Oregon Drought Vulnerability Assessment

May 2026

Background

Droughts are frequently slow-moving disasters, with impacts developing over time and exacerbating existing water challenges and limited water supplies. In Oregon, droughts have been occurring more frequently in recent years driven by a changing climate. The 2015 drought in particular, was characterized as a warning shot of what was to come in terms of temperature driving increased drought conditions across the state, including significantly lower than normal snowpack with much earlier melt out.

In recognition of this, after the severe 2015 drought conditions, a state Drought Taskforce was convened to research and evaluate potential tools to prepare for or deal with drought emergencies. The Taskforce made 13 recommendations to help ensure that the State is prepared to respond to drought in the future (OWRD 2016). Around the same time, the Oregon Integrated Water Resources Strategy (IWRS) was updated and began to more explicitly address drought (Mucken & Bateman 2017). This emphasis has continued in subsequent IWRS updates (OWRD 2025). In addition to the Taskforce report and the IWRS, the state's Natural Hazard Mitigation Plan (NHMP) also defines several mitigation actions to help mitigate the statewide risk from drought (OEM 2025).

One of the Drought Taskforce's recommendations was to 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. This recommendation is echoed in the state's Integrated Water Resources Strategy and the state's Natural Hazard Mitigation Plan (OWRD 2016, OEM 2025, OWRD 2025). To help implement this recommendation, the legislature authorized funding to support the development of a state-wide drought vulnerability assessment focused on instream and out-of-stream vulnerability, in areas such as agriculture, environment/ecosystems, and municipal and domestic.

Process

This was the first time the state undertook such an assessment, and it was unknown what data would be available to support this work. With the amount of funding available and timing of the funding, the project necessarily had to be limited in scope. As such, this assessment was approached with the goal of learning more about how to approach a drought vulnerability assessment, what data exists to perform such an assessment, and to identify, where possible, drought vulnerabilities in the state. The Oregon Water Resources Department (OWRD) explored opportunities with local universities to leverage their expertise with data and policy analysis, environmental and water justice, and climate and droughts. Oregon State University (OSU) and the University of Oregon Environmental and Natural Resources Law Center (UO-ENR) agreed to participate. OWRD also reached out to the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln, which has developed foundational guidance documents for states on best practices in drought mitigation and response. OSU, NDMC, and UO-ENR each examined a different component of drought vulnerability, and given the limited time for completing the work, produced separate reports for each component (attached).

Assessment Overview

This Drought Vulnerability Assessment is organized around the basic concept that vulnerability is a product of exposure, sensitivity, and adaptive capacity. The assessment examines each of these components, along with water justice considerations.

- **Exposure:** The degree (frequency and intensity) to which people and the things they value experience drought. To assess drought exposure in Oregon, researchers from OSU completed a history of drought using different climatological datasets and drought indices and evaluated changes to drought risk using future projections of climate conditions.
- **Sensitivity:** The degree to which people and the things they value are affected by drought exposure. To assess drought sensitivity, researchers from NDMC focused on drought impacts to drinking water supplies, agriculture, and water-dependent recreation. NDMC used a variety of data sources to better understand impacts in each sector, highlighting where sensitivity to drought impacts may be higher and where additional measurement and monitoring may be needed to better understand those impacts. Drought impacts are diverse and far reaching; due to limited time and budget, this vulnerability assessment does not attempt to define vulnerability across all areas impacted by drought. Rather, this assessment seeks to understand the multitude of impacts seen in recent years and then more specifically focus on vulnerability impacts in three key areas: (1) drinking water supplies, (2) agriculture, and (3) water-dependent recreation.
- **Adaptive Capacity:** The ability to mitigate, cope with and recover from drought. To assess adaptive capacity to drought, researchers from UO-ENR examined state drought policies, identified vulnerability gaps in how the state responds to and plans for drought, and highlighted opportunities to enhance drought resilience.
- **Water Justice:** This assessment examines water justice considerations related to drought. Researchers from UO-ENR used Oregon Water Futures Collaborative findings and its Water Justice Framework to identify substantive issues to consider when planning for and during droughts to serve environmental justice communities.

Outcomes and Future Work

Understanding where and when future drought impacts may occur can assist with maximizing limited resources for planning and preparing for a secure and resilient water future. This drought vulnerability assessment is a first step towards understanding and identifying opportunities to improve drought resilience across the state and also provides insights into the process of doing a drought vulnerability assessment. Several key lessons emerged during the development of these reports that could inform future drought vulnerability assessments and related efforts:

- **Future Methods and Outputs**
  While most statewide drought vulnerability assessments are organized around the three core components of vulnerability—exposure, sensitivity, and adaptive capacity—there is considerable variation in how these concepts are applied. As a result, this effort was just as much an exercise in understanding the availability of data, potential methods, and assessment costs, as much as it was an attempt to better understand drought vulnerability. Throughout this Drought Vulnerability Assessment, researchers identified areas where more data and research could better inform future assessments. For example, future research could investigate whether increased drought frequency post-2000 is a result of climate cycles or increased aridification in Oregon. As the climate warms and the hydrologic cycle changes, the western United States is becoming more arid, and the process and effects of aridification are

intensifying. Aridification refers to gradual, long-term drying of the climate system and will lead to a changing definition of drought over time as the historical baseline of precipitation and evapotranspiration shift toward drier conditions.

A better understanding of drought vulnerability across sectors would allow the state to target investments more effectively, particularly for projects that enhance drought resilience during the summer months when water demand is highest for both instream and out-of-stream uses.

- **Data Availability and Limitations**
  Relevant data can be difficult to obtain and developing new datasets through surveys, monitoring efforts, or other means can be resource intensive. Continued investment in data collection, integration, and accessibility would improve the quality of future analyses and support more robust decision-making.

  For example, adding additional observation stations for both weather and streamflow would address gaps in the monitoring network and build more confidence in future modeling efforts to better understand on-the-ground conditions. In eastern Oregon, where observations stations are relatively sparse compared to the west, additional information would improve the understanding of the relationship between meteorological and hydrological drought, given the influence of snow and groundwater in watersheds east of the Cascades.

- **Adequate staff time and resources.**
  Conducting comprehensive drought vulnerability assessments and implementing mitigation strategies require sustained staff capacity and financial resources. Historically, Oregon—like many states—has relied primarily on existing authorities and programs to respond during drought emergencies. Although the state has begun expanding its focus toward mitigation and resilience in recent years, funding has often been limited or temporary, and dedicated positions focused on drought planning and policy development remain scarce. Strengthening institutional capacity would allow for more consistent evaluation of drought risk and more effective coordination of planning efforts. At the same time, the need for these resources is counterbalanced with the need to invest more in efforts that create more resilience to our changing water future and that what was once considered drought conditions may be a new normal.

As drought becomes a more frequent occurrence in Oregon, a range of strategies will be needed to address drought vulnerability, including for Oregon's most vulnerable communities and ecosystems. Many of these are outlined in the 2016 Report of the Task Force on Drought Emergency Response, the Integrated Water Resources Strategy, and the state's Natural Hazard Mitigation Plan. Since 2016, Oregon has made progress towards implementing some of those strategies. Examples include:

- Improving water data systems to better anticipate and respond to drought
- Funding and technical assistance for place-based water planning, which can help communities identify drought challenges and local solutions
- State funding for water projects, which can help improve infrastructure to improve drought resiliency (e.g., Water Project Grants and Loans, Feasibility Study Grants, Aquifer Recharge Funding program)

- Financial assistance to low to moderate income homeowners experiencing well supply issues (i.e., Well Abandonment, Repair, and Replacement Fund, Harney Domestic Well Remediation Fund)
- Drought relief grants and financial assistance for impacts from natural disasters
- An Interagency Water Reuse Team to help identify policy change priorities and technical assistance needs to support reuse projects
- Drought education and outreach

The Drought Vulnerability Assessment identifies new considerations, while also highlighting some of these same strategies, like expanding funding and outreach for the Water Well Abandonment, Repair, and Replacement Fund (WARRF) Program, and improving water data to better anticipate and respond to drought. As Oregon moves forward on refining our approach to not only drought response and mitigation, but also long-term adaptation to our changing climate and water, this Drought Vulnerability Assessment will be a tool to inform our efforts.

References

Oregon Department of Emergency Management & Oregon Department of Land Conservation and Development. (2025). *Oregon Natural Hazards Mitigation Plan: 2025–2030* (Volume 1, approved Sept. 15, 2025). State of Oregon. Retrieved from https://www.oregon.gov/oem/emresources/plans_assessments/pages/hazard-mitigation-planning.aspx

Oregon Water Resources Department. (2016, November 1). *Report of the Task Force on Drought Emergency Response* (Report pursuant to House Bill 4113, 2016). State of Oregon. Retrieved from https://www.oregon.gov/owrd/WRDReports/DO_Drought_Emergency_Response_Task_Force_Report_11_1_2016.pdf

Mucken, A., & Bateman, B. (Eds.). 2017. Oregon's 2017 Integrated Water Resources Strategy. Oregon Water Resources Department. Salem, OR. Retrieved from https://www.oregon.gov/owrd/wrdpublications1/2017_IWRS_Final.pdf

Oregon Water Resources Department. (2025). *Oregon's integrated water resources strategy* (Final report, adopted September 11, 2025). State of Oregon. Retrieved from https://www.oregon.gov/owrd/programs/Planning/IWRS/Documents/2025

Oregon Drought History

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I. Introduction

There are many conceptual and quantitative definitions of drought (Wilhite and Glantz, 1985; Rasmussen et al., 1993), some of which are objective and some of which are subjective. The simplest definition of drought is insufficient water to meet demand (Redmond, 2002; Swann, 2018). However, the precise definition of drought depends on the location and context. Meteorological drought traditionally has been defined by lack of precipitation, but is better defined as evaporative demand that exceeds precipitation over a prolonged period. Hydrological drought occurs when extended periods of meteorological drought affect surface water supply or soil moisture, and is most consequential for society when water supply does not meet human demand. Meteorological and hydrological drought are driven by physical factors and do not describe impacts on humans or ecosystems. Several other types of drought are defined on the basis of their effects on particular components of human and natural systems. For example, agricultural drought occurs when lack of surface or subsurface water supply adversely affects agricultural production.

The conceptual definition of drought is insufficient to define drought severity in operational or research applications. Drought severity is a metric that incorporates both drought duration and intensity relative to historical conditions at a given location. Therefore, the dependence of drought severity and extent on variability in historical weather, climate, and soil moisture is a major consideration in classifying drought. This dependence has led to use of long-term meteorological observations, mainly precipitation and temperature, to estimate surface water balances and, in turn, drought severity and extent. Additional long-term measurements of streamflow, snow water equivalent (SWE), and soil moisture content augment assessment of drought severity with information on availability of surface water.

The weekly U.S. Drought Monitor is based entirely on assessment of physical drought indicators and the duration of dry conditions. The U.S. Drought Monitor drought classification reflects an assessment of physical indicators of drought severity and extent, most of which are meteorological or hydrological (e.g., precipitation, SWE, streamflow, soil moisture, shallow groundwater, and evapotranspiration), at several temporal extents (Svoboda et al., 2002). Drought classification is determined through the confluence of indicators, an approach in which a given drought designation is supported by multiple physical drought indicators. The result is a national map of drought severity that differentiates short-term drought (duration less than 6 months) from long-term drought (duration greater than 6 months). The U.S. Drought Monitor drought classification has several uses, including the consideration of administrative drought declarations. Examples include emergency drought declarations issued at the county level by the Governor of Oregon or drought declarations issued by the U.S. Department of Agriculture

(USDA) to trigger financial relief and crop insurance programs for agricultural producers. In contrast to the U.S. Drought Monitor, administrative drought declarations are based not only on the existence of drought, but also its impacts. These impacts may include shortages of water for municipal use, irrigation, livestock rearing, and other social and economic priorities. The USDA drought designation is triggered by the U.S. Drought Monitor classification.

The Pacific Northwest is prone to seasonal drought due to gaps in wet season precipitation. Flash droughts also occasionally occur throughout Oregon (Otkin et al., 2018; Pendergrass et al., 2020). Flash droughts are characterized by rapid-onset periods of elevated surface temperatures, low relative humidities, precipitation deficits, and a rapid decline in soil moisture. These conditions often occur in Oregon during summer heat waves, and the impacts of flash drought can emerge in as little as a week (Mo and Lettenmaier, 2015; Rupp et al., 2017). One week also tends to be the shortest duration of conditions that are characterized as flash drought.

As the climate warms and the hydrologic cycle changes, the western United States is becoming more arid, and the process and effects of aridification are intensifying (Sherwood and Fu, 2014; Cook et al., 2016; Overpeck and Udall, 2020; Williams et al., 2022). As distinct from drought, aridification refers to gradual, long-term drying of the climate system and will lead to a changing definition of drought over time as the historical baseline of precipitation and evapotranspiration shift toward drier conditions. Most of the southwestern United States, extending north to southern and eastern Oregon, is experiencing a megadrought that is estimated to be one of the most severe since at least 800 CE (Williams et al., 2020, 2022). Megadrought generally refers to droughts that persist for longer than a decade, although isolated wet years can occur during a megadrought. Additionally, as of late November 2023, much of Oregon is either in or recovering from a multiple-year drought (drought that persists for more than one water year) that began in water year 2020 (Bumbaco et al., 2021, 2022, 2023). Impacts on human and natural systems can become more severe in each consecutive year of drought as groundwater, soils, and surface-water bodies continually dry without normal recharge.

Here, we explore historical drought occurrences in Oregon on the basis of common meteorological and hydrological drought indices. We also investigate drought projections for Oregon on the basis of state-of-the-art downscaled climate model simulations for the twenty-first century.

II. Defining Drought

II.A. Overview

Conceptual definitions of drought, although useful, cannot fully describe the duration and intensity of drought. Diverse indices have been used to quantify drought. Most of these indices are based on standard meteorological observations, mainly precipitation and temperature, or an estimate of surface evaporative water loss. Streamflow observations also have been used to assess drought at the watershed level or snow water equivalent in snowmelt-dominated basins.

Drought indices that are based on meteorological observations attempt to represent simplified water balances between precipitation input and evaporative losses.

II.B. Drought metrics

Below, we outline three drought indices commonly used to quantify drought severity and extent in the western United States, especially Oregon. We illustrate statewide time series of water year values as an introduction to statewide drought variability. We then examine how these three indices reflect differences in drought occurrence among regions within Oregon.

II.B.1. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was designed to quantify precipitation deficits and surpluses over multiple temporal extents that reflect the availability of water (McKee et al., 1993; Edwards and McKee, 1997). The SPI skillfully determines drought in northwest Oregon (Keyantash and Dracup, 2002). The SPI calculation is based on a long-term precipitation record at temporal resolutions of months or longer, but can be adapted to any temporal resolution and region. Long term precipitation records are fitted to a probability distribution that typically best describes the statistical distribution of precipitation. Perhaps the most common distribution, and the distribution we use here, is the two-parameter Gamma distribution. This fitted Gamma distribution is transformed into a Gaussian (or normal) distribution with zero mean and unit variance. The SPI is then calculated as the transformed precipitation value. The latter transformation allows precipitation departures from the mean value to be compared across seasons at a given location or across regions with different climates. Because the SPI is normalized, wetter and drier climates and seasons can be compared. Positive SPI values indicate greater than mean precipitation, whereas negative values indicate less than mean precipitation over the period of interest.

As an example of what the SPI represents and how it is computed, SPI12 at any grid cell for October 2021 reflects the cumulative precipitation over the previous 12 months (from October 1, 2020 through September 30, 2021). The gamma distribution is fitted to the cumulative precipitation for all complete water years in the data record. These fitted precipitation totals then are transformed into the normal distribution. The resulting SPI values typically lie between –3 and 3, with negative values indicating precipitation deficits and positive values precipitation surpluses.

To illustrate, we used ERA5-Land data (section III.B) for the 73-year period 1950–2022 to calculate monthly precipitation and an SPI12 time series for a grid cell in southeastern Oregon (Figure 1). The seasonal precipitation cycle is well-defined, with a clear concentration of precipitation during winter and spring. The SPI12 time series (Figure 1, bottom panel, black curve) reflects SPI during each month in the time series. Because SPI12 is based on precipitation totals for the preceding 12 months, it serves as a trailing indicator of precipitation variability. Any time scale and data aggregation can be used in the SPI calculation.

The SPI is a widely used drought index. It is skillful in drought determination, easily understood, and effectively characterizes the rarity and intensity of drought caused by lack of precipitation. The U.S. Drought Monitor's drought categories are based in part on ranges of SPI values that align with the expected frequency of drought occurrence. The least severe drought category, moderate drought (D1), corresponds to an SPI of -0.8 to -1.29, and is expected to occur, on average, in 10% of time periods. Severe drought (D2) corresponds to an SPI of -1.3 to -1.59, and is expected to occur in 5% of time periods. Extreme drought (D3) corresponds to an SPI of -1.6 to -1.99, and is expected to occur in 3% of time periods. The category corresponding to the most intense drought, exceptional drought (D4), corresponds to an SPI less than -2, and is expected to occur in 2% of time periods. Accordingly, drought (D1-D4) is expected to occur at a given location in approximately 20% of time periods. Abnormally dry (D0), which is not a formal drought designation, corresponds to an SPI of -0.5 to -0.79, and is expected to occur in 10% of time periods.

However effectively the SPI captures water input from precipitation, it represents just one component of the surface water balance and does not account for variation in evaporative losses or runoff. Therefore, the SPI does not account for the supply and demand concept of surface water availability. Water loss from evaporation or evapotranspiration can affect surface water availability substantially. Neglecting these losses can lead to miscategorization of drought conditions, particularly in climates with well-defined wet and dry seasons, such as those in Oregon. The Standardized Precipitation-Evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010) improves on the SPI by incorporating evaporative loss estimates to more accurately quantify variation in surface water availability. Uncertainty in values of the SPI increase during the dry season in arid climates (Wu et al., 2007). However, there are few such cases in Oregon at seasonal and longer temporal extents.

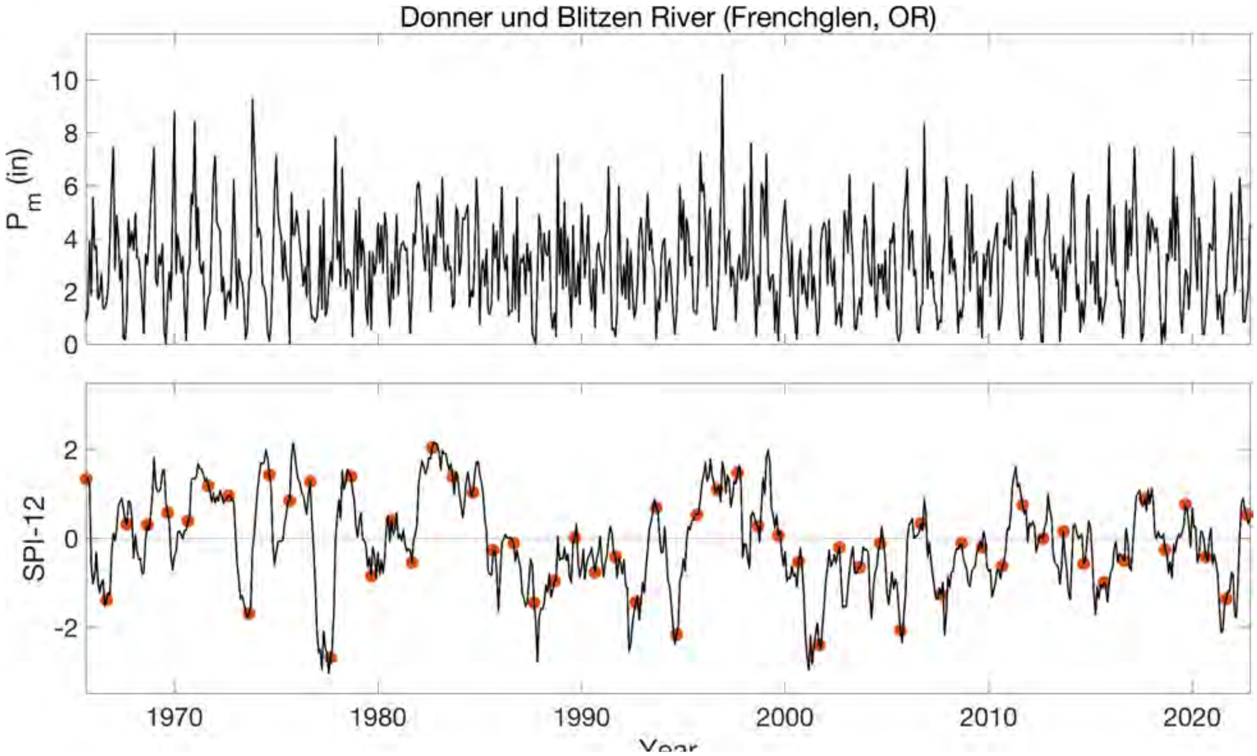

Figure 1. Monthly precipitation (top) and SPI12 (bottom) derived from the ERA5-Land reanalysis data (see III.B) for the Donner und Blitzen River near Frenchglen, Oregon. SPI12 for water years (orange dots) highlight the interannual variability of SPI12.

II.B.2. Standardized Precipitation-Evapotranspiration Index (SPEI)

The dimensionless Standardized Precipitation-Evapotranspiration Index (SPEI) is a primary metric used operationally to assess the existence and severity of meteorological and hydrological drought, especially in the western United States (Vicente-Serrano et al., 2010). The SPEI compares the net water balance between precipitation and potential evapotranspiration (evapotranspiration from a large area with uniform vegetation and unlimited soil water) between a recent period of time and a historical period (Vicente-Serrano et al., 2010). The SPEI allows for evaluation of drought severity in different locations and time periods, identification of different drought types (Ahmadalipour et al., 2017), and consideration of the role of temperature-driven evapotranspiration in drought. SPEI12 is a reliable predictor of annual streamflow in the Pacific Northwest (Abatzoglou et al., 2014; Peña-Gallardo et al., 2019) and water levels in lakes and reservoirs (McEvoy et al., 2012). Accordingly, the SPEI at extents from 3 to 24 months is a key indicator of drought severity and extent in the U.S. Drought Monitor for Oregon.

Calculation of the SPEI is similar to calculation of the SPI, but is based on the difference (D) between precipitation (P) and potential evapotranspiration (PET). Few direct observations of PET are available to compute SPEI. As a result, numerous approximations, two of which we describe below, have been developed to estimate PET. Similar to the SPI calculation, monthly average D is fit to a probability distribution function (here, we use a conventional three parameter log-logistic distribution), then transformed to a normal distribution. A conventional method, the unbiased Probability Weighted Moments (Hosking, 1990; Beguería et al., 2014), approximates this fitting and transformation procedure. The Probability Weighted Moments calculation produces transformed D values akin to SPI values and with similar properties, such as the ability to compare drought across time scales and climates. The same ranges of SPEI and SPI values correspond to U.S. Drought Monitor categories (D0-D4).

Given the sparseness of direct PET observations, approximate evapotranspiration models are used to estimate PET on the basis of standard surface meteorological variables. We used two standard methods to estimate PET, the Thornthwaite and Penman-Monteith equations, and assessed the sensitivity of the SPEI, hence drought classification, to the formulation of PET.

The Thornthwaite equation (Thornthwaite, 1948) depends on near-surface air temperature. Surface air temperature is measured at a variety of heights; the most common is 2 meters above ground. Although skillful in estimating PET in the historical data record, the Thornthwaite equation overestimates PET and therefore future probability of drought when projected air temperatures exceed the historical values used to calibrate the model (Vicente-Serrano et al., 2009; Hoerling et al., 2011). The Thornthwaite method is the main method used to estimate PET from Parameter-elevation Regressions on Independent Slopes Model (PRISM) data (Daly et al., 1994; section III.A), and for operational drought monitoring with the SPEI (e.g., from information provided by the WestWide Drought Tracker [wrcc.dri.edu/wwdt/], Abatzoglou et al., 2017, or the Climate Toolbox [climatetoolbox.org]).

The Thornthwaite equation for PET in a given month is

$$PET = 16 \quad \frac{t_{daylight}}{12}\,\frac{N_{days}}{30}\,\frac{10 \quad T_{avg}}{I}^{\alpha}, \qquad (1)$$

where $t_{daylight}$ is the average number of hours of daylight during the month, N_{days} is the number of days in the month, and T_{avg} is the average 2-m air temperature during the month. I, the annual heat index for the month, is computed as

$$I = \sum_{i=1}^{12} \frac{T_{avg}}{5}^{1.5},$$

and α is a cubic function of I of such that $\alpha = 0.49 + 0.079\,I - 7.71 \times 10^{-5}\,I^2 + 6.75 \times 10^{-7}\,I^3$. This definition of I differs from the traditional heat index variable of the same name, which estimates human-perceived temperatures. In the computation of I, the summation includes the 12 months preceding the month for which PET is being estimated.

The Penman-Monteith equation is a more realistic and sophisticated method of estimating PET. This equation depends not only on near-surface air temperature but also on relative humidity, wind speed, net surface radiation, and surface vegetation. These variables are available from ERA5-Land but not from PRISM. We followed the standard practice of using the reference crop Penman-Monteith equation adopted by the United Nations Food and Agriculture Organization (FAO) in its Irrigation and Drainage Paper No. 56 (FAO-56 PM; Allen et al., 1998). This method, a global standard, is based on meteorological data that are derived for a reference grass surface that is 0.12 m tall. The traditional FAO-56 PM equation was modified to account for reduced transpiration by plants as CO_2 concentrations increase (Yang et al., 2018):

$$PET = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273.15} u_{2m}\, VPD}{\Delta + \gamma[1 + u_{2m}\{0.34 + 2.4\times10^{-4}([CO_2] - 300)\}]}, \qquad (2)$$

where Δ is the change in saturation vapor pressure with warming (Pa/K), R_n is the net downward flux of radiation at the surface, G is the net heat flux into the ground, γ is the psychrometric constant that relates water vapor to air temperature, u_{2m} is the wind speed 2 m above the surface, VPD is the vapor pressure deficit 2 m above the surface (i.e., the difference between the saturated and actual vapor pressures), and CO_2 is the atmospheric concentration of carbon dioxide in parts per million (ppm).

The denominator in Equation 2 differs from that in the FAO-56 Penman-Monteith equation by the addition of $2.4 \times 10^{-4}([CO_2] - 300)$ to 0.34, which primarily is derived from the ratio of bulk surface resistance and aerodynamic resistance. We call this method of calculating PET, expressed by Equation 2, the CO_2-aware Penman-Monteith equation. The surface evaporative resistance is projected to increase, reducing PET, as projected CO_2 concentrations increase over the next century (Swann et al., 2016). We address projected changes in PET in more detail in section VII.

II.B.3. Standardized Streamflow Index (SSI)

We calculated the Standardized Streamflow Index (SSI) from stream gage data (see III.C, III.D). The SSI is computed in the same manner as the SPI, with the same gamma distribution and Gaussian transformation, but from observations of monthly streamflow rather than precipitation. The SSI commonly is used to quantify streamflow-based hydrological droughts (e.g., Modarres, 2007; Vicente-Serrano et al., 2012).

III. Data

Data selection affects definitions of drought severity and extent on the basis of drought indices. Among the considerations in selecting data are the need for long-duration historical records, the available variables, and the spatial and temporal resolutions of the data. With these considerations in mind, we used two sources of atmospheric data, PRISM and the ERA5-Land reanalysis. We also used two sources of streamflow data, the second version of the U.S. Geological Survey (USGS) Geospatial Attributes of Gages for Evaluating Streamflow (GAGES-II) and the Oregon Water Resources Department (OWRD) stream gages.

III.A. PRISM Monthly Gridded Precipitation and Temperature

The PRISM (Parameter-elevation Regressions on Independent Slopes Model) Climate Mapping Program is an ongoing effort to produce and disseminate detailed, high-quality spatial climate data (Daly et al., 1994). PRISM uses surface meteorological observations from weather stations (Figure 2), a digital elevation model, and other spatial data to generate fine resolution (nominally 4-km) gridded estimates of monthly precipitation and temperature from 1895 to present. PRISM uses these point measurements of observed weather and a digital elevation model to produce gridded climate data fields that are continually updated to map climate variables across all regions, topographic features, and associated climates, such as high mountains, rain shadows, temperature inversions, coastal regions, and associated complex mesoscale climate processes. The locations of stations in the network that were used to produce the precipitation field for July 2021 (Figure 2) illustrate that the station density is greatest in western Oregon and relatively sparse in much of central and eastern Oregon. One consequence of the difference in station density is higher uncertainties in the PRISM climate fields in data-sparse regions. In Oregon, these uncertainties are most prevalent near steep elevation gradients in the state's numerous mountainous areas.

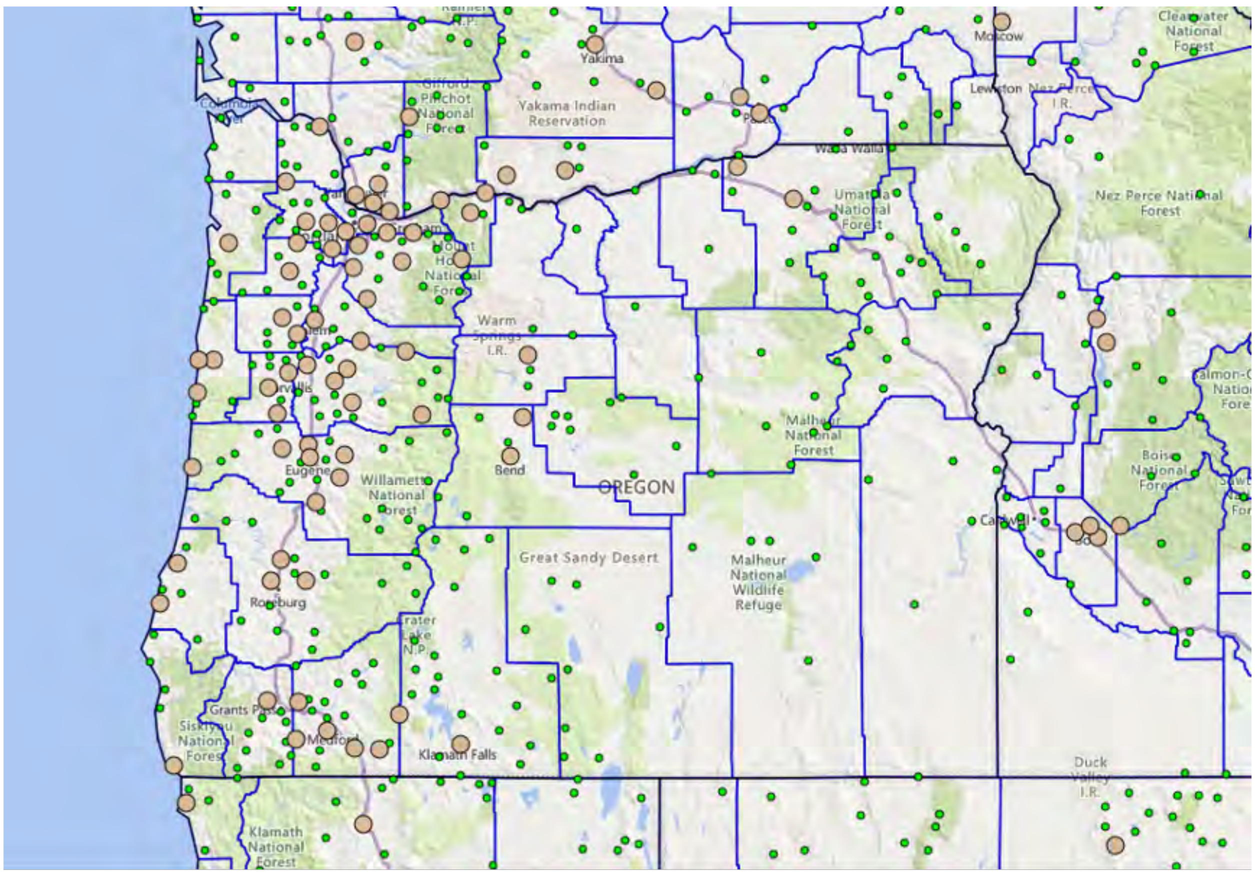

Figure 2. Locations of stations at which precipitation was measured during all seasons and that were incorporated into the PRISM analysis of precipitation during July 2021. Courtesy of Chris Daly, OSU PRISM Climate Group.

The PRISM data we use here are monthly 4-km gridded accumulated precipitation and average temperature. These data are available from January 1895 to present. We do not consider the daily PRISM 4-km analyses from 1981 to present because the daily data record is too short to provide a reliable indicator of historical conditions. Advantages of the PRISM data are that they are based on observations, incorporate elevation-dependent variability through the use of a statistical model to estimate values of climate variables in spatial and temporal data gaps, and have a long record. The disadvantages are that the station density varies in space and time, and measurement errors and data gaps can affect the accuracy of the gridded analyses. Even with these shortcomings, the PRISM data are among the best estimates of precipitation and temperature in the highly variable terrain of the western United States. PRISM data are a key component of operational drought monitoring in Oregon.

The PRISM climate analysis is updated regularly as more observations become available. PRISM temperature and precipitation fields are provisional for 6 months and considerable changes can be expected for up to 2 years. Therefore, in this report, drought indices derived from PRISM data since November 2021 should be considered preliminary.

III.B. ERA5-Land Hourly Surface Meteorological Analyses

The ERA5-Land product (Muñoz-Sabater et al., 2021) extends the primary reanalysis product, ERA5, from the European Centre for Medium-Range Weather Forecasts (ECMWF). Reanalysis is a process by which observational data that were irregularly sampled in space or time are placed on a regular grid and then used in a consistent analysis of the full atmosphere over the historical period by maintaining the data assimilation and model framework. A benefit of ERA5-Land is that it includes more terrestrial observations from periods further in the past than does ERA5. The spatial resolution of ERA5-Land also is finer than that of ERA5. ERA5-Land is available over land only and has a horizontal spatial resolution of 0.1° (9 km native resolution). The hourly product is available from 1950 to present.

The primary reason we used ERA5-Land in this drought history is that it supports computation of evapotranspiration with the more sophisticated and accurate Penman-Monteith equation (Eq. 2). By contrast, the variables available from PRISM only support use of the less sophisticated Thornthwaite equation (Eq. 1). Because PET is estimated from a nonlinear equation, use of hourly instantaneous data available from ERA5-Land should produce a more accurate estimate of PET than use of monthly data from PRISM. ERA5-Land includes all components needed to estimate the surface energy balance from which evapotranspiration is derived. It also incorporates a land surface model that allows soil moisture and infiltration to vary.

Values of PET are necessary for calculation of the SPEI. As noted above, PET can be approximated with the Thornthwaite equation, which depends only on the 2-m air temperature, or the Penman-Monteith equation, which depends on the 2-m air temperature, 2-m relative humidity, 2-m wind speed, net surface radiation, surface skin temperature, surface soil moisture, and, optionally, surface pressure. The ERA5-Land data provides estimates of these variables.

III.C. U.S. Geological Survey GAGES-II streamflow data

The Geospatial Attributes of Gages for Evaluating Streamflow, version II (GAGES-II; Falcone, 2011) network (Figure 3) includes reference and non-reference gages maintained by the U.S.

Geological Survey (USGS) that have measured streamflow for at least 20 years. Data from some gages are not continuous or do not extend past the 2009 water year. A water year encompasses October 1 through September 30 and references the year in which it ends; for instance, water year 2023 began on October 1, 2022 and ended on September 30, 2023. Reference gages, from which we obtained the data in this report, are located in watersheds with minimal upstream flow regulation or disturbance relative to non-reference gages in the same U.S. Environmental Protection Agency Level I ecoregion (12 Level 1 ecoregions in the continental United States; Omernik, 1987). Accordingly, the reference gages are ideal for studying long-term regional climate and drought conditions.

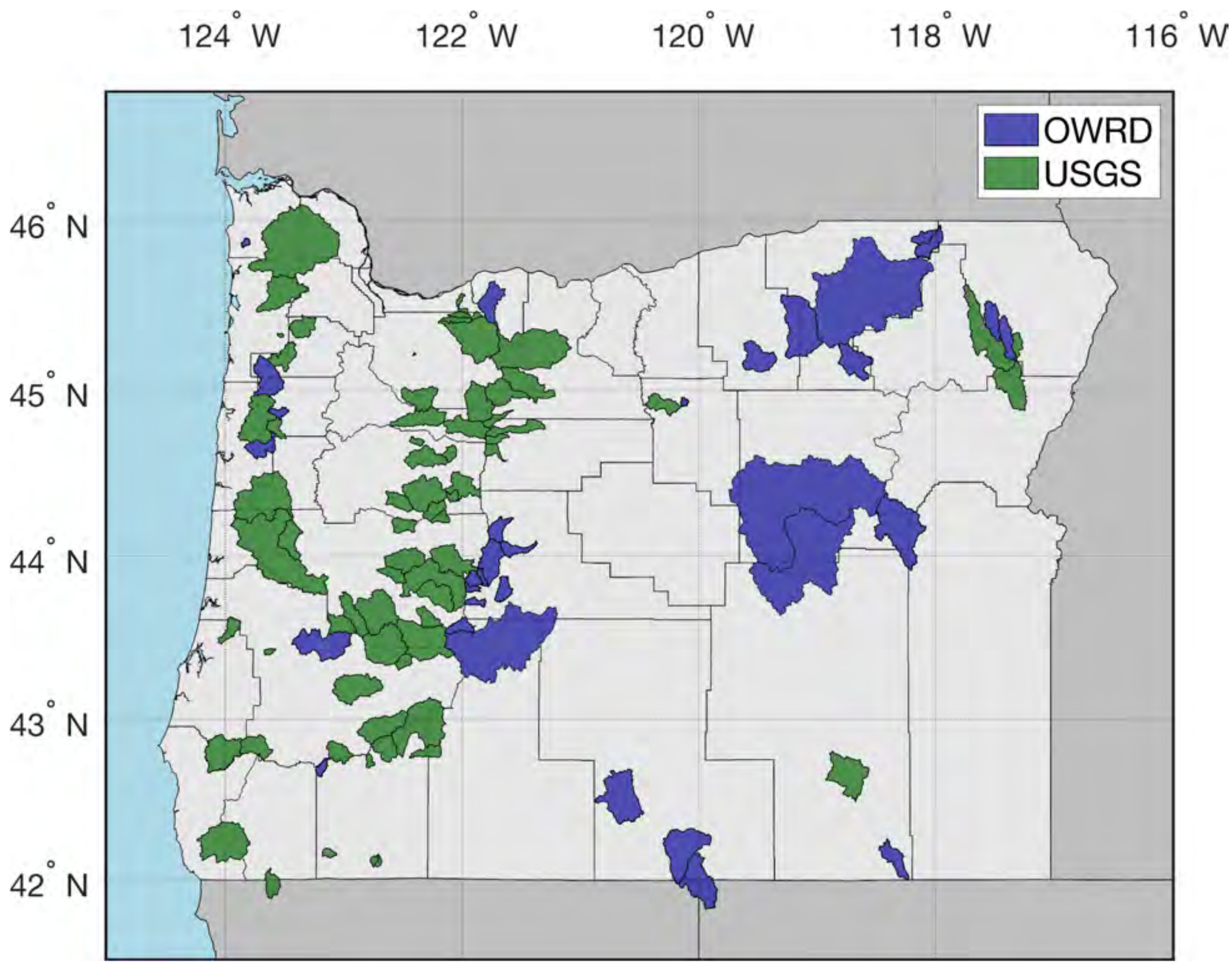

Figure 3. Boundaries of watersheds that encompass the stream gages in the GAGES-II network (operated by the U.S. Geological Survey [USGS]) and the Oregon Water Resources Department (OWRD) networks.

III.D. Oregon Water Resources Department streamflow data

The Oregon Water Resources Department (OWRD) maintains a distinct network of stream gages in watersheds throughout the state (Figure 3) that are used to supplement data from the

GAGES-II reference gages. OWRD used a method similar to that of GAGES-II to classify reference stations. The density of reference gages in eastern Oregon fills some gaps in the spatial coverage of the GAGES-II network.

III.E. Projections of future climate

Our projections of future climate are based on output from an ensemble of regional climate model (RCM) simulations performed through the North American Coordinated Regional Downscaling Experiment (NA-CORDEX; Mearns et al., 2016). The simulations have a horizontal resolution of 25 km and were applied to multiple RCMs. The boundary conditions of the RCMs were derived from diverse coupled global climate model (GCM) simulations that assumed a continuation of current levels of greenhouse gas emissions through the year 2100 (RCP 8.5). We included seven GCM-RCM combinations in our analyses: GFDL-ESM2M + WRF, GFDL-ESM2M + RegCM4, MPI-ESM-LR + RegCM4, MPI-ESM-LR + CRCM5-UQAM, MPI-ESM-MR + CRCM5-UQAM, CanESM2 + CanRCM4, and CanESM2 + CRCM5-UQAM.

IV. Comparison of drought depictions from PRISM and ERA5-Land

Including both PRISM and ERA5-Land reanalysis products in our analyses allowed us to compare distinct representations of the severity and extent of historical droughts. Estimates of annual mean precipitation, near-surface (2-m) air temperature, and potential evapotranspiration from PRISM and ERA5-Land vary (Figures 4 and 5).

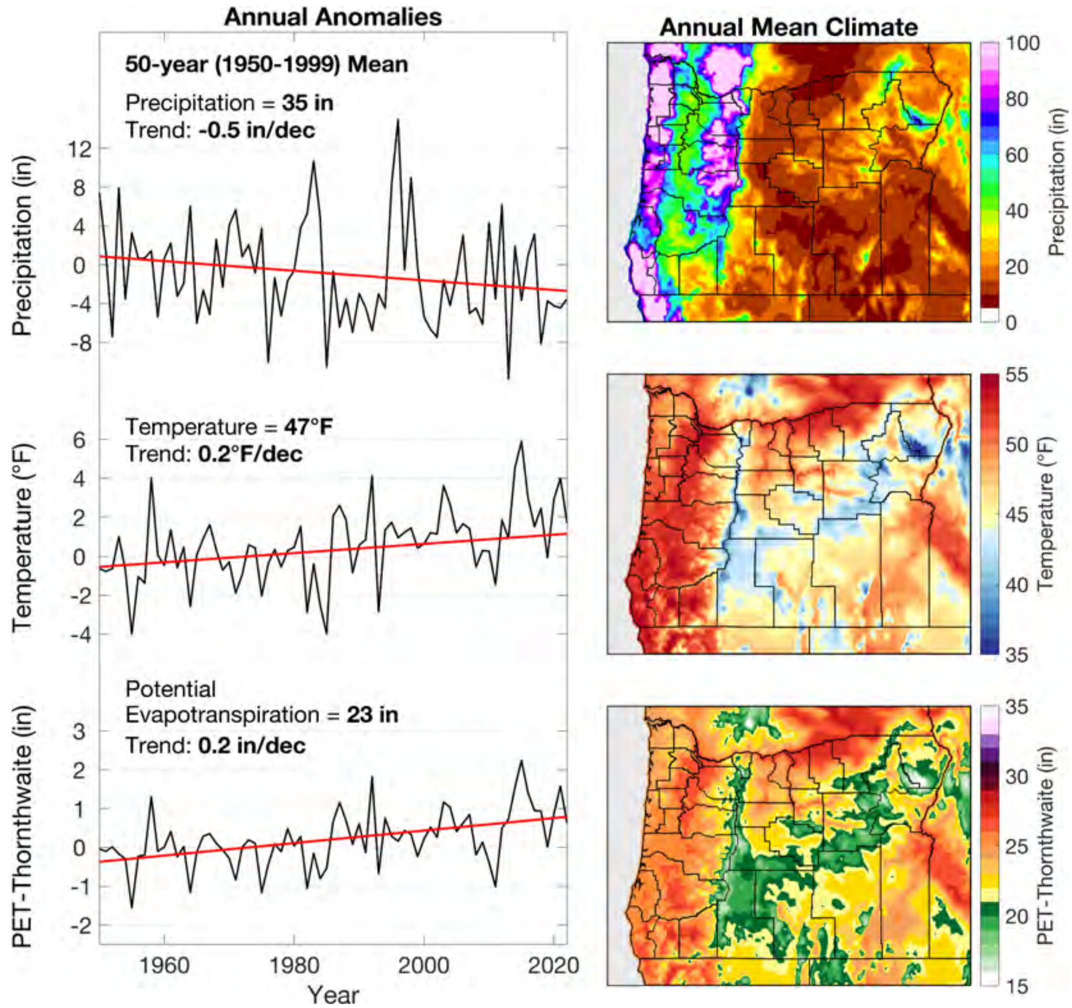

Figure 4. Data derived from PRISM. (Left) Annual anomalies of (top to bottom) precipitation, temperature, and potential evapotranspiration (PET) as calculated with the Thornthwaite equation. Anomalies are the departure from the 1950–1999 mean. Trends were significant above the 95% confidence level. (Right) Time series of annual (top to bottom) precipitation, temperature, and PET as calculated with the Thornthwaite equation for the period 1950–2022.

