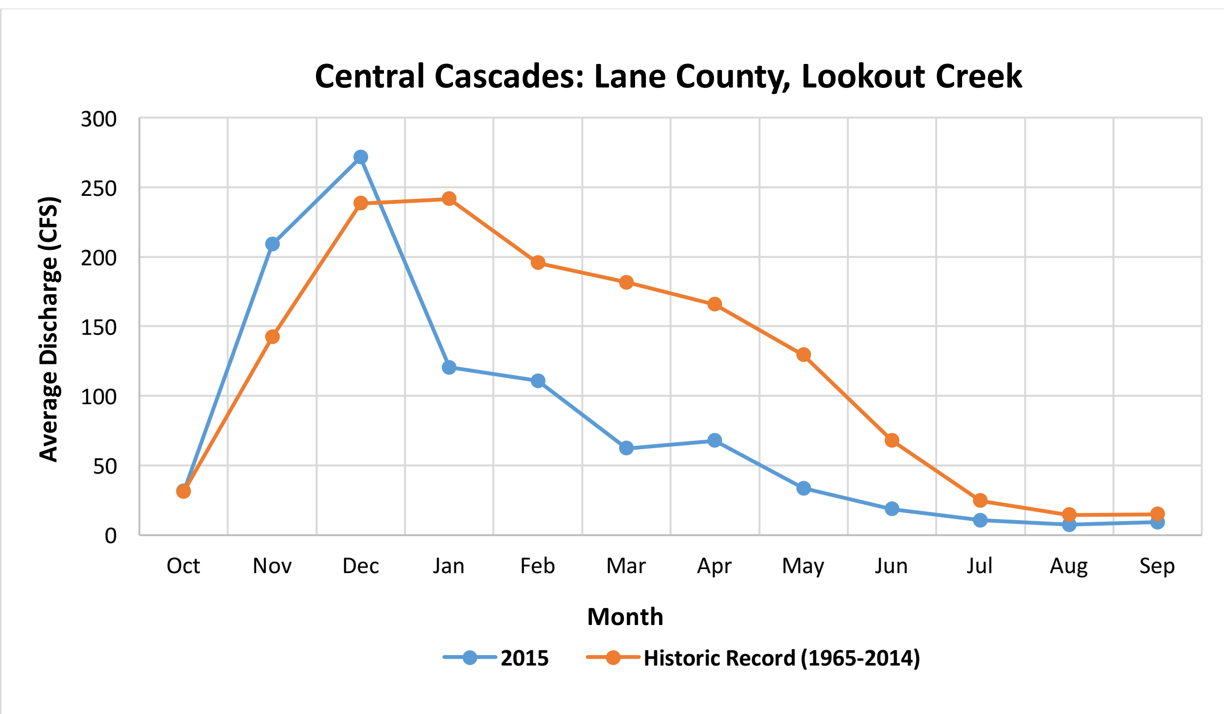

Figure A-3. The monthly average discharge at a station along Lookout Creek during the 2015 water year compared to the historic average. Discharge peaked in December as usual, however there was a sharp drop in January. From January through June, flow was approximately half of the historic average. There are no flow regulations or diversions upstream from this station. (USGS Site Number: 14161500)