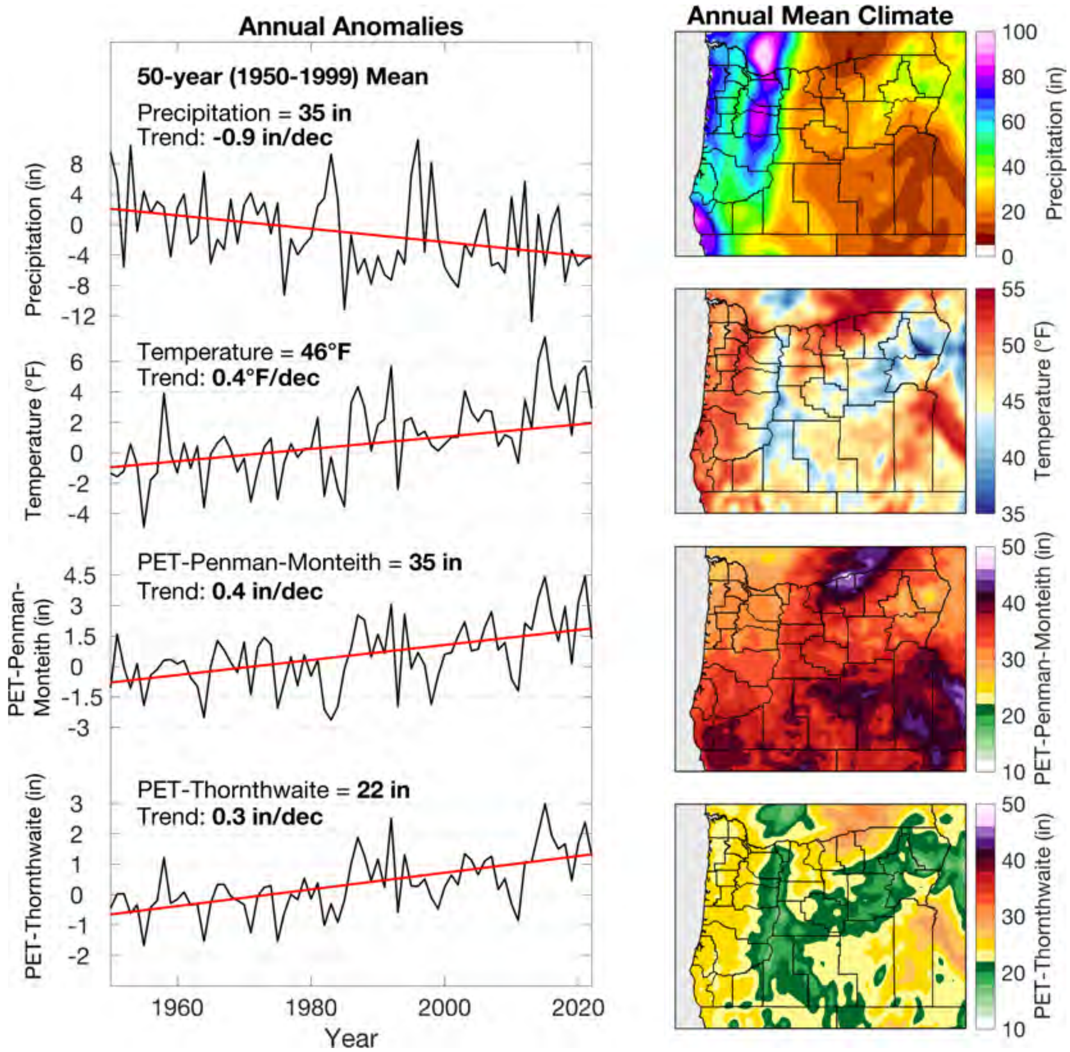

Figure 5. Data derived from ERA5-Land. (Left) Time series of annual anomalies of (top to bottom) precipitation, temperature, and potential evapotranspiration (PET) as calculated with the CO_2-aware Penman-Monteith and Thornthwaite equations. Anomalies are departures from the 1950–1999 mean. Trends were significant at the 95% confidence level. (Right) Time-mean (top to bottom) precipitation, temperature, and PET as calculated with the CO_2-aware Penman-Monteith and Thornthwaite equations for the period 1950–2022.

Trends in annual mean precipitation (P), near-surface (2-m) air temperature (T), and potential evapotranspiration (PET) anomalies from 1950–2022 that were based on PRISM data and defined relative to the 1950–1999 mean were significant at the 95% confidence level. P decreased by 0.5 inches per decade (in dec^{-1}), T increased by 0.4°F dec^{-1}, and PET increased by 0.2 in dec^{-1} (Figure 4). Trends in P, T, and PET that were based on data from the ERA5-Land reanalysis also were statistically significant (Figure 5).

Because ERA5-Land includes more variables than PRISM (sections III.A, III.B), ERA5-based estimates of PET can be calculated with either the Thornthwaite or Penman-Monteith equation

(Equations 1 and 2, respectively). Trends in P, T, and PET that were based on the ERA5-Land data were somewhat greater than those based on PRISM, but the signs and statistical significance of the trends derived from the two sources of data did not differ. The two methods of estimating PET from the ERA5-Land data yielded different annual means (Figure 5). Much larger PET values were predicted by the Penman-Monteith equation than by the Thornthwaite equation. The difference likely reflects that the Thornthwaite equation incorporates monthly data whereas the Penman-Monteith equation incorporates hourly data. The Penman-Monteith equation captures the typically large increase in evapotranspiration that occurs during the warmest part of the day, when the vapor pressure deficit is greatest. Nevertheless, the two equations yielded a similar trend: a robust increase in PET across Oregon since 1950.

Estimates of the trend in annual mean precipitation derived from the PRISM and ERA5-Land data differed substantially. The trend derived from ERA5-Land was nearly double that derived from PRISM (Figures 4 and 5). The differences are most apparent before about 1980, where PRISM indicates about 5–10% less annual precipitation than does ERA5-Land (Figure 6). These differences may be due in part to biases in one or both datasets. However, the differences more likely reflect the relatively coarse spatial resolution of the ERA5-Land precipitation data, which may not adequately resolve the steep elevational gradients characteristic of Oregon's mountain ranges. Despite these differences, the two estimates of statewide precipitation from 1950–2022 were highly correlated (0.97) (Figure 6). Estimates of water year SPI12 that were based on PRISM and ERA5-Land data also were highly correlated (0.95; Figure 6).

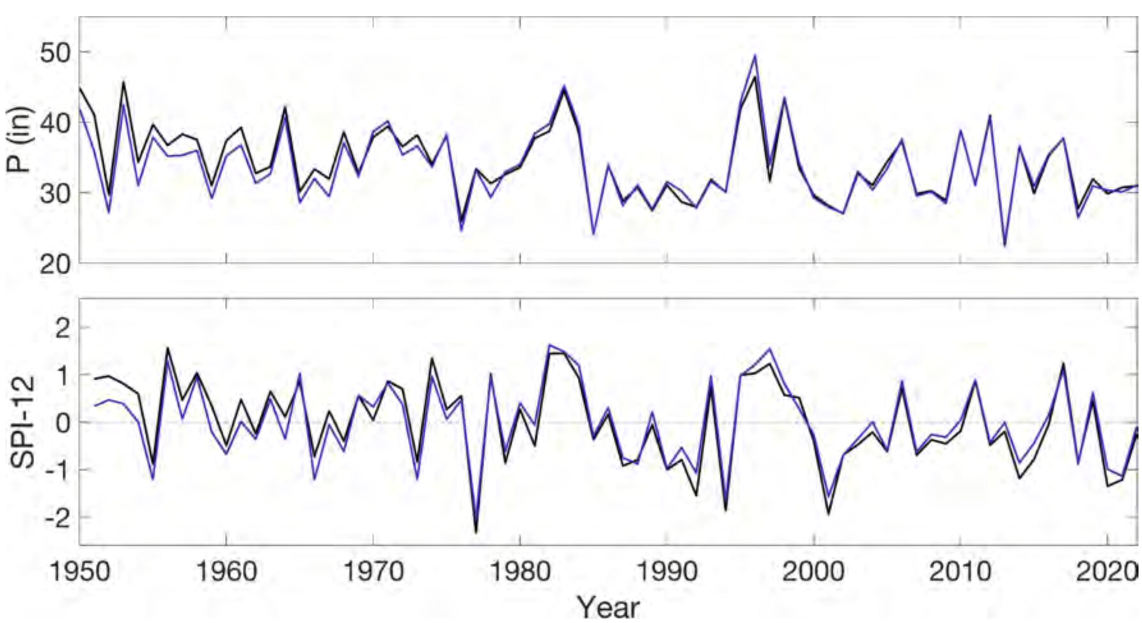

Figure 6. Annual water year precipitation (top) and SPI12 (bottom) in Oregon as estimated from PRISM (blue) and ERA5-Land (black) data. The correlations between the PRISM and ERA5-Land precipitation and SPI12 estimates are 0.97 and 0.95, respectively.

For additional context, we include the monthly mean precipitation correlation between PRISM and ERA5-Land with respect to time (Figure A1) and space (Figure A2). Monthly values were highly correlated in time (Figure A1; $R > 0.95$), which suggests that drought indices derived from either source should be quite similar. The spatial correlations between monthly PRISM and ERA5-Land data (Figure A2) were highest in winter and lowest in summer. The lower correlations in summer may be due in part to the inability of the coarser-resolution ERA5-Land reanalysis to accurately represent summer convection, which usually is the primary source of precipitation, but this shortcoming mainly affects the intensity of drought and not the temporal distribution of drought.

V. Relations between meteorological drought indices and streamflow indices

We investigated the historical relation between drought and streamflow to identify the statewide drought index and temporal extent that best characterizes the co-occurrence of meteorological and hydrological drought. Doing so allows us to analyze a small subset of drought indicators and time scales in our drought history and in future projections. Building on the analysis by Abatzoglou et al. (2014), we examined the relation between the standardized streamflow index (SSI) and various drought indices over a range of temporal extents to determine the best predictors of hydrological drought within different watersheds.

The coefficient of determination (i.e., the squared correlation coefficient, R^2) represents the proportion of variance in the water year Standardized Streamflow Index (SSI_{WY}) that is explained by a given drought index. Values close to one indicate that the drought index is a good proxy for interannual streamflow variability. Although both the SPI and the SPEI were highly correlated with the SSI (R^2>0.7) across all months and temporal extents, the strongest correlations were at extents between 6 and 12 months (i.e., long enough to capture most of the wet season) and over periods beginning in October and ending in spring or summer (i.e., in phase with the wet season) (Figure 7). We were somewhat surprised that the SPI explained a bit more variance in the SSI than either the Thornthwaite or Penman-Monteith version of the SPEI, indicating that streamflow variability is more strongly influenced by precipitation than by potential evapotranspiration. Nevertheless, the correlations with SSI_{WY} were similar across the indices, suggesting that both the SPI and SPEI, when computed over the water year, are reasonable proxies for interannual streamflow variability, and thus reasonable metrics of hydrological drought.

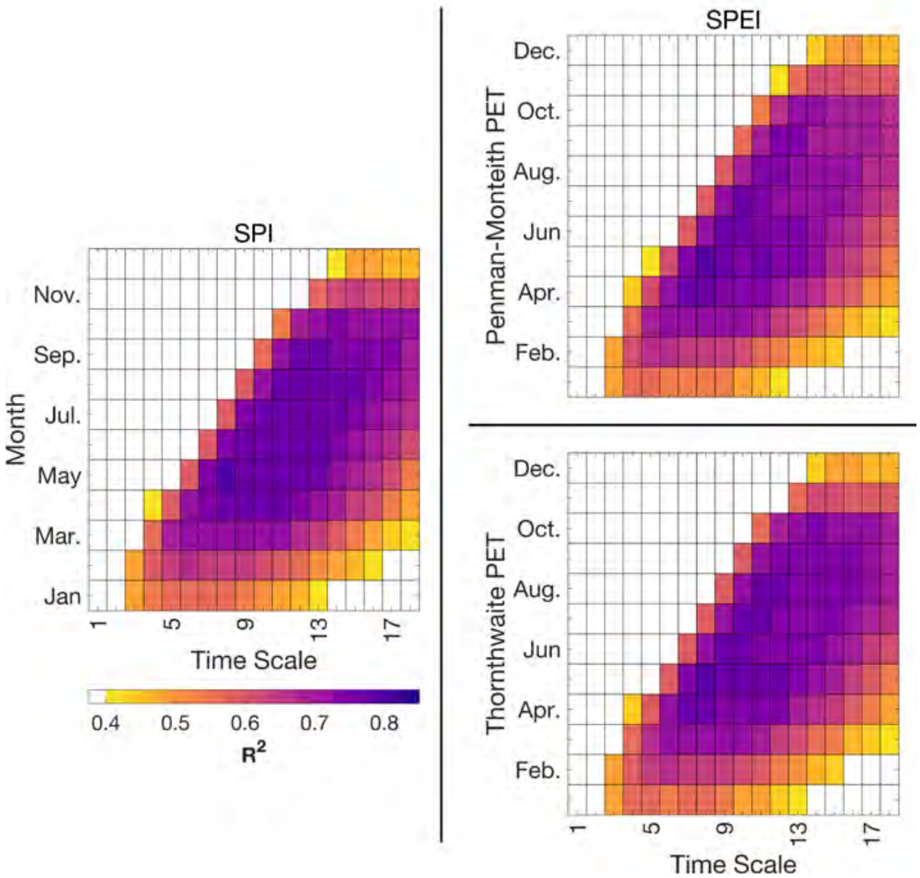

Figure 7. Mean coefficient of determination (R^2) between meteorological drought indices (SPI and SPEI) and the standardized streamflow index (SSI_{WY}) as functions of month (y axis) and temporal extent in months (x axis).

We calculated the coefficient of determination between the SPI12 ending in September and the SSI_{WY} for each watershed upstream of the USGS and OWRD reference gages. Although R^2 values generally exceeded 0.8 in western Oregon, they tended to be weaker east of the Cascade crest ($0.5 < R^2 < 0.75$) (Figure 8). The reasons for the longitudinal gradient are not clear, but we speculate that it reflects a stronger influence of groundwater sources and sinks on annual streamflows in watersheds in eastern Oregon. Alternatively, actual evapotranspiration may not be accurately represented by PET in eastern Oregon. Whatever the cause, the gradient implies that the SPI12 is a more reliable proxy for interannual streamflow variability in watersheds west of the Cascade crest than in watersheds east of the Cascade crest.

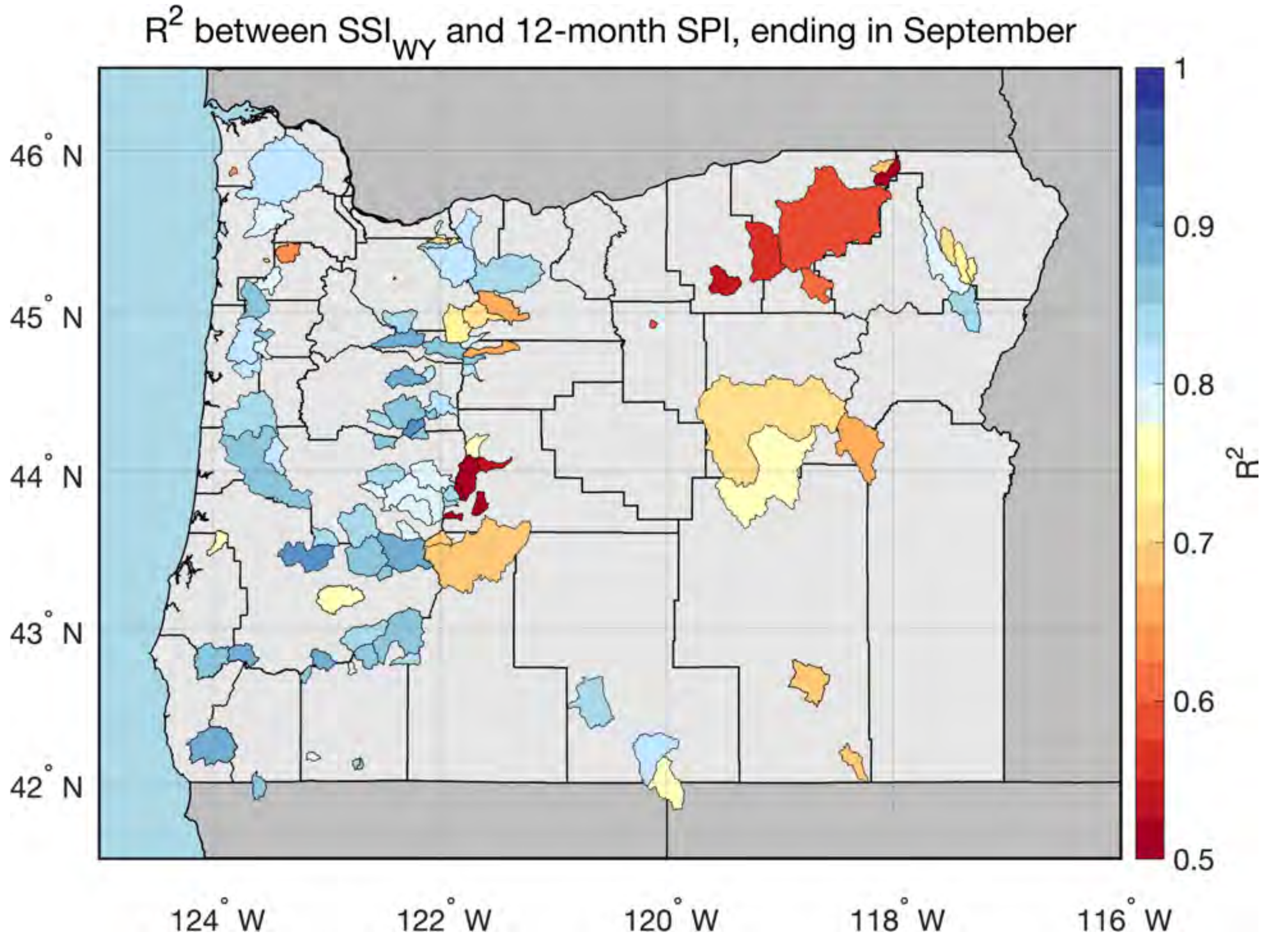

Figure 8. R^2 between SPI12 ending in September and SSI_{WY} for watersheds monitored by the USGS and OWRD reference gages (Figure 3).

VI. Drought history

We provide two perspectives on Oregon's drought history. The first is a statewide characterization that provides perhaps the simplest summary of drought conditions across the state. This summary is incomplete because historical drought varied significantly across the state, particularly east and west of the Cascade Range. To account for this gradient, we provide a summary of the drought history for each of Oregon’s 36 counties.

VI.A. State-level drought history

During 18 of the last 24 water years, Oregon’s water year precipitation was below average (Figure 9). Measured by total statewide precipitation, water years 2001 and 2020 ranked as the third and fifth driest on record, respectively. Since 1896, the five water years with the lowest precipitation statewide were 1977, 1924, 2001, 1994, and 2020. The average temperature in

Oregon was also warmer than normal in 21 of the last 24 water years (Figure 10), which contributed to higher rates of evapotranspiration and more-frequent drought.

The lowest precipitation during a single water year was in 1977, following an exceptionally dry winter (Dickson, 1977). Precipitation was highest during water year 1998. Below-average annual precipitation was common in the 1920s and 1930s. Multiple moderately to extremely wet years occurred during the early 1980s and late 1990s and were at least partially associated with years associated with a Very Strong El Niño, the strongest category.

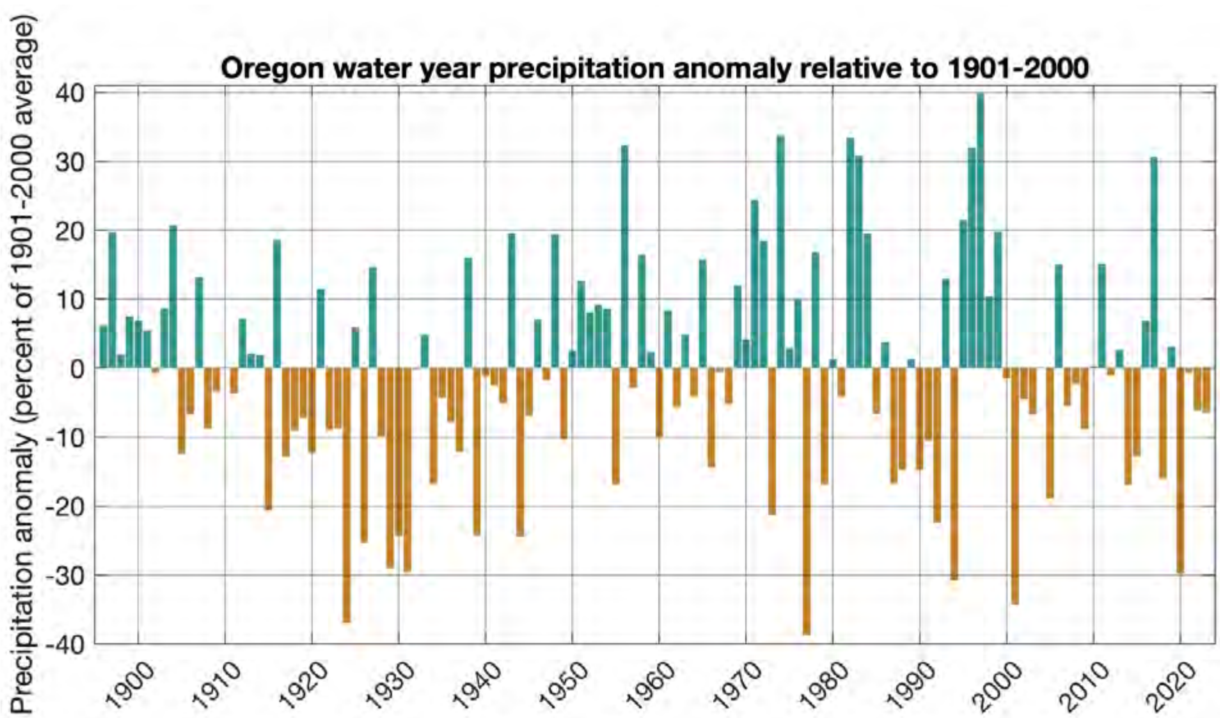

Figure 9. Total water year precipitation (percentage of the 1901–2000 statewide average, 35.32”) averaged across Oregon for each water year from 1896 through 2023. Data from the PRISM Climate Group.

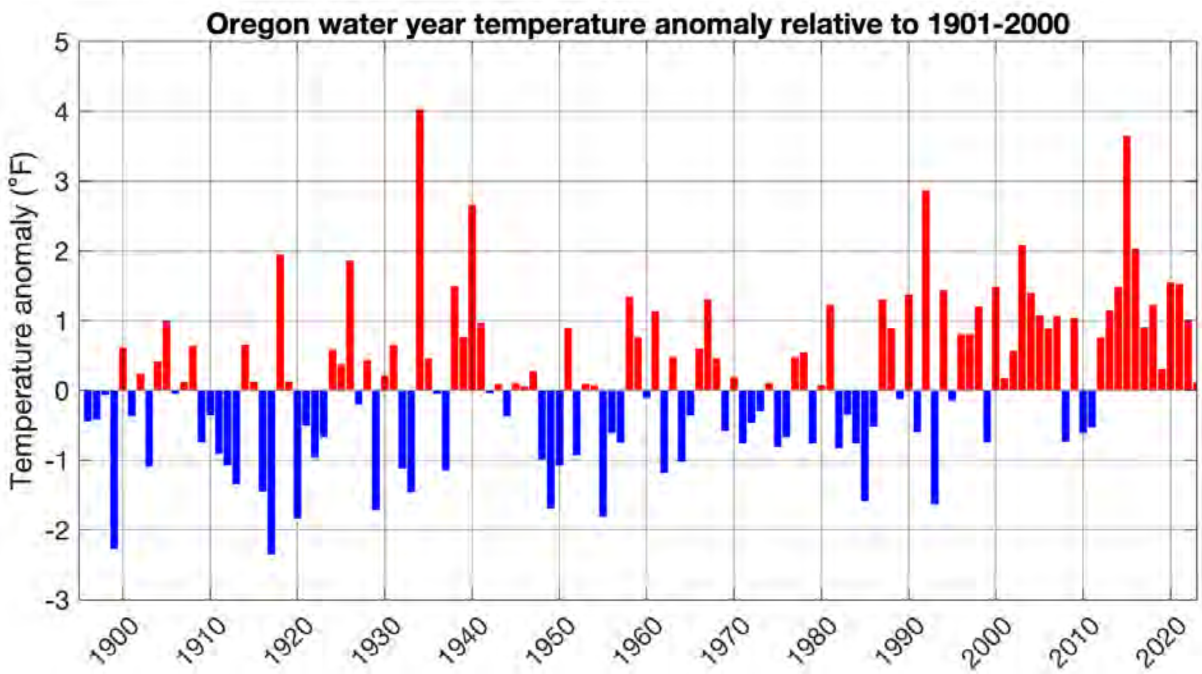

Figure 10. Average temperature in Oregon for each water year from 1896 through 2023. Data from the PRISM Climate Group.

On the basis of the relation between drought and streamflow (section II.B.2), we chose two drought indices for this summary: SPI12, which is based on precipitation only, and SPEI12, which also accounts for potential evapotranspiration as approximated by either the Thornthwaite or Penman-Monteith equation (II.B.2). On the basis of the correlations between streamflow and drought indices, we evaluated state and county-level drought classification with SPI12 and SPEI12 for each county in Oregon. Correlations between drought and streamflow indices in some watersheds were slightly higher over shorter periods of time, but use of a single metric that encompassed the water year retained major drought periods while simplifying presentation. We chose the 12-month period to coincide with each water year represented in the monthly PRISM data (1896–2023). The background colors in the SPI12 and SPEI12 time series (Figures 11 and 12), respectively, correspond to dry conditions as represented by the U.S. Drought Monitor and wet conditions as represented by the Climate Toolbox's U.S. Water Watcher tool (climatetoolbox.org/tool/Historical-Water-Watcher).

To estimate the statewide SPI12 and SPEI12, we computed each index for all grid cells within Oregon, then used an area-weighted mean to average the grid cell values. The SPI12 and SPEI12 indicated three periods of intense drought in Oregon: 1924–1938, 1977, 1987–1993, and 2000–2022. The 1977 drought, while the most exceptional of all single-year droughts according to most metrics, was preceded by three water years that were wetter than normal (1974–1976) and followed by a moderately wet water year (1978). Two multi-year wet periods since 1950 are clear from SPI12 and SPEI12: 1982–1984 and 1995–1999. Both encompassed a Very Strong El Niño (1982–1983 and 1997–1998). Average precipitation across the state during the only other Very Strong El Niño (2015–2016) was slightly lower than normal (Figure 9).

SPI12 calculated from PRISM data indicated that the five water years with the most severe drought were 1924, 1977, 1931, 1994, and 2020 (Figure 11). SPEI12 calculated with the Thornthwaite equation identified 1924, 2020, 1977, 1994, and 1931 as the five water years during which drought was most severe (Figure 12).

Because the SPI and SPEI account for regional and temporal variation in precipitation surpluses and deficits and their relation to historical climate, the most severe drought years according to the statewide SPI12 and SPEI12 are not necessarily the same as those with the lowest average precipitation. January precipitation that is one inch below normal, for example, has a different effect on people living near coastal Newport than inland near Bend or Burns. Precipitation surpluses in one part of the state may be masked by precipitation deficits in other parts. The statewide SPI and SPEI values average such variation and yield a more robust estimate of which areas are experiencing drought conditions.

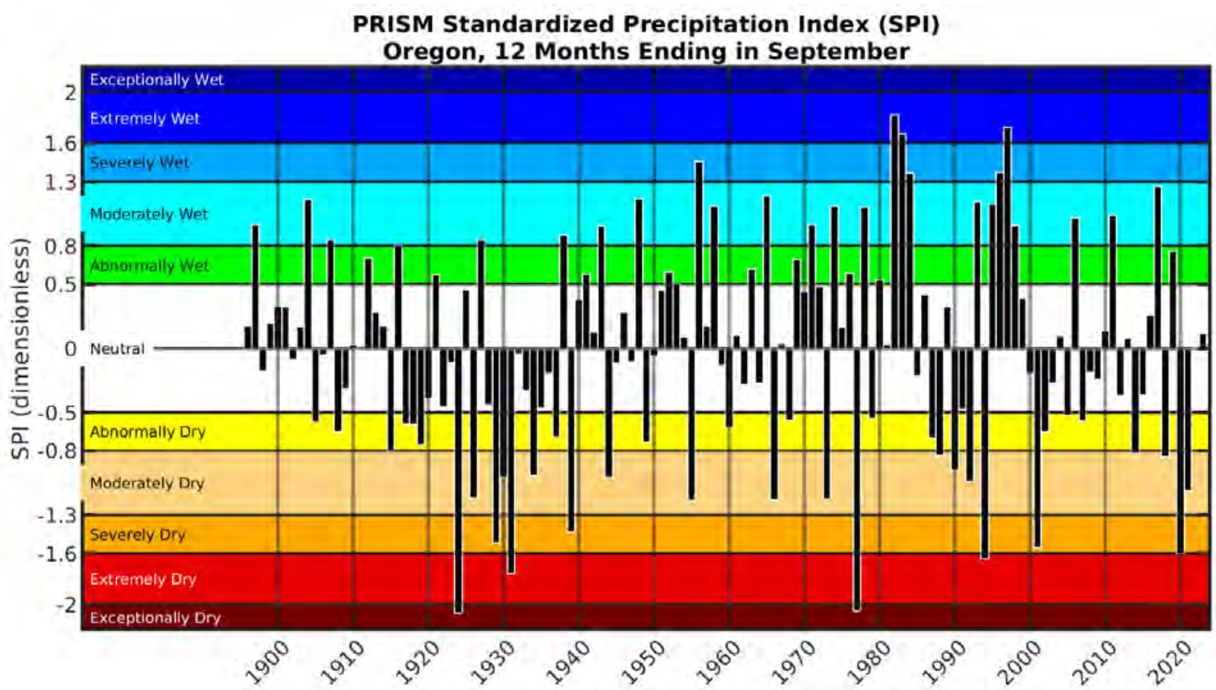

Figure 11. PRISM-derived SPI12 in Oregon for each water year from 1896 through 2023.

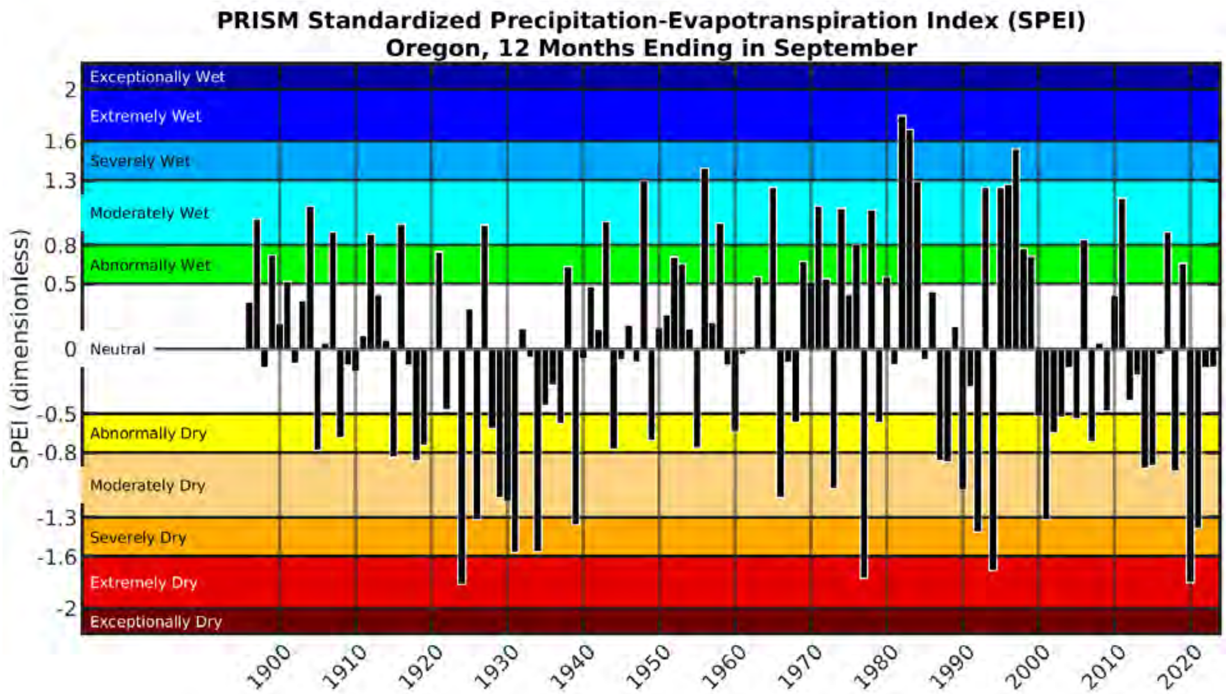

Figure 12. PRISM-derived SPEI12 in Oregon for each water year from 1896 through 2023.

SPI12 and SPEI12 from the ERA5-Land reanalysis data yielded a similar time series of drought in Oregon. In terms of precipitation alone, the five most severe drought years since 1950, in order of SPI12 value (Figure 13), were 1977, 2001, 1994, 1992, and 2020. These years are consistent with those identified by the PRISM-derived SPI12. SPEI12 as calculated with the Thornthwaite and CO_2-aware Penman-Monteith equations for PET yielded slightly different results. SPEI12 in which PET was calculated by the Thornthwaite equation identified the five most severe drought years as 1977, 1994, 1992, 2000, and 2021 (Figure 14). SPEI12 in which PET was calculated by the CO_2-aware Penman-Monteith equation identified the five most severe drought years as 1994, 1977, 1992, 2021, and 2020 (Figure 15). Despite the noticeably different magnitudes of PET as estimated by the Thornthwaite and CO_2-aware Penman-Monteith equations (see Figures 4 and 5), the time series of water year PET predicted by the two methods were almost perfectly correlated (Figures 4 and 5), explaining the strong similarity between the two versions of the SPEI12 (Figures 14 and 15).

According to the PRISM data, drought was relatively rare in Oregon from about 1939 through 1976. During this period, conditions during four water years were categorized as moderate drought on the basis of SPI12: 1944, 1955, 1966, and 1973 (Figure 11). Of these four years, the SPEI12 (Figure 12) categorized 1944 and 1955 as abnormally dry, which is not a formal drought designation, and conditions in 1966 and 1973 as moderate drought. In contrast to PRISM, ERA5-Land water year SPI12 categorized conditions in 1955, 1966, and 1973 as either abnormally dry or moderate drought, but with slightly different intensities and categorizations (Figure 13). The SPEI12 derived from ERA5-Land data and the Thornthwaite equation identified conditions in 1966 and 1973 as abnormally dry, and did not identify drought during the water years of 1951 through 1977 (Figure 14). Results from SPEI12 derived from ERA5-Land data and the Penman-Monteith equation (Figure 15) were the same, with the caveat that conditions during water year 1973 were categorized as moderate drought rather than abnormally dry. We conclude that statewide, Oregon experienced relatively little drought, and primarily drought of low intensity, from 1939 through 1976.

Trends in drought as quantified by these SPEI12 indices derived from ERA5-Land data (Figures 13–15), which appeared to shift from a relatively wet regime during the period from about 1950 through 1980 (with some notable exceptions, e.g., 1977) to a drier regime after 2000, coincide with what has been referred to as a megadrought in the western United States (Williams et al., 2020; Williams et al. 2022). The SPI12 trends indicated a decrease in the drought index of 0.14 per decade (Figure 13), resulting in a shift from abnormally wet in 1950 (y-intercept = 0.51) to abnormally dry in 2022. SPEI12 calculated with the Thornthwaite equation decreased by 0.17 per decade (Figure 14), resulting in a shift from abnormally wet in 1950 (y-intercept = 0.64) to abnormally dry in 2022. SPEI12 calculated with the CO_2-aware Penman-Monteith equation also decreased by 0.17 per decade (Figure 15), resulting in a shift from abnormally wet in 1950 (y-intercept = 0.63) to abnormally dry in 2022. The three trends for the ERA5-Land water year drought indices were statistically significant (two-tailed Student's t-Test, 95% confidence level).

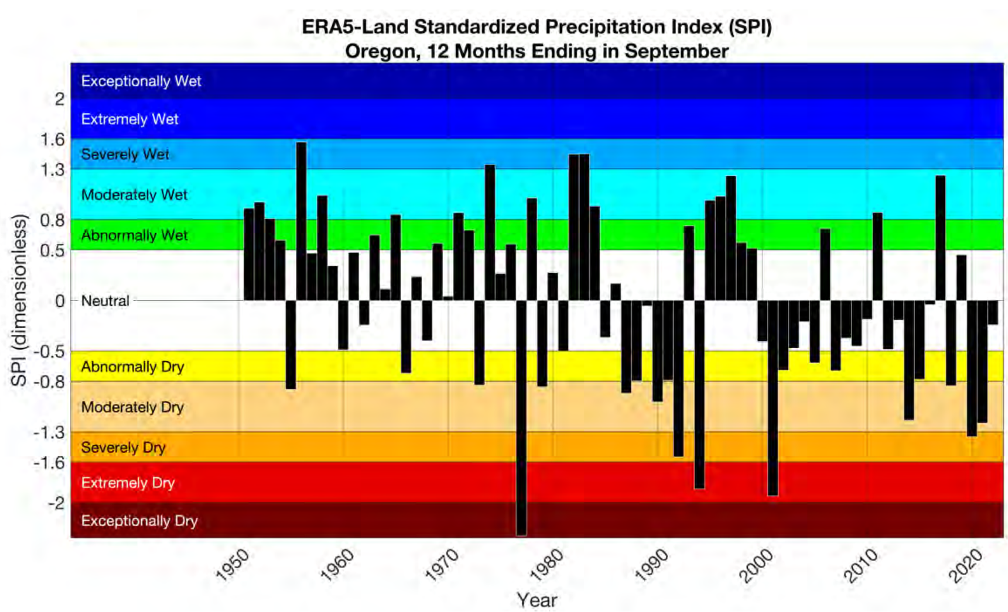

Figure 13. SPI12 in Oregon, calculated from ERA5-Land data, for each water year since 1951.

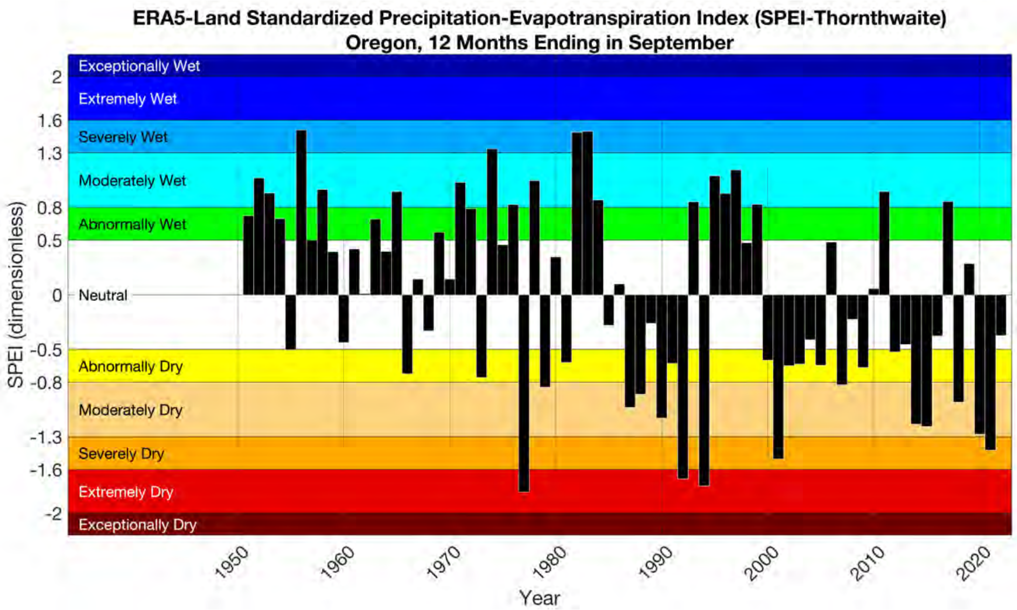

Figure 14. SPEI12 in Oregon, calculated from ERA5-Land data and the Thornthwaite equation for potential evapotranspiration, for each water year since 1951.

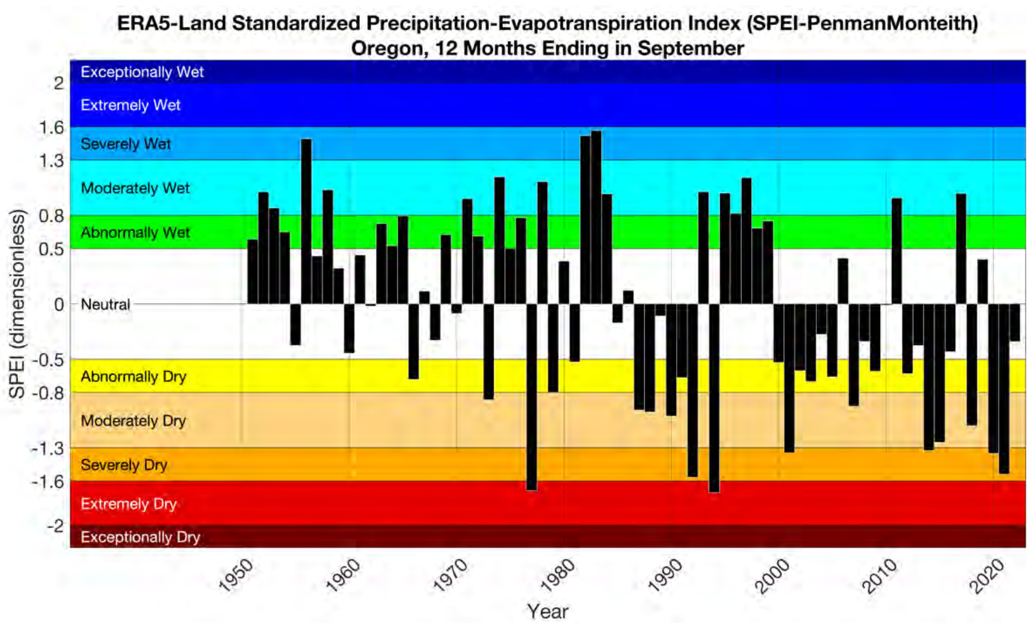

Figure 15. SPEI12 in Oregon, calculated from ERA5-Land data and the CO_2-aware Penman-Monteith equation for potential evapotranspiration, for each water year since 1951.

VI.B. Regional and county-level drought history

The statewide assessment is a useful summary of drought history in Oregon, but may not accurately reflect regional conditions. Oregon is a large state with diverse climate regions and water sources, and environmental conditions can vary substantially from north to south or on either side of the Cascade Range, leading to considerable variability in drought classification. We accounted for regional variability in this drought history by classifying drought at the county level and grouping Oregon's thirty-six counties into six geographic regions, Northwest, Southwest, Northcentral, Southcentral, Northeast, and Northwest (Figure 16). Climate among counties within each region tends to be similar over time. We focused on drought periods at the county level since 1950 because station data that underly the gridded PRISM data prior to 1950 are relatively sparse and uncertain.

Regional human population size decreases from Northwest (which includes the cities of Portland and Salem) to Southwest (Eugene, Roseburg, Grants Pass, and Medford), Northcentral (Bend, The Dalles, and Hood River), Northeast (Pendleton, La Grande, Baker City, and Enterprise), Southeast (Burns), and Southcentral (Klamath Falls, and Lakeview).

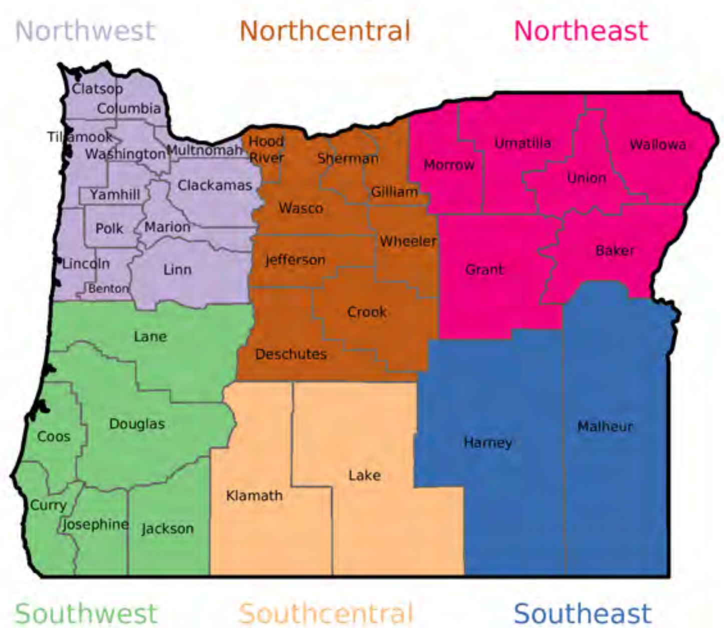

Figure 16. Oregon's thirty-six counties grouped into six regions on the basis of drought conditions.

We identified drought periods in each region, outlining major drought episodes and how these differed from the statewide conditions described above. We based our assessment on time series of regional and county-level drought classification from the PRISM and ERA5-Land-derived water year SPI12 and SPEI12 and seasonal (3-month) SPI and SPEI (denoted as SPI3 and SPEI3, respectively) since water year 1951 (Figures 17–22).

We classified historical drought at the state and regional levels with the PRISM and ERA5-Land-derived SPI and SPEI since 1950 (Figures 17 and 18). We classified drought on the basis of both the water year SPI12 and the water year SPEI12. Additionally, we classified seasonal drought at the state and regional levels on the basis of the 3-month SPI and SPEI. For the seasonal time series, we considered the meteorological seasons of winter (December-January-February; DJF), spring (March-April-May; MAM), summer (June-July-August; JJA), and autumn (September-October-November; SON). The meteorological definition of seasons is shifted by one month relative to the water year. Even so, it is generally clear which seasons contributed most to water year drought. On the whole, the SPEI3 indicated more severe drought during summer than the SPI3 for all regions and in both the PRISM and ERA5-Land data, particularly since about 2014. By contrast, the SPI3 occasionally indicated more severe drought during spring and autumn than the SPEI3.

We compared state and regional level drought on the basis of the ERA5-Land data and both the Thornthwaite and FAO-56 Penman-Monteith formulations of potential evapotranspiration (Figure 19). In general, both equations yielded similar drought classifications. An exception was summer 2021, for which the Thornthwaite SPEI indicated more severe drought than the Penman-Monteith SPEI.

We classified drought at the county level on the basis of water year SPI12 and SPEI12 from PRISM and ERA5-Land data (Figures 20–22). County-level and regional drought histories did not differ appreciably.

VI.B.1. Northwest region

All metrics identified drought in Northwest Oregon during the water years of 1973 (~D1), 1977 (~D4), 1979 (~D2), 1993 (~D2), 1994 (D2-D3), 2001 (D3-D4), 2005 (~D3), 2009 (~D1), 2014–2015 (~D1), and 2019–2021 (D1-D3).

From 1950 through 1973, the Northwest region was essentially drought free with the exception of 1957, when, according to PRISM SPI12, five counties were in D1 (Figure 17). In contrast, ERA5-Land indicated no counties in D1, and three in D0, during 1957 (Figure 18). The SPI12 and SPEI12 values from PRISM and ERA5-Land were similar. The ERA5-Land SPEI12 indicated more intense drought (about one category) during water years 2014–2015 than the SPI12 (Figure 18). The drought categorizations for 2020–2022 from PRISM SPEI12 were about one category less intense than those based on ERA5-Land, particularly for water year 2021 (Figures 17, 18).

VI.B.2. Northcentral region

All metrics identified droughts in Northcentral Oregon during the water years of 1955 (~D2), 1960 (~D1), 1963 (D1-D3), 1965 (~D1), 1967 (~D1), 1973 (D2-D3), 1977 (D2-D4), 1994 (D1-D4), 2001–2002 (~D1-D3), 2004 (D1-D4), 2018 (~D1), and 2020–2021 (~D2-D3). Drought classifications in Hood River County were distinct from those in other counties in the region.

The 1955, 1960, and 1963 droughts in Northcentral Oregon were not apparent across all regions. During 1965, drought also affected the Northeast, Southeast, and possibly the Southcentral regions. The PRISM SPI12 indicated that during 2020, drought was most intense in the Northcentral and Southwest regions (Figure 20). However, the ERA5-Land SPI12 data suggested that drought was most intense in the Northcentral region (Figure 21).

The PRISM SPEI12 indicated that in 2021, the Northcentral region was in D3 (Figure 17), whereas PRISM SPI12 indicated that the region was in ~D2 (Figure 17). The ERA5-Land SPEI12-PM identified ~D3, whereas the ERA5-Land-Thornthwaite indicated ~D2 (Figure 19). The PRISM SPEI12-Thornthwaite indicated ~D3 during 2021.

VI.B.3. Northeast region

All metrics identified droughts in Northeast Oregon during the water years of 1955 (~D2), 1965 (D2-D4), 1973 (D1-D3), 1977 (D3-D4), 1987-1988 (D1-D2), 1990 (~D1), 1992 (D1-D3), 1994 (D1-D3), 2001 (D1-D3), 2004 (D1-D3), 2006 (~D1), and 2020–2021 (~D1). Drought in Morrow County, especially as identified by PRISM, tended to be more intense than in surrounding counties during the last decade. The apparent difference in the regional and county-level drought intensity may reflect low station density.

VI.B.4. Southwest region

All metrics identified droughts in Southwest Oregon during the water years of 1955, 1973, 1977 (D4), 1979 (D1), 1986 (D1), 1990 (~D1), 1992 (~D1), 1994 (D3-D4), 2001 (D4), 2014 (D1-D3), 2018 (D1), 2020 (~D3), and 2021 (~D1).

VI.B.5. Southcentral region

All metrics identified droughts in Southwest Oregon during the water years of 1955 (D2-D3), 1959 (D1), 1967 (D1), 1977 (D2-D3), 1992 (D1-D2), 1994 (D2-D3), 2001 (D1-D3), 2020 (D3), and 2021 (D2-D3).

VI.B.6. Southeast region

All metrics identified droughts in Southeast Oregon during the water years of 1954–1955 (D1), 1965 (D3-D4), 1977(D3), 1988 (D1-D2), 1990 (~D2), 1992 (D1), 1994 (D2), 2002 (D2), 2006 (D2), 2012 (D1-D2), 2014 (D1), 2018 (D1), and 2020-2021 (D1-D2). The ERA5-Land estimate of the intensity of the 2020–2021 drought was one or two categories more intense than the PRISM estimate (SPI12, Figures 17 and 18; SPEI12, Figures 19–21).

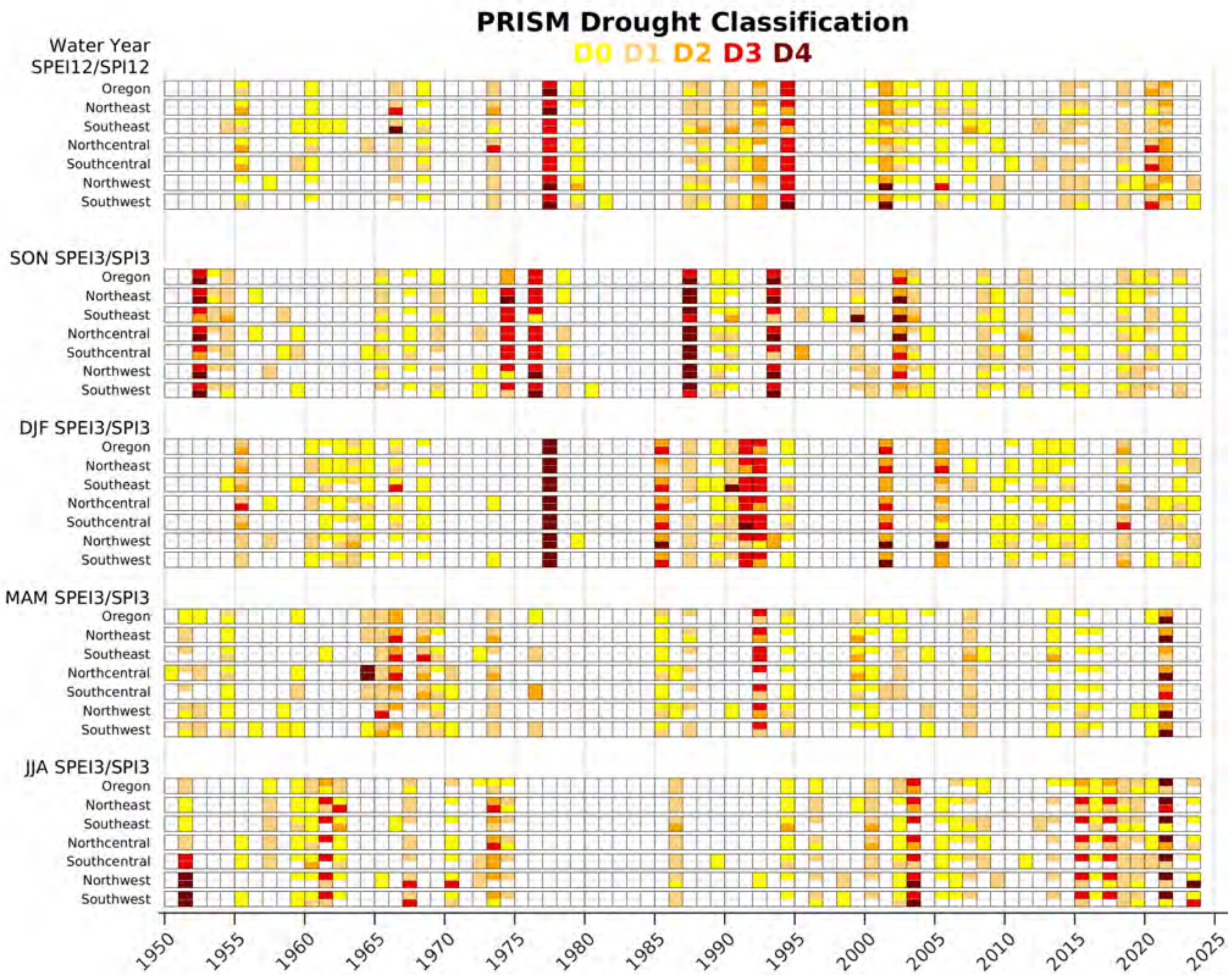

Figure 17. Regional drought categorization based on the PRISM-derived SPEI (top of split tile; computed with the Thornthwaite PET equation) and SPI (bottom of split tile) for each water year. Top set of rows: water-year SPEI12 and SPI12. Lower sets of rows: SPEI3 and SPI3 for each meteorological season. Colors correspond to the U.S. Drought Monitor drought classes D0-D4 according to the legend in the title. Tiles without color indicate either neutral or wet meteorological conditions.

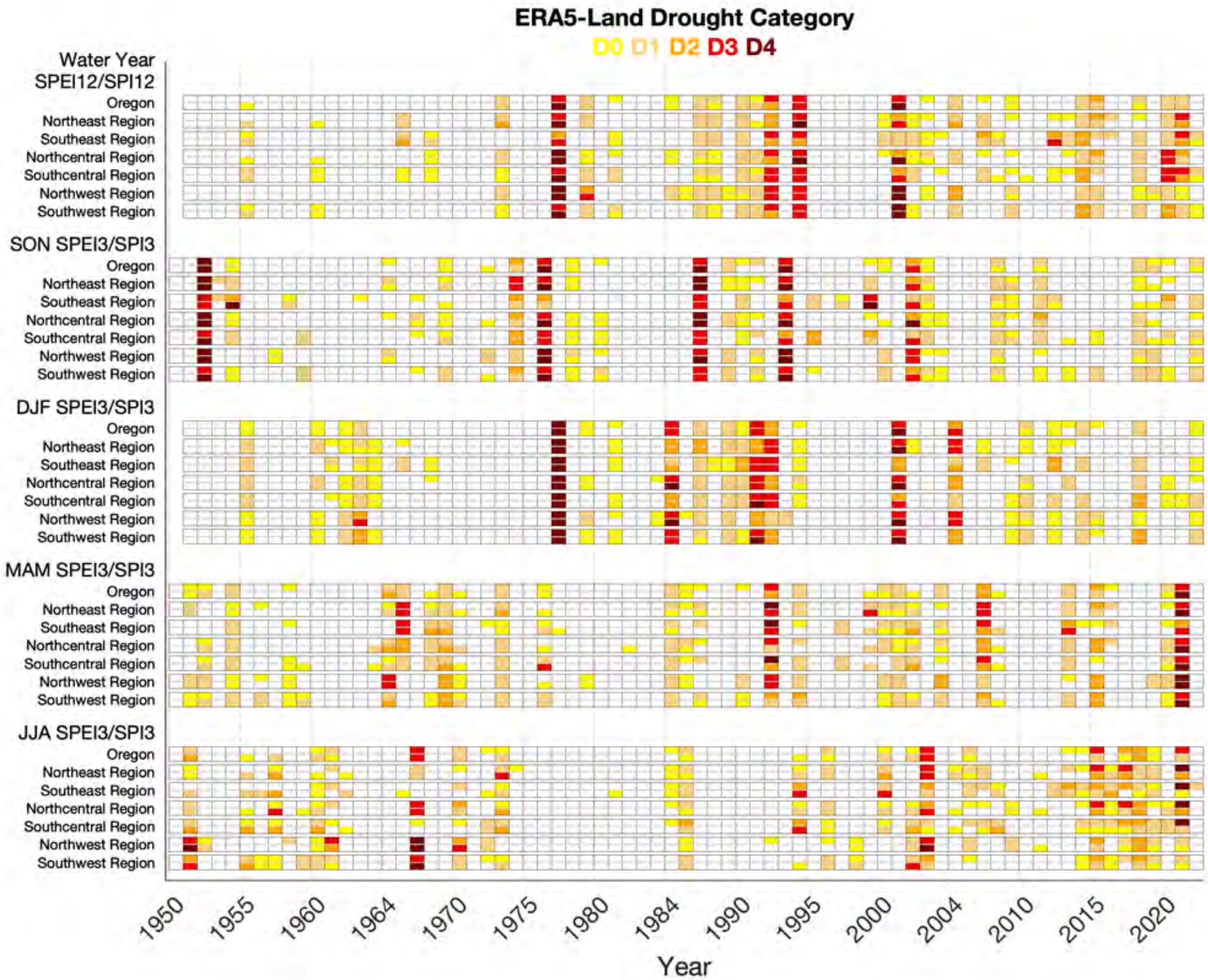

Figure 18. Regional drought categorization based on the ERA5-Land-derived SPEI (top of split tile; computed with the Thornthwaite PET equation) and SPI (bottom of split tile) for each water year since 1950. Top set of rows: water-year SPEI12 and SPI12. Lower sets of rows: SPEI3 and SPI3 for each meteorological season. Colors correspond to the U.S. Drought Monitor drought categories D0-D4 according to the legend in the title. Tiles without color indicate either neutral or wet meteorological conditions.

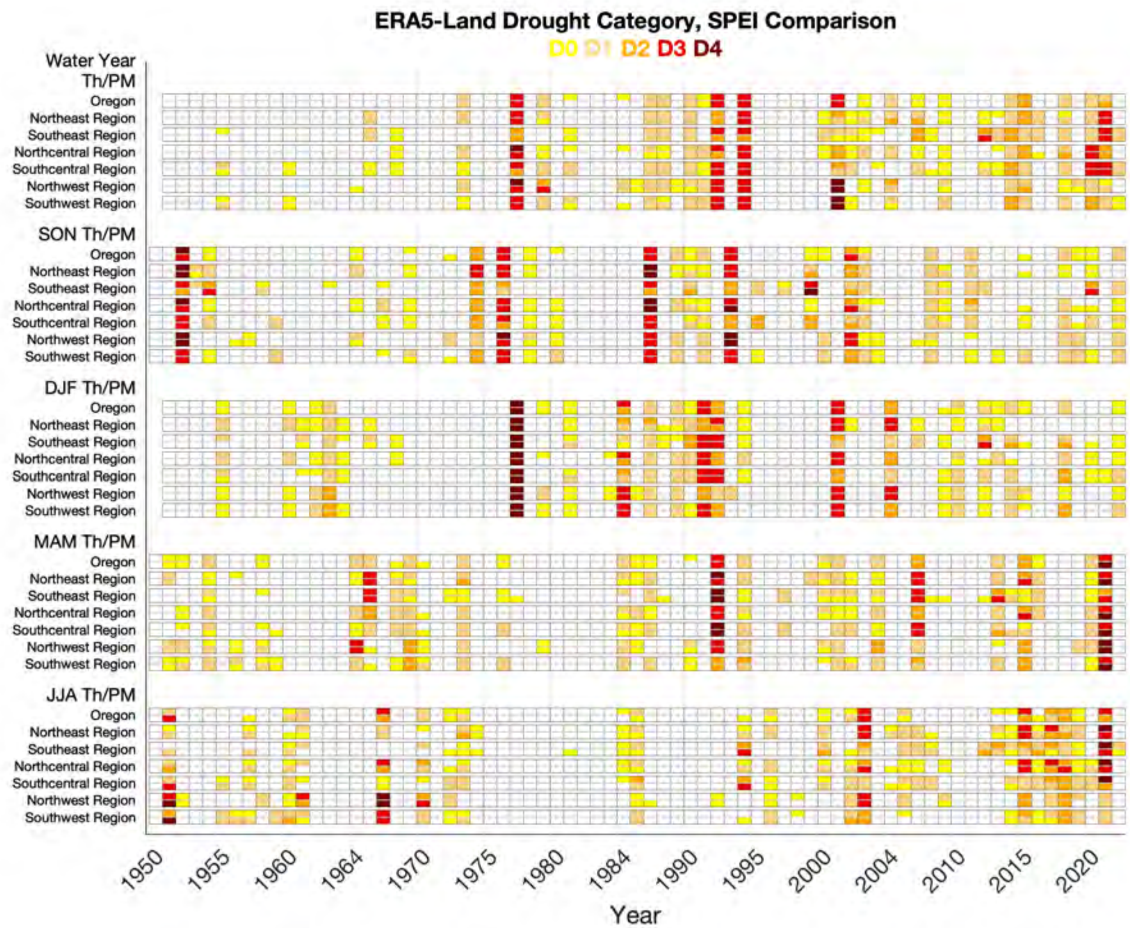

Figure 19. Regional drought categorization based on the ERA5-Land SPEI computed with the Thornthwaite PET (Th; top of tile) and FAO-56 Penman-Monteith PET (PM; bottom of tile) equations. Top set of rows: water year SPEI12. Lower sets of rows: SPEI3 for each meteorological season. Colors correspond to the U.S. Drought Monitor drought categories D0-D4 according to the legend in the title. Tiles without color indicate neutral or wet meteorological conditions.

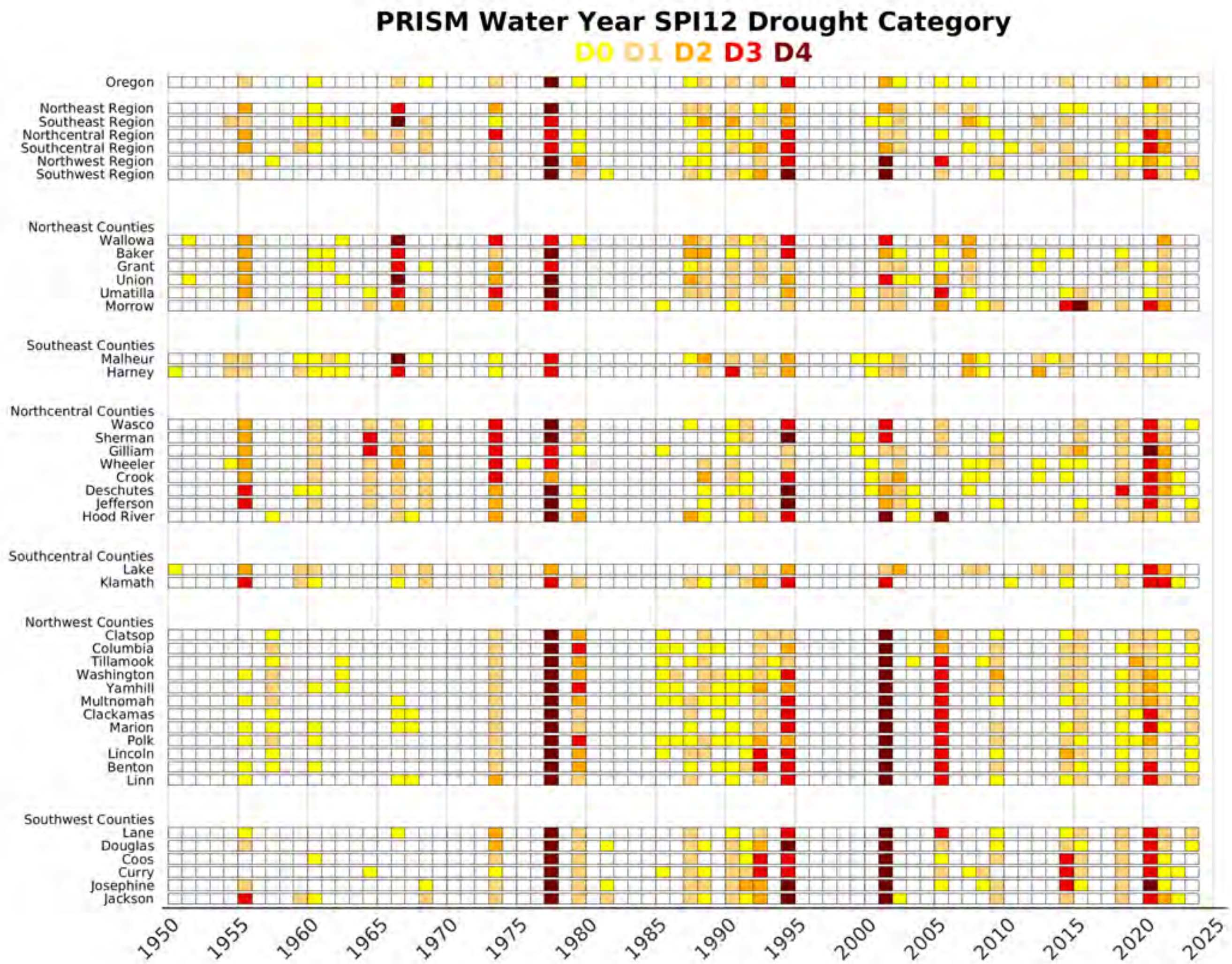

Figure 20. County-level drought categorization based on the PRISM-derived SPI12 for each water year. Colors correspond to the U.S. Drought Monitor drought categories D0-D4 according to the legend in the title. Tiles without color indicate either neutral or wet meteorological conditions.

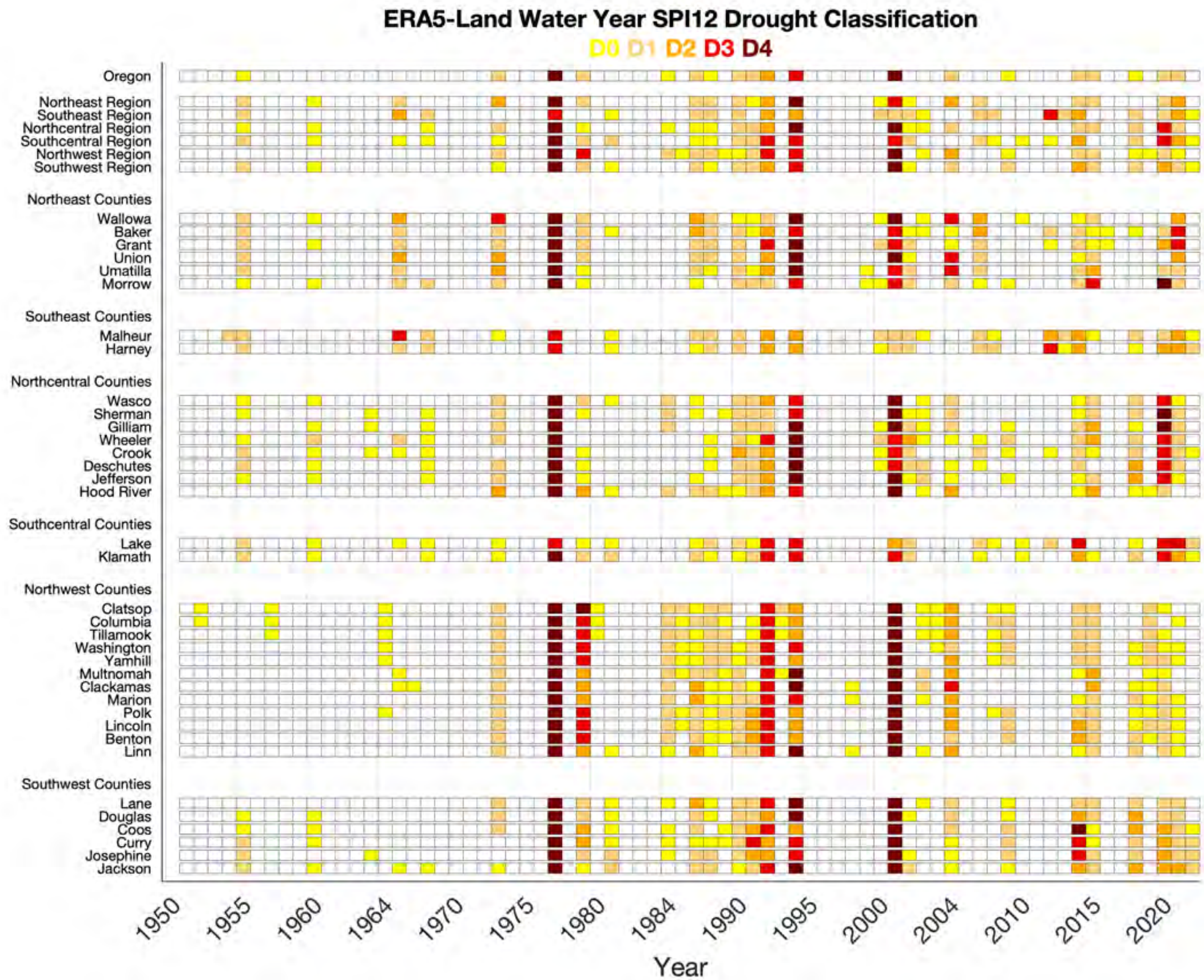

Figure 21. County-level drought categorization based on the ERA5-Land SPI12 for each water year. Colors correspond to the U.S. Drought Monitor drought categories D0-D4 according to the legend in the title. Tiles without color indicate either neutral or wet meteorological conditions.

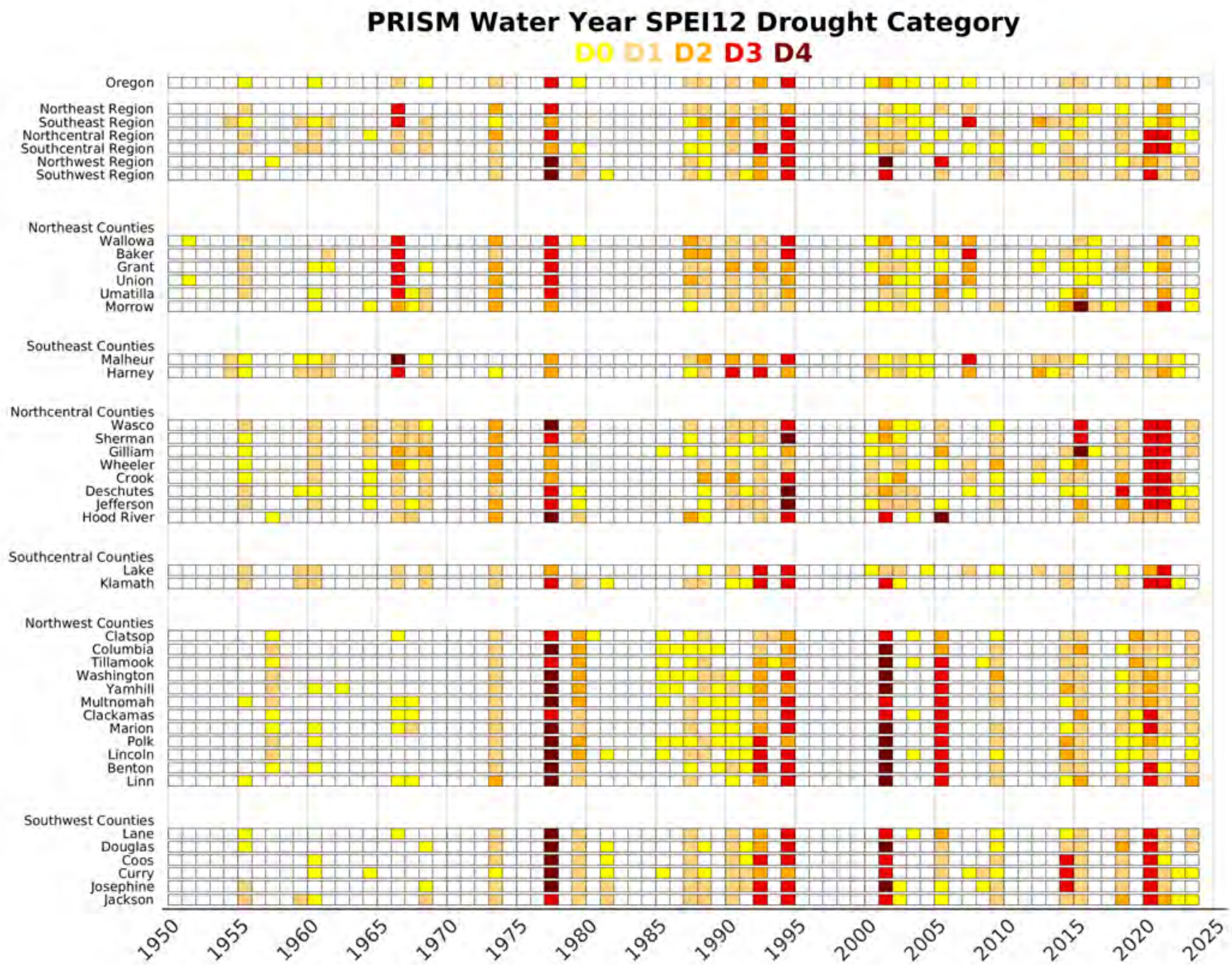

Figure 22. County-level drought categorization based on the PRISM-derived SPEI12 for each water year. Colors correspond to the U.S. Drought Monitor drought categories D0-D4 according to the legend in the title. Tiles without color indicate either neutral or wet meteorological conditions.

VII. Projections of future drought

Projections of future drought usually are based on one of two types of analysis (Hrachowitz et al., 2017). The first, sometimes called the bottom-up approach, directly simulates changes in streamflow and soil moisture on the basis of Earth System Models (ESM) forced with projected greenhouse gas concentrations. ESMs include atmospheric and ocean models that are similar to those in traditional climate models, but incorporate an interactive land-surface model that allows vegetation, surface albedo, and soil moisture to respond dynamically to changes in climate and greenhouse gas concentrations. ESM simulations generally predict that over the twenty-first century, streamflow and root-zone soil moisture in Oregon will decrease in summer, increase in winter, and have a similar annual mean (Lai et al., 2023; Zhou et al., 2023). However, the ~100-km horizontal resolution of most ESM simulations is too coarse to resolve the coastal and orographic effects that modulate Oregon's climate and hydrology.

A second method of projecting drought is to calculate the indices used to assess historical drought conditions, but with meteorological variables derived from climate model simulations rather than historical observations or reanalysis. This type of analysis does not require an interactive land-surface model, and therefore can be performed with output from any standard climate model. There are three major caveats to this second method.

First, most global climate models have the same resolution limitations as ESMs. We attempted to mitigate this limitation by restricting our analysis to an ensemble of regional climate model simulations (NA-CORDEX) with horizontal resolutions of 25 km (Mearns et al., 2016). Although this resolution is too coarse to capture the sharpest climate gradients in the Coast Range and Cascade Range, it is a substantial improvement over standard global models in which these mountain ranges are unresolved.

Second, accurate calculation of indices that incorporate PET, such as SPEI, requires accounting for changes in plant physiology driven by rising CO_2 concentrations. If these changes are not incorporated into the PET calculation, the indices will exaggerate the increase in aridification and drought risk as climate changes (Lemordant et al., 2017; Yang et al., 2018; Scheff et al., 2022). To address this issue, we calculated the SPEI with a version of the Penman-Monteith equation that accounts for rising CO_2 concentrations (Equation 2) (Yang et al., 2018). When forced with meteorological inputs from ESM simulations, this equation yields future drought trends that are in good agreement with drought metrics computed directly by the same ESMs, whereas the Thornthwaite and non-CO_2-aware (FAO-56) Penman-Monteith equations exaggerate the magnitude and intensity of future aridification (Yang et al., 2018; Scheff et al., 2022). For the sake of comparison, however, we also included projections based on the Thornthwaite and FAO-56 approximations of PET.

Third, CO_2-aware drought indices such as the SPEI are better predictors of long-term changes in root-zone soil moisture than of streamflow (Yang et al., 2018; Scheff et al., 2022). This is because the ratio of runoff to precipitation (the runoff ratio) is highly sensitive to changes in the temporal characteristics of precipitation, which might include shifts in the seasonal cycle and changes in the relative frequency of extreme versus moderate precipitation events (Scheff et al., 2022). Such changes are widely expected with projected climate change, but their hydrologic impacts are not well captured by any drought index, including those that account for rising CO_2 concentrations.

The 7 NA-CORDEX simulations from 1950 to 2100 projected statistically significant (95% confidence level) increases in statewide P and PET (Figures 23 and 24). Annual-mean P increased by 0.27 inches per decade (Figure 23). PET estimated with the CO_2-aware Penman-Monteith equation increased by 0.25 inches per decade (Figure 24), which can be expected to largely offset the projected increase in precipitation. The Thornthwaite and FAO-56 Penman-Monteith equations, which again do not account for expected changes in plant physiology driven by rising CO_2 concentrations, yielded larger (and likely unrealistic) PET trends of 0.47 and 0.41 inches per decade, respectively (Figure 24).

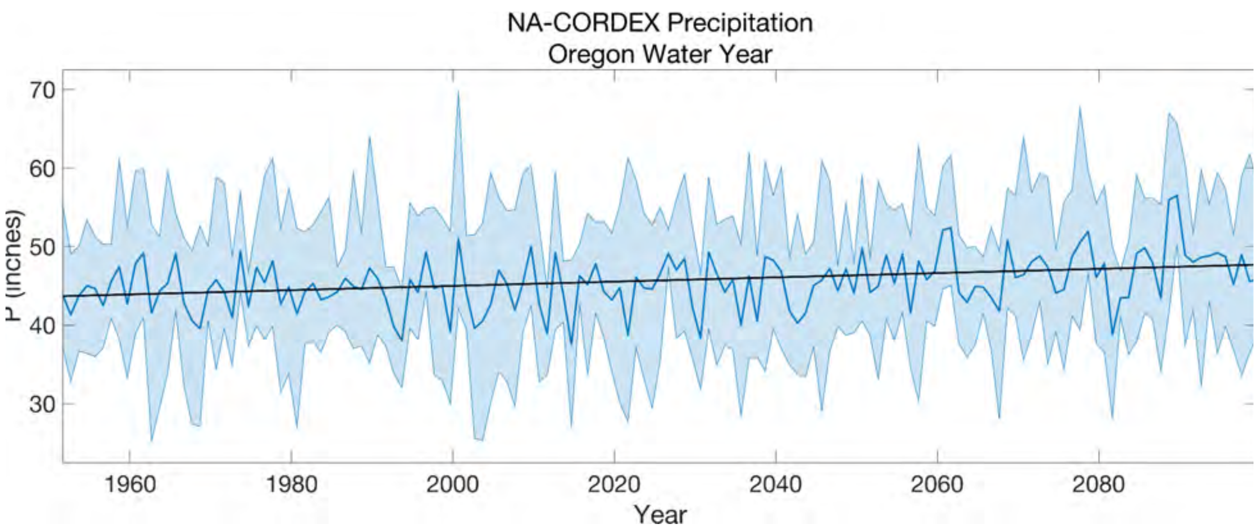

Figure 23. Statewide water year precipitation (inches) in the 7-member NA-CORDEX-22i ensemble from 1950–2099. The solid blue line represents the ensemble mean and the blue shading represents the ensemble range. The linear trend (solid black line) is +0.27 inches per decade and was statistically significant (two-tailed Student's t-test, 95% confidence level).

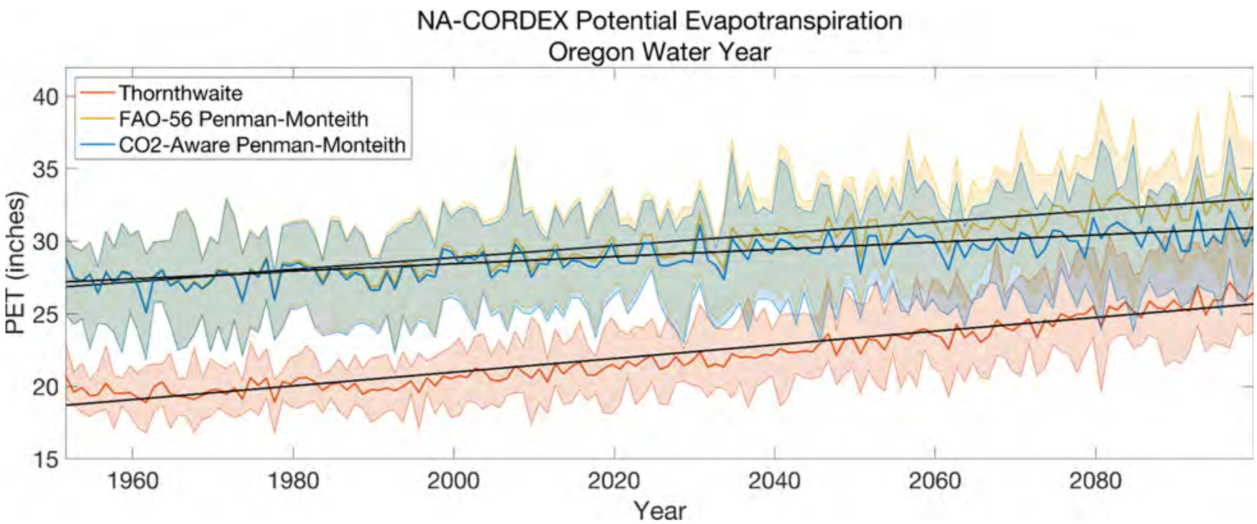

Figure 24. Statewide water year potential evapotranspiration (inches) in the 7-member NA-CORDEX-22i ensemble from 1950–2099. We used three different equations to estimate PET: FAO-56 Penman-Monteith (yellow), CO_2-aware Penman-Monteith (blue), and Thornthwaite (orange). Solid lines represent the ensemble mean and shading represents the ensemble range. The linear trends (solid black lines) were significant at the 95% confidence level, and were 0.41 (FAO-56 Penman-Monteith), 0.25 (CO_2-aware Penman-Monteith), and 0.47 (Thornthwaite) inches per decade.

Consistent with the projected increase in P, the ensemble mean NA-CORDEX simulations projected significant positive increases of 0.05 per decade in statewide SPI12 (Figure 25; green). Because of the increase in PET, however, the CO_2-aware Penman-Monteith equation did not project a statistically significant change in SPEI12 (Figure 25, blue), whereas the Thornthwaite equation projected a statistically significant negative trend of -0.023 per decade (Figure 25, orange).

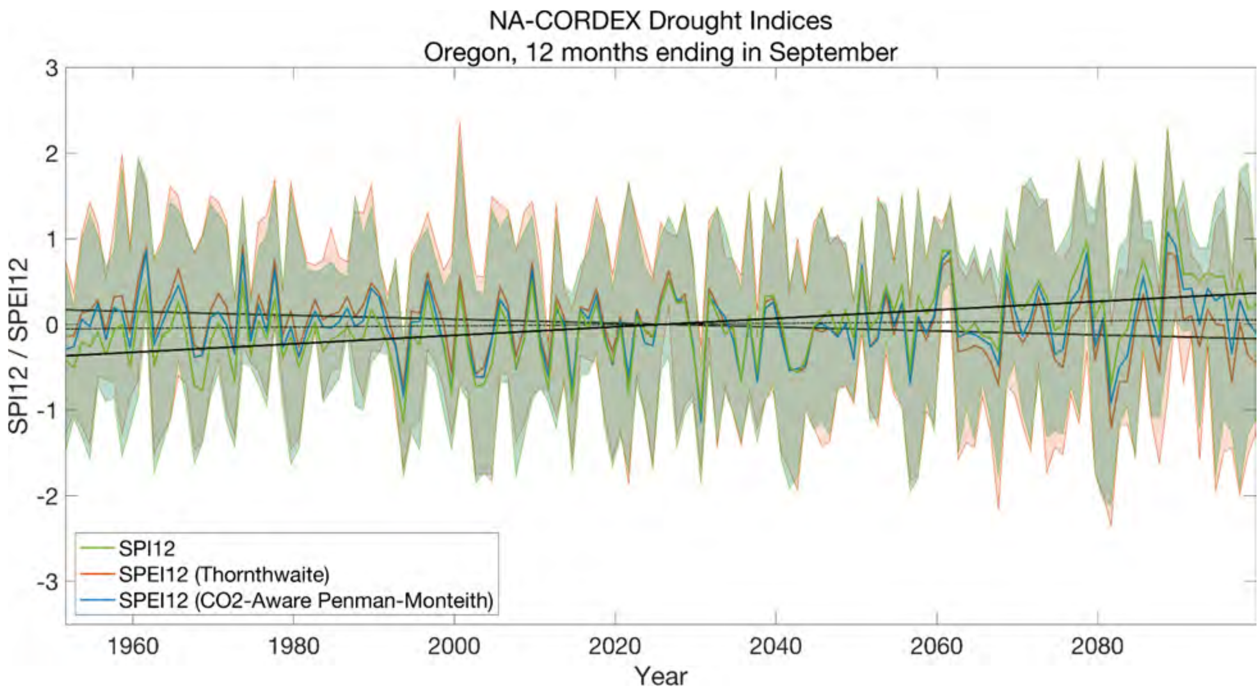

Figure 25. Statewide estimates of water year SPI12 (green), SPEI12 (CO_2-aware Penman-Monteith; blue), and SPEI12 (FAO-56 Penman-Monteith; orange) based on precipitation and PET projections from the 7-member NA-CORDEX-22i ensemble from 1950–2099. The linear trends (solid black lines) are +0.05 per decade (statistically significant) for the SPI, +0.0073 per decade (not statistically significant) for the CO_2-aware Penman-Monteith SPEI12, and -0.023 per decade (statistically significant) for the Thornthwaite SPEI12.

Regional projections are more complex, with significant variability in both the magnitude and sign of the trends (Figure 26). Most increases in precipitation were projected to occur east of the Cascade Range, where the average trends exceeded 0.3 inches per decade. Significantly positive trends occurred west of the Cascade Range in the Rogue Valley and northern Willamette Valley. In contrast, a decrease in P was projected for much of the west slopes of the Cascade and Coast Ranges, but the negative trends were statistically significant only in the southwestern corner of the state (Curry County) and in parts of eastern Linn and Marion Counties near Detroit Lake.

Regional trends in PET were less variable, with significant increases projected across the state regardless of the equation used to compute PET. Consistent with the statewide trends (Figure 24), the CO_2-aware Penman-Monteith equation yielded a smaller negative trend than the FAO-56 Penman-Monteith or the Thornthwaite equations.