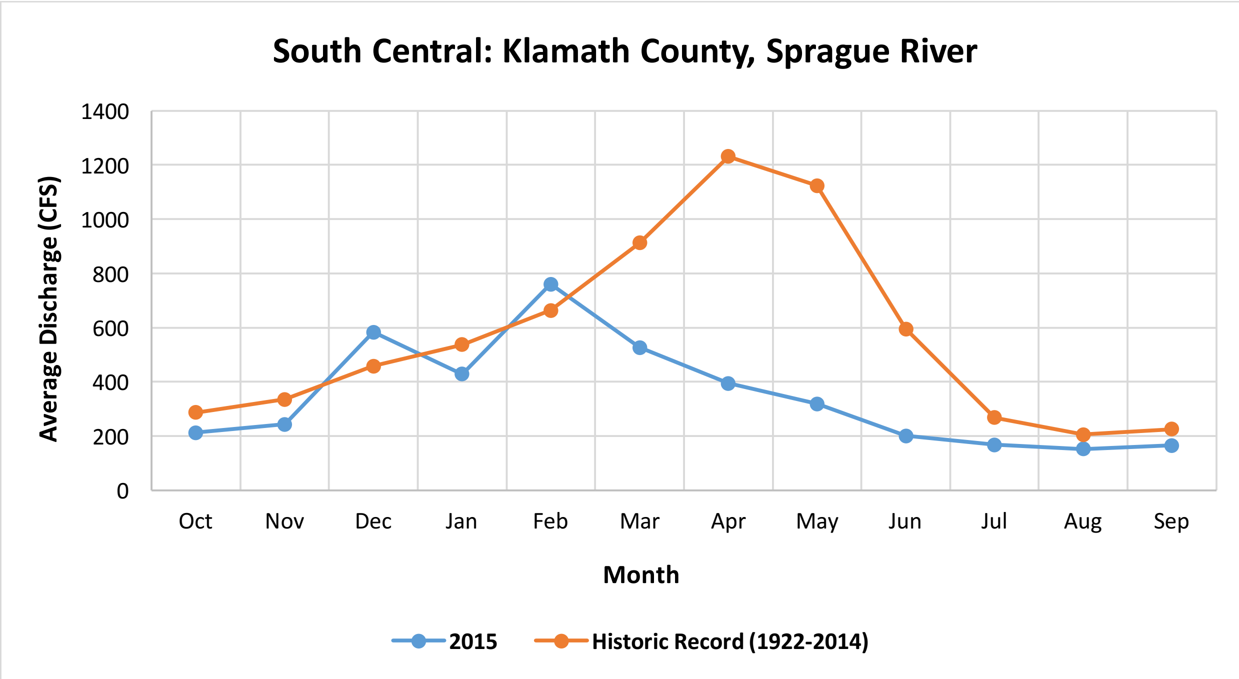

Figure A-4. The monthly average discharge at a station along Sprague River during the 2015 water year compared to the historic average. Discharge peaked in February than in April and steadily declined from February through June. Flow from April through June was severely low, at approximately one-third that of the historic average. There are no flow regulations upstream from this station, however there are upstream diversions for irrigation. (USGS Site Number: 11501000)

Appendix B | Potential Interview Questions

Below is an example interview guide for interviewing water resource managers and users about drought impacts, drought monitoring, and drought impacts reporting.

Background

1. Please tell me about your role at your agency/organization.
2. Does your agency's work relate to planning for, responding to, or studying drought impacts? If so, in what ways? According to your agency, what constitutes a "drought impact"?

Current Impacts Reporting/Documentation

3. Does your agency/organization collect information about the environmental, social, and/or economic impacts of drought? If so, what type of information?

If not, skip to question 9.

If so, continue on.

4. What is the purpose of collecting this information?
5. At what points and for how long does your agency/organization collect information on drought impacts. For example, are these efforts continuous and year-round? If not, at what point in the year, or at what "trigger points," does your agency start and stop collecting this information?
6. What does the information collection process include?
  6a. What steps or methods are used?
  6b. What positions within your agency are involved in these efforts?
  6d. Is there collaboration with external people or entities at any point in the process?
7. How is this information maintained?
  7a. Is the information saved anywhere (e.g., internal file, online database)?
  7b. Is the information synthesized or compiled in any way? If so, through what steps and in what format?
  7c. Is the information and/or summary shared externally or made publicly accessible?
8. How feasible is the process for collecting information on different types of drought impacts? Do barriers exist?
  8a. Have the opportunities or barriers in collecting this information changed over time? How might they change in the future?

Potential for Impacts Reporting/Documentation

9. Has the agency/organization considered future goals for collecting, using, and/or compiling information about drought impacts?
10. If any, what are the potential pros and cons to collecting, compiling, and/or synthesizing information about drought impacts?

Recommendations

11. What should Oregon water resource managers and decision makers prioritize in terms of drought research, mitigation, or adaptation?

12. Could the collection, synthesis, and sharing of information about drought impacts be improved, be it at the local, state, intrastate, or national level? If so, in what ways?
13. Are there any contacts or resources you recommend for learning more about the impacts of the 2015 drought in Oregon or drought impacts reporting?
14. Is there anything else you think I should know?