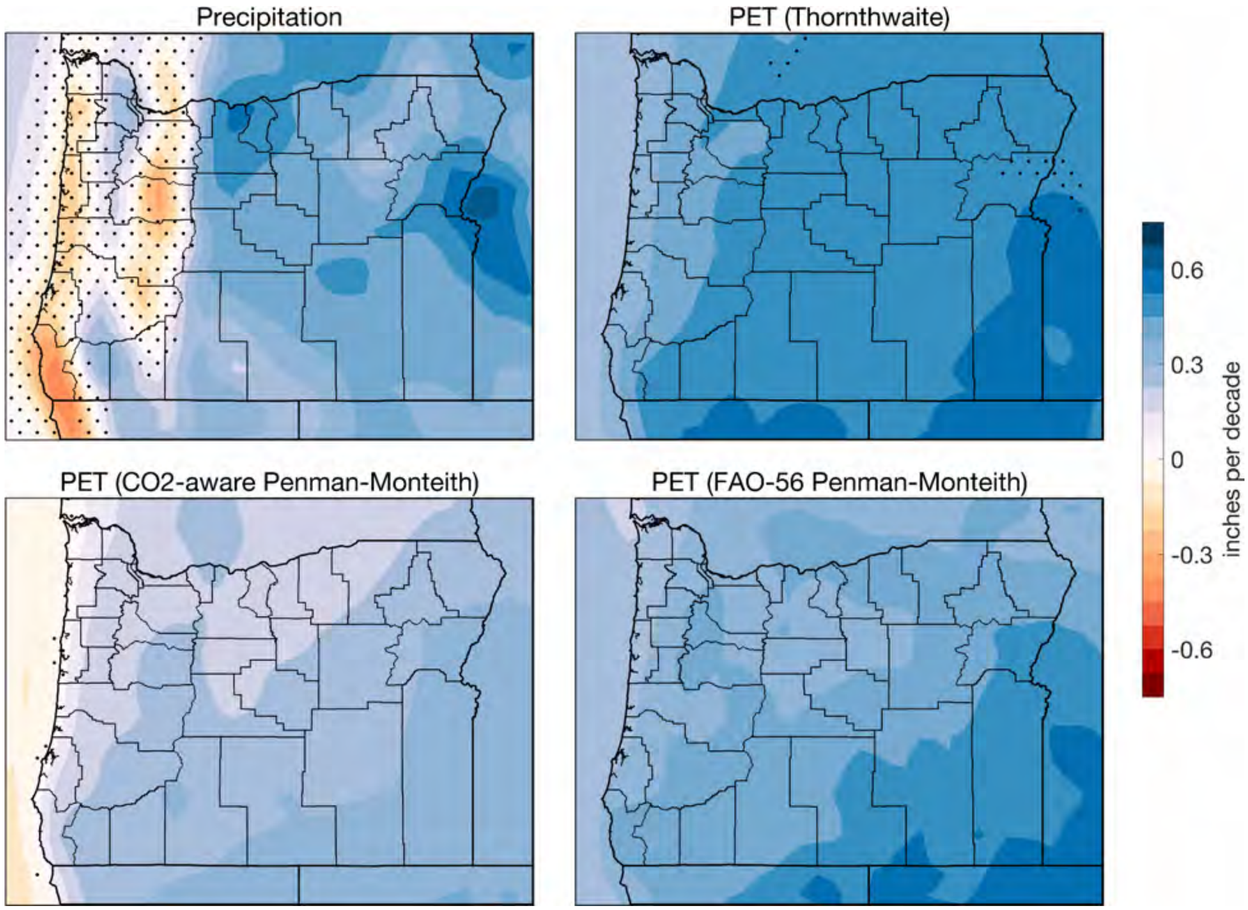

Figure 26. Linear trends in P and PET from 1950–2099 in the ensemble mean of the NA-CORDEX simulations. Stippling indicates that trends were not statistically significant at the 95% confidence level.

The spatial trends in SPI12 (Figure 27) and precipitation (Figure 26) were similar, albeit with somewhat different magnitudes. The spatial pattern of SPEI12 and P trends was also similar, but offset by the relatively spatially uniform increase in PET. The Thornthwaite and FAO-56 Penman-Monteith equations projected significant decreases in SPEI12 across most of the state, whereas the more realistic CO_2-aware Penman-Monteith equation yielded a significant decrease only along the western slopes of the Cascade and Coast Ranges, with a significant increase in the lower Deschutes basin of north-central Oregon; changes elsewhere were not statistically significant.

Even in regions where trends in the SPI12 and SPEI12 were positive, changes in the seasonal cycle of precipitation still may result in a greater risk of drought during parts of the year. Seasonal trends in the 3-month SPI (SPI3; Figure 28) suggest that precipitation across most of the state likely will increase during winter and spring but decrease during summer, particularly in western Oregon. Increases in PET also will be greatest during summer, resulting in a significant statewide decrease in the 3-month SPEI (SPEI3; Figure 29) and increased incidence of short-term drought during the growing season in which water demand is greatest.

In summary, whereas the NA-CORDEX simulations indicate that precipitation likely will increase across much of the state during the twenty-first century, the increase is most likely to occur east of the Cascade Range. Projected changes in precipitation in western Oregon are more uncertain. In contrast, PET is projected to increase across the state, with the effects of increasing CO_2 concentrations on plant physiology only partially offsetting the increase in vapor pressure deficit due to warmer temperatures. If SPEI12 is interpreted as a proxy for root-zone soil moisture, then these results suggest that drought risk likely will increase over the twenty-first century on the western slopes of the Cascade Range and the southern Coast Range, decrease in the Deschutes and John Day basins in north-central Oregon, and change little elsewhere. However, due to a shift in the seasonal distribution of precipitation, drought risk during summer is likely to increase statewide.

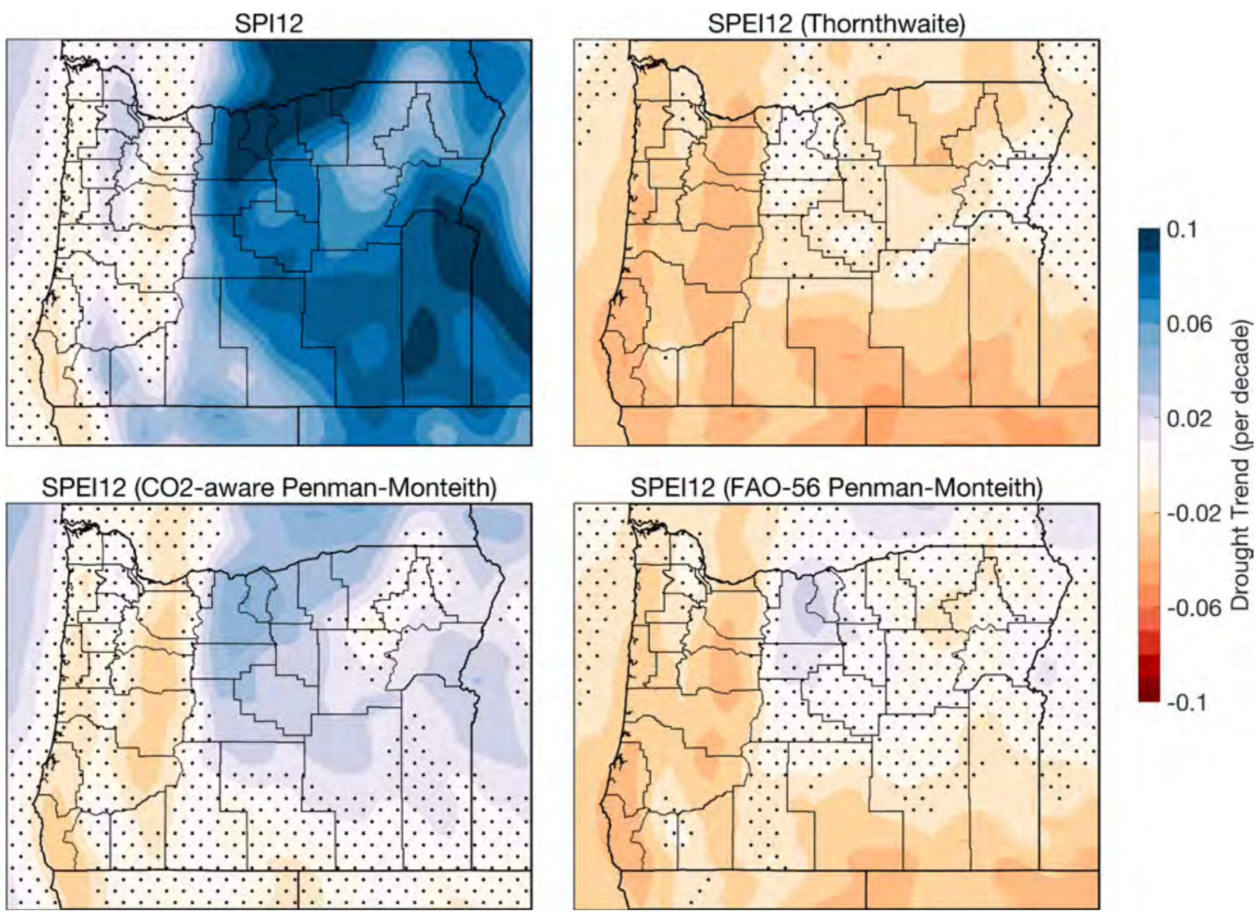

Figure 27. Linear trends in SPI12 and SPEI12 from 1950 through 2099 in the ensemble mean of the NA-CORDEX simulations. Stippling indicates that trends were not statistically significant at the 95% confidence level.

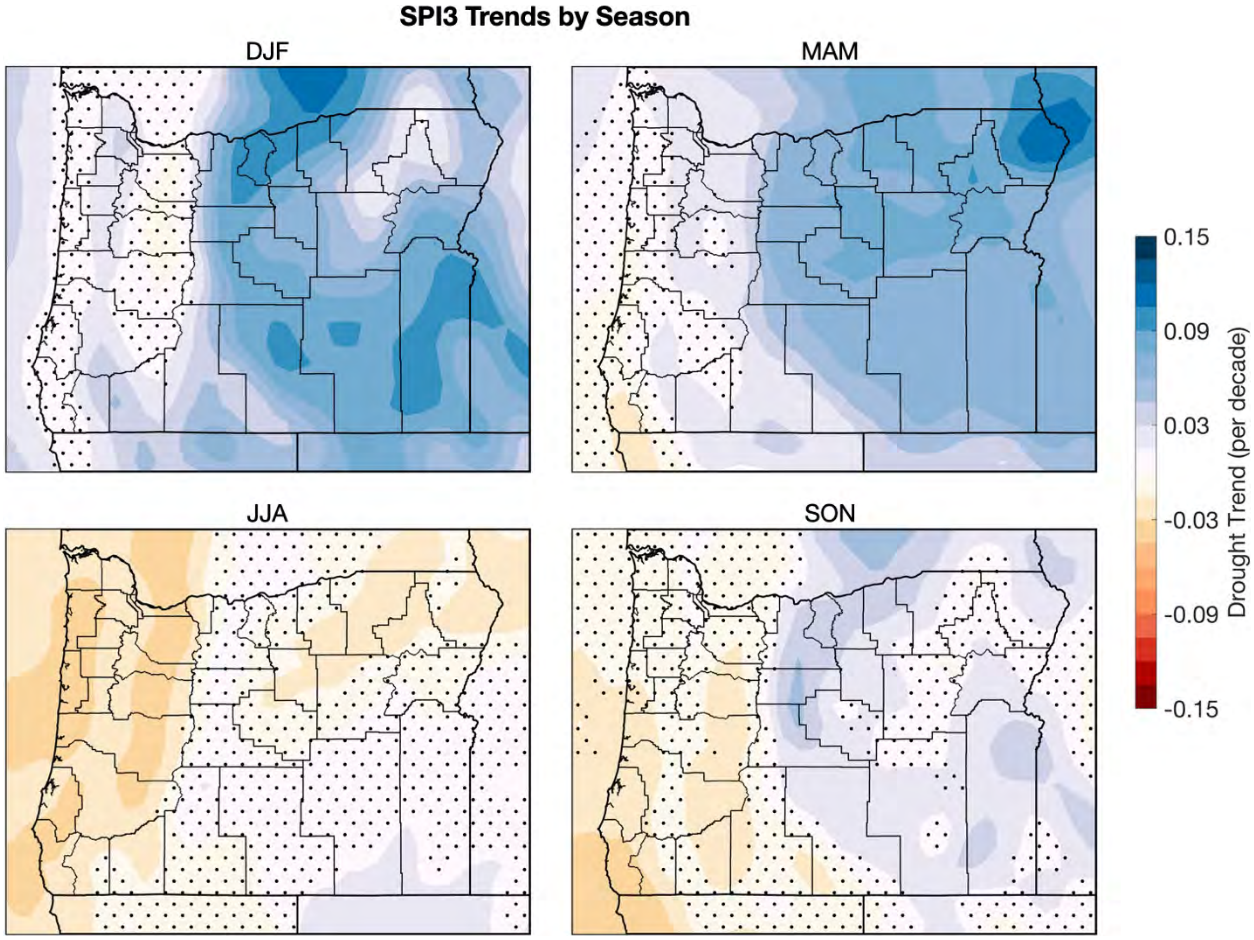

Figure 28. Linear trends in SPI3 by season from 1950 through 2099 in the ensemble mean of the NA-CORDEX simulations. Stippling indicates that trends were not statistically significant at the 95% confidence level.

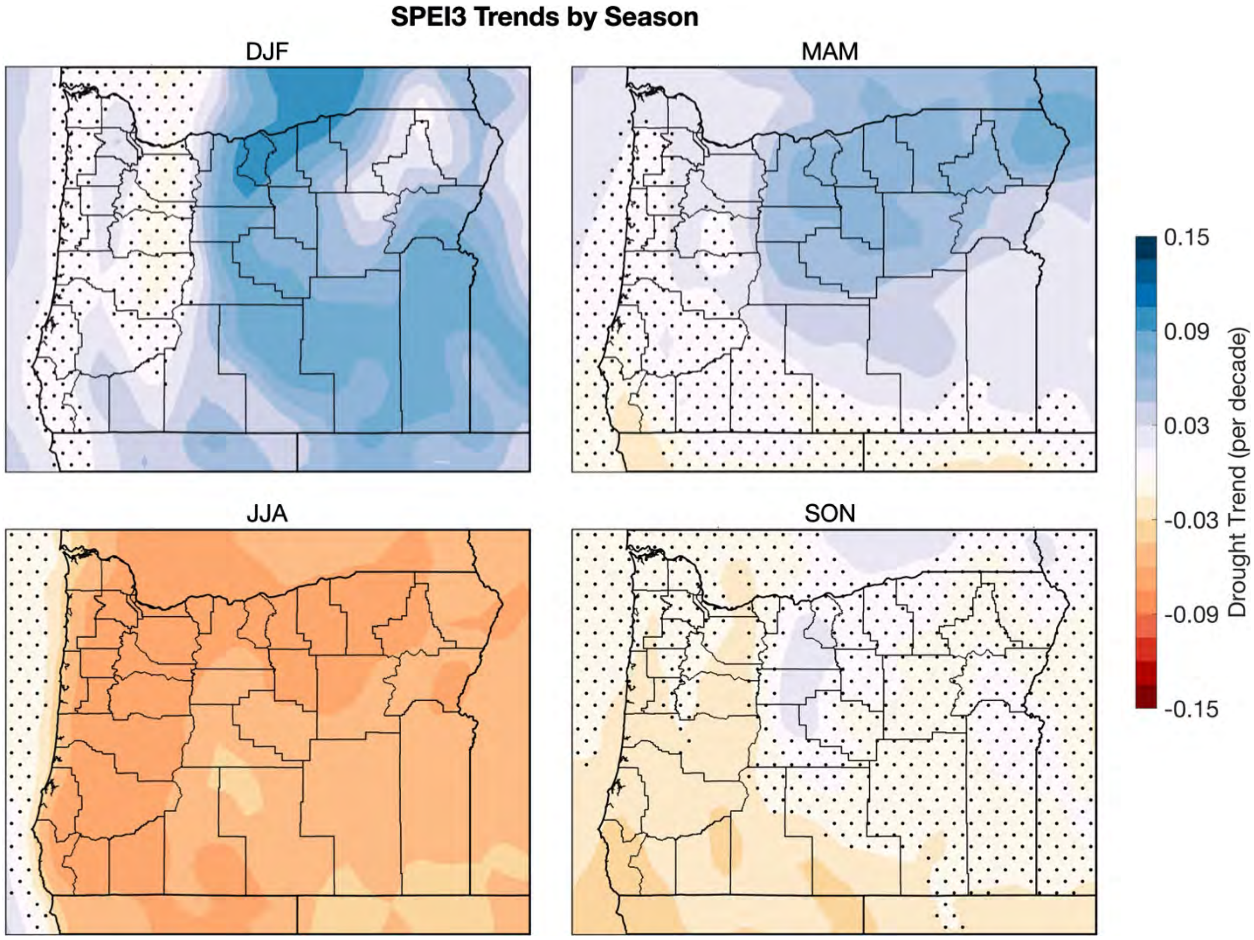

Figure 29. Linear trends in SPEI3 by season from 1950 through 2099 in the ensemble mean of the NA-CORDEX simulations. PET was calculated with the CO_2-aware Penman-Monteith equation. Stippling indicates that trends were not statistically significant at the 95% confidence level.

Literature Cited

Abatzoglou, J.T., R. Barbero, J.W. Wolf, and Z.A. Holden. 2014. Tracking interannual streamflow variability with drought indices in the U.S. Pacific Northwest. Journal of Hydrometeorology, 15, 1900–1912.

Abatzoglou, J.T., D.J. McEvoy, and K.T. Redmond. 2017. The West Wide Drought Tracker: drought monitoring at fine spatial scales. Bulletin of the American Meteorological Society, 98, 1815–1820.

Ahmadalipour, A., H. Moradkhani, and M. Svoboda. 2017. Centennial drought outlook over the CONUS using NASA-NEX downscaled climate ensemble. International Journal of Climatology, 37, 2477–2491.

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. www.fao.org/3/X0490E/X0490E00.htm.

Beguería, S., S.M. Vicente-Serrano, F. Reig, and B. Latorre. 2014. Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. International Journal of Climatology, 34, 3001–3023.

Bumbaco, K.A., C.L. Raymond, L.W. O'Neill, and D.J. Hoekema. 2021. 2020 Pacific Northwest water year impacts assessment. www.drought.gov/documents/2020-pacific-northwest-water-year-impacts-assessment.

Bumbaco, K.A., C.L. Raymond, L.W. O'Neill, A. Mehta, and D.J. Hoekema. 2023. 2022 Pacific Northwest water year impacts assessment. www.drought.gov/documents/2022-pacific-northwest-water-year-impacts-assessment.

Bumbaco, K.A., M.H. Rogers, L.W. O'Neill, D.J. Hoekema, and C.L. Raymond. 2022. 2021 Pacific Northwest water year impacts assessment. www.drought.gov/documents/2021-pacific-northwest-water-year-impacts-assessment.

Cook, B.I., E.R. Cook, J.E. Smerdon, R. Seager, A.P. Williams, S. Coats, D.W. Stahle, and J.V. Díaz. 2016. North American megadroughts in the Common Era: reconstructions and simulations. Wiley Interdisciplinary Reviews Climate Change, 7, 411–432.

Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology, 33, 140–158.

Dickson, R.R. 1977. Weather and circulation of February 1977: widespread drought. Monthly Weather Review, 105, 684–689.

Edwards, D.C., and T.B. McKee. 1997. Characteristics of 20th century drought in the United State at multiple time scales. Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado. Mountain Scholar. http://hdl.handle.net/10217/170176.

Falcone, J., 2011. GAGES-II: Geospatial Attributes of Gages for Evaluating Streamflow. U.S. Geological Survey data release. DOI: 10.5066/P96CPHOT.

Hoerling, M., and A. Kumar. 2003. The perfect ocean for drought. Science, 299, 691–694.

Hosking, J.R.M. 1990. L-Moments: analysis and estimation of distributions using linear combinations of order statistics. Journal of the Royal Statisical Society, Series B, 52, 105–124.

Hrachowitz, M., and M.P. Clark. 2017. Hess opinions: the complementary merits of competing modelling philosophies in hydrology. Hydrology and Earth System Sciences, 21, 3953–3973.

Keyantash, J., and J.A. Dracup. 2002. The quantification of drought: An evaluation of drought indices. Bulletin of the American Meteorological Society, 83, 1167–1180.

Lai, E.N., L. Wang-Erlandsson, V. Virkki, M. Porkka, and R.J. van der Ent. 2023. Root zone soil moisture in over 25% of global land permanently beyond pre-industrial variability as early as 2050. Hydrology and Earth System Sciences, 27, 3999–4018.

Lemordant L., P. Gentine, A.L.S. Swann, B.I. Cook, and J. Scheff. 2018. Critical impact of vegetation physiology on the continental hydrologic cycle in response to increasing CO_2. Proceedings of the National Academy of Sciences, 115, 4093–4098.

McEvoy, D.J., J.L. Huntington, J.T. Abatzoglou, and L.M. Edwards. 2012. An evaluation of multiscalar drought indices in Nevada and eastern California. Earth Interactions 16:18. DOI: 10.1175/2012EI000447.1.

McKee, T.B., N.J. Doesken, and J. Kleist. 1993. The relationship of drought frequency and direction to time scales. Eighth Conference on Applied Climatology, Anaheim, California, American Meteorological Society, 179–184.

Mearns, L.O., et al. 2017. The NA-CORDEX dataset, version 1.0. NCAR Climate Data Gateway, Boulder, Colorado, accessed April 16, 2023. DOI: 10.5065/D6SJ1JCH.

Mo, K.C., and D.P. Lettenmaier. 2015. Heat wave flash droughts in decline. Geophysical Research Letters, 42, 2823–2829.

Modarres, R. 2007. Streamflow drought time series forecasting. Stochastic Environmental Research and Risk Assessment, 21, 223–233.

Muñoz-Sabater, J., et al. 2021. ERA5-Land: a state-of-the-art global reanalysis dataset for land applications. Earth System Science Data, 13, 4349–4383.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers 77, 118–125.

Overpeck, J.T., and B. Udall. 2020. Climate change and the aridification of North America. Proceedings of the National Academy of Sciences, 117, 11856–11858.

Pendergrass, A.G., et al. 2020. Flash droughts present a new challenge for subseasonal-to-seasonal prediction. Nature Climate Change, 10, 191–199.

Peña-Gallardo, M., S.M. Vicente-Serrano, J. Hannaford, J. Lorenzo-Lacruz, M. Svoboda, F. Domínguez-Castro, M. Maneta, M. Tomas-Burguera, and A. Kenawy. 2019. Complex influences of meteorological drought time-scales on hydrological droughts in natural basins of the contiguous United States. Journal of Hydrology, 568, 611–625.

Rasmussen, E.M., R.E. Dickinson, J.E. Kutzbach, and M.K. Cleveland. 1993. Climatology. Pages 2.1–2.4 in D.R. Maidment, editor. Handbook of hydrology. McGraw-Hill, New York.

Redmond, K.T. 2002. The depiction of drought: a commentary. Bulletin of the American Meteorological Society 83:1443–1147.

Scheff, J., S. Coats, and M.M. Laguë. 2022. Why do the global warming responses of land-surface models and climatic dryness metrics disagree? Earth's Future, 10(8), e2022EF002814. DOI: 10.1029/2022EF002814.

Sherwood, S., and Q. Fu. 2014. A drier future? Science, 343, 737–739.

Svoboda, M., et al. 2002. The Drought Monitor. Bulletin of the American Meteorological Society, 83, 1181–1190.

Swann, A. L.S., F.M. Hoffman, C.D. Koven, and J.T. Randerson. 2016. Plant responses to increasing CO_2 reduce estimates of climate impacts on drought severity. Proceedings of the National Academy of Sciences, 113, 10019–10024.

Swann, A.L.S. 2018. Plants and drought in a changing climate. Current Climate Change Reports, 4, 192–201.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geography Review, 38, 55–94.

Vicente-Serrano, S.M., S. Beguería, and J.L. López-Moreno. 2010. A multi-scalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. Journal of Climate, 23, 1696–1718.

Vicente-Serrano, S.M., J.I. López-Moreno, S. Beguería, J. Lorenzo-Lacruz, C. Azorin-Molina, and E. Morán-Tejeda. 2012. Accurate computation of a streamflow drought index. Journal of Hydrologic Engineering, 17, 318–332.

Wilhite, D.A., and M.H. Glantz. 1985. Understanding the drought phenomenon: the role of definitions. Water International, 10, 111–120.

Williams, A.P., B.I. Cook, and J.E. Smerdon. 2022. Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. Nature Climate Change, 12, 232–234.

Williams, A.P., E.R. Cook, J.E. Smerdon, B.I. Cook, J.T. Abatzoglou, K. Bolles, S.H. Baek, A.M. Badger, and B. Livneh. 2020. Large contribution from anthropogenic warming to an emerging North American megadrought. Science, 368, 314–318.

Wu, H., M.D. Svoboda, M.J., Hayes, D.A. Wilhite, and F. Wen. 2007, Appropriate application of the standardized precipitation index in arid locations and dry seasons. International Journal of Climatology, 27, 65–79.

Yang, Y., M.L. Roderick, S. Zhang, T.R. McVicar, and R.J. Donohue. 2019. Hydrologic implications of vegetation response to elevated CO_2 in climate projections. Nature Climate Change, 9, 44–48.

Zhou, S., B. Yu, B.R. Lintner, K.L. Findell, and Y. Zhang. 2023. Projected increase in global runoff dominated by land surface changes. Nature Climate Change, 13, 442–449.

Appendix. Estimated mean monthly precipitation across Oregon derived from ERA5-Land and PRISM data.

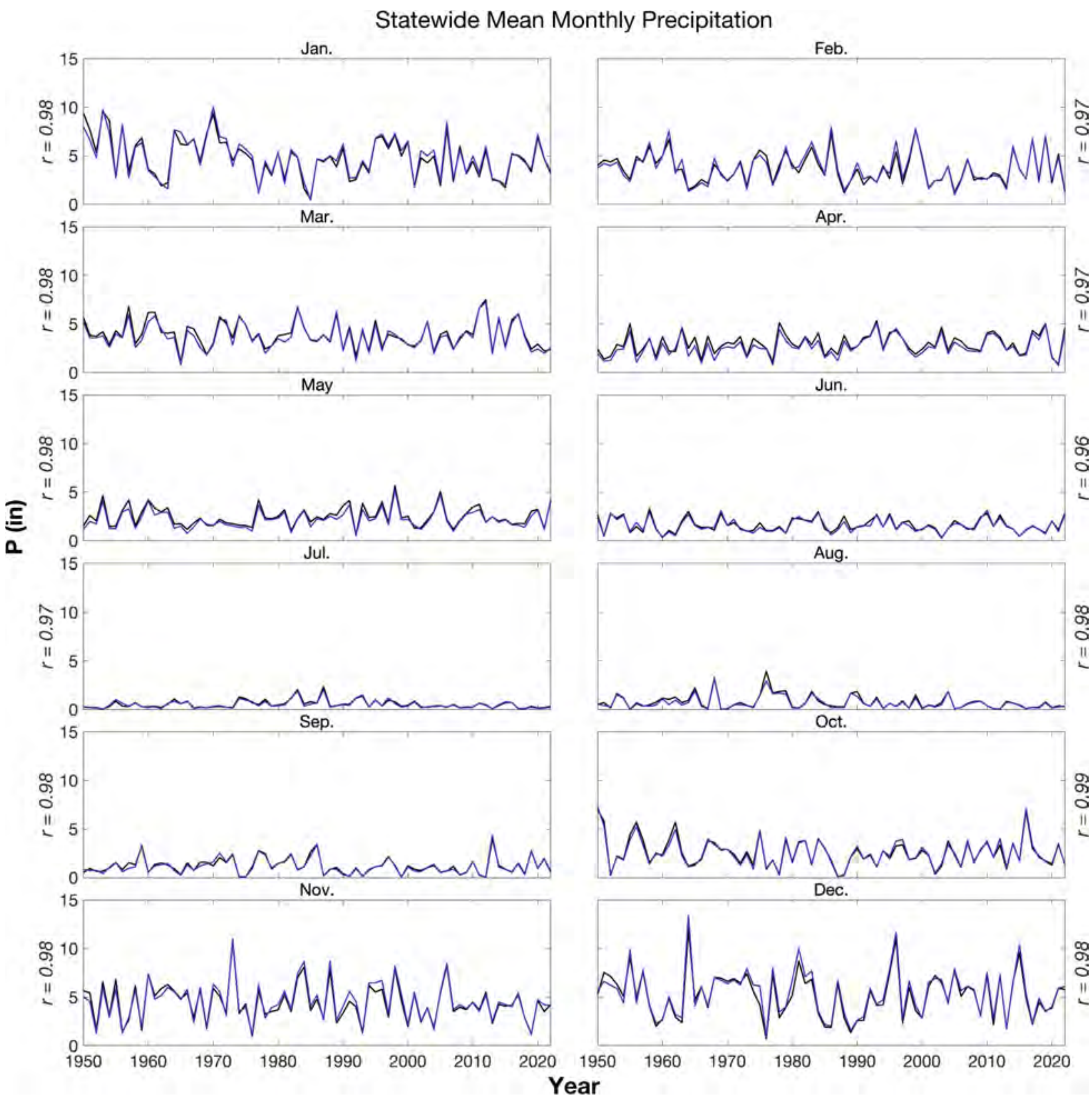

Figure A1. Monthly mean precipitation across Oregon derived from PRISM (blue) and ERA5-Land (black). The correlation between the two data sources for each month is indicated on the left side of the panel (left column) or right side of the panel (right column).

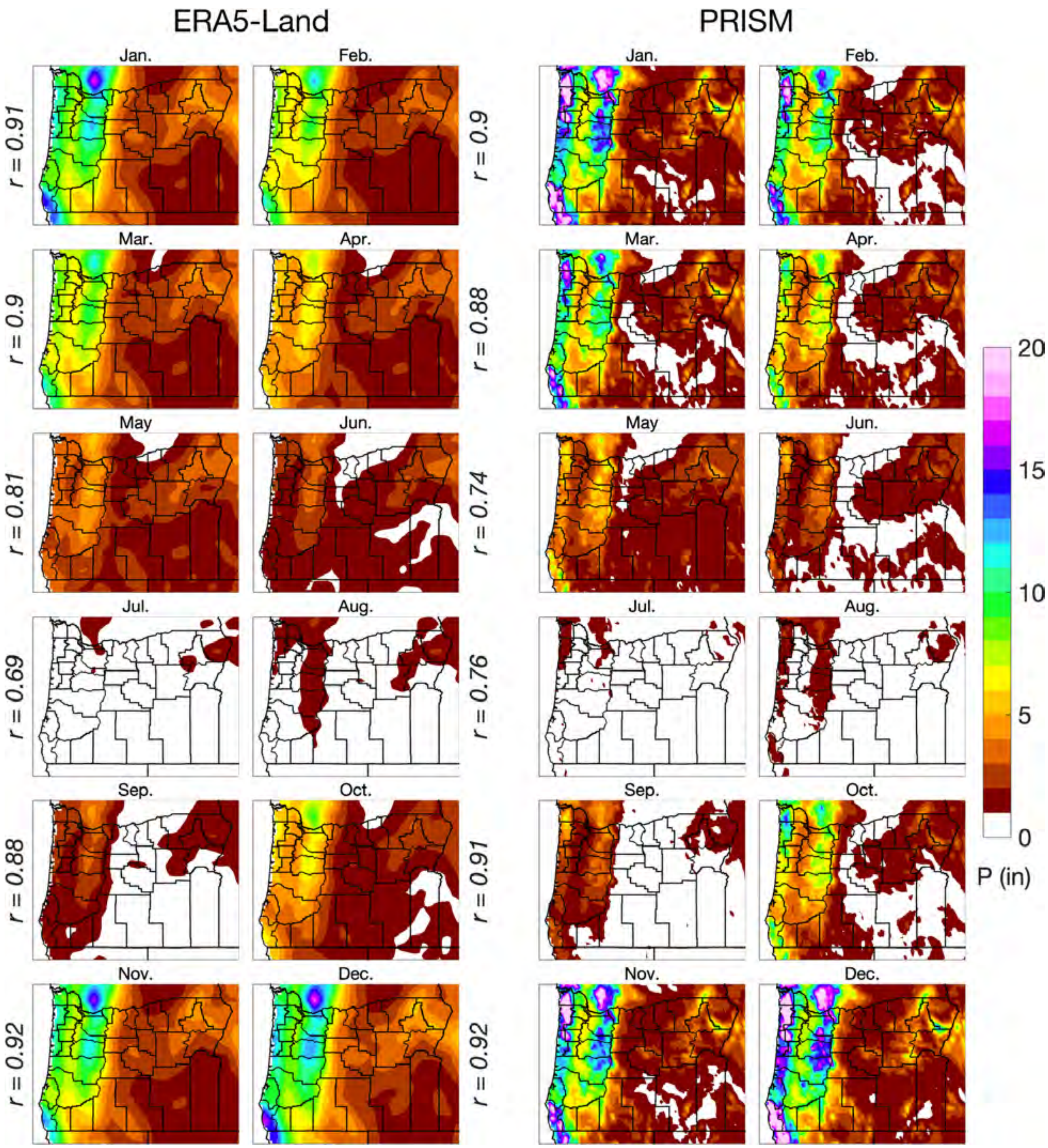

Figure A2. Monthly mean precipitation derived from ERA5-Land (left) and PRISM (right). The spatial correlation between the two data sources for each month is indicated on the side of the panels in the ERA5-Land columns.

Oregon Drought Vulnerability Assessment

Prepared by the National Drought Mitigation Center, University of Nebraska-Lincoln, for the Oregon Water Resources Department

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Brie Paladino and Curtis Riganti

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Preface

The Oregon Water Resources Department (OWRD) contracted for a drought vulnerability assessment in 2023, focusing on drinking water supplies, agriculture, and water-dependent recreation. In the report, we divide water-dependent recreation into three categories: aquatic recreation (swimming, paddling and boating), recreational fishing, and waterfowl viewing and hunting. This report focuses on fish and waterfowl in relation to recreational use and should not be interpreted as a comprehensive review of how drought may impact the ecology or economics of Oregon wildlife. Wildfire, though often related to drought, is also not addressed in this assessment as substantial resources are already dedicated to that topic in Oregon. The National Drought Mitigation Center (NDMC) and the Oregon Climate Change Research Institute worked in tandem with the OWRD to complete this work, along with the University of Oregon.

Vulnerability is often assessed as a product of exposure, sensitivity and adaptive capacity. Exposure is the degree (frequency and intensity) to which people and the things they value are exposed to drought; sensitivity is the degree to which they are affected by that exposure; and adaptive capacity is the ability to mitigate, cope with and recover from drought. This report focuses on areas where data was available in the State of Oregon and highlights data gaps.

Glossary of Acronyms

APHIS: Animal and Plant Health Inspection Service. Part of the U.S. Department of Agriculture.

CDC: Centers for Disease Control and Prevention.

CMOR: Condition Monitoring Observer Reports. A crowdsourcing system to gather drought-related observations and photos administered by the National Drought Mitigation Center. go.unl.edu/cmor_drought

CWS: Community Water System. Defined by the Oregon Health Authority as public water systems with at least 15 service connections used by year-round residents, or that regularly serve at least 25 year-round residents.

DIR: Drought Impact Reporter. A product of the National Drought Mitigation Center that records drought impacts reported in media across the U.S. Go.unl.edu/dirdash

DSCI: Drought Severity and Coverage Index. A method for summarizing the intensity and spatial extent of U.S. Drought Monitor drought levels for a specific area to a single value ranging from 0 to 500. Zero means that none of the area is abnormally dry or in drought, and 500 means that all of the area is in D4, exceptional drought. The DSCI is a weighted sum of the percentage of an area in each category of drought.

DWS: Oregon Drinking Water Services.

FIPS: Federal Information Processing System. FIPS codes are used to identify geographic regions such as counties and states.

FSA: Farm Service Agency. Part of the U.S. Department of Agriculture.

FWS: U.S. Fish and Wildlife Service

HPAI: Highly Pathogenic Avian Influenza.

n.d.: No date of publication indicated on an information source.

NASS: National Agricultural Statistics Service. Part of the U.S. Department of Agriculture.

NASA: National Aeronautics and Space Administration.

NDMC: National Drought Mitigation Center, based at the University of Nebraska-Lincoln.

NRCS: Natural Resources Conservation Service, part of the U.S. Department of Agriculture.

OAR: Opportunities Access Report. A product of the Oregon State Marine Board that reports boating closures/reopenings due to water conditions in Oregon.

ODFW: Oregon Department of Fish and Wildlife.

OHA: Oregon Health Authority.

ODEQ: Oregon Department of Environmental Quality.

OSMB: Oregon State Marine Board.

OSOS: Office of the Secretary of State.

OWRD: Oregon Water Resources Department.

RMA: Risk Management Agency. Part of the U.S. Department of Agriculture.

SNOTEL: Snow Telemetry Network. Automated data collection by the Natural Resources Conservation Services to measure remote, high-elevation snowpack.

SPEI: Standardized Precipitation-Evapotranspiration Index. A measure of drought that uses precipitation and temperature data to determine whether a location is unusually dry or wet for the specified time period. Negative values indicate dry and/or hot conditions, while positive values indicate wet and/or cool conditions.

SPEI-WY: Water-Year Standardized Precipitation-Evapotranspiration Index. A measure of drought (SPEI) determining whether conditions during the current water year (the 12-month period following October 1) are unusually dry or wet. Negative values indicate dry and/or hot conditions, while positive values indicate wet and/or cool conditions.

USBR: U.S. Bureau of Reclamation.

USDA: U.S. Department of Agriculture.

USDM: U.S. Drought Monitor. A joint product of the National Drought Mitigation Center, the USDA and the National Oceanic and Atmospheric Administration, that assesses the location and intensity of drought in the U.S. each week with categorization from None to D4 (Exceptional Drought).

USEPA: U.S. Environmental Protection Agency.

USGS: U.S. Geological Survey.

Executive Summary

The Oregon Water Resources Department (OWRD) contracted for a drought vulnerability assessment in 2023, with the National Drought Mitigation Center's portion of the assessment focusing on drinking water supplies, agriculture and water-dependent recreation. Due to time constraints, the report relies on existing, readily available data, rather than new data collection. Drought impacts can point to underlying vulnerability. The NDMC used its Drought Impact Reporter (DIR), which records impacts reported in media, and Condition Monitoring Observer Reports (CMOR), a crowdsourcing system for collecting drought-related observations and photos, to construct preliminary narrative accounts of the effects of drought in Oregon. Quantitative analyses supplemented these efforts, where data was available.

Two recent periods of drought were particularly impactful to the sectors of interest: 2013-2015 and 2020-2023. Those time intervals are among those that stand out on Figure 1, the U.S. Drought Monitor time series for the entire state of Oregon, 2000-2023.

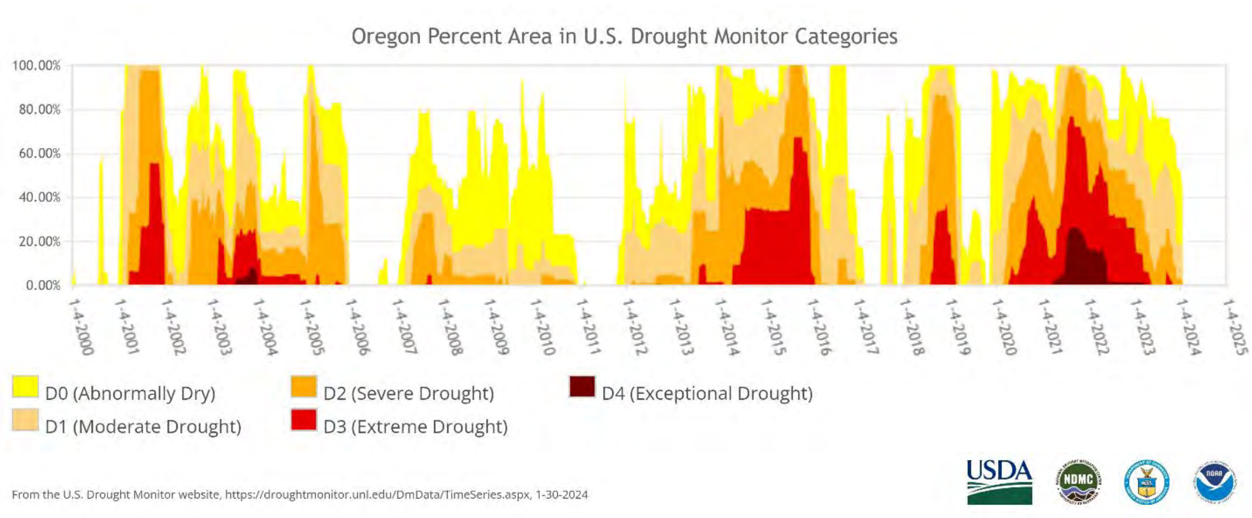

Figure 1. The U.S. Drought Monitor time series for Oregon.

Drinking Water

Oregon relies on a combination of groundwater and surface water for its drinking supply. Drinking water demand is expected to increase as Oregon's population grows, especially in the Willamette Valley. There are many ways to assess drinking water vulnerability, and this report focuses on aspects that were seen as especially relevant by state water agencies and for which data was available. The investigation identified areas in Oregon that have recently experienced drought impacts to the drinking water supply, including mapping the locations of reported domestic wells with limited or no production. It also highlights Community Water Systems (public water systems with at least 15 service connections used by year-round residents, or that regularly serve at least 25 year-round residents) with characteristics that could potentially make them susceptible to drought conditions.

Drinking water impacts reported by Oregon news media were relatively rare, with only 23 stories collected between 2010 and 2022. The most drinking water impacts were reported in Klamath County. Limited or dry wells emerged as a major concern across the state in 2021. More than 1,100 domestic wells were reported through the OWRD’s newly developed online Dry Well Reporting form between July 2021 and July 2023, with the highest density of reports in Deschutes, Klamath and Jackson counties (Figure 2). It’s important to note dry well reports were submitted voluntarily and the reporting system may not have been known to all private domestic well users.

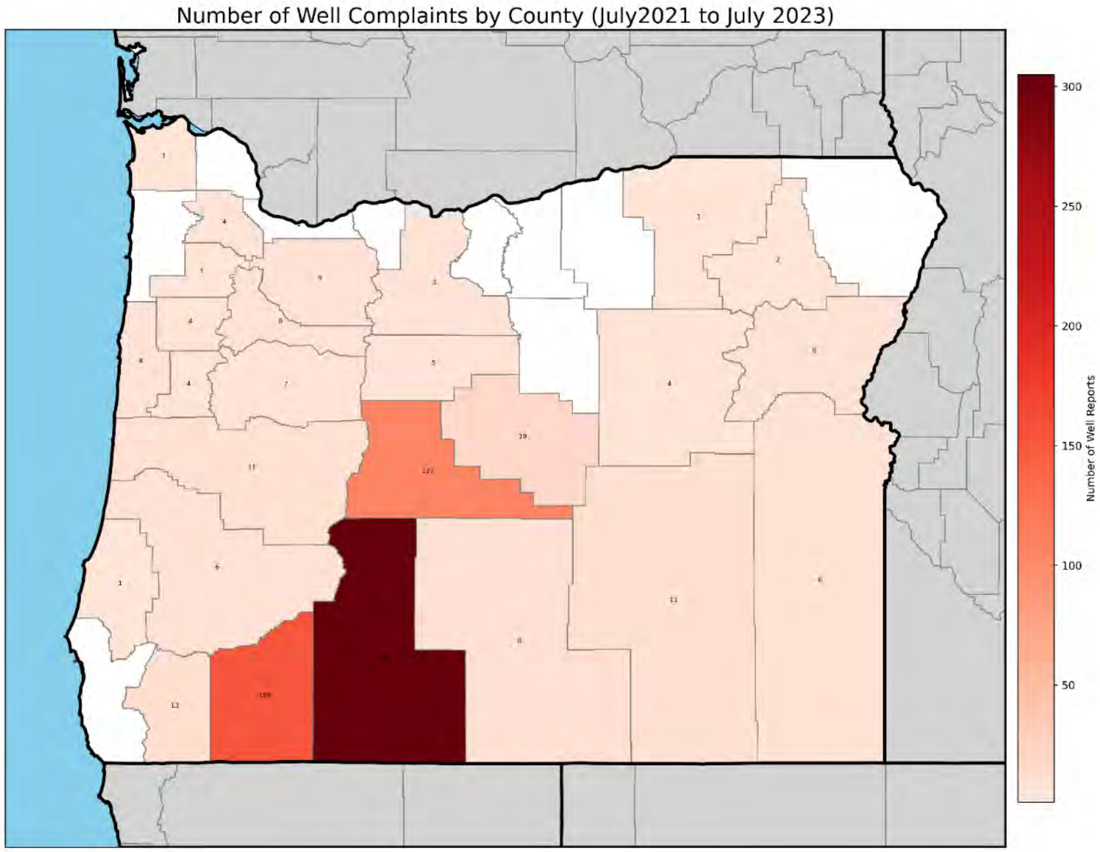

Figure 2. Limited and dry well reports by county via the OWRD Dry Well Reporting Form from July 2021 to July 2023 (Source: OWRD Dry Well Database).

Community water systems (CWS) that serve fewer people and those with only one source of self-supplied water (no interties with other systems) were deemed more susceptible to drought (Figure 3). In addition to not having backup water sources, previous studies and discussions with Oregon water agencies both noted that these smaller systems often lack the capacity and resources to apply for infrastructure grants and seek technical assistance opportunities. In total, 310 smaller CWS (with at least 15 connections or serving between 25 and 3,300 people) rely on a single water source (making them potentially vulnerable to drought) were identified. These CWS are clustered in the Willamette Valley and the Rogue, Deschutes, Klamath and Umatilla River Basins, and the majority rely on groundwater.

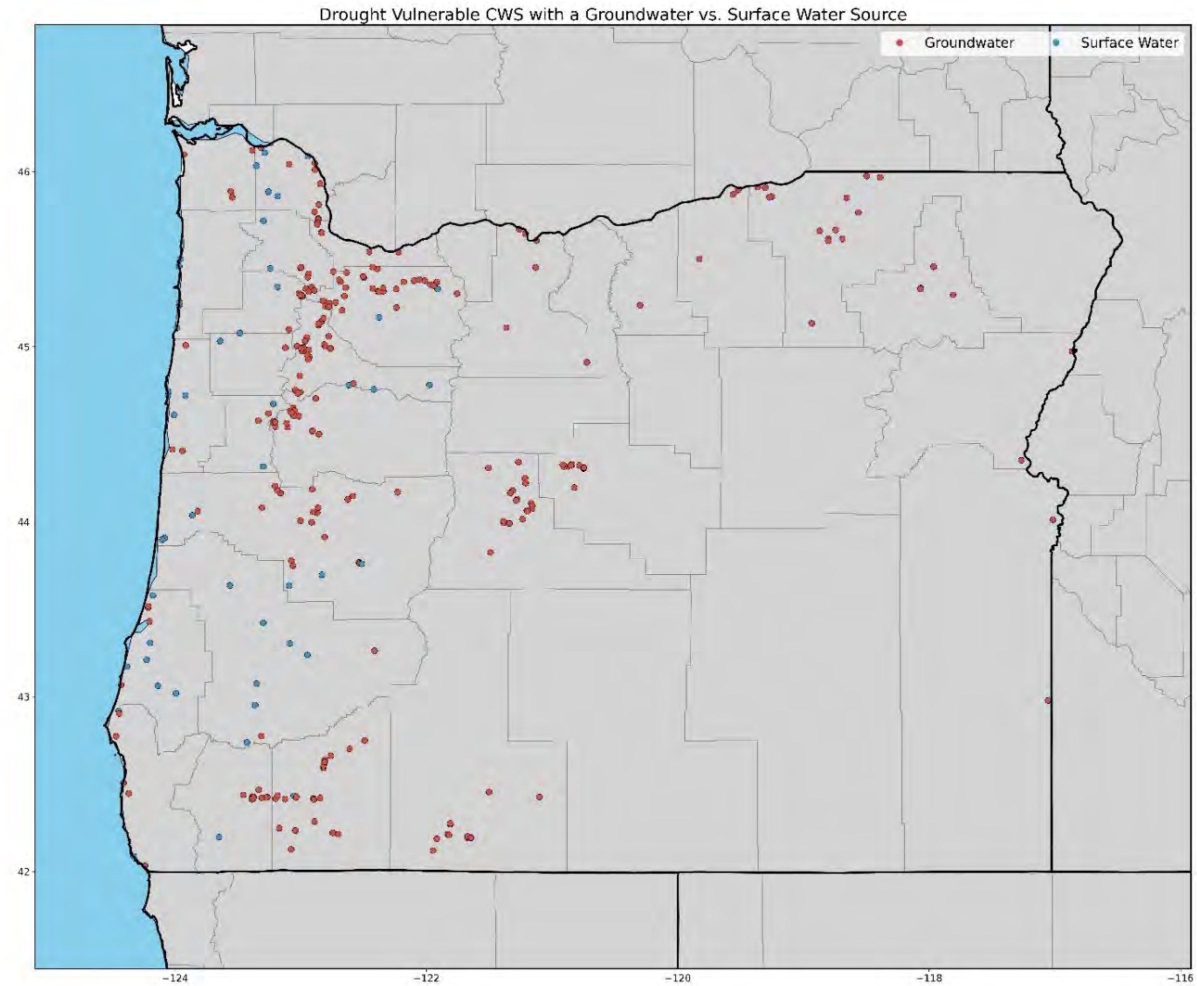

Figure 3. Small and Very Small CWS with one water source and no interties with other systems differentiated by groundwater and surface water sources.

Including additional socioeconomic and physical drought vulnerability indicators, along with systematic methods for enhanced communication with water suppliers and users, could help refine this vulnerability analysis. To what extent this is necessary depends on how this information will be used and the level of detail necessary for effective decision making.

Agriculture

Drought is a major, recurrent concern for agricultural producers in Oregon. While DIR impacts were available from 2010 through 2023, CMOR reports were mainly available for 2020-2023, with a handful from 2018. Specific periods including 2010, 2012-2015, 2018-2019 and

2020-2023 stand out as particularly difficult years for agriculture. Impacts were seen across the entire state, with Klamath County recording the highest number of impacts (Figure 4). Common impacts were related to inadequate irrigation supply, poor pasture and range conditions, low livestock weights, high hay prices and reduced crop yield. The Klamath Basin and Deschutes River Basin reported severe irrigation impacts between 2020 and 2023. In contrast, the DIR recorded no agricultural impacts for coastal counties that typically receive abundant precipitation: Clatsop, Tillamook, Lincoln, Coos and Curry, or for adjacent Columbia County.

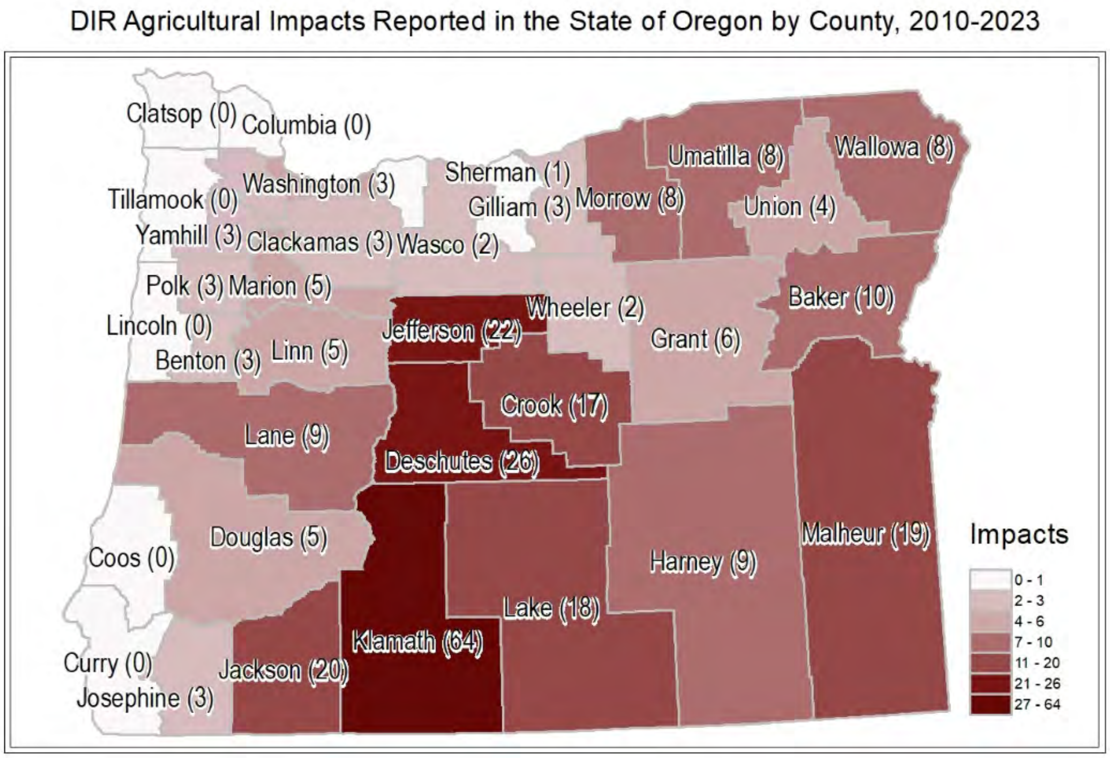

Figure 4. Agricultural impacts reported to the DIR across the State of Oregon, 2010-2023.

We visualized and analyzed publicly available quantitative data on Oregon crops. We used CropScape data to map which counties grow each of 60 different crops. We used Risk Management Agency Cause of Loss data to map where drought-related claims were filed and computed the ratio of claims paid to the total amount insured. We also compared National

Agricultural Statistics Service data with the Drought Severity and Coverage Index to see whether drought was associated with changes in crop yield. We also compared CropScape data regarding where producers planted different crops to RMA's Summary of Business data on where producers insured different crops, to see whether producers are fully insuring crops. We mapped each of these visualizations and analyses. Maps for wheat and for alfalfa and forage-related crops are included in this report, and an expanded set of maps for all crops for which data was available was provided to the Oregon Water Resources Department. These data-driven maps provide a starting point for further qualitative inquiry and validation.

Many of the maps suggest spatial patterns of drought vulnerability, which are driven by crop choice and practices such as irrigation, which are in turn driven by the geography of soil, water and climate. The greatest drought-related losses to wheat yield occur, not surprisingly, in the areas where wheat is cultivated most intensively. In the case of winter wheat, where some of the data distinguished between irrigated and non-irrigated wheat, analysis found that drought was associated with lower yields for non-irrigated wheat and higher yields for irrigated wheat (Figure 5).

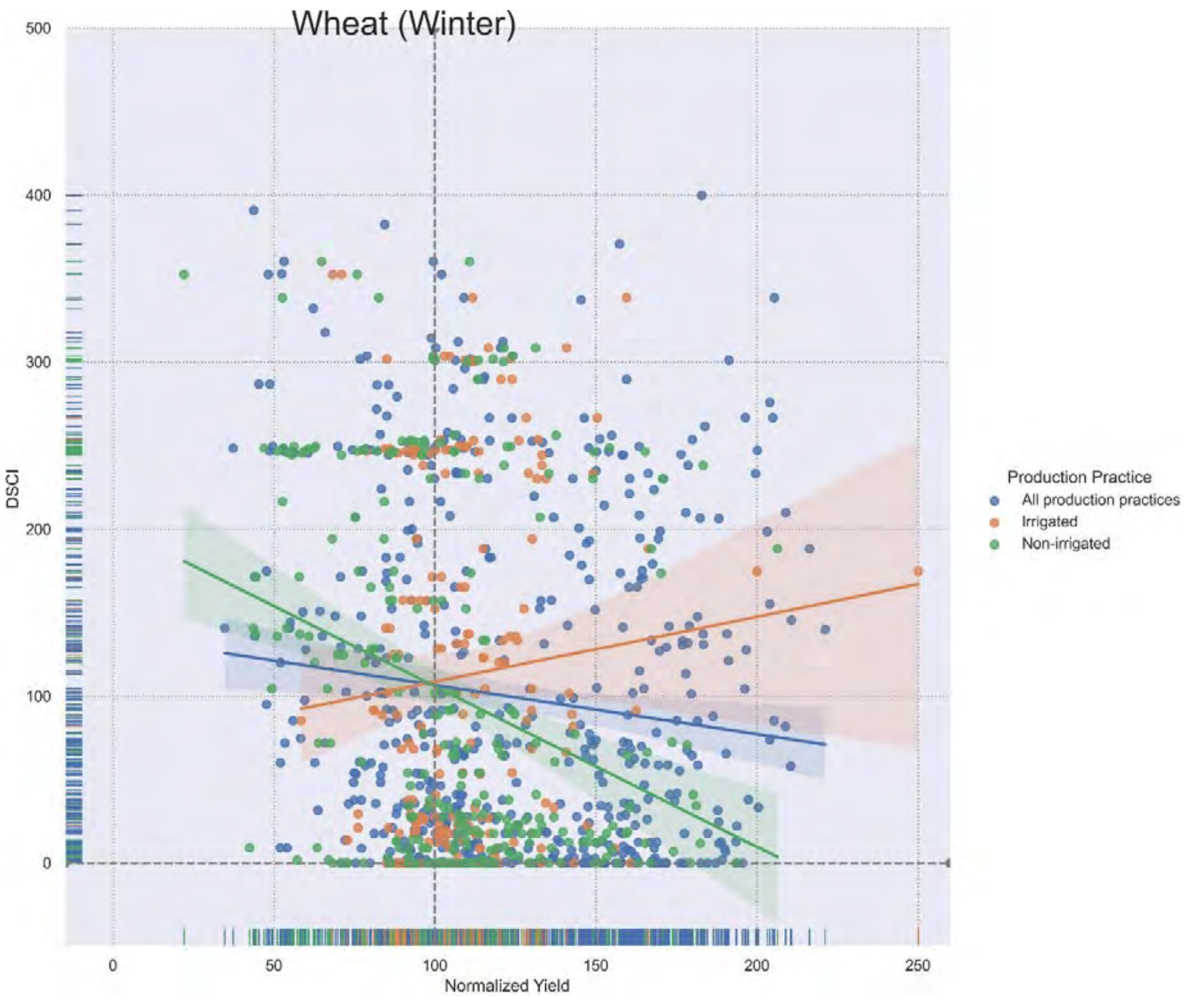

Figure 5. The relationship of drought (DSCI) on the y axis and normalized yield on the x axis. Each point represents yield for a county and year, with its placement determined by yield and DSCI. The regression lines help generalize the relationship between the two. Confidence intervals show how well the lines describe the relationship between DSCI and yield. Confidence intervals are represented by shading above and below lines.

Quantitative data for other important Oregon crops such as Christmas trees and grass seed was not available. As previous drought researchers have noted, data that is collected systematically over time normally does not exist without a centralized coordinating body. The Oregon Department of Agriculture may wish to determine whether it is feasible to begin collecting data on key crops.

Several of the drought impacts from news mentioned farmers fallowing crops in response to curtailed irrigation. Cropscape includes data on fallowed acres. Quantifying what portion of fallowed acres is due to drought would be a separate and interesting study.

Aquatic Recreation

Aquatic recreation opportunities such as boating are available throughout the State of Oregon and depend on sufficient water in reservoirs, rivers and lakes. Drought can lead to decreased visitor satisfaction, unsafe conditions and boat ramp closures. In this report, we identify parks and regions that have experienced recreational drought impacts in the past and may be more vulnerable to future impacts, analyze whether attendance at 62 Oregon state parks featuring aquatic recreation (swimming, paddling and boating) is associated with drought, and interview park managers to gain further understanding of the impact of drought on recreation. Future research into this topic might include analysis of park revenue compared to drought metrics. We found that boating impacts were primarily recorded during two major drought periods: 2013-2015 and 2020-2022. It is important to note that boating closures are relatively rare, especially in rivers, even when conditions are dangerous (Salem Statesman-Journal, personal communication). In many cases, warning signs are posted at locations with low water levels, but formal communication of conditions is not made. Thus, our report cannot be viewed as a comprehensive record of all instances where water bodies, especially rivers, were unsuitable for boating.

Jackson County had the most aquatic recreation impacts (Figure 6), with reports coming primarily from Howard Prairie Lake, Hyatt Reservoir and Emigrant Lake. Deschutes County had the second highest number of impacts, including stories from Wickiup Reservoir, Prineville Reservoir and East Lake.

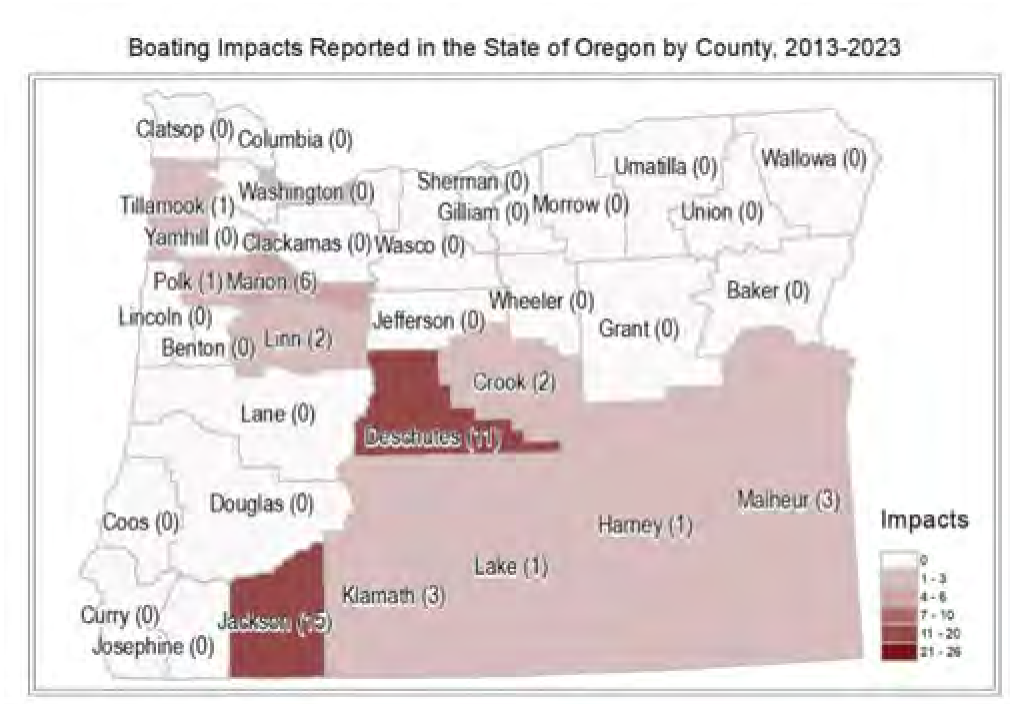

Figure 6. Boating impacts across the State of Oregon by county, 2013-2023.

Statistical analysis indicated that, overall, drought may have a positive effect on park attendance. Only four individual parks (Ben and Kay Dorris State Recreation Area – Lane County, Joseph H. Stewart State Recreation Area – Jackson County, Unity Lake State Recreation Area – Baker County, and Willamette River Greenway – Cloverdale access, Lane County) showed a negative impact of drought on visitation. All four of those parks are popular for boating, so visitors may be driven away when drought conditions inhibit the ability to launch and use watercraft.

Park managers indicated that even parks that do not experience a decrease in visitation are still negatively impacted by drought. Visitor conflict was a key concern related to drought and managers stated that increased education for visitors regarding what to expect at parks during drought would be highly beneficial in reducing staff stress and turnover.

Recreational Fishing

Cold-water and warm-water fish alike are susceptible to declines in distribution, production, survival, abundance, growth and body condition due to drought-induced habitat degradation. In response to drought conditions, the Oregon Department of Fish and Wildlife may enact voluntary or legally enforced restrictions on angling to protect fish populations. This report records the impact of recent droughts on recreational fishing in Oregon and determines which locations have historically been affected by compiling reports from the DIR, media and academic literature.

Recreational fishing impacts were recorded in nearly every county of the state (Figure 7) and encompassed instances of habitat degradation, parasites and disease, and impaired spawning during droughts. Fish kills, fishing closures or restrictions, and reductions in fish distribution, abundance and survival also occurred. Two periods of drought were particularly hazardous for fish in Oregon: 2013-2015 and 2020-2022. Jackson County had the highest number of fish-related impacts reported (seven impacts), while Klamath and Deschutes counties each had six impacts.

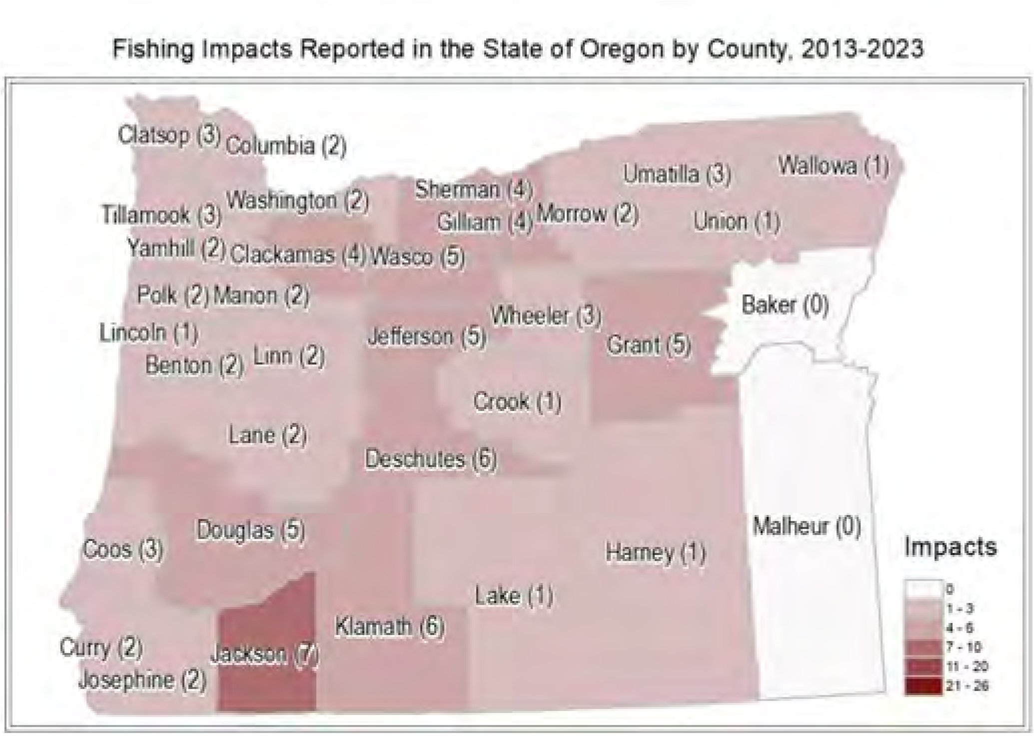

Figure 7. Impact reports on fish in Oregon by county, 2013-2023.

Review of DIR reports indicated that media attention to fish ecology is often tied to the ways humans are affected, such as through angling restrictions. Though angling restrictions are generally due to habitat degradation, fish disease outbreaks and other fish health concerns, they should not be interpreted as a comprehensive record of all the ways drought may affect fish in Oregon. Future analysis of the impact of drought on fishing and fish ecology would benefit from greater formal collaboration with tribal communities and the Oregon Department of Fish and Wildlife. Useful data would include comprehensive records of instances that angling restrictions were put into place (dates and locations) and the criteria used to determine when angling restrictions are necessary.

Waterfowl Viewing and Hunting

Oregon is a critical location for waterfowl due to its location along the Pacific Flyway. In this report, we document impacts of recent droughts on waterfowl in Oregon using DIR, academic literature and correspondence with wildlife experts. The findings in this report should not be interpreted as a comprehensive analysis of all the ways drought may affect waterfowl and their habitats in Oregon, but rather an initial overview of locations and topics for further examination. Impacts on waterfowl included reduced visitation to wildlife refuges due to a lack of food and water, disease outbreaks attributed to crowding and reports of reduced bird sightings. An extreme situation was encountered at the Lower Klamath Basin National Wildlife Refuge, where all hunting was closed for the September 2022–March 2023 season.

We found that the Klamath Basin National Wildlife Refuge Complex (Klamath County; Figure 8) dominated instances of drought impacts on waterfowl. Lake Abert (Lake County) and the High Desert (approximately the southeast quarter of Oregon) also emerged in our investigation as crucial waterfowl habitats vulnerable to drought. Future investigations into the effects of drought on waterfowl ecology, hunting and viewing in Oregon should include greater formal collaboration with the Oregon Department of Fish and Wildlife.

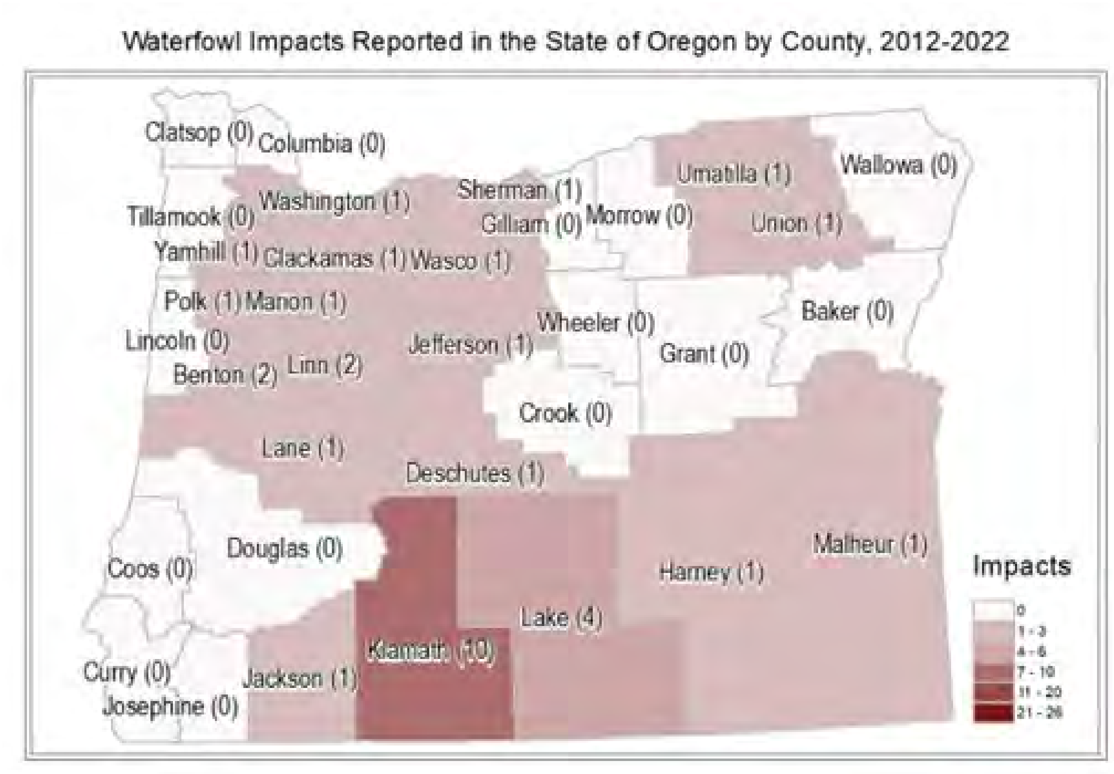

Figure 8. Impact reports on waterfowl in Oregon by county, 2012-2022.

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Chapter 1: Data Overview

NDMC's approach is grounded in acknowledgement that successful data interpretation relies on local, traditional and sectoral expertise, especially to sift through the complex interactions between policy and regulation, human behavior, ecology and other considerations. Below are several sources of qualitative data and drought metrics used throughout the analysis. They are defined here to avoid repeating the descriptions in several locations.

Drought Impact Data

There is no single definitive source or method for collecting drought impact data. Choosing vulnerability metrics for assessment is determined in large part by data availability. Awareness of an issue may first surface as narrative, i.e., the description of an experience. Systematically gathered qualitative data may help determine what quantitative data needs to be collected. The existence of numeric data to quantify drought impacts is often limited and generally depends on a coordinating body and adequate resources for collection, archiving and dissemination (Redmond 2002). Gaps in quantitative data can be, in part, filled by qualitative reports of drought impacts. Each part of the Oregon vulnerability assessment incorporates data from two systems maintained by the NDMC, the Drought Impact Reporter and Condition Monitoring Observer Reports, which respectively rely on media and on crowdsourcing, as an indicator of when and where drought impacts occurred. This analysis also sought and incorporated other qualitative and quantitative data as available.

Drought Impact Reporter (DIR)

In 2005, the National Drought Mitigation Center launched the Drought Impact Reporter (DIR; go.unl.edu/dirdash) to be the nation's archive of drought impacts, in response to the identified need for such an archive (Wilhite et al. 2007). Impacts are based on media monitoring, an ongoing search of news stories with expert determination as to whether a "loss or change at a specific place in time" occurred. Each observed impact includes a text description, date, location(s), sector, and source information. Benefits of relying on media are that it provides at least some measure of objectivity, and information is attributed in ways that can at least in theory be verified. Statements from state climatologists, agricultural producers and others may provide a link between impacts such as reduced crop yield and drought that would not otherwise be recorded. The Washington Post has helped popularize the idea that "news is the first rough draft of history." Likewise, the DIR is a useful starting point for constructing a narrative account of how drought has affected people and their livelihoods at a given place, over time, and identifying key themes and issues. The DIR database includes both links to media reports and the full text of the stories.

One of the main drawbacks of relying on media as a source of data is that it is event-driven rather than ongoing. As data is traditionally described, drought impacts are sparse (infrequent). Media-based drought impacts can be considered categorical and binary – whether or not an impact occurred at a place and time – rather than numeric and longitudinal, i.e., an ongoing numeric measurement at regular intervals over time. To use a health analogy, a drought impact would be like a heart attack – a rare event, typically described in terms of whether or not it happened, perhaps with some indication of severity. In contrast, a blood pressure or cholesterol reading is a numeric data point. Blood pressure or cholesterol readings over time are longitudinal data, and can help identify trends and provide warnings as key thresholds are crossed. Part of building resilience is deciding on metrics – what data to collect – on an ongoing basis to prevent events such as heart attacks or drought impacts. If a patient wasn't monitoring blood pressure and cholesterol before a cardiac event, they may well follow medical advice and start to do so afterward. Drought impacts may follow a similar pattern. Systematic data collection, as noted earlier, rarely happens without a coordinating body such as state government deciding that collecting data could help anticipate and reduce impacts, or a financial incentive such as insurance.

Condition Monitoring Observer Reports (CMOR)

In 2018, the NDMC implemented Condition Monitoring Observer Reports (CMOR, go.unl.edu/cmor_drought), a crowdsourcing system to gather drought-related observations and photos. CMOR includes a questionnaire and invites people to check off impacts in different sectors, to provide a text description and to upload photos. Each report has a date and geographic coordinates that map as a point rather than an area. Observers can choose whether to enable geo-location or enter a less-precise location such as a city or county. CMOR reporting provides the general public, particularly ranchers and farmers, with a voice in the U.S. Drought Monitor process (Smith et al. 2021), but this opportunity is generally not utilized until there is some sort of external prompting, such as a request from Oregon Forestry for help identifying drought-related conditions in the state’s forests. Narrative observations included in CMOR reports are typically first-person (“I” or “we”) and are directly based on individual experience. CMOR observers can report on any of several sectors, including crop production, livestock production, household issues, recreation and tourism, and aquatic and terrestrial wildlife.

Drought Metrics

Drought metrics used for in-stream recreation and for agriculture analyses in this report are the U.S. Drought Monitor (USDM) and the Drought Severity and Coverage Index (DSCI), which is calculated from the USDM.

U.S. Drought Monitor (USDM)

The USDM is a widely used weekly assessment of the location and intensity of drought across the U.S. (Svoboda et al. 2002, Figure 1.1). It incorporates many different variables as well as expert and local feedback. Each week the USDM categorizes the entire area of the country as being in one of six drought-related categories: None, Abnormally Dry (D0), Moderate Drought (D1), Severe Drought (D2), Extreme Drought (D3) or Exceptional Drought (D4). A limit of the USDM is that it is only computed for dry and drought conditions.

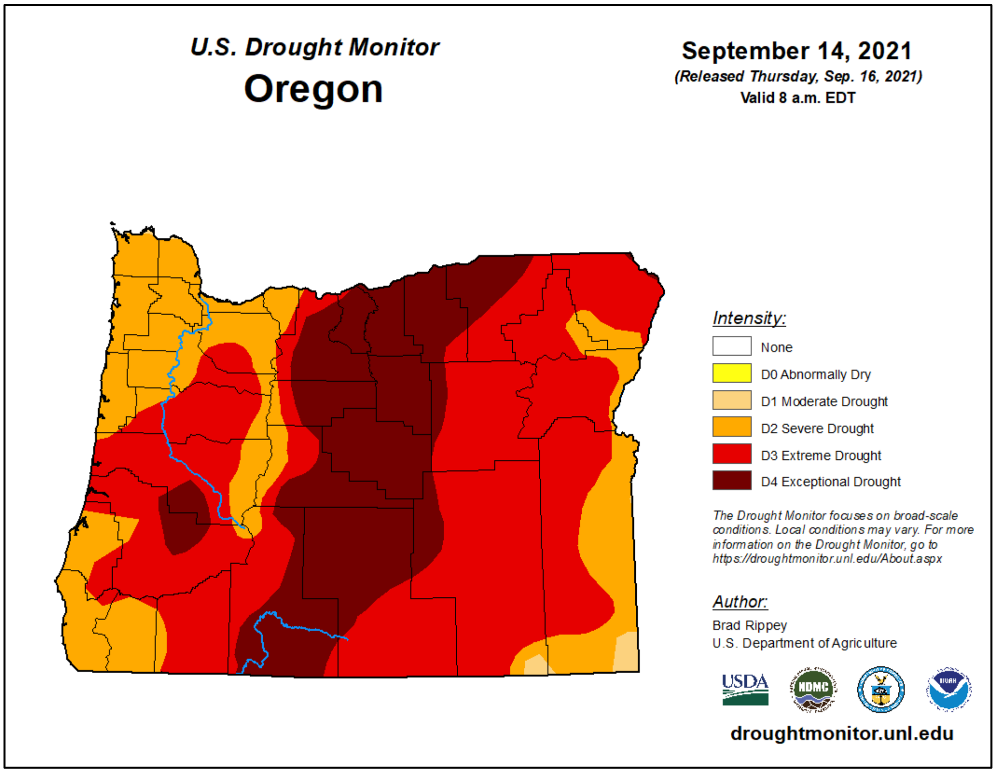


Figure 1.1. The USDM from September 14, 2021, shows Oregon drought at its most intense.

USDM data is computed and visualizations are created for states, counties and other areas and updated weekly (Figure 1.2). In the discussion below, some reports of impacts include drought status for the week and county where the impact occurred. USDM data is available for download at https://droughtmonitor.unl.edu/DmData/DataDownload.aspx.

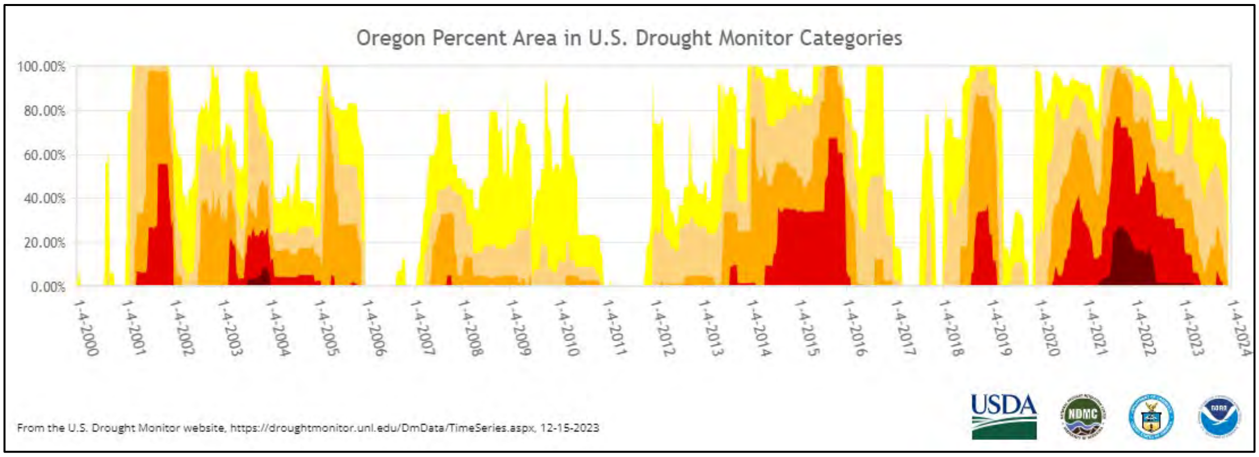


Figure 1.2. The time series chart showing the proportion of Oregon in each category of drought from 2000 through 2023 helps identify drought periods.

For impacts related to soil moisture and vegetation condition, we associate impacts with the USDM status on the recorded start date of the impact. Dating drought impacts is not a precise science but this provides a rough means of describing drought intensity when media reported on a given impact. These appear in parentheses along with the source of the impact as, for example, "USDM status = D4." USDM status is less relevant for hydrologic impacts such as curtailed irrigation, given that hydrologic impacts are more likely to be offset in space and time from drought conditions. In managed hydrologic systems, reservoirs provide a buffer from drought, and the amount of water may be affected by drought in a remote upstream location.

Drought Severity and Coverage Index (DSCI)

The DSCI is a method for summarizing the intensity and spatial extent of USDM drought levels for a specific area to a single value ranging from 0 to 500. Zero means that none of the area is abnormally dry or in drought, and 500 means that all of the area is in D4, exceptional drought. The DSCI is a weighted sum of the percentage of an area in each category of drought, which sounds more complicated than it is. For more explanation, see https://droughtmonitor.unl.edu/About/AbouttheData/DSCI.aspx. The DSCI is calculated weekly by the NDMC and is available to download (https://droughtmonitor.unl.edu/DmData/DataDownload/DSCI.aspx).

Figure 1.3 shows the DSCI for Oregon, statewide, from 2000 through fall 2023.

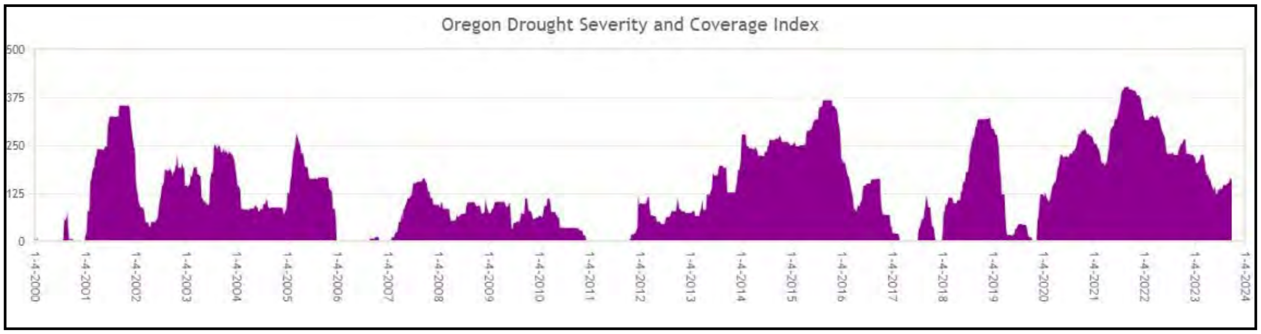


Figure 1.3. The Drought Severity and Coverage Index combines the intensity and percent of area in each drought status into a single number, shown here for 2000-2023 for the state of Oregon.

References

Redmond, K.T. (2002). The depiction of drought: A commentary. Bulletin of the American Meteorological Society, 83(8), pp.1143-1147. Doi: 10.1175/1520-0477-83.8.1143

Smith, K. H., Burbach, M. E., Hayes, M. J., Guinan, P. E., Tyre, A. J., Fuchs, B., Haigh, T., & Svoboda, M. D. (2021). Whose Ground Truth Is It? Harvesting Lessons from Missouri's 2018 Bumper Crop of Drought Observations. Weather, Climate, and Society, 13(2), 227–244. https://doi.org/10.1175/WCAS-D-19-0140.1

Svoboda, M., LeComte, D., Hayes, M., Heim, R., Gleason, K., Angel, J., Rippey, B., Tinker, R., Palecki, M., Stooksbury, D., Miskus, D., & Stephens, S. (2002). The Drought Monitor. Bulletin of the American Meteorological Society, 83(8), 1181–1190. https://doi.org/10.1175/1520-0477-83.8.1181

Wilhite, D. A., Svoboda, M. D., & Hayes, M. J. (2007). Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. Water Resources Management, 21(5), 763–774. https://doi.org/10.1007/s11269-006-9076-5

Chapter 2: Drinking Water

Drinking Water Summary

Oregon relies on a combination of groundwater and surface water for its drinking supply. Drinking water demand is expected to increase as Oregon's population grows, especially in the Willamette Valley. There are many ways to assess drinking water vulnerability, and this report focuses on aspects that were seen as especially relevant by state water agencies and for which data was currently available. The investigation identified areas in Oregon that have recently experienced drought impacts to the drinking water supply, including mapping the locations of reported domestic wells with limited or no production. It also highlights Community Water Systems (public water systems with at least 15 service connections used by year-round residents, or that regularly serve at least 25 year-round residents) with characteristics that could potentially make them susceptible to drought conditions. Drinking water impacts reported by Oregon news media were relatively rare, with only 23 stories collected between 2010 and 2022. The most drinking water impacts were reported in Klamath County. Limited or dry wells emerged as a major concern across the state in 2021. More than 1,100 domestic wells were reported through the Oregon Water Resources Department’s (OWRD) newly developed online Dry Well Reporting form between July 2021 and July 2023, with the highest density of reports in Deschutes, Klamath and Jackson counties. It’s important to note dry well reports were submitted voluntarily and the reporting system may not have been known to all private domestic well users. Community water systems (CWS) that serve fewer people and those with only one source of self-supplied water (no interties with other systems) were deemed more susceptible to drought. In addition to not having backup water sources, previous studies and discussions with Oregon water agencies both noted that these smaller systems often lack the capacity and resources to apply for infrastructure grants and seek technical assistance opportunities. In total, 310 smaller CWS (with at least 15 connections or serving between 25 and 3,300 people) that rely on a single water source (making them potentially vulnerable to drought) were identified. These CWS are clustered in the Willamette Valley and the Rogue, Deschutes, Klamath and Umatilla River basins, and the majority rely on groundwater. Including additional socioeconomic and physical drought vulnerability indicators, along with systematic methods for enhanced communication with water suppliers and users, would potentially help refine this vulnerability analysis. To what extent this is necessary depends on how this information will be used and the level of detail necessary for effective decision making.

Introduction

Drinking water in Oregon is monitored and regulated by agencies such as the Drinking Water Services section of the Oregon Health Authority (OHA), the Oregon Department of Environment Quality (ODEQ) and the OWRD. About 80% of Oregonians rely on the state's 3,315 public water systems, which may utilize surface water, groundwater, or a mix of the two (OHA 2023, ODEQ 2018a, ODEQ 2018b). Private wells make up the remaining estimated 20% of drinking water supply in the state (ODEQ 2018a). Private wells are not regulated in Oregon, but the OHA Domestic Well Safety Program provides information, testing and other resources for private well users (OHA, n.d.). Drought affects quantity and potentially the quality of drinking water, whether it comes from above or below the earth's surface.

Oregon has 1,400 named lakes and more than 160,000 km of rivers and streams (ODEQ 2018b; Figure 2.1). Around 10% of public water systems in Oregon use surface water for drinking water, including some of the state's largest cities: Portland, Salem, Eugene, Bend and

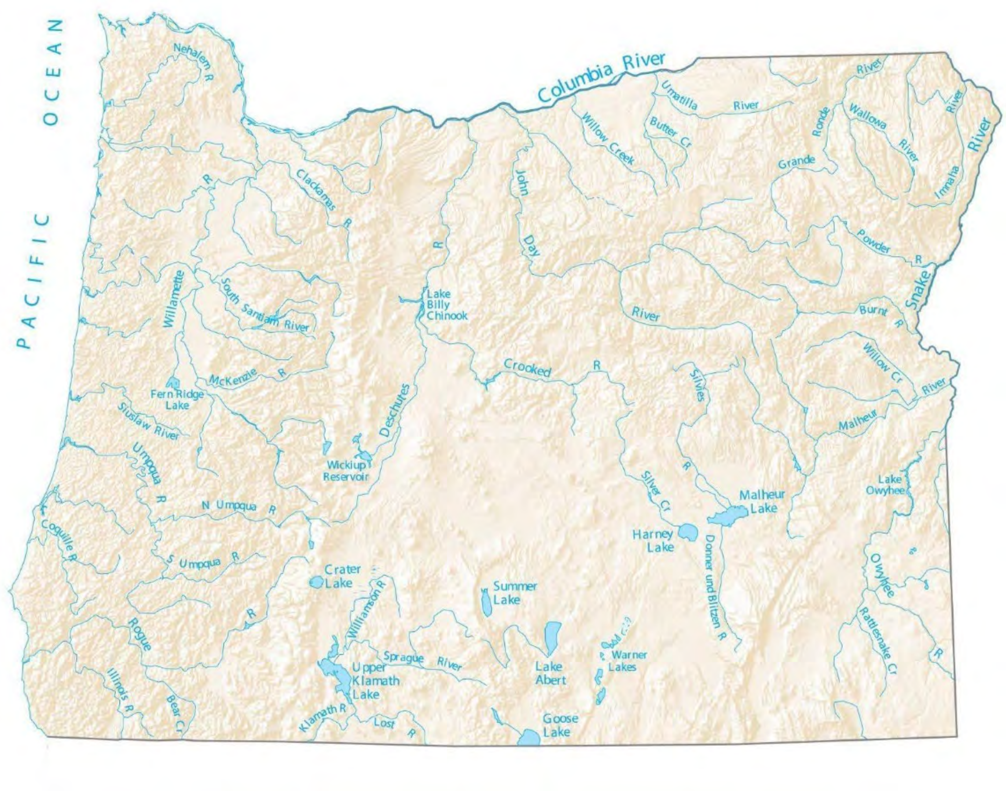


Figure 2.1. Major water bodies in Oregon. Source: GISGeography.com (https://gisgeography.com/oregon-lakes-rivers-map/).

Medford uses surface water for at least a portion of their drinking and domestic water needs (ODEQ 2018b). For example, Portland's main water sources are the reservoirs in Bull Run Watershed and secondary wells in the Columbia South Shore Well Field. Central Oregon relies heavily on snowpack and rain coming off the Cascades. Surface water use is less common in Eastern Oregon, but water from the Blue Mountains provides drinking water for some localities in the northeastern part of the state.

As of 2018, approximately 35% of Oregon residents relied solely on groundwater for drinking, with an additional 55% using a combination of surface and groundwater (ODEQ 2018a). There are also reported to be about 350,000 private water wells across the state, which may be used for drinking and domestic uses (ODEQ 2017). According to the OWRD (n.d.), "Oregon's most productive regional aquifer systems occur in the Willamette Valley, High Cascades, and Deschutes-Columbia geologic provinces". Although, additional small aquifers can be found throughout the state that provide water for domestic use (Figure 2.2). Groundwater resources are not infinite, however, and aquifers often replenish slowly. Issues can arise when groundwater is extracted more quickly than it can be replenished, either through natural or artificial means.

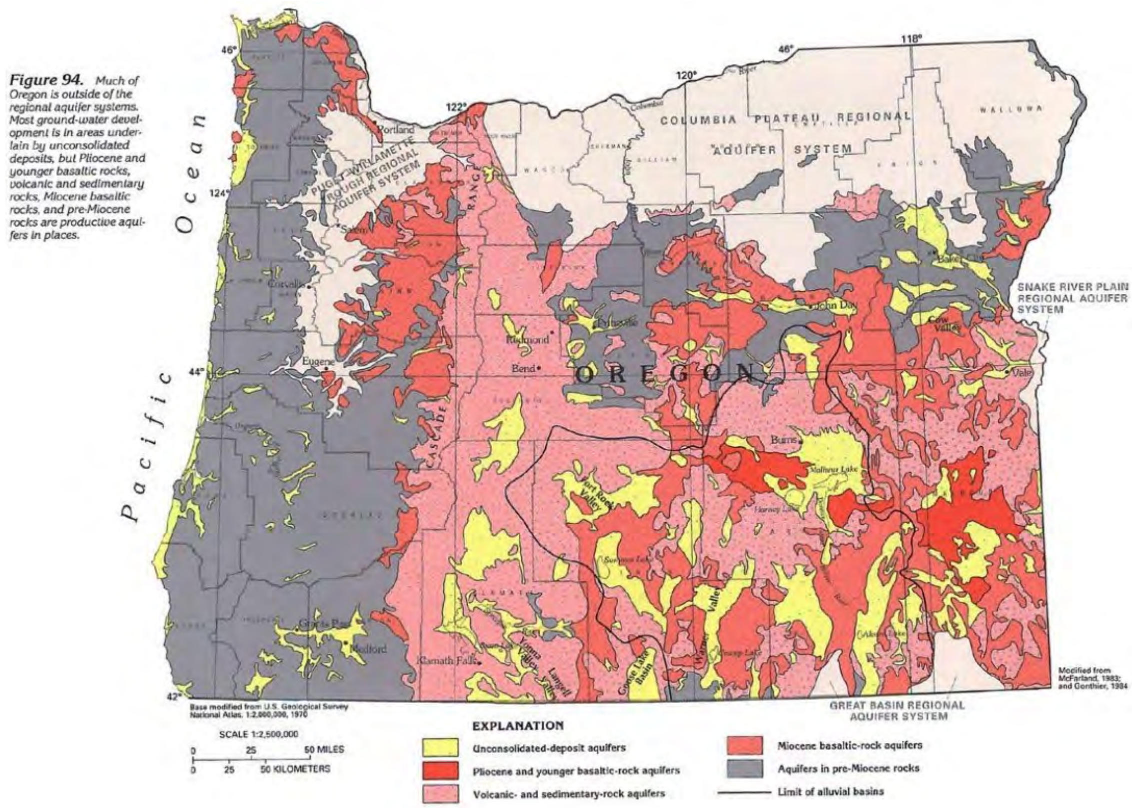


Figure 2.2. Aquifers in Oregon (Groundwater Atlas of the United States: Oregon, https://pubs.usgs.gov/ha/ha730/ch_h/jpeg/H094.jpeg).

Drinking water demand is expected to increase as Oregon's population grows, especially in the Willamette Valley, where 70% of Oregon residents currently live (Jaeger et al. 2017). Simultaneously, research indicates that the Cascade Mountain Range on the western side of the Willamette Valley may have no snow at all by 2070 (Siirila-Woodburn et al. 2021). Oregon State

University found that the snow water equivalent at low elevations in the Willamette Valley may be completely gone by mid-century (Oregon State University Institute for National Resources, n.d.). Loss of snowpack in the Cascades, combined with growing water demand in the Willamette Valley, puts this region of Oregon at risk of future water scarcity under some modeling scenarios (Jaeger et al. 2017).

Reduced water availability is a critical concern when considering the impact of drought on drinking water, which can stress already water-scarce regions. Two Oregon towns, Prairie City and Sodaville, are among locations in Oregon that are prone to water shortages during summer months (McDuff 2016, Mitchell 2021, Paul 2019). Drought exacerbates existing water supply issues. For example, the town of Prairie City has struggled to supply adequate amounts of water since at least 1969 (Hall 2023). Prairie City ran out of drinking water due to drought in 2018 and 2021 and needed to truck in water from the nearby community of John Day (Hanners 2018, Oregon Public Broadcasting 2021). A $1 million grant from the USDA Rural Development program was used in 2018 to cover the cost of hauling water and to offset a loan to connect Prairie City's water system to an additional source (Hall 2023). Sodaville, likewise, is similarly often low on water during the summer. Drought conditions during 2015, 2019 and 2022 depleted Sodaville’s groundwater source capacity, and the town was forced to haul water from the nearby town of Lebanon to meet the needs of their 310 users at a substantial cost (Paul 2019; Mann 2022).

Drinking water quality may also deteriorate during hot, dry conditions. Although OHA staff noted a common perception of a link between drought and drinking water quality in Oregon, they haven’t seen systematic evidence to support the claim generally (Oregon Health Authority, personal communication, 2023). Drought-related water quality issues do arise at times, though. Canby, Oregon, has dealt with undesirable tastes and odors in their drinking water in recent years, which has been attributed to the proliferation of cyanobacteria in warm, low-flowing water (Canby Utility 2021). Drinking water in Canby is sourced from a major tributary of the Willamette River, the Molalla River, which typically experiences low flow and warm temperatures in the summer (Canby Utility 2023). Drought conditions are known to increase the likelihood of cyanobacterial blooms, which can cause unpleasant tastes and odors in drinking water (CDC 2020, Lisboa et al. 2020). Cyanotoxins may also be released by some cyanobacteria species and threaten humans and animals alike (CDC 2020). According to Canby Utility, cyanotoxins exceeding the OHA's advisory level for vulnerable populations (0.3 μg/L total microcystins) were found in the city's treated drinking water in September 2014 (Canby Utility 2023).

The vulnerability of private domestic wells and public water systems is fluid due to changing climatic variability, water system and management characteristics, and user demands. Therefore, vulnerability must be evaluated on an ongoing basis with an ever-expanding list of potential data and methods. There are many potential drought vulnerability issues related to drinking water, so this report focused on aspects that were seen as especially relevant by state water agencies and for which data was currently available. Specifically, we identified and mapped impacts on drinking water supplies reported by the media during recent drought, the locations of reported wells with limited production or that went dry during a two-year period of the current ongoing drought, and CWS (public water systems with at least 15 service connections used by year-round residents, or that regularly serve at least 25 year-round residents) with characteristics that could make them susceptible to drought conditions. Over time, further data collection and analysis will help create a more comprehensive picture of where and why

Oregon’s drinking water systems are vulnerable to drought.

Drought impacts to drinking water reported in the media

In this section, news media reports of drought impacts in Oregon that have been archived within the NDMC’s Drought Impact Reporter (DIR) were evaluated. This work included identifying recent intervals of time when drought impacts were recorded and then determining which regions within the state experienced those impacts. Drinking water impacts reported by Oregon news media and archived in the DIR were relatively rare, with only 23 stories collected between 2010 and 2022. Impacts were reported in 2010, 2014, 2018, 2021 and 2022. The most drinking water impacts were reported in Klamath County (Figure 2.3).

According to reports, in 2010 and 2014, drought impacts to drinking water arose in Klamath County, while the Willamette Valley experienced problems in 2018. Between 2021 and 2023, dry or limited production wells emerged as a major concern across the entire state. More than 300 well complaints were reported across Oregon in 2021, with Deschutes County and Klamath County making up a large proportion of the reports (Flaccus 2021, Cureton Cook 2021). Diminished well reports continued into the following years, and more than 1,100 domestic wells were reported across the state between July 2021 and July 2023 (OWRD 2023).

Klamath County

Klamath County residents experienced issues with domestic wells in 2010. Issues arose around Malin and in the town of Merrill (Beaver 2010, Associated Press 2010). Pumps were

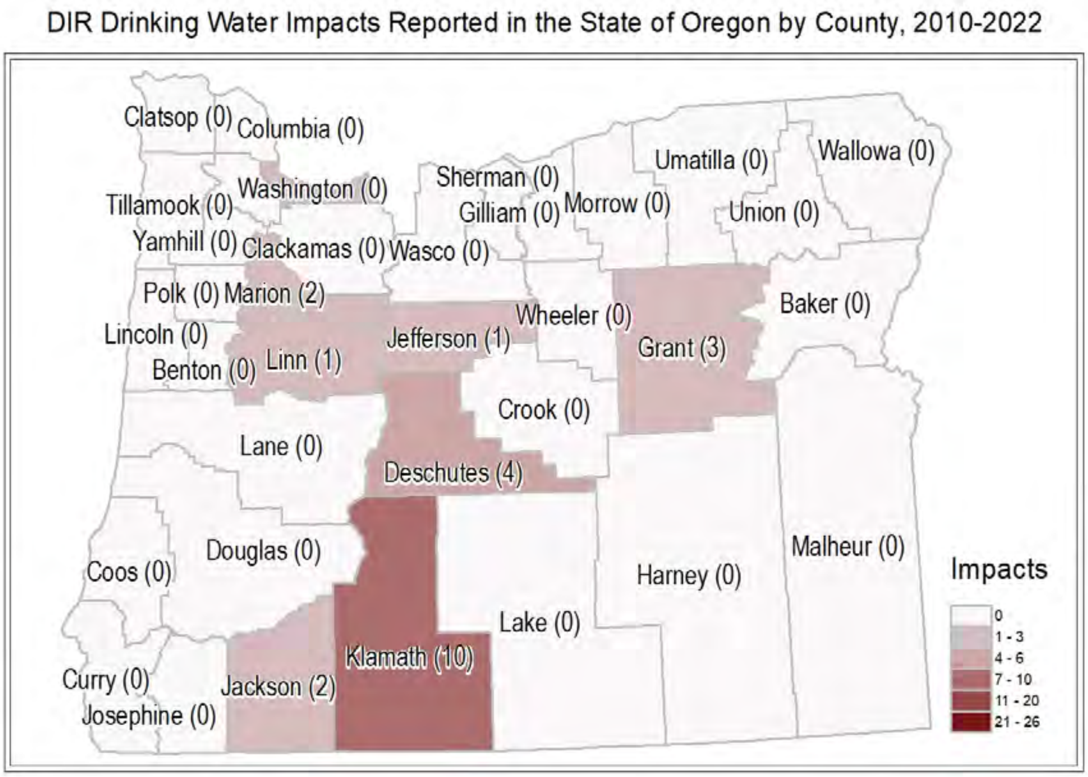


Figure 2.3. Drinking water impacts reported in the State of Oregon by County, 2010-2022 (Source: NDMC Drought Impact Reporter).

unable to reach groundwater, with one person near Malin reporting they had to lower a well by 40 feet. The water shortages were attributed to pumping for irrigation as the Klamath Reclamation Project was only able to provide 30% of the required irrigation water to nearby farmers. Water was transported to Malin by the Oregon National Guard (Beaver 2010), while the town of Merrill had two water tankers supplying their water (Associated Press 2010). In 2014, Klamath County struggled again with domestic wells due to increased pumping for farm irrigation due to ongoing drought, and most groundwater measurements were even lower than they had been in 2010, according to the Oregon Water Resources Department (Jarrell 2014).

Willamette Valley

Water supplies in the Willamette Valley were impacted by drought in 2018. In May, a toxic algae bloom in Detroit Lake negatively impacted Salem's drinking water source (Salem Statesman Journal 2018). Toxins from the cyanobacteria entered the town's drinking water supply, prompting a do-not-drink alert in Salem on June 6, 2018. The severity of the toxic bloom was attributed in part to the ongoing drought. Examination of a water level time series from Detroit Lake indicates that, indeed, the lake was low at this time (Figure 2.4). Cyanobacterial blooms are typical in Detroit Lake during late spring, but normally dissipate in the rain. That spring was very hot and dry, so the cyanobacterial bloom was able to continue growing.

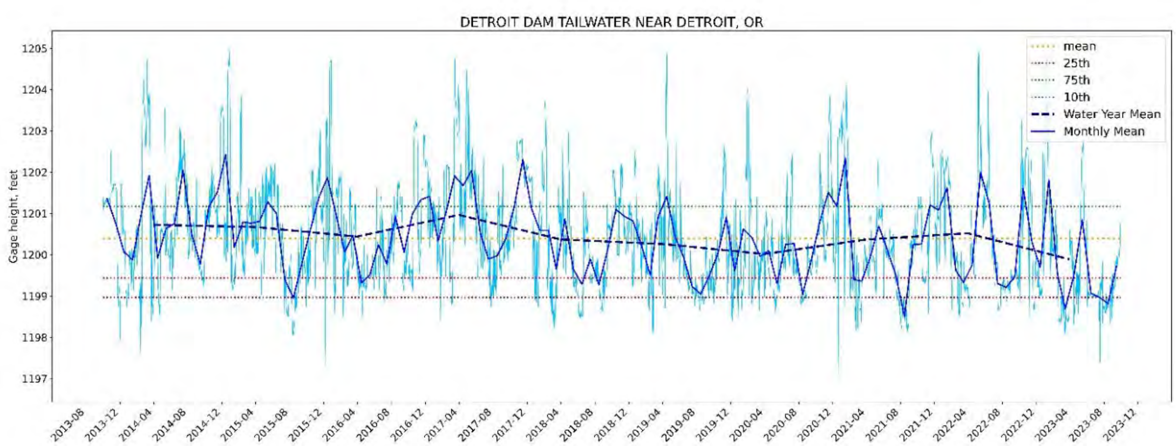


Figure 2.4. Water level time series for Detroit Lake, 2013-2023 (NDMC 2024 from USGS).

Later that spring, Portland's water supplies began to dwindle. The Portland Water Bureau supplemented its normal supply from the Bull Run Watershed with groundwater from the Columbia North Shore Well Field in June 2018 until rainfall could contribute adequate amounts of water (Redden 2018). The town of Prairie City, in eastern Oregon, also needed supplemental water supplies in August that year (Hanners 2018).

Limited and dry well reporting

In this section, the number and location of limited or dry wells in Oregon were mapped based on user reports submitted through the OWRD database of dry wells (https://www.oregon.gov/owrd/programs/gwwl/pages/drywell.aspx) during the drought period from July 2021 to July 2023. To better track well problems, the OWRD launched the online Dry Well Reporting Form on July 27, 2021. However, there are reports in the dry well database back to April 2021, since some reports were backdated to document well problems earlier in the year. Communication with water officials in Oregon revealed that, as of December 2023, awareness of the Dry Well Reporting form was still growing and it may not be known by all well owners, which should be taken into consideration when evaluating results from the database. Efforts to increase awareness of the form may be beneficial in assessing the true extent of issues experienced by domestic well owners.

Nonetheless, by July 2023, 1,126 reports had been submitted by domestic well owners. Of these, 28 duplicate reports were submitted within the same month for the same well, and some cases where the same well was reported on an annual basis (e.g., each April). Even so, 97% of the well reports were unique, and the number and location of reports are shown in Figures 2.5 and 2.6. The reports in Figure 2.5 are grouped by county and Figure 2.6 by the zip code of the person submitting the report, which was the finest resolution of analysis available for all reports. The mapping reveals the highest density of reports from Deschutes, Klamath and Jackson counties in the Deschutes River, Klamath River and Rogue River basins, respectively. Other reports are scattered from across the state.

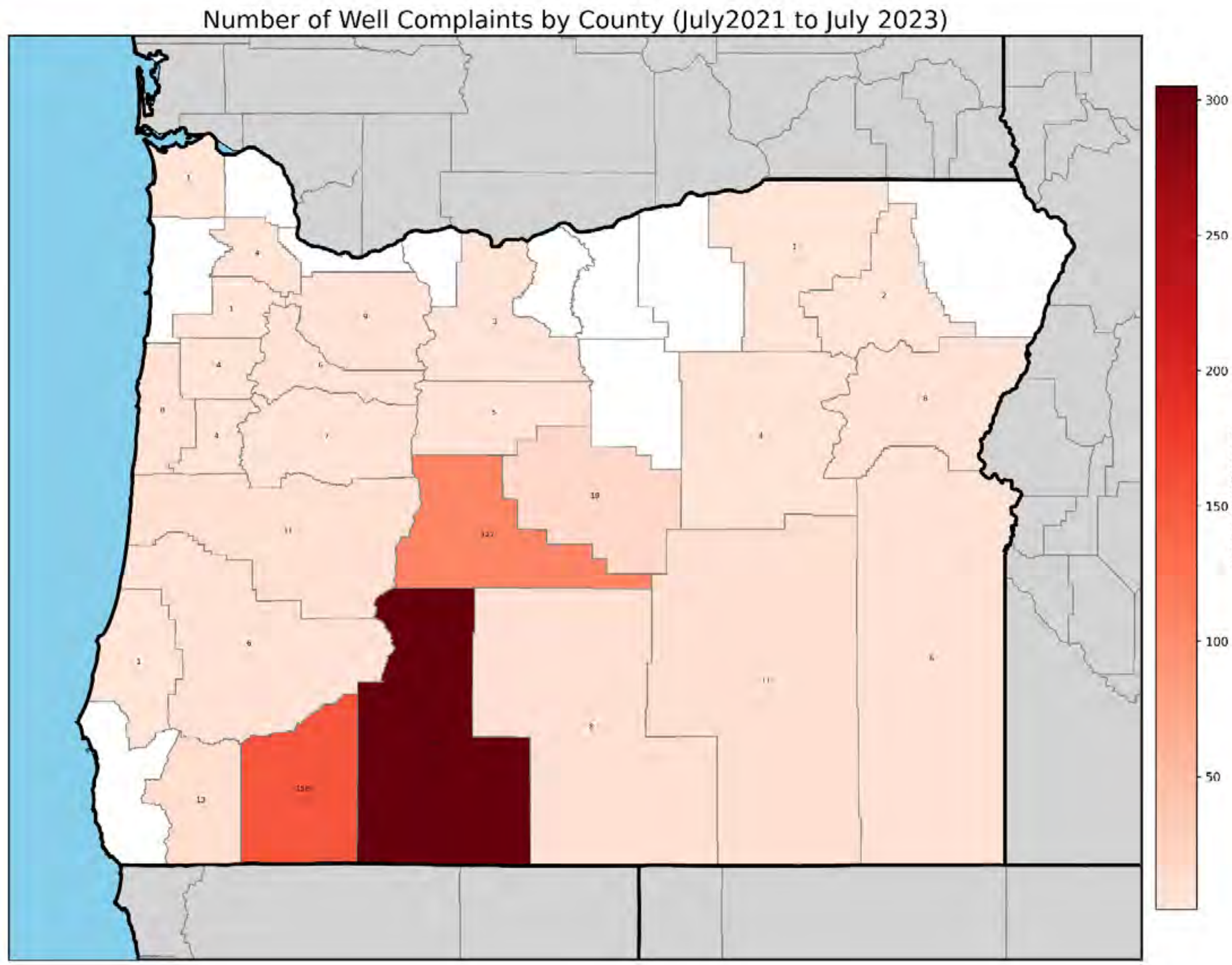


Figure 2.5. Limited and dry well reports by county via the OWRD Dry Well Reporting Form from July 2021 to July 2023 (Source: OWRD Dry Well Database).

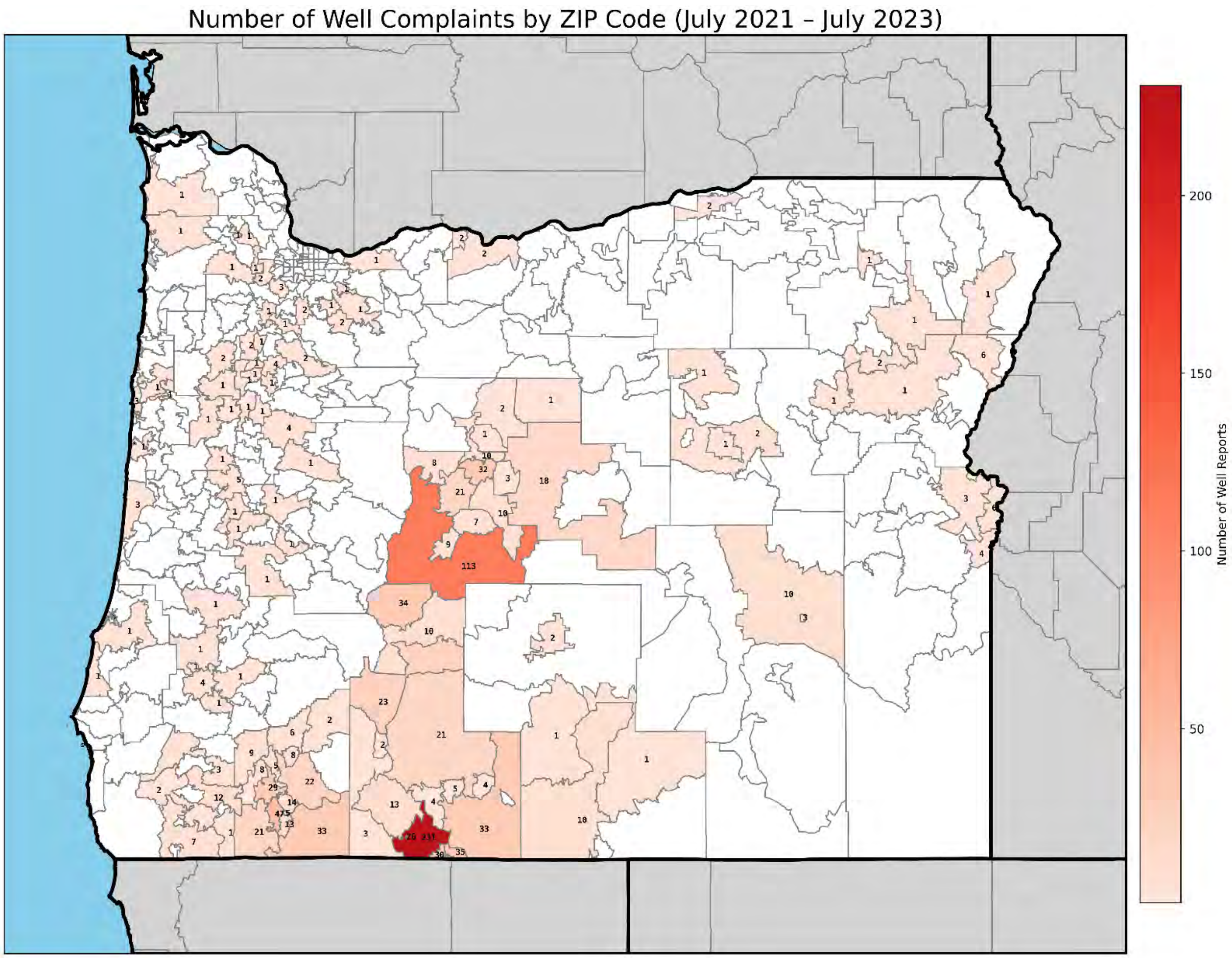


Figure 2.6. Limited and dry well reports by zip code submitted via the OWRD Dry Well Reporting Form from July 2021 to July 2023 (Source: OWRD Dry Well Database).

In contrast, Figure 2.7 shows dry well reports by month in comparison to the Drought Severity Coverage Index (DSCI). The DSCI is a method for converting drought levels from the weekly U.S. Drought Monitor map to a single value for an area, the State of Oregon in this case. Possible values of the DSCI are from 0 to 500. Zero means that none of the area is abnormally dry or in drought, and 500 means that all the area is in D4, exceptional drought, as measured by the U.S. Drought Monitor (see https://droughtmonitor.unl.edu/About/AbouttheData/DSCI.aspx).

Figure 2.7 illustrates several things: 1) drought conditions expanded across the state during the spring and summer of 2021 (although the drought began in December 2019) and continued through 2023, although at a reduced extent and/or severity, and 2) dry well reports were submitted every month but more frequently during the spring and late summer months, when demand is high and supply is often low. However, drought relief program requirements were also likely a primary cause for the submission of some dry well reports. For example, in response to drought conditions in 2021, Klamath County and its partners initiated programs to assist households whose well was dry or producing less water than needed for household purposes, including a free potable water filling station, free water storage tanks and free water delivery to fill the tanks (Klamath County 2021; Klamath County 2021a). However, the filing of a dry well report was required to obtain a free tank or water delivery.

During the December 2021 Special Session, the Oregon Legislature authorized funding to provide support for individuals experiencing dry well issues in Jackson County, Klamath County and Deschutes County. Utilizing this funding, the Klamath County Domestic Well Financial Assistance Grant Program was able to reimburse homeowners 75% of eligible costs up to a $40,000 maximum grant to address issues with an approved domestic well. Grant

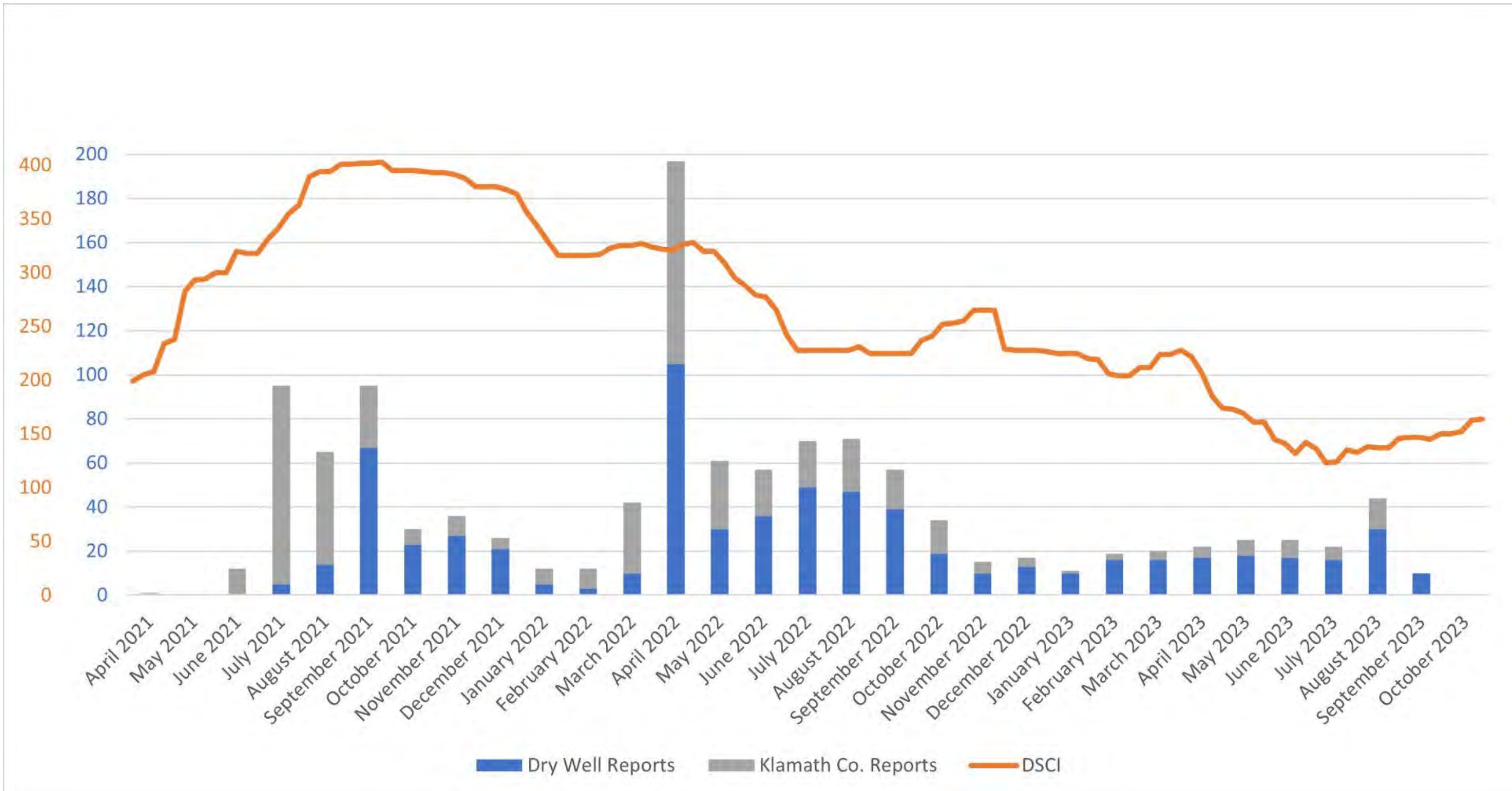


Figure 2.7. Dry well reports by month compared to the Drought Severity Coverage Index (DSCI) with Klamath County reports highlighted in gray. This graph represents the month in which the reported impacts occurred (Source: National Drought Mitigation Center and OWRD Dry Well database).

applications were accepted April 1-30, 2022, to address problems during the Klamath drought declaration period lasting from March 31, 2021 to December 31, 2021, but required that a dry well report be submitted. This likely amplified the large influx of dry well reports from Klamath County in April 2022 (i.e., 83 of 187 reports for the month).

Overall, this analysis reveals where and when dry well reports were submitted, which can help in showing areas of concern. However, program requirements and any variability in the successfulness of outreach efforts to inform well owners about the reporting system likely biased the submissions of well reports, which should be kept in mind when evaluating trends in their occurrence. It is also important to note that a report of a "dry well" does not necessarily mean that the well was dry. For example, in some cases, it could have been a maintenance issue, although even that could have been caused by excessive pump use to meet water requirements during drought. Well issues were self-reported and were not necessarily verified by an outside party, except for cases in which funding requests were submitted to OWRD or Klamath County. Cooperation with county governments may help in efforts to complete a thorough survey of dry wells across the state in future analyses.

Community Water Systems that are potentially vulnerable to drought

In this section, community water systems (CWS) that are potentially vulnerable to drought were identified and mapped based on characteristics that could make them susceptible to the effects of drought. Several other states have initiated efforts to evaluate the vulnerability of their public water systems. The methods undertaken are dependent on the availability of system data and the ability to use proxy data to estimate potential vulnerabilities. For instance, during the creation of Washington's drought plan, the State Department of Health developed preliminary drought vulnerability assessment criteria to identify water systems most vulnerable to drought-caused water supply interruptions (WSDE 2018). The criteria included metrics to qualitatively assess the individual source susceptibility (i.e., source depth, construction, aquifer characteristics, age, use and capacity); quantitatively assess system aggregate sources' capacity (i.e., water capacity, operational capacity [system size] and redundancy); and included a weight for the availability of information (i.e., higher risk when data is not available). Similarly, California recently assessed the drought and water shortage vulnerability of the state's domestic wells and small, non-public water systems using 27 physical and social vulnerability indicators (CDWR 2023, CDWR 2021).

For this initial Oregon assessment, three important community water system vulnerability metrics were identified for which data is currently available: the number of people served by the system (system size), the number of water sources (single or multiple), and whether a water system is interconnected with another system. Oregon Drinking Water Services (DWS), which administers and enforces drinking water quality standards for public water systems in the state (DWS 2023), maintains Drinking Water Data Online to provide information about the state's public water systems (see https://yourwater.oregon.gov). There are several different types of public water systems in Oregon, but most residents are served by CWS. Therefore, they were selected for this initial assessment. A survey of CWS staff was considered to gather additional data and local perspectives on drought vulnerability but a previous survey of the state's CWS yielded very few responses, so data from the Drinking Water Data Online database was viewed as the most appropriate data source at the current time.

Oregon's definition of a CWS is "a public water system that has 15 or more service connections used by year-round residents, or that regularly serves 25 or more year-round residents” (https://yourwater.oregon.gov/dwpgloss.htm). The U.S. Environmental Protection Agency also classifies water systems from very small to very large systems, which was used to further categorize Oregon CWS as:

- Very Small systems serve fewer than 25[1]-500 people
- Small systems serve from 501 to 3,300 people
- Medium systems provide water to between 3,301 and 10,000 people
- Large systems provide water to between 10,001 and 100,000 people
- Very Large systems serve communities of greater than 100,000 people

Figure 2.8 shows the location and size of CWS in Oregon from data extracted from the Drinking Water Data Online database in September 2023. The map shows 927 CWS, with the majority being Small and Very Small systems. A breakdown of the categories includes Very Small (649 systems), Small (157), Medium (55), Large (60) and Very Large (6).

Size is often one determinant of drought vulnerability. As stated by Davis et al. (2021), “Community water suppliers in Oregon range in size from the Portland Water Bureau with over 500 employees and an organized, multi stakeholder working group that collaborates on management and produces an annual report, to very small rural systems serving only a handful of households and managed by a single staff member. Some of the smallest systems in Oregon are staffed by volunteers only. Regardless of size, every community water system requires a certain minimum level of infrastructure and treatment capability. Economies of scale often work against smaller water providers because treatment costs per unit [gallon] of finished water typically decline as system size and volume treated increase. Therefore, smaller systems usually face higher costs per unit of finished water delivered, have smaller budgets, and operate with fewer dedicated staff. One important consequence of this disparity is that smaller systems have

[1] There are four community water systems with less than 25 people served but they had at least 15 connections, so they were included in this category for the purposes of this study.

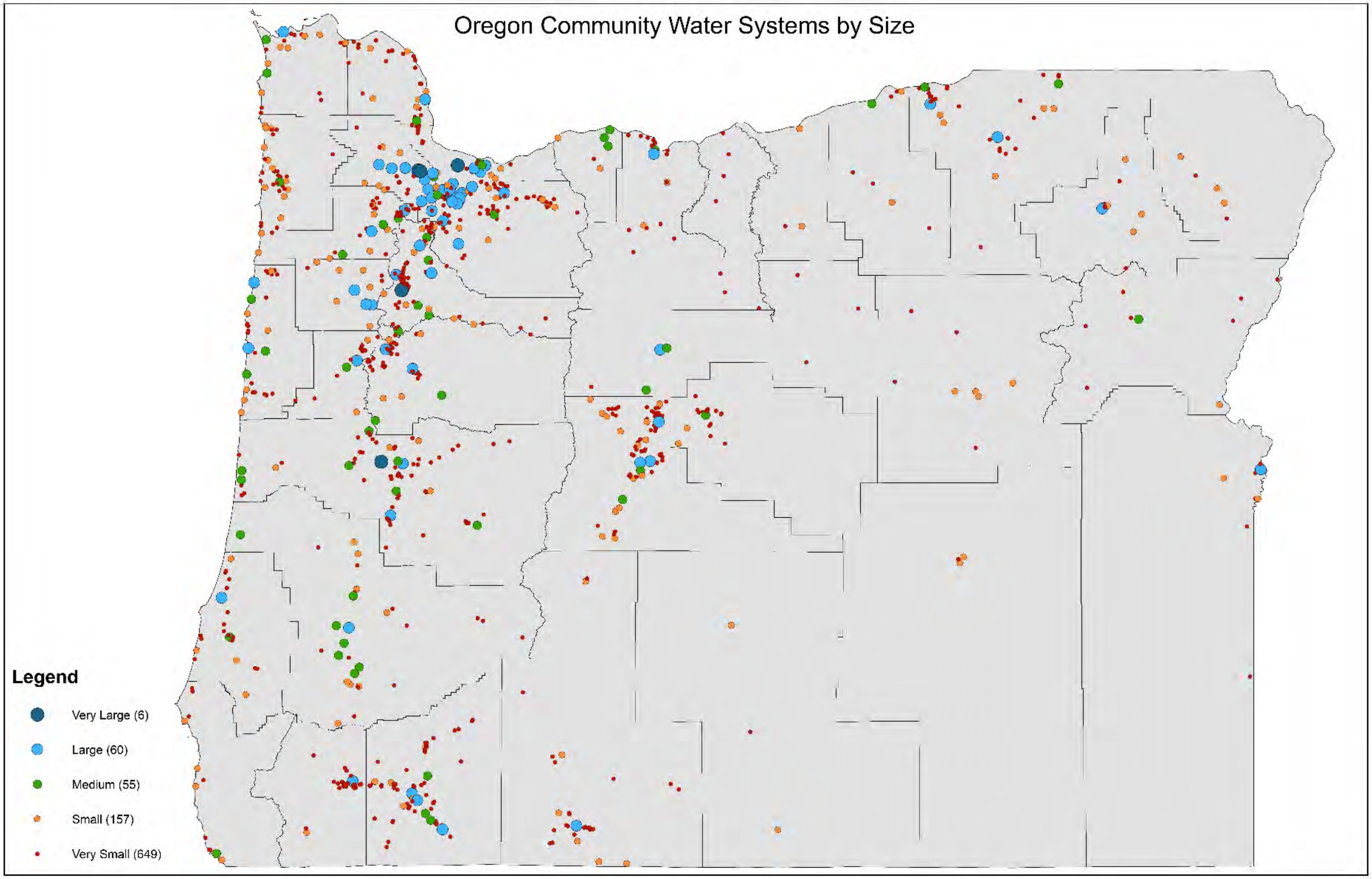


Figure 2.8. Oregon Community Water Systems by number of people served (Source: NDMC from Oregon Water Data Online).

correspondingly less capacity to identify, publicize and mitigate threats or impacts to the quality and quantity of their drinking water sources."

A 2023 Oregon Secretary of State audit of the state's water resources management echoes these sentiments, stating, "Communities that lack access to state decision makers or the resources to confront water insecurity concerns on their own are at risk of not being prioritized in the state's water decisions and not receiving necessary funding to address water infrastructure and planning needs (OSOS 2023)." Therefore, smaller CWS may be more susceptible to the effects of hazards, such as drought, and benefit from additional technical support (e.g., grant-writing, planning, implementation) from state agencies and other relevant organizations.

Other common characteristics of more resilient water systems are those with more than one water source and/or interties with other systems, which can provide flexibility and back-up sources during emergency situations (CISA 2021, CDWR 2021). For this analysis, "multiple sources" means the system has more than one well and/or surface water intake, a combination thereof, or opportunities to purchase water from another system, in addition to their primary source. Figure 2.9 shows CWS in Oregon with one source of water vs. those with multiple sources. This data was also available from the Oregon Health Authority's Drinking Water Data Online database and reveals that a total of the 403 CWS (43%) rely on a single water source to meet their needs. These systems are scattered across the state.

As an initial, relatively simple method of identifying potentially vulnerable CWS in Oregon with existing data, we combined system size and single source metrics. Systems that purchase water from another CWS as their sole water source were also removed from the dataset. Figure 2.10 shows the location of the 310 Small and Very Small CWS that rely on a single water source, representing roughly one-third of Oregon's smaller water systems and

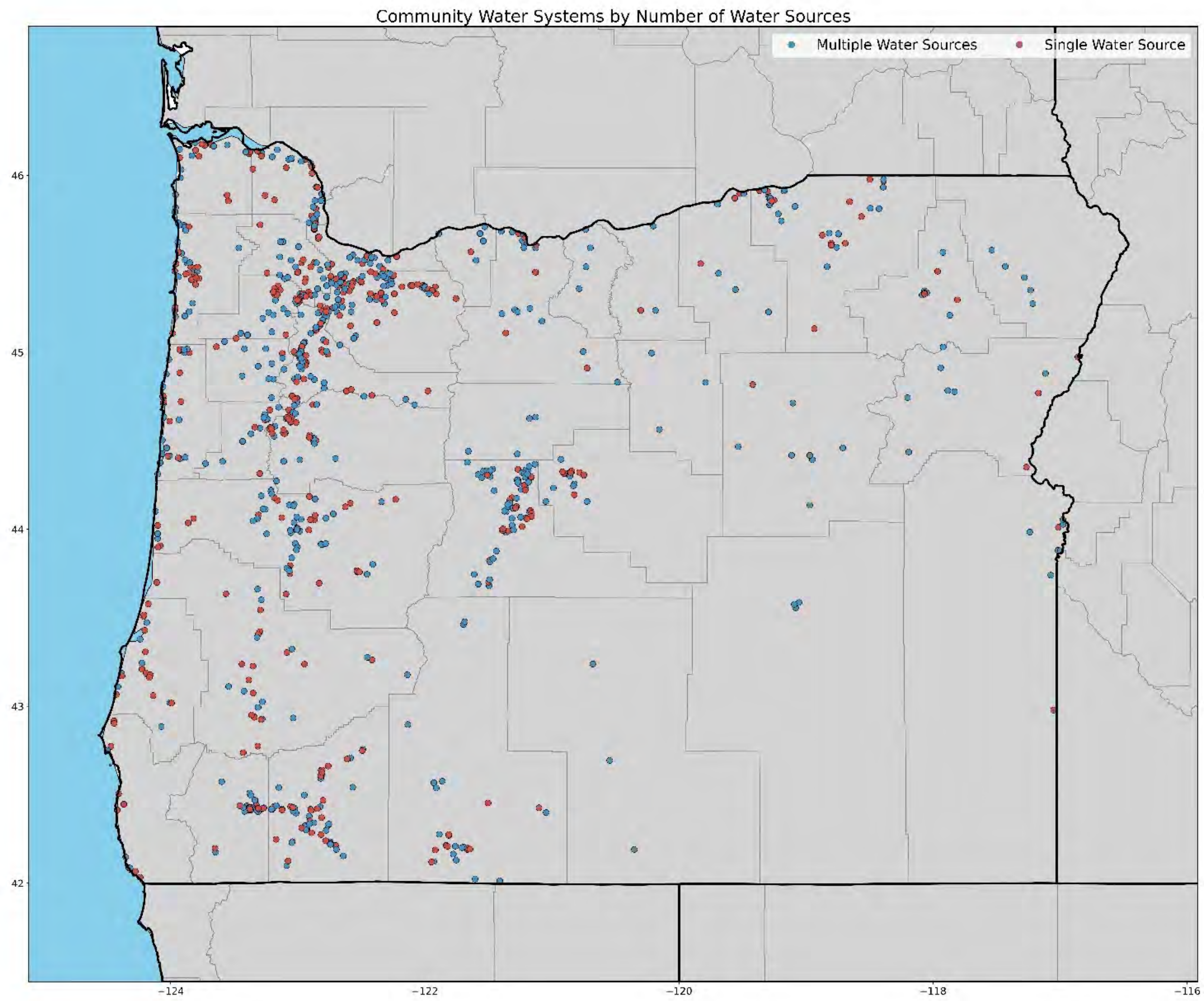


Figure 2.9. Community water systems with one vs multiple water sources (Source: NDMC from Oregon Water Data Online).

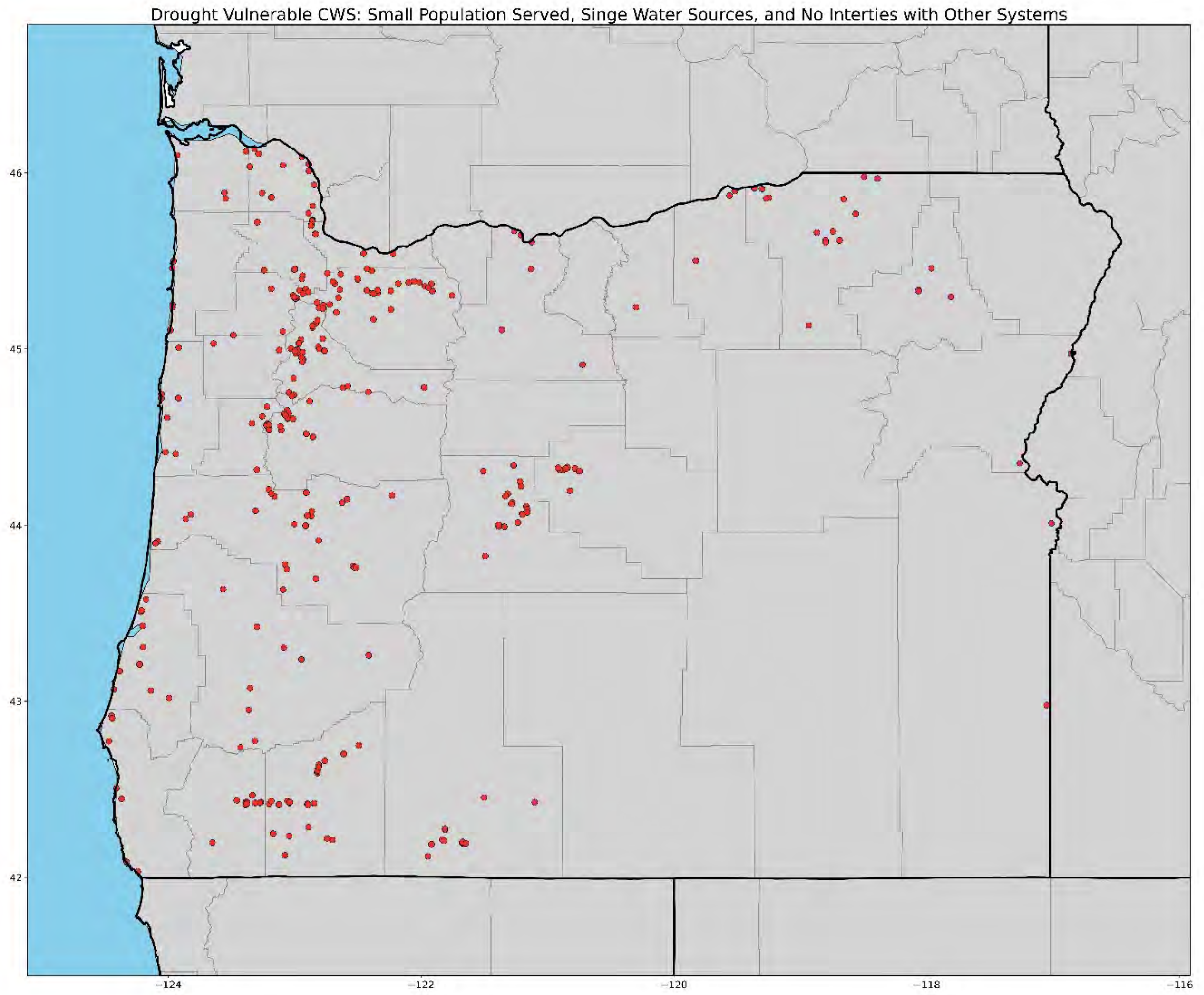


Figure 2.10. Small and Very Small CWS with one water source and no interties with other community water systems (Source: NDMC from Oregon Water Data Online).

serving nearly 65,000 people combined. Twenty-five of the identified systems were considered Small and 285 were classified as Very Small. Many of the vulnerable CWS (140) were found within counties of the Willamette Valley, which may be related to the high population density in that region. Other clusters of vulnerable CWS emerge in the Klamath River Basin (southern Klamath County – 12 CWS), the Deschutes River Basin (Deschutes and Crook counties – 29 CWS), the Umatilla River Basin (Umatilla County – 14 CWS) and the Rogue River Basin (Jackson and Josephine counties – 40 CWS). Examination of the vulnerable CWS names found that at least 58 are associated with mobile home parks.

Most of the small, single-source systems (262) rely on groundwater, and the 48 relying on surface water are mainly in the western portion of the state (Figure 2.11). These types of analyses provide a starting point to help target and inform further evaluation, outreach and assistance programs to increase drought resilience. The State of Oregon should investigate whether the inclusion of additional vulnerability metrics would be appropriate and desirable to further investigate the susceptibility of their water systems to drought conditions. For example, future assessments of vulnerability could potentially include information regarding aging water infrastructure in Oregon and economic disparities between communities. The ongoing selection of additional vulnerability metrics will largely be determined by the availability of primary and appropriate proxy vulnerability data, along with the cost and feasibility of collecting new data balanced with the type and scale of information necessary to make informed water management decisions.

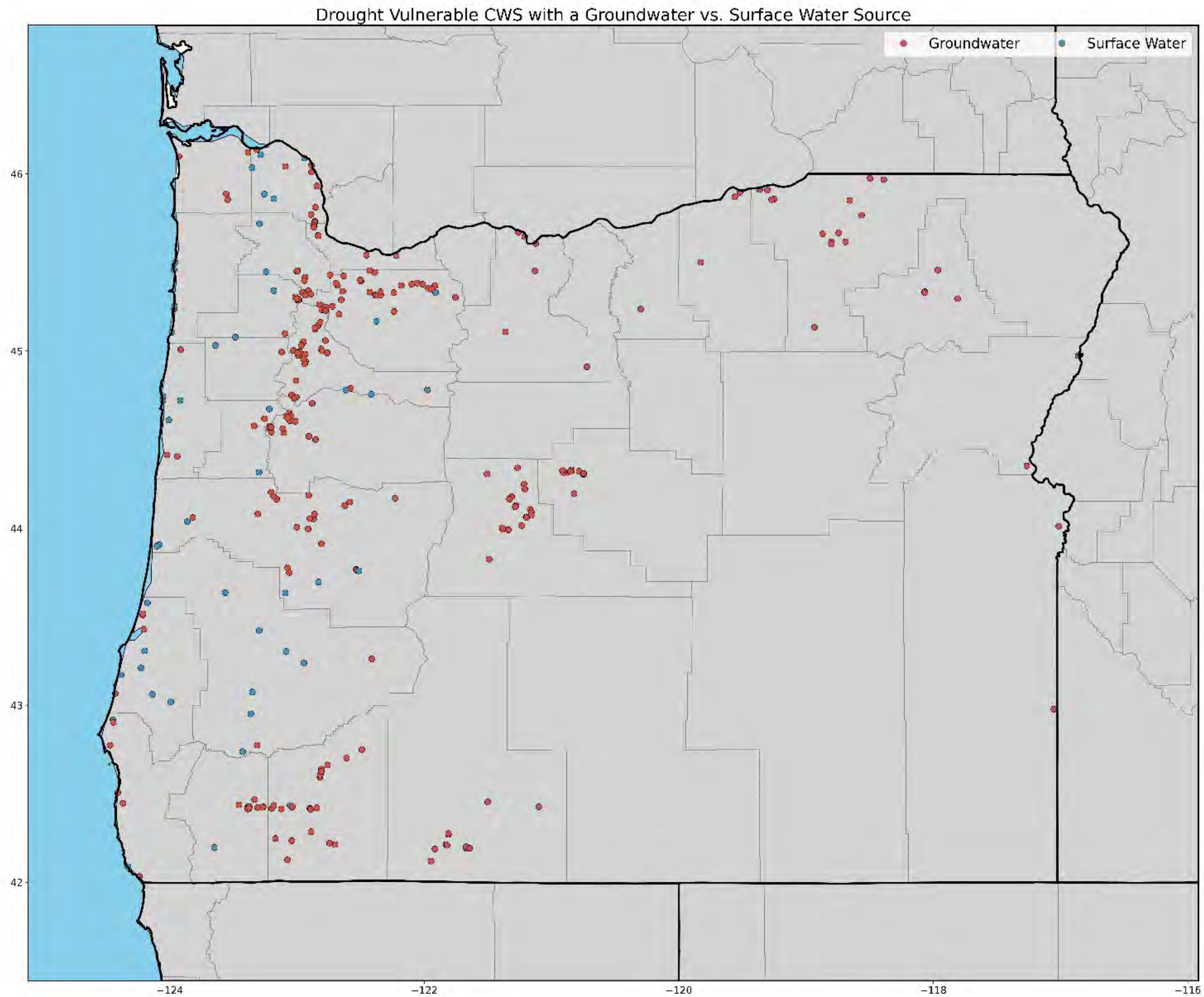


Figure 2.11. Small and Very Small CWS with one water source and no interties with other systems differentiated by groundwater and surface water sources (Source: NDMC from Oregon Water Data Online).

References

Associated Press. Irrigation wells leave Klamath Basin town of Merrill without water. The Oregonian (OR), July 1, 2010. http://www.oregonlive.com/news/index.ssf/2010/07/irrigation_wells_leave_klamath.html.

Beaver, Ty. Governor: "It affects the fabric of the community." Klamath Falls Herald and News (OR), June 11, 2020. https://www.heraldandnews.com/top_story/article_cc4d29b4-7520-11df-96da-001cc4c002e0.html

California Department of Water Resources (CDWR) (2023). Technical Methods for the Drought and Water Shortage Vulnerability Assessment Update 2023: California's Domestic Wells and State Small Water Systems. https://data.cnra.ca.gov/dataset/water-shortage-vulnerability-technical-methods/resource/fe040d6a-ed1b-4f0f-9ad9-50aada68ba03

California Department of Water Resources (CDWR) (2021). Small Water Systems and Rural Communities Drought and Water Shortage Contingency Planning and Risk Assessment, Part 2 – Drought and Water Shortage Vulnerability Assessment and Risk Scoring. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency/CDAG/PART-2-CDAG-Report-Final.pdf

Canby Utility. "Strange" Taste in Canby Water has Returned. July 15, 2021. https://www.canbyutility.org/news-releases/strange-taste-in-canby-water-has-returned/

Canby Utility. Special Board Meeting. March 21, 2023. https://www.canbyoregon.gov/sites/default/files/fileattachments/canby_utility_board/meeting/packets/25511/3-21-23_special_board_meeting_packet.pdf

CDC. Health implications of drought. Centers for Disease Control and Prevention. 2020. https://www.cdc.gov/nceh/drought/implications.htm

Cureton Cook, Emily. Fall rains can't undo pains of drought in Oregon and Washington. Oregon Public Broadcasting (OR), November 18, 2021. https://www.opb.org/article/2021/11/18/fall-rains-cant-undo-pains-of-drought-in-oregon-and-washington/

Cybersecurity and Infrastructure Security Agency with the National Drought Resilience Partnership (CISA) (2021). Drought and Infrastructure: A Planning Guide. https://www.cisa.gov/sites/default/files/publications/Drought_and_Infrastructure_A_Planning_Guide_508c.pdf

Davis, E.J., J. Souder, and J. Behan (2021). Community Drinking Water Systems in Oregon. Chapter 2 in Trees to Tap: How Forest Practices Affect Oregon Municipal Water (J. Souder), Oregon State University, pp. 298.

Drinking Water Services (DWS) (2023). Working to Keep Drinking Water Safe for Oregonians, Oregon Health Authority. https://www.oregon.gov/oha/ph/healthyenvironments/drinkingwater/pages/index.aspx

Flaccus, Gillian. Homes lose water as wells run dry in drought-ravaged basin. Associated Press (NY), June 29, 2021. https://apnews.com/article/business-science- environment-and-nature-oregon-aeb372d01f4ef69f64f7dd3294b8e44c

Hanners, Richard. State funding will address Prairie City water emergency. Blue Mountain Eagle (OR), August 24, 2018. https://www.bluemountaineagle.com/news/state-funding-will-address-prairie-city-water- emergency/article_c49af52c-90fd-59f0-9de0-6c31c1880c42.html

Hall, Bennett. Outgoing Prairie City mayor looks back on struggle to fix failing water system. Blue Mountain Eagle (OR), January 11, 2023. https://www.bluemountaineagle.com/news/outgoing-prairie-city-mayor-looks-back-on-struggle-to-fix-failing-water-system/article_927024cc-8f01-11ed-84a0-b75781273b73.html
Jaeger, W.K., A.J. Plantinga, C. Langpap, D. Bigelow, and K. Moore (2017). Water, economics, and climate change in the Willamette Basin, Oregon. Oregon State University Extension. https://catalog.extension.oregonstate.edu/em9157/html
Jarrell, Lacey. Groundwater aquifers under stress. Klamath Falls Herald and News (OR), August 14, 2014. https://www.heraldandnews.com/news/local_news/groundwater-aquifers-under- stress/article_97ef294a-2379-11e4-bccd-0019bb2963f4.html
Klamath County (2021). Frequently Asked Questions: Free Water Storage Tanks, Water Filling Station and Water Delivery in Response to Dry Wells in Klamath County, Oregon. https://www.klamathcounty.org/DocumentCenter/View/29316/Oregon-Water-Resources-Klamath-Drought-Dry-Well-FAQ
Klamath County. Klamath County Domestic Well Financial Assistance Grant Program (2021a). https://alerts.klamathcounty.org/DocumentCenter/View/32157/Klamath- County-Domestic-Well-Financial-Assistance-Program-Info?bidId=
Lisboa, M.S., R.L. Schneider, P.J. Sullivan, and M.T. Walter (2020). Drought and post-drought rain effect on stream phosphorus and other nutrient losses in the Northeastern USA. Journal of Hydrology: Regional Studies, Volume 28. https://doi.org/10.1016/j.ejrh.2020.100672
Mann, Joanna. Fate, meet irony: Sodaville doesn't have enough water. Albany Democrat Herald (OR), July 24, 2022. https://democratherald.com/lebanon/news/local/fate-meet-irony-sodaville-doesnt-have-enough-water/article_14ecb00c-0a0d-11ed-ba63-bf5d74915c2e.html
McDuff, Erin. USDA Grant Helps City of Sodaville Recover from Drought. USDA Rural Development, May 5, 2016. https://www.rd.usda.gov/newsroom/news-release/usda-grant-helps-city-sodaville-recover-drought
Mitchell, Steven. Prairie City to break ground on Faiman Springs water project next month. Blue Mountain Eagle (OR), November 17, 2021. https://www.bluemountaineagle.com/news/prairie-city-to-break-ground-on-faiman-springs-water-project-next-month/article_812d5a88-4400-11ec-8587-9fb6c59bb091.html
Oregon Department of Environmental Quality (ODEQ) (2017). Oregon Public Water Systems: Groundwater resource guide for drinking water source protection. https://www.oregon.gov/deq/FilterDocs/gwresguide.pdf
Oregon Department of Environmental Quality (ODEQ) (2018a). Fact Sheet: Introduction to Oregon's Drinking Water Protection Program. https://www.oregon.gov/deq/FilterDocs/dwpIntro.pdf
Oregon Department of Environmental Quality (ODEQ) (2018b). Oregon Public Water Systems: Surface water resource guide for drinking water source protection. https://www.oregon.gov/deq/FilterDocs/SurfaceWaterResourceGuide.pdf
Oregon Health Authority (OHA) (2023). Drinking Water Data Online. https://yourwater.oregon.gov/.
Oregon Health Authority (OHA) (no date). Oregon's domestic well safety program. https://www.oregon.gov/oha/ph/healthyenvironments/drinkingwater/sourcewater/domesti

cwellsafety/pages/index.aspx
Oregon Public Broadcasting. Fall rains can't undo pains of drought in Oregon and Washington - Oregon Public Broadcasting (OR), November 18, 2021 https://www.opb.org/article/2021/11/18/fall-rains-cant-undo-pains-of-drought-in-oregon-and-washington/.
Oregon Secretary of State (OSOS). Advisory Report: State Leadership Must Take Action to Protect Water Security for All Oregonians, Report 2023-24, https://sos.oregon.gov/audits/Documents/2023-04.pdf
Oregon Water Resources Department (OWRD) (2023). Internal Dry Well Reporting Form Database.
Oregon Water Resources Department (OWRD) (no date). Groundwater and Wells, https://www.oregon.gov/owrd/programs/gwwl/pages/default.aspx
Paul, Alex. Sodaville considering water line to Lebanon. Corvallis Gazette-Times (OR), December 4, 2019. https://gazettetimes.com/news/sodaville-considering-water-line-to-lebanon/article_3d7fb004-ab1d-564b-9161-b9a6fef224b4.html
Redden, Jim. Water bureau using groundwater well. Portland Tribune (OR), June 19, 2018. https://www.portlandtribune.com/news/water-bureau-to-begin- using-groundwater-well-wednesday/article_155c6a5d-8d76-5260-a23a- 7b33de3efb09.html
Salem Statesman Journal. Salem drinking water crisis: Oregon's dry spring may have fueled toxic algae spread - Salem Statesman-Journal (OR), June 6, 2018. http://www.statesmanjournal.com/story/news/2018/06/06/salem-water-update-alert-toxic-algae-crisis-dry-spring/677872002/.
Siirila-Woodburn, E.R., A.M. Rhoades, B.J. Hatchett, et al. (2021). A low-to-no snow future and its impacts on water resources in the western United States. Nat Rev Earth Environ 2, 800–819. https://doi.org/10.1038/s43017-021-00219-y
Washington State Department of Ecology (WSDE) (2018). Washington State Drought Contingency Plan, Publication 18-11-005. https://apps.ecology.wa.gov/publications/SummaryPages/1811005.html

Chapter 3: Agriculture

Agriculture Summary

Drought is a major, recurrent concern for agricultural producers in Oregon. Here we use qualitative data to construct a narrative describing the effect of drought on Oregon agriculture and use the limited quantitative data that is available to further explore the effects of drought on different crops and determine drought-vulnerable crops and regions. Narrative drought impact data comes mainly via the National Drought Mitigation Center's (NDMC) Drought Impact Reporter (DIR) and Condition Monitoring Observer Reports (CMOR). While DIR impacts were available from 2010 through 2023, CMOR reports were only available for 2020-2023. Specific periods including 2010 (25 DIR impacts), 2012-2015 (94 DIR impacts), 2018-2019 (18 DIR impacts) and 2020-2023 (131 DIR impacts and 186 CMOR reports) stand out as particularly difficult years for agriculture. Impacts were seen across the entire state, with Klamath County recording the highest number of impacts. Common impacts were related to inadequate irrigation supply, poor pasture and range conditions, low livestock weights, high hay prices, and reduced crop yield. The Klamath Basin and Deschutes River Basin reported severe irrigation impacts from 2020 to 2023. In contrast, the DIR recorded no agricultural impacts for coastal counties that typically receive abundant precipitation: Clatsop, Tillamook, Lincoln, Coos and Curry, or for adjacent Columbia County.

We visualized and analyzed publicly available quantitative data on Oregon crops. We used CropScape data to map which counties grow each of 60 different crops. We used Risk Management Agency Cause of Loss data to map where drought-related claims were filed and computed the ratio of claims paid to the total amount insured. We also compared National Agricultural Statistics Service data with the Drought Severity and Coverage Index to see whether drought was associated with changes in crop yield. We also compared CropScape data regarding where producers planted different crops to RMA's Summary of Business data on where producers insured different crops, to see whether producers are fully insuring crops. We mapped each of these visualizations and analyses. Maps for wheat and for alfalfa and forage-related crops are included in this report, and an expanded set of maps for all crops for which data was available was provided to the Oregon Water Resources Department. These data-driven maps provide a starting point for further qualitative inquiry and validation.

Many of the maps suggest spatial patterns of drought vulnerability, which are driven by crop choice and practices such as irrigation, which are in turn driven by the geography of soil, water, and climate. The greatest drought-related losses to wheat yield occur, not surprisingly, in the areas where wheat is cultivated most intensively. In the case of winter wheat, where some of the data distinguished between irrigated and non-irrigated wheat, analysis found that drought was associated with lower yields for non-irrigated wheat and higher yields for irrigated wheat.

Quantitative data for other important Oregon crops such as Christmas trees and grass seed was not available. As previous drought researchers have noted, data that is collected systematically over time normally does not exist without a centralized coordinating body. The Oregon Department of Agriculture may wish to determine whether it is feasible to begin collecting data on key crops.

Several of the drought impacts from news reports mentioned farmers fallowing crops in response to curtailed irrigation. Cropscape includes data on fallowed acres. Quantifying what portion of fallowed acres is due to drought would be a separate and interesting study.

Overview of Oregon agriculture

Oregon's 37,000 farms produce at least 225 agricultural commodities, feeding not only the residents of their own state but the entire nation and countries abroad (Sorte et al. 2021). About 80% of agricultural products grown in Oregon are exported, with nearly 40% going to other countries (AgClassroom 2023). In 2020, nursery stock and greenhouses produced over $1 billion annually in Oregon, making it Oregon's highest production value commodity within agriculture (Oregon Department of Agriculture 2022). Cattle production ranked second, at nearly $600 million per year (Oregon Department of Agriculture 2022). Oregon produces 100% of the U.S. hazelnut crop and leads the nation in production of several grass and clover seeds, potted azaleas, Christmas trees and rhubarb (Oregon Department of Agriculture 2022). Much of the U.S. fruit production also takes place in Oregon, especially pears and blueberries (Oregon Department of Agriculture 2022).

Livestock

Beef cattle dominate Oregon's animal agriculture sector and rely heavily on rangeland, pasture and hay production (USDA NASS 2017). A smaller number of farms are dedicated to horses, sheep, goats, pigs, poultry, dairy cattle, aquaculture, rabbits, bison, captive deer or elk, llamas, alpacas, honeybees and mink. (Figure 3.1; Table 3.1; USDA NASS 2017).

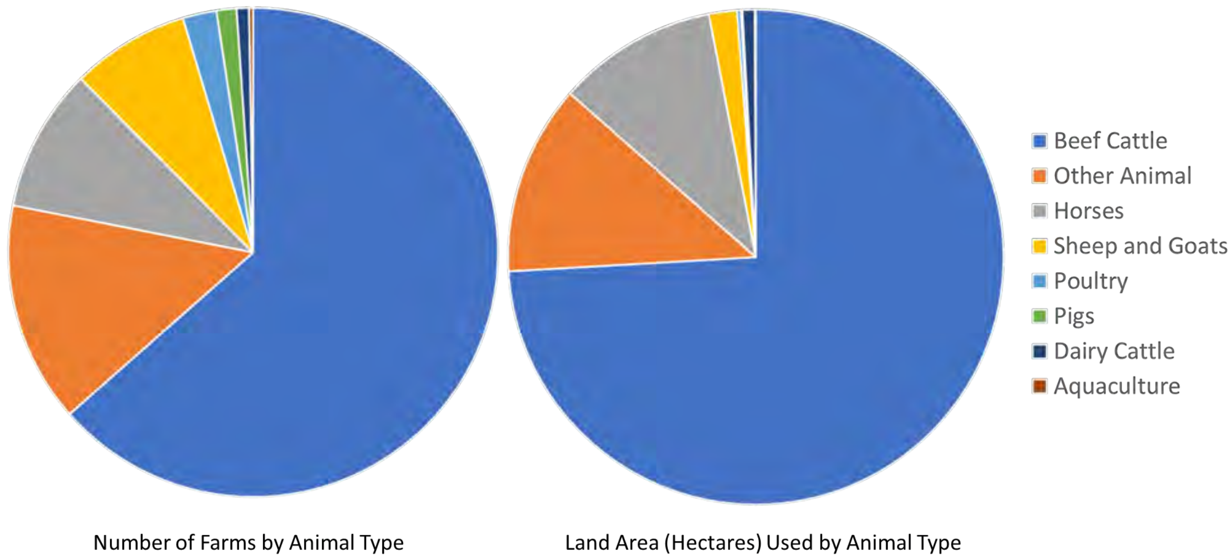


Figure 3.1. Number of farms raising each type of animal in Oregon and total land use by animal type in 2017. Source: USDA NASS 2017, Census of Agriculture, Oregon State and County Data. "Other animals" may include rabbits, bison, captive deer or elk, llamas, alpacas, honeybees or mink.

Animal	Farms	Total Land Area Used (Hectares)
Beef Cattle	20,924	3,368,289
Other Animal	4,806	564,665
Horses	3,126	475,466
Sheep and Goats	2,569	83,123
Poultry	736	10,800
Pigs	434	4,688
Dairy Cattle	269	36,728
Aquaculture	88	2,741

Table 3.1. Number of farms and land area dedicated to raising each type of agricultural animal in Oregon in 2017. Source: USDA NASS 2017, Census of Agriculture, Oregon State and County Data.

Livestock health may suffer during drought because of inadequate forage sources, dust, water quality and stress due to limited water resources. Poor livestock health ultimately translates into reduced profits for the producer and higher prices for the consumer (Sinclair et al. 2019). Pastures and rangeland are of major concern for animal agriculture producers during drought. Drought reduces quality and quantity of forage, and the lack of forage for grazing animals leads farmers and ranchers to purchase supplemental feed and hay for livestock. Meanwhile, demand and scarcity increase the price of hay. The time and financial cost of transporting hay and water also negatively impact livestock producers.

Dry soils can contribute to worsening insect infestations during droughts. Grasshoppers, in particular, thrive in drought conditions, as dry soil keeps fungal pathogens under control (Zukoff 2021). Drought conditions also reduce natural vegetation, leading grasshoppers to consume crops and forage. Plant stress and reduced yields resulting from dryness and insect infestations are commonplace during drought. Abnormally large outbreaks of grasshoppers and crickets were seen in Oregon as recently as 2021 (Rush 2022). Ranchers in Oregon that year spent thousands of dollars to provide supplemental hay due to insufficient rangeland forage and the destruction of nearby hayfields.

Barren ground during drought also provides space for invasive plants to take hold, further decreasing the productive value of the pasture or rangeland (NDMC, n.d.). The dry, exposed soil may also turn into dust that blows in the faces of livestock, putting them at risk of pneumonia and making it harder for their caretakers to breathe (Clarke 2021). Multiple reports of dusty conditions were submitted to CMOR in Oregon from 2020 to 2023.

During drought, water sources for livestock may be stagnant and occur across greater distances, if they do not disappear altogether (NDMC, n.d.). Producers may have fewer natural sources of available water during drought, forcing animals to walk greater distances to reach it. The increased activity can cause heat stress and weight loss in the animals, and without careful management, animals may destroy riparian habitat as they overgraze near the water source. Producers may haul in water from outside sources to supplement their natural waterbodies, but this is expensive and time-consuming. Livestock producers may decide to sell off livestock due to the financial, physiological and psychological stress of drought.

Crop production

Oregon's plant agriculture industry covers an extremely wide array of products. In fact, the Willamette Valley is one of the world's most diverse agricultural regions, growing over 170 types of crops on its more than 19,000 farms (Oregon Department of Agriculture 2020). Grains and oilseeds, hay, vegetables, fruits, nuts and horticultural plants are commonly grown in Oregon (Figure 3.2; Table 3.2; USDA NASS 2017). Plants vary widely in their water needs, so Oregon's seven agricultural regions utilize different crops and depend on varied amounts of irrigation based on their climates (Table 3.3; Oregon Department of Agriculture 2020).

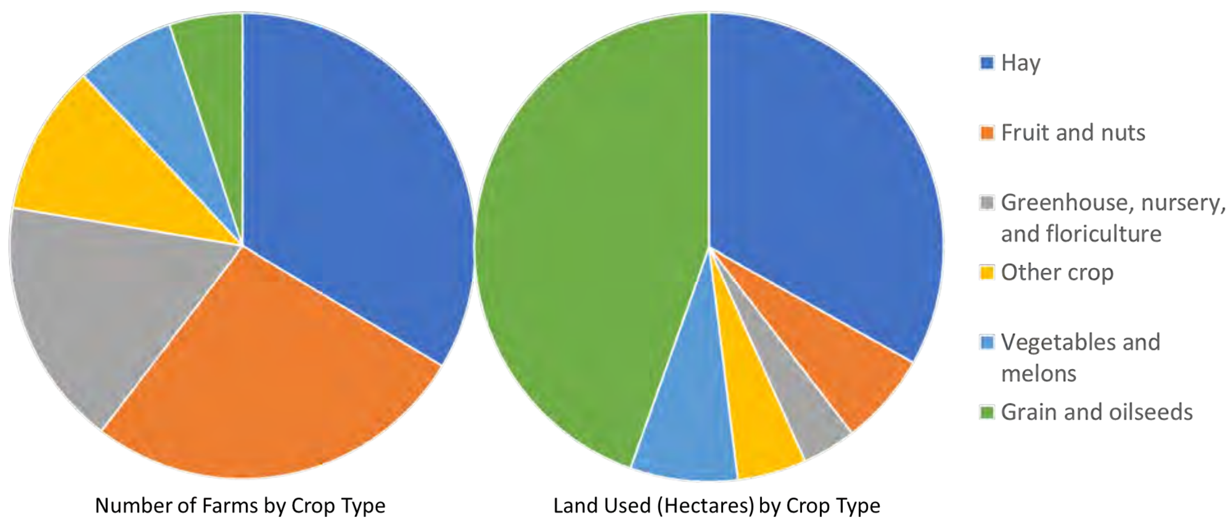


Figure 3.2. Number of farms growing each crop in Oregon and total land use by crop type in 2017. Source: USDA NASS 2017, Census of Agriculture, Oregon State and County Data.

Crop	Farms	Land Area Used (Hectares)
Hay	5,415	621,239
Fruit and nuts	4,316	119,527
Greenhouse, nursery and floriculture	2,775	69,431
Other crop	1,680	89,199
Vegetables and melons	1,111	138,620
Grain and oilseeds	819	834,270

Table 3.2. Number of farms and land area dedicated to producing each type of crop in Oregon.

Region	Counties	Leading Crops by Acreage Planted	Percent of Farmland that is Irrigated
Central	Crook, Deschutes, Jefferson	Grass seeds, garlic, hay	8.7
Coastal	Clatsop, Coos, Curry, Lincoln, Tillamook	Cranberries, lilies	7.0
Columbia Plateau	Gilliam, Hood River, Morrow, Sherman, Umatilla, Wasco	Wheat, fruit trees	5.3
Northeast	Baker, Grant, Union, Wallowa, Wheeler	Hay, potatoes, mint	8.4
Southeast	Harney, Klamath, Lake, Malheur	Onions, potatoes, sugar beets	16.7
Southern	Douglas, Jackson, Josephine	Tree fruit, hay, wine, potatoes	10.0
Willamette Valley	Benton, Clackamas, Columbia, Lane, Linn, Marion, Multnomah, Polk, Washington, Yamhill	Wheat, potatoes, vegetables, alfalfa, tree fruit	18.0

Table 3.3. Top crops by acreage planted and percent of farmland that is irrigated in each of Oregon's agricultural regions. Oregon Department of Agriculture 2020; USDA NASS 2017.

Irrigation is often limited during droughts as water supplies dwindle. The Oregon Water Resources Department watermasters distribute water based on the system of prior appropriation, with more water rights being shut off to meet senior water rights during dry years. Farmers may decide to fallow fields to avoid losing money by planting seeds if they are aware of irrigation restrictions in time.

Reported Drought Impacts

In this section we examine data from the DIR, CMOR, and governor's drought declarations (https://apps.wrd.state.or.us/apps/wr/wr_drought/declaration_status_report.aspx) to identify intervals of time when drought impacts were recorded and then compile accounts for regions within the state.

The DIR recorded 298 effects of drought on Oregon agriculture from 2010 to 2023. The CMOR system for gathering crowdsourced reports logged 92 livestock-related reports and 94 crop-related reports from 2020 through late 2023 (many reports including both crop and livestock), and a total of 114 agriculture reports from 2018 through late 2023. (An earlier data collection scheme did not distinguish between crop and livestock reports, including them both under agriculture.) Common impacts were related to inadequate irrigation supply, poor pasture and range conditions, reduced crop yield, low livestock weights and high hay prices. Klamath County had the highest number of DIR impacts, with 64 reports between 2010 and 2023 (Figure 3.3). Malheur County had the highest number of CMOR reports, with 51 from 2018 to 2023, and Klamath County had 30 during the same time (Figure 3.4) Specific periods including 2010 (25 DIR impacts, six drought declarations), 2012-2015 (94 DIR impacts, 52 drought declarations), 2018-2019 (18 DIR impacts, 11 drought declarations) and 2020-2023 (131 DIR impacts, 107 CMOR reports, 71 drought declarations) stand out as particularly difficult years for agriculture (Table 3.4).

Sector	2010 Impacts	2012-2015 Impacts	2018-2019 Impacts	2020-2023 Impacts
Crops	7	29	3	14
Drought declarations	6	52	11	71
Hay	0	5	3	30
Irrigation	9	49	7	58
Livestock	0	19	3	26

Table 3.4. DIR impacts and governor's drought declarations per drought period separated by agricultural sector.

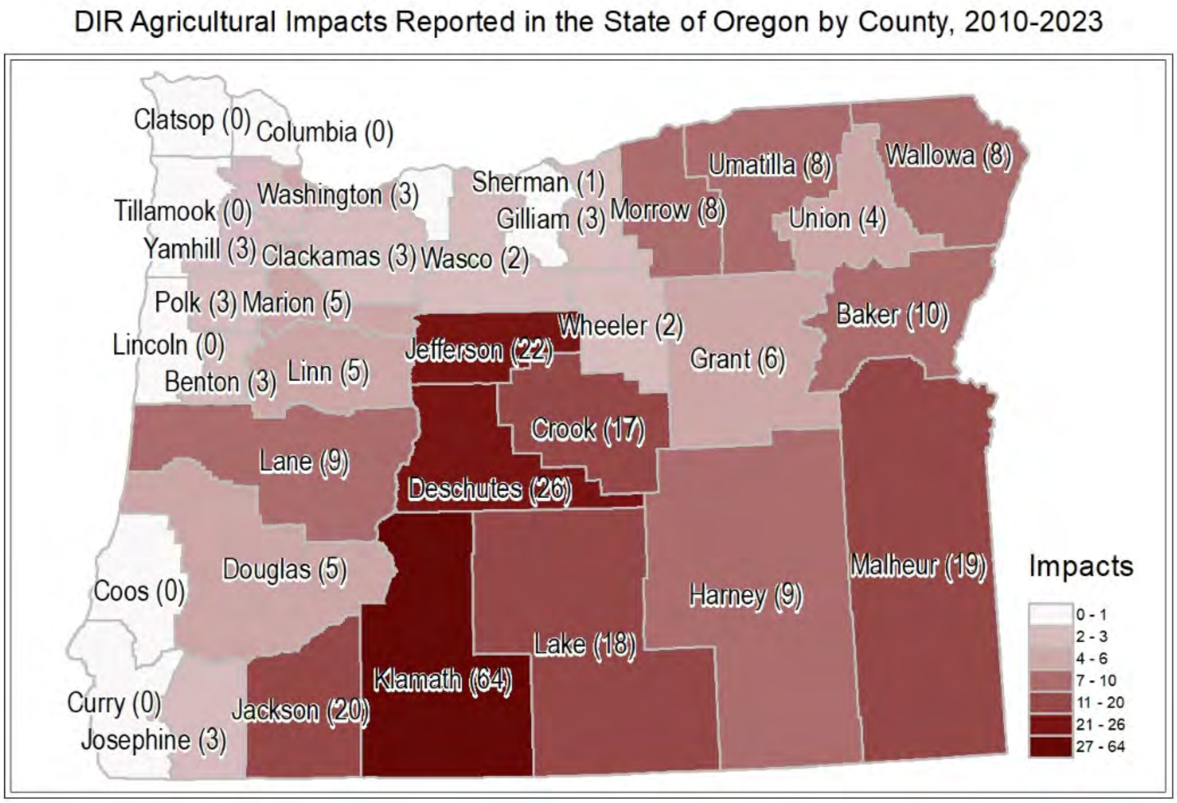


Figure 3.3. Agricultural impacts reported to the DIR across the State of Oregon, 2010-2023.

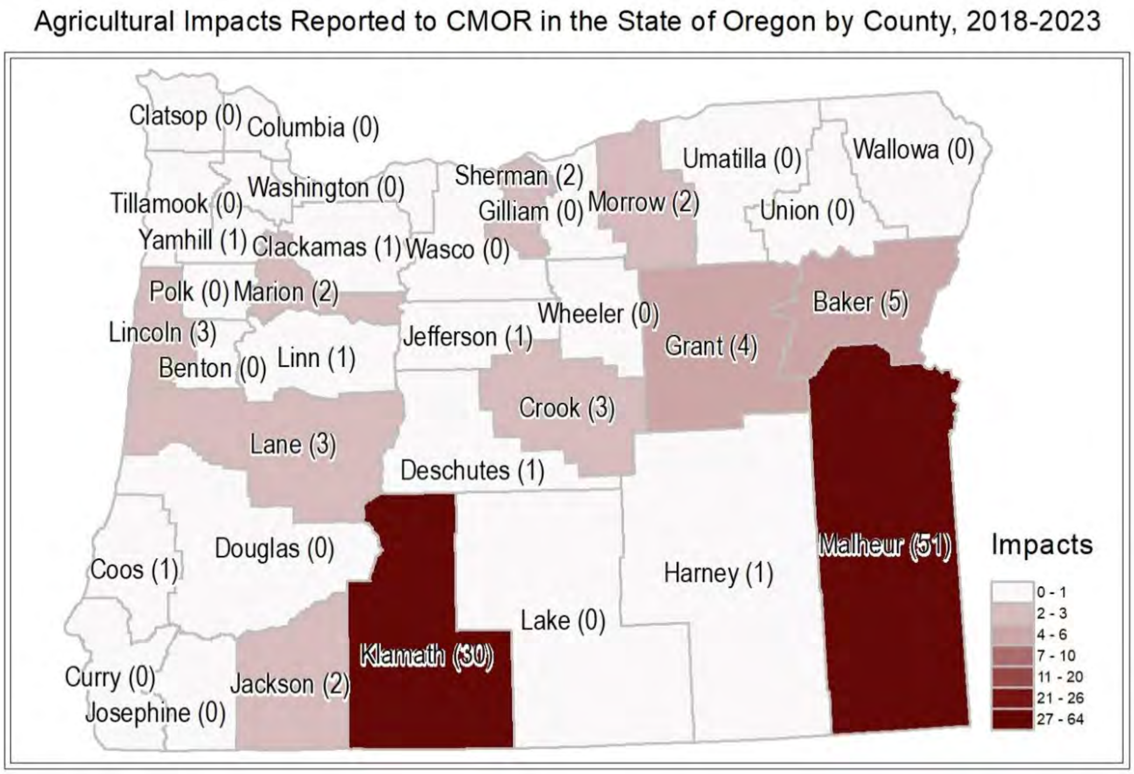


Figure 3.4. Crop and livestock-related CMOR reports for the State of Oregon by county, 2018-2023. CMOR reports collected prior to 2020 followed a slightly different collection scheme with a single "agriculture" sector, so those are not included in counts of crop or livestock reports elsewhere in the discussion.

2010

Twenty-five drought impacts were reported to the DIR in 2010, with 17 impacts coming from Klamath County alone (Figure 3.5).

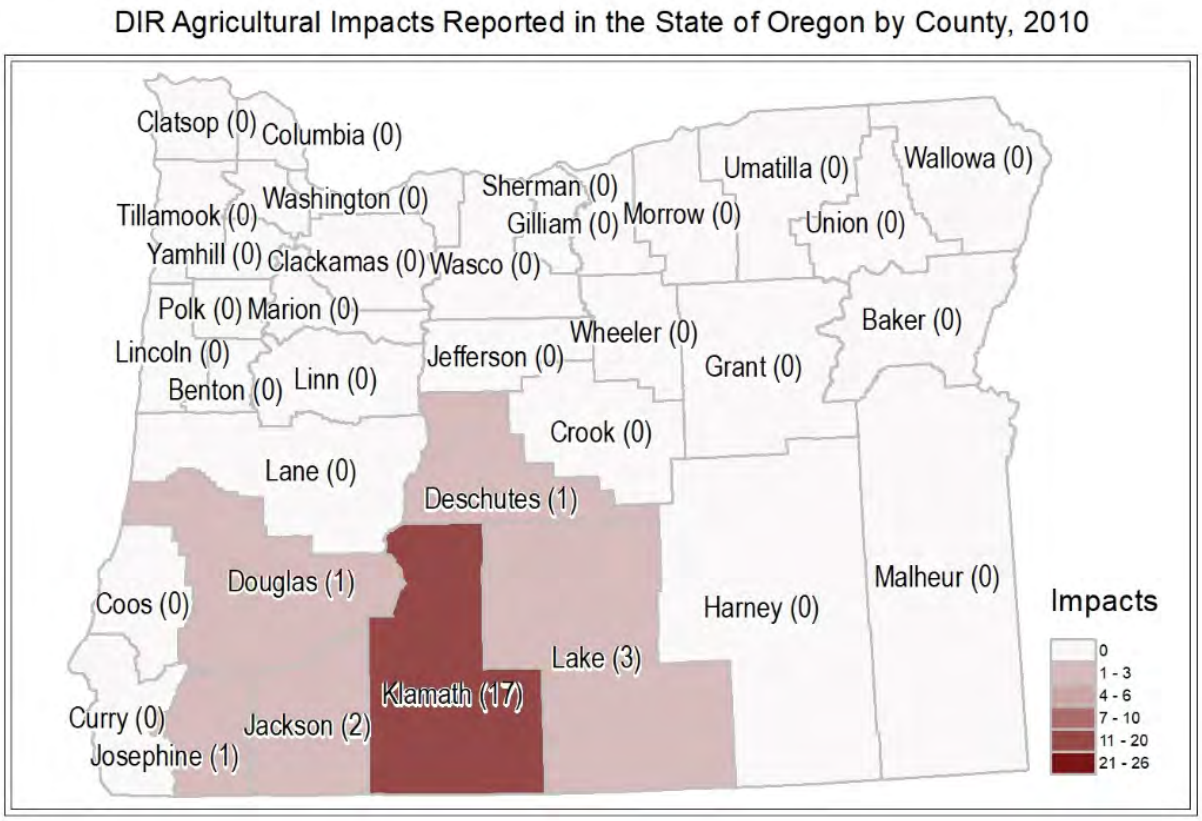


Figure 3.5. Agriculture-related DIR reports for the State of Oregon by county, 2010.

2012-2015

Ninety-four impacts were reported in the DIR from 2012 through 2015. USDA drought disaster declarations were made in all 36 counties during this period (FSA n.d.). Irrigation-related impacts dominated reports, with 49 instances. An additional 19 impacts were related to livestock. Southern Oregon was heavily affected between 2012 and 2015, with Klamath, Jackson, Lake and Malheur counties standing out (Figure 3.6).

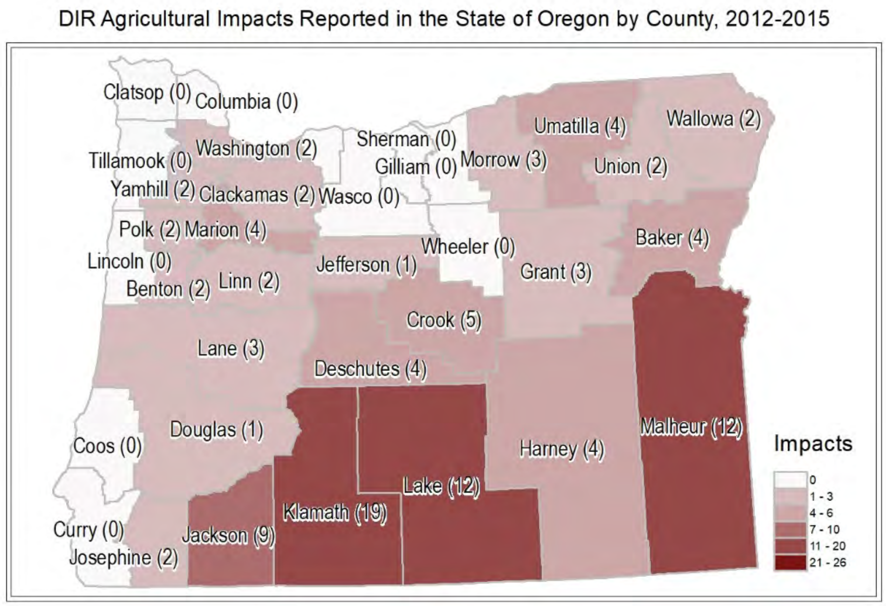


Figure 3.6. Agriculture-related DIR reports for the State of Oregon by county, 2012-2015.

All of Oregon experienced record-low snowpack in 2015, 90% below average (NASA, 2015; Oregon State University, 2016), due to a combination of less precipitation and warm winter temperatures that led to precipitation falling as rain rather than snow and melting early. The National Resources Conservation Service issued an advisory on June 1 saying that despite welcome May rains in the driest parts of the state, the record-low winter snowpack would cause low streamflow and water shortages across the state during the summer (NRCS 2015). The summer of 2015 was very warm, which led to issues in the rain-dominated streams in the coastal areas.

2018-2019

Fewer impacts were reported to the DIR between 2018 (18 impacts) and 2019 (13 impacts), but drought still had serious negative effects for the Christmas tree industry and Klamath County (Figure 3.7). USDA drought disasters were declared in all 36 counties during this period (FSA n.d.).

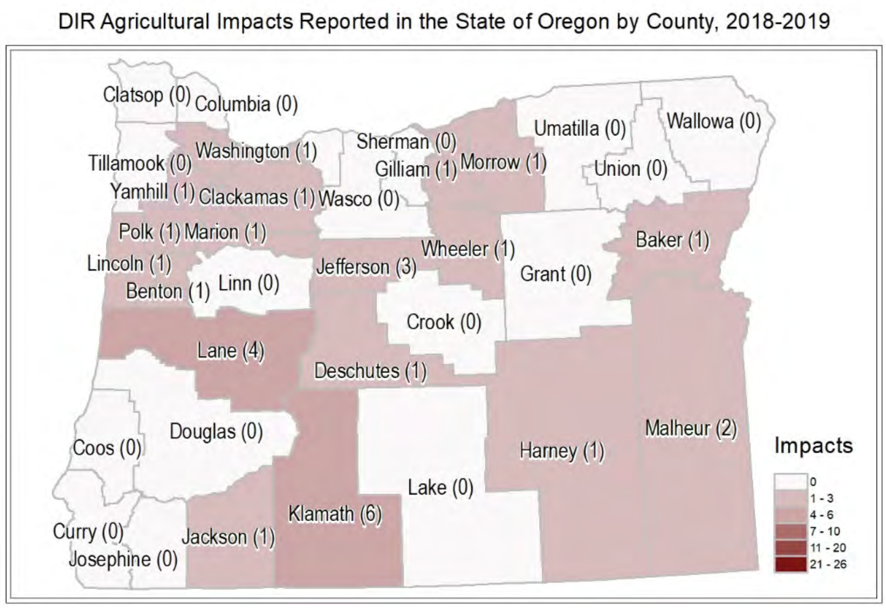


Figure 3.7. Agriculture-related DIR reports for the State of Oregon by county, 2018-2019.

2020-2023

Oregon endured a multi-year drought in the early 2020s, the worst in 127 years of records for some parts of the state.

Between 2020 and 2023, the DIR recorded 131 agriculture-related impacts (Figure 3.8), with 58 mentioning irrigation. CMOR observers submitted 92 livestock-related reports and 94 crop-related reports (some including both) during the same time period, with 67 including mention of irrigation (Figure 3.9). Sixty-five CMOR reports indicated reduced crop yields. Central Oregon was heavily hit during this time, with Klamath, Deschutes, Jefferson, Crook and Jackson counties standing out. USDA drought disasters were declared in all of Oregon's 36 counties during this period (FSA n.d.). A statewide report noted that grass seed yields were as low as 50% of normal in 2021 due to drought (Cerullo, September 3, 2021). The seeds were smaller and lighter than normal (Shinn 2021).

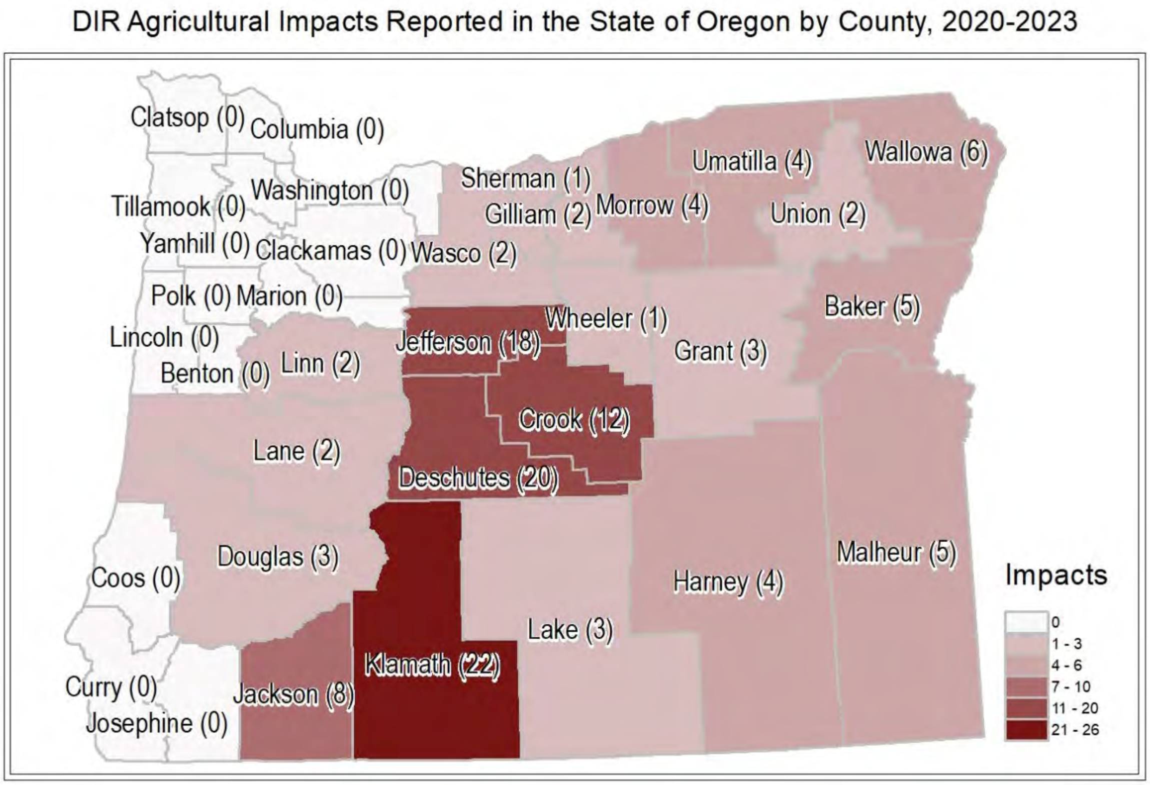


Figure 3.8. Agricultural impacts in Oregon counties recorded in the DIR, 2020-2023.

Livestock concerns were also prominent, with some media reports describing statewide or regional conditions. The DIR recorded 26 livestock-related impacts. Poor pasture conditions dominated livestock-related reports submitted to CMOR from 2020 to 2023, with 84 reports of reduced pasture forage submitted during that time. In response to poor pasture and rangeland conditions, livestock farmers removed cattle from public grazing lands and/or purchased hay early in many cases. Sixty producers reported to CMOR that their livestock were lower weights than normal from 2020 to 2023. Nine producers reported animal mortality due to drought to CMOR from 2020 to 2023.

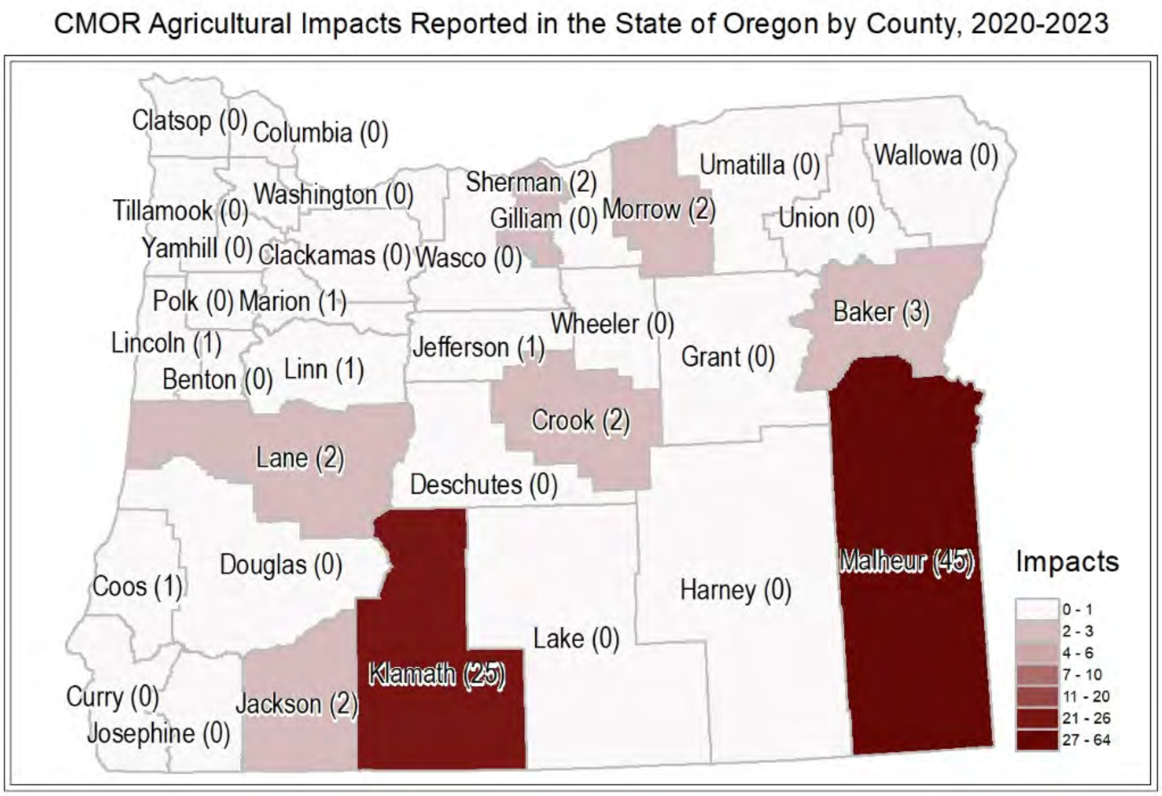


Figure 3.9. Agriculture-related CMOR reports for the State of Oregon by county, 2020-2023. Malheur County had 45 impacts and Klamath, 35.

Hay prices contributed to high costs for livestock producers as well as large and early livestock sales. Hay was up to 20% more expensive than usual in 2021, and sheep and cattle farmers were forced to travel farther distances than usual to purchase hay due to local drought conditions (Callahan 2021; McClain 2021; Dinman 2021). By August, the Oregon Cattleman's Association reported that hay could not be found locally at any price (Kohn 2021). Producers also reported dry streams and difficulty providing water for livestock (Callahan 2021; McClain 2021; Dinman 2021). Thirty-two reports of livestock producers hauling water were submitted to CMOR from 2020 to 2023.

Klamath County

Klamath County had the highest number of DIR impacts, with 64 reports between 2010 and 2023. Drought had a major impact on Klamath County’s agriculture in 2010, with the agricultural industry generating $13.2 million less that year than it had in 2009 and $72.8 million less than in 2008 (Hottman 2010). Many farmers in Klamath County left their land fallow or changed their cropping plans due to drought and insufficient water supplies in 2010 (Hottman 2010).

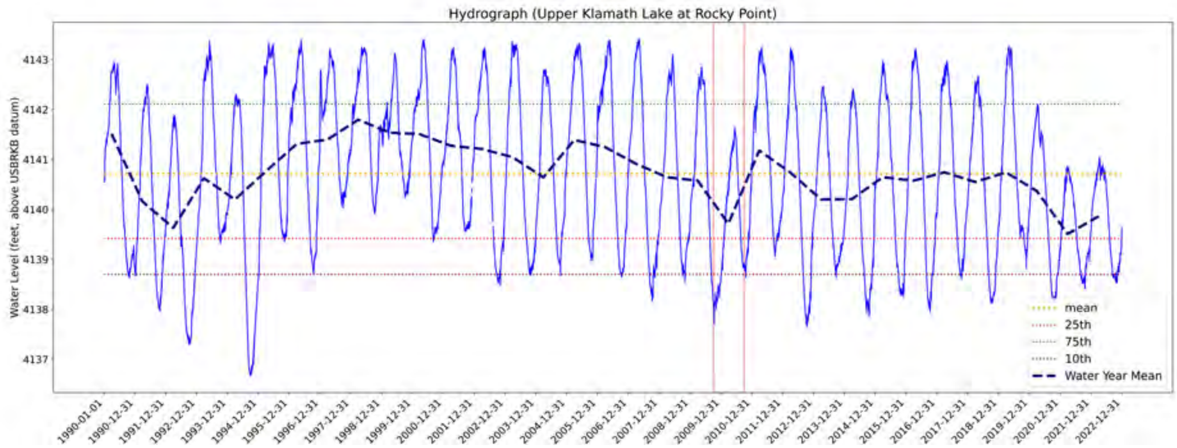


Figure 3.10. Klamath Lake levels, 1990-2022; data from U.S. Geological Survey. The dotted blue line shows the water year mean, which was low going into 2010 and lower in 2021 and 2022. Vertical red lines mark the start and end of the 2010 water year, October 1, 2009-September 30, 2010.

In 2010, Klamath County felt the effects of drought by early March, when the Klamath Water Users Association warned that as much as 80% of the Klamath Reclamation Project was at risk of receiving no water that year (Medford Mail Tribune 2010). Oregon's governor was reportedly working on getting assistance for Klamath Basin farmers who would be affected by the lack of water (Medford Mail Tribune 2010). Two Oregon senators were also seeking drought relief for farmers in the Basin (Pope 2010), and compared lake levels to 1992, the most severe drought on record in the Klamath Basin (Figure 3.10). On March 17, the governor of Oregon declared that Klamath County and neighboring counties were in a drought disaster, allowing farmers to apply to use emergency wells for crops (Learn 2010).

The Klamath Reclamation Project announced in early April that only 30% of its water deliveries would be fulfilled in 2010, prompting farmers in the affected area to look for land with pre-existing wells, although land with water resources had become more expensive to rent (Bend Bulletin, April 5, 2010). Potato farmers near Merrill and in the Klamath Basin struggled with the lack of water and sought leases elsewhere to grow their crops in 2010 (Bend Bulletin, May 13, 2010; Klamath Falls Herald and News, May 22, 2010). Meanwhile, agricultural business and irrigation districts were hiring fewer employees than previously (Bend Bulletin, May 13, 2010).

In early May 2010, the USDA declared Klamath County to be a natural disaster area, along with neighboring Deschutes, Douglas, Jackson, Lake and Lane counties (Klamath Falls Herald and News, May 4, 2010). Through this declaration, agricultural producers were allowed to apply for low-interest emergency loans from the Farm Service Agency. Additional aid was available through the Klamath Water and Power Agency, which had been allotted $7.25 million to compensate farmers to fallow land, purchase alternate water sources, and pump water (Klamath Falls Herald and News, April 30, 2010). The funds were allotted for irrigators who received water from Upper Klamath Lake, Clear Lake, and Gerber Reservoir (Klamath Falls Herald and News, May 5, 2010).

The Klamath Soil and Water Conservation District reported in July 2010 that three times the usual number of farmers were applying for financial aid for well repairs, new wells or equipment purchases related to drought (Klamath Falls Herald and News, July 10, 2010). By the end of that month, an additional $10 million in drought aid had been approved by Congress for Klamath Basin farmers and ranchers (Klamath Falls Herald and News, July 28, 2010).

Extreme drought conditions in 2010 prompted agricultural producers to change their practices in Klamath County. Some irrigators increased water efficiency by implementing new practices such as terracing their fields, switching from flood irrigation to spray irrigation, and installing irrigation pipes to reduce the use of irrigation canals, which are prone to losing water to evaporation (Klamath Falls Herald and News, July 10, 2010). Another farmer in Merrill grew their potatoes in new, rocky fields, which required them to buy a new $100,000 harvester that was able to collect potatoes while leaving behind rocks (Klamath Falls Herald and News, July

10, 2010).

By March 2012, Klamath County recognized there would be insufficient water to meet the needs of both farms and coho salmon in the Klamath River Basin that year (San Francisco Chronicle 2012). The county was declared to be in a drought on March 21, with the aim of providing state and federal financial aid as well as emergency well pumping (San Francisco Chronicle 2012). The Bureau of Reclamation estimated in May that only about 17% of the amount of irrigation water needed would be available that summer (Klamath Falls Herald and News 2012). Farmers were encouraged to sign up for a voluntary land-idling program to help reduce the need for irrigation in the Klamath Basin (Klamath Falls Herald and News 2012).

Drought conditions continued in Klamath County in 2013. In April, another drought declaration was made for the county as low reservoir storage and snowpack were observed (Learn 2013). Klamath County commissioners sought to increase the disaster declaration to the state level and reported that streamflow was anticipated to be 49-65% of average in the county through September (Learn 2013). Water allocations in the Klamath Irrigation District would be only two-thirds of the normal amount that year, prompting farmers to fallow fields and pump additional groundwater (Sacramento Bee 2013). Klamath Tribe members whose farms and ranches were cut off from water that year were eligible for $250 an acre from the Bureau of Reclamation (Owens 2013). Klamath County cattle farmers were deciding whether to move or sell cattle due to dry conditions and expensive feed that summer (Tipler 2013; USDM Status = D2).

Conditions in 2014 were already severe enough to warrant drought declarations in several counties including Klamath by February 6, 2014 (Salem Statesman-Journal 2014). Just two days later, livestock producers sold their cattle at the 54th Annual Klamath Bull and Heifer Sale to help offset the effects of their depleted pastures (Dillemuth 2014).

For the third year in a row, the Klamath Reclamation Project announced that the 1,200 farmers in the district would receive less water than contracted. Snowpack in the region as of April 2014 was only 31% of normal, precipitation was 75% of normal, and overall, only 61% of the normal amount of irrigation water would be available (Barnard 2014). The shortage of irrigation water would be offset by groundwater pumping and by paying farmers not to plant that year.

Tension over water use in the Klamath Basin led to a compromise between affected parties, in which the Klamath Tribes received the most senior water rights in most of Upper Klamath Lake and some of its tributaries (Bend Bulletin 2014). Pre-season forecasts of water levels in the Klamath Reclamation Project proved to be overly optimistic, and water deliveries ended for about a third of irrigators in the Klamath Basin in early August 2014 (Jarrell 2014; USDM Status = D3). Farmers in the region were expected to lose up to half of their crop, 50,000 acres of primarily hay, due to the early water shutoff. Heavy irrigation pumping and the ongoing drought led to domestic wells going dry on the Oregon-California border in August 2014.

The Klamath Reclamation District announced substantial shortfalls in spring 2015. For the fourth consecutive year, most farmers in the region would not receive their contracted amount of water (Barnard 2015). A crucial difference in 2015 was that additional groundwater pumping was unlikely to be permitted due to over-pumping the previous three years.

In 2018, drought in Klamath County led to irrigators receiving only 60% of their demand (Plaven 2018) and prompted a discussion of changes to irrigation policies and land valuation. A bill was proposed to allow Klamath Project irrigators to transfer their water claims between properties (Floyd, February 20, 2018). The U.S. Bureau of Reclamation also proposed a strategy to provide more irrigation water to the Klamath Basin by releasing less water for coho salmon in the Klamath River (Houston 2018). By early May 2018, the U.S. Office of Management and Budget had allotted $10.3 million in drought relief for the Klamath Project irrigators (Dillemuth 2018). Drought conditions ultimately prompted assessors in Klamath County to reassess the value of around 315,000 acres of farmland in the county (Floyd, June 27, 2018). The county risked losing $300,000 to $400,000 in property taxes (Floyd, June 27, 2018).

In March 2020, the Klamath Project estimated less than 50% of full allocation for irrigators, as snowpack was only 64% of normal (Alexander 2020). Oregon's governor announced a drought declaration for Klamath County on March 2. April 2020 also proved to be dry for Klamath County, and precipitation for the 2020 water year was at 66% of normal by April 24. Growers were encouraged to idle their land in May, and in June 2020 the Bureau of Reclamation confirmed that only 140,000 acre-feet of water would be available for irrigation that year, compared to 325,000 acre-feet in 2019.

Drought was devastating to the Klamath Project in 2021. The governor declared a drought in Klamath County on March 31, when the snow water equivalent for Klamath County was at 81% of normal (O'Conner 2021). April inflows into Upper Klamath Lake were the lowest on record in 2021, leading to Upper Klamath Lake levels being a foot lower than normal (LeCroy 2021). Early evaluations estimated that the Klamath Project would allocate 33,000 acre-feet for 2021, which would have been the lowest amount in its history and only one-tenth of the normal amount (Flaccus 2021). However, in mid-May it was announced that the Klamath Project's A Canal would stay closed for the season, completely cutting irrigators off from water for the year (Flaccus 2021). This was the first time since the Project's creation in 1907 that it would not provide irrigation water. The Bureau of Reclamation provided $15 million to impacted agricultural producers as well as $3 million for local tribes to benefit endangered fish, but Klamath area farm groups requested additional funding for producers enduring extreme conditions (Plaven 2021; USDM Status = D4). Another $15 million was provided by the USDA for farmers who agreed to reduce their irrigation use in the Klamath Basin (Parfitt 2021). One hay grower in the Klamath Basin only produced 10% of his normal harvest in 2021 (Morgan 2021; USDM Status = D4).

The Klamath Project announced in April 2022 that its more than 1,000 customers would be receiving about one-seventh of their normal irrigation allocations for the year (Flaccus 2022). Upper Klamath Lake was experiencing record low inflows, and the Bureau of Reclamation warned farmers and ranchers that water allocations could be cut back even further if drought worsened or individuals used excessive amounts of water. Ultimately, farmers received 20% of their normal irrigation need in 2022 and crops were expected to die early (Neumann 2022).

In February 2023, OWRD issued a press release saying that if a drought emergency were declared, OWRD probably would not approve Emergency Use Permits for groundwater, known as “drought permits” (OWRD, February 10, 2023). The drought permits mainly affect farmers and ranchers who don’t have groundwater rights, and the release noted that a portion of permit application fees are non-refundable, even if the permit is denied. OWRD based its decision on an analysis finding that groundwater levels in the Bureau of Reclamation Project Area within the Upper Klamath Basin declined 20-30 feet from 2021 through January 2023, and in some areas, 40 feet since 2001. The analysis found a long-term decline, as well as seasonal declines during the 2021 and 2022 irrigation seasons. The release said that domestic wells had been running dry since 2020, continuing into January 2023. In related news coverage, an agency official also linked the groundwater decline to multi-year drought (Vaughn 2023). According to OWRD’s

Public Declaration Status Report dashboard, there have been 16 drought declarations for Klamath County since 1992, but there wasn't one in 2023 (OWRD, December 14, 2023).

Eastern Oregon

Eastern Oregon has also experienced drought impacts, with the DIR recording 19 for Malheur County, 10 for Baker County and 8 for Wallowa County, from 2010 through late 2023. Figure 3.11, a U.S. Drought Monitor time series, indicates that recent drought periods were observed in Malheur County during 2012-2017, 2018 and 2020-2023. Eastern Oregon farmers lost tens of millions of dollars in unplanted crops over the three consecutive years of drought from 2012 to 2014 (Ellis 2014).

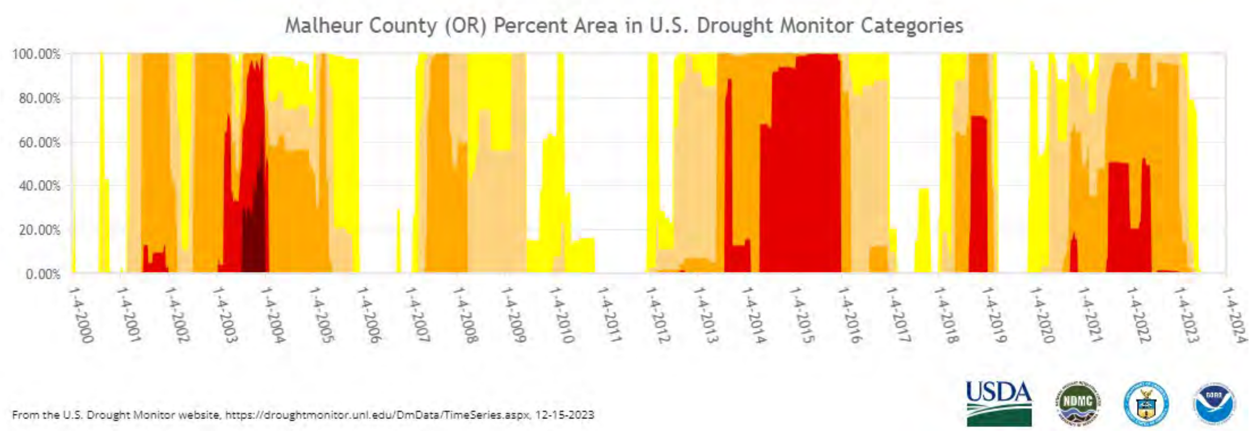


Figure 3.11. Proportion of Malheur County in each USDM category from 2000 to 2024.

Wildfires and drought in eastern Oregon were detrimental to forage supplies and grazing lands in the high desert in 2012 (Harney and Malheur Counties; Cockle 2012). By fall, ranchers were searching for grazing land, and some decided to wean their calves early to send them to feedlots.

More agricultural producers in Eastern Oregon were struggling early in 2013. By early May, farmers in the area had already begun irrigating due to low rainfall (Salem Statesman-Journal 2013). Others had opted not to plant that year or switched to water-saving crops in anticipation of inadequate irrigation (Cockle 2013). Many irrigation reservoirs in Malheur County started the summer at around one-third of their normal capacity, leading to early irrigation shutoffs: the Jordan Valley Irrigation District stopped its water deliveries on May 28, while the Succor Creek Irrigation District ended on June 7. A farmer near Jordan Valley, in Malheur County, needed to haul water for his cattle by June, while he and his neighbors also sold cattle due to high prices of feed and hay caused by poor pasture conditions.

Malheur, Harney, Lake and Klamath counties received drought declarations on February 6, 2014 (Salem Statesman-Journal 2014). The Owyhee Project in Malheur County reduced its water allotments by over 50% in 2014 and was dry by August, reportedly two months earlier than normal. In anticipation of another dry year, an estimated 15-20% of fields in Malheur County had not been planted in 2014, especially sugar beets and corn.

Poor conditions in Eastern Oregon carried over from fall 2014 into spring 2015, intensified by the snow drought of 2015. Drought emergencies were declared in Lake and Malheur counties in March 2015 (Loew, March 16, 2015). A rancher in Lake County reported selling cattle in March to pay for feed as drought had reduced hay production (Harbarger 2015; USDM Status = D3). The Owyhee Reservoir in Malheur County was only 25% full, prompting the Owyhee Irrigation District to warn farmers that their water allotment might be even lower than the year before, just one-third of their normal amount (House 2015). Farmers responded by leaving fields unplanted or planting more water-efficient crops than usual.

Livestock producers encountered drought-related challenges in 2018. Ranchers in southeast Oregon (Harney County, King 2018; Malheur County, Meyer 2018) found their pastures dry and unable to meet the needs of their cattle. Effects on the cattle included reduced milk production and low calf weights, despite ranchers' efforts to haul water, relocate cattle and purchase hay (King 2018). Ultimately, ranchers lost profits when selling their cattle and experienced conflict related to a shared water supply for irrigation (King 2018).

Fewer drought impacts came from Eastern Oregon in 2019, but dry conditions persisted in Baker County that year. In May 2019, Baker Valley farmers began irrigating in earnest, despite a wet April (Jacoby 2019).

In 2021, wheat crops were stunted in Morrow and Wallowa counties (Dole, June 24, 2021; Bradshaw 2021; D3-D4). Dryland dark northern spring wheat yielded less than 10% of its normal crop in Wallowa County. Irrigated wheat fared better at about 92% of its normal crop. Peas, timothy grass and barley crops were left unharvested due to poor quality (Bradshaw 2021; USDM Status = D4). In Harney County, a farmer reported needing to use a draper head to harvest unusually short corn that year (Morgan 2021; USDM Status = D3)

In 2021, several producers in southeast Oregon reported pulling their cattle off rangeland one to two months earlier than usual and weaning calves early in 2021 (Malheur Enterprise 2021; Morgan 2021; USDM Status = D2-D3). Cattle producers in Umatilla County started buying hay by April that year (Dole, April 22, 2021; USDM Status = D2). In Harney County, some operators began to consider selling their herds due to lack of grass by late May in 2021 (King 2021; USDM Status = D3). Sales in Vale, Oregon, were two to three times larger than usual (Malheur Enterprise 2021; USDM Status = D3) and eight producers reported to CMOR that drought had forced them to sell livestock. Direct impacts to the cattle were evident in calves that were 20-30 pounds lighter than usual, making them less valuable. Producers were concerned about the possibility that breeding cows would struggle maintaining pregnancies due to their diminished body condition (Jacoby et al. 2021).

Grasshopper infestations also worsened due to drought. They began in Harney County by

August 2021 (Morgan 2021), and 12 CMOR reports of grasshopper infestations emerged from Malheur County between June and August 2021. Eastern Oregon was hit particularly hard by grasshoppers again in summer 2023, reportedly devastating grass and alfalfa crops in Baker, Harney, Malheur, Umatilla, Union and Wallowa counties (Jacoby 2023). Dusty conditions in Malheur County were also a major concern, according to 11 reports submitted to CMOR between September 2020 and March 2022.

Deschutes River Basin

A range of drought impacts emerged from the Deschutes River Basin (Crook, Jefferson and Deschutes counties; 65 impacts). A USDM time series indicates that recent periods of drought occurred in Crook County during 2014-2016, 2018 and 2020-2023 (Figure 3.12).

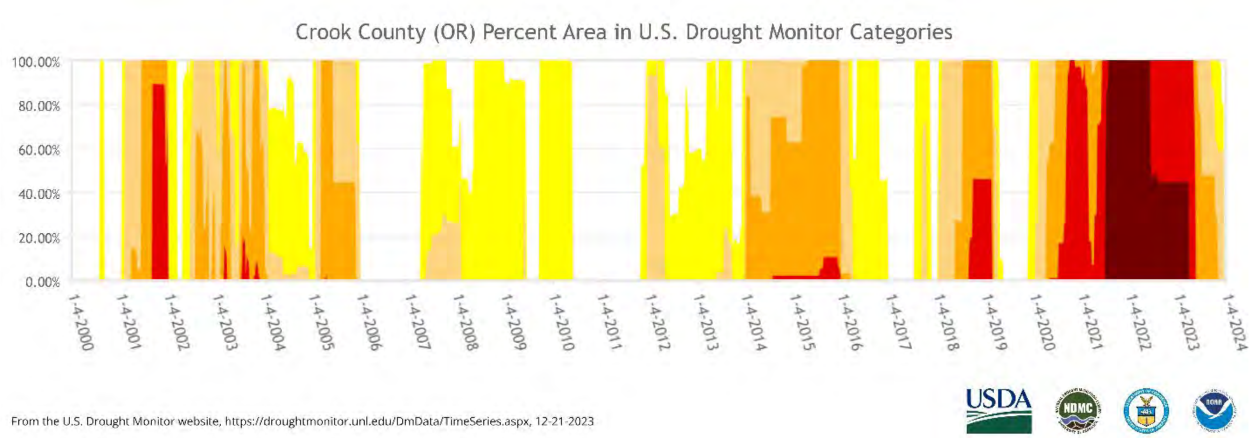


Figure 3.12. Drought time series for Crook County.

By mid-February 2014, Crook County had declared a drought emergency (Ditzler 2014). Snowpack in the county was at about half its normal amount and streamflows into the Ochoco and Prineville reservoirs were likely to diminish earlier than usual, in late April or early May.

In 2015, the Ochoco Irrigation District in Crook County was only able to provide about

60% of its normal water allotment to its customers (Darling 2015). Three Sisters Irrigation District in Deschutes County was perhaps the most affected district, announcing in May that a maximum of 30% of normal water allotments could be provided that year (Ditzler 2015). Farmers in the district were expected to lose $1 million to $1.5 million as many of the 180 farms grow alfalfa and would likely only manage one cutting that year (Ditzler 2015). In Crook County, a rancher was unable to grow any hay in 2015 as the pond used for irrigation had gone dry (Ditzler 2015; USDM Status = D3). Another hay grower in Post (Crook County) was only able to get one cutting of hay due to low water in the Crooked River (Darling 2015).

At the beginning of the 2019 irrigation season, Wickiup Reservoir, which provides water for the North Unit Irrigation District, was 66% full, which represented a record low level for the start of the season. As a result, farmers in Deschutes and Jefferson counties fallowed around 25-30% of their fields (Kohn, September 8, 2019). By September 2019, the reservoir was only 11% full. The low levels were attributed to drought as well as Endangered Species Act water releases in the spring and fall.

Prineville Reservoir, in the Ochoco Irrigation District, started the 2020 water year at its lowest level since 1992 (Crook County; Chaney 2020). Ongoing warm, dry weather led to predictions of low water supplies. Ultimately, the Ochoco Irrigation District allocated 2.5 acre-feet of water for its customers in Crook County, compared to its normal 3 acre-feet of water.

At the 2020 start of the irrigation season, the Wickiup Reservoir was at 70% of capacity, its second-lowest level (Deschutes County; Kohn, June 16, 2020). Some ranchers' pastures in Crook County were unusable due to lack of water. Farmers in the North Unit Irrigation District fallowed 20-40% of their fields in anticipation of low water supplies (Kohn, July 13, 2020). Wickiup Reservoir was at 60% capacity on April 30, which was a record low, and reached 34%

capacity by July 7. Farmers in the district received 1.25 acre-feet of water in 2020, compared to their normal allocation of 2 acre-feet, and fallowed 20-40% of their fields. By mid-September, Wickiup Reservoir was at a record low of 1% capacity and provided no flow to the Deschutes River (Kohn, September 15, 2020). The reservoir could not be completely refilled in one winter. Dry, dusty conditions in Jefferson County caused soil erosion and poor visibility in 2020, and restricted allotments were projected for 2021 as well (Kohn, October 8, 2020).

Two irrigation districts in the Deschutes River Basin depleted water supplies and shut off deliveries in late August 2020. The Habitat Conservation Plan for the Deschutes Basin, signed in late 2020, impacted reservoir and irrigation operations. Protecting habitat for endangered species such as the Oregon spotted frog and bull trout was a consideration in irrigation restrictions (Kohn, August 27, 2020). Arnold Irrigation District shut off deliveries on August 15 (Kohn, August 16, 2020), while Lone Pine Irrigation District did so on August 26 (Kohn, August 27, 2020). Livestock producers and crop growers alike felt the effects. Cattle farmers had to purchase hay, and one said he would need to buy 5,000-7,000 gallons of water daily for his livestock. Another farmer would need to buy hay for his livestock as he would be unable to get a second cutting of his own hay in 2020 (Allen 2020).

Farmers in the North Unit Irrigation District received reduced water in 2021 and chose to fallow 30-60% of their lands (Kohn, May 15, 2021). Some farmers opted to grow cover crops, such as mustard, which only would need one watering. Effects of the water shortage trickled down to other agricultural businesses as farmers bought less equipment, fuel and fertilizer than usual. Wickiup Reservoir was only 43% full on May 14.

The owner of a cattle feedlot was at risk of losing her farm in 2021 due to the lack of water for livestock and hay (Kohn, August 19, 2021). She planned to sell all of her 4,000 cattle in November. An Oregon State University Crook County Extension Service agronomist was concerned by the end of 2021 that difficulties due to water shortages, stunted crops and smaller livestock herds would lead to farms being sold in Central Oregon (Roig 2021).

Crook, Jefferson and Deschutes counties had declared drought by mid-March 2022 (Snavely 2022; Kohn, March 17, 2022). With the Wickiup Reservoir only 55% full at the end of March, the North Unit Irrigation District was only able to provide 0.45 acre-feet of water to farmers in 2022, which was the lowest it had ever allocated for its customers (Kohn, October 14, 2022). The reservoir was almost drained again by October 11, 2022, when it was only 3% full after providing record low irrigation that season.

Streamflow and reservoir storage were at record low levels again in January 2023, prompting another drought declaration in Crook County (Snavely 2023). The Deschutes River dwindled due to warm, dry weather throughout the year. Irrigation in the region (Crook County, Deschutes County, Jefferson County) was affected early in 2023, with several irrigation districts not being able to deliver water past July 2023 (Kohn, July 18, 2023). The North Unit Irrigation District was able to continue supplying water, but only supplied half the normal amount.

By early 2023, news stories indicated that some farmers in Crook County and Jefferson County had reduced herd sizes or left the livestock industry completely due to drought over the previous four years (Kohn, February 7, 2023). Farmers cited dry pastures and the high prices of hay that limited dairy and beef production and made the industry unprofitable. Jefferson County was also affected by the 2023 grasshopper outbreak in the state (Jacoby 2023).

Willamette Valley and Christmas Tree Farms

The Willamette Valley was affected by drought, especially in the Christmas tree sector. Although drought was not as severe or as long in the Willamette Valley as in other parts of the state, the USDM drought time series shows that periods of drought occurred in 2014-2015, 2018, and 2020-2021 (Figure 3.13).

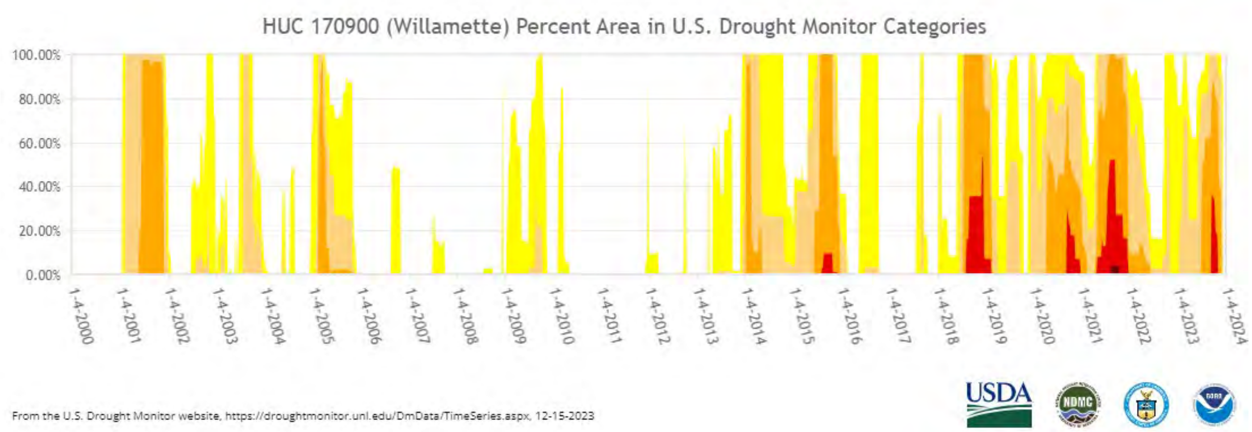


Figure 3.13. Proportion of the Willamette Valley in each USDM category from 2000 through 2023.

Grass seed and hay farmers suffered due to lack of irrigation in summer 2015. Farmers in the Willamette Valley harvested their grass seed crop about two weeks early due to drought conditions (Loew, July 8, 2015). Yields across the state were reduced by an average of 25% as the grasses produced fewer, smaller seeds (Albany Democrat-Herald 2015).

Fourteen reports of impacts to the Willamette Valley's Christmas tree industry emerged between August 2018 and October 2019. In the Pleasant Hill area, Lane County, a tree farmer reported minimal growth due to dry conditions. Normally, according to the farmer, the trees would have grown two to three feet by the time of the news story, in August 2018 (KEZI News, August 9, 2018). The farmer also reported his decision to avoid using farm machinery to avoid the risk of wildfire. Later that year, in November, a grower in Portland reported that all but a few hundred of the 9,000 trees he had planted in spring had died due to lack of water, whereas normally around 95% of newly planted Christmas trees survive (Klamath Falls Herald and News, November 26, 2018). A farmer in Gresham indicated in November 2018 that 200-300 dead trees had to be cut down and that drought could reduce their tree sales by over 50% (Azar 2018). By

October 2019, another report on the Willamette Valley Christmas tree industry indicated that farms were going out of business, especially those that grew noble firs (Gutierrez 2019). One farmer had lost 50-60% of his seedlings over the past three years, with noble firs dying off in the highest numbers. Tree farmers also struggled in 2021. Willamette Valley trees began dying as farmers could only irrigate once every three weeks (Mendez 2021). Some farmers lost all of their 2021 tree plantings.

Christmas tree farmers suffered elsewhere in the state, too. A Christmas tree farmer in Pleasant Hill, Lane County, lost 70-80% of his 2,000 seedlings due to the 2021 drought, when normally 90% of seedlings survive (Cerullo, October 25, 2021). Another Christmas tree grower near Medford lost 4,500 trees and observed minimal growth in those that survived that year (Kobi5 Newsroom Staff 2021).

Rogue Valley

In 2018, ranchers in Jackson County found their pastures dry and unable to meet the needs of their cattle. Ranchers hauled water and purchased hay for over $200 a ton, but reducing herd sizes was a real possibility (Stiles 2018).

In 2020, irrigation districts in the Rogue Valley (Jackson and Josephine counties) reported concerns by early May. A drought disaster was declared in Jackson County on April 21 due to low snowpack while local reservoirs were between 39-89% below normal fill (Ashland Daily Tidings, April 21, 2020). Rogue Valley irrigation districts delayed the start of their water deliveries but expected to have adequate supply for the season (Ashland Daily Tidings, May 4, 2020).

In March 2021, Jackson County reservoir levels were low again (Medford Mail Tribune, March 31, 2021). A drought disaster was declared on March 31 and irrigation districts warned customers to be prepared for a very short period of water. Pear trees in the Rogue Valley fared poorly that year. Fruits were smaller and of low quality, while harvest was only about 25% of normal (Medford Mail Tribune, October 6, 2021). One grower removed all of the pear trees planted on his 75-acre farm near Talent.

Quantitative Data and Analysis

Data availability bounded the scope of our quantitative analysis of drought's effects on agriculture in Oregon. Data was not available for Christmas trees, grass seed or greenhouse and nursery plants. Analysis pertaining to livestock focused on various forms of forage, as animal management decisions and longer time scales associated with animal agriculture introduce complexity that is outside of the scope of this report. The quantitative data we used included:

- Crop yield, from USDA's National Agricultural Statistics Service (NASS) annual producer survey. NASS uses an annual survey of producers to estimate acres planted, yield and other key statistics, by county.
- Indemnified losses and related data from the USDA Risk Management Agency (RMA) Cause of Loss datasets. RMA's Cause of Loss data details why producers filed insurance claims.
- CropScape data describing where the various crops were planted. CropScape, based on remote sensing, complements NASS surveys, providing a different means of estimating where different crops are grown.

Depending on how drought vulnerability is defined, simply knowing where different crops are grown is a first step. A comparison of yield with drought where enough data is available provides additional insight as to where drought has an effect, as does a record of drought-related insurance claims paid. The Normalized Insured Index suggests additional areas for inquiry related to producers' risk management decisions.

To the extent possible, this analysis uses NASS, RMA and CropScape data for a "convergence of evidence" approach on what crops are planted where and on yield losses, but their categories do not align exactly, especially as related to different types of pasture and forage. The maps and analyses presented here focus on wheat and forage, two of the most important crops for which data is available. Recognizing that specialty crop growers and others may have other interests, all of the maps generated and described below were provided to the Oregon Water Resources Department as zip files.

Analysis: NASS crop yield and drought

The USDA's National Agricultural Statistics Service (https://quickstats.nass.usda.gov/) had annual data on several Oregon crops at county level, with the number declining over time (Table 3.5). Differentiation between practices such as irrigated and non-irrigated also declined over time, with more crops being labeled as "all practices." NASS estimates county crop production based on annual surveys of agricultural producers. We normalized crop yield to show the relative influence of drought across different crops. Normalization involved dividing individual yield values for each crop by the mean value for that crop and multiplying the result by 100.

Years with data	**Crops**
2000-2008	Peas
2000-2009	Corn
2000-2013 and 2015	Potatoes
2000-2016	Barley
2000-2018	Sugar beets

2000-2022	Oats, wheat, hay

Table 3.5. Details on the declining number of Oregon crops tracked by NASS.

Where data existed, we compared key agricultural metrics such as normalized crop yield and forage production with drought, using DSCI as our measure of drought. Figure 3.14 compares normalized yield for winter wheat in Morrow County with DSCI, 2000-2022. On these graphs, lower yield is associated with more drought. In contrast, alfalfa production in Malheur County does not seem to show a drought signal, and in fact had lower yield in 2011, a non-drought year (Figure 3.15). Expert opinion was that this showed the negative effects of a wet year on alfalfa production.

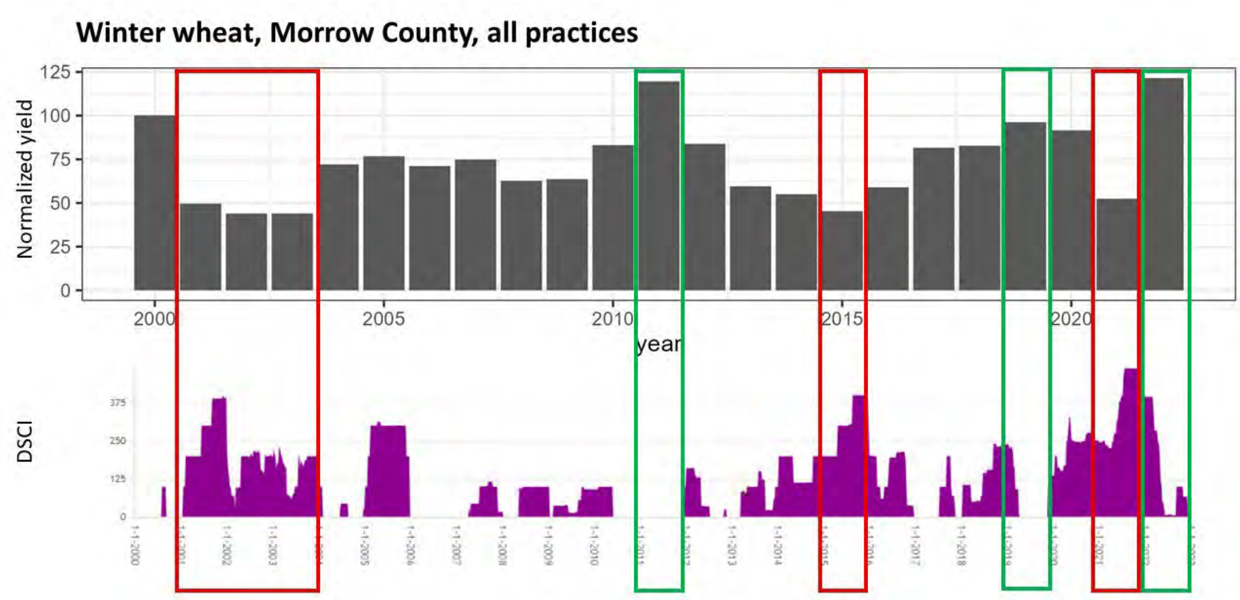


Figure 3.14. Normalized winter wheat yield and drought (DSCI), 2000-2022. Red boxes highlight drought years with lower yield and green boxes highlight non-drought years with higher yield.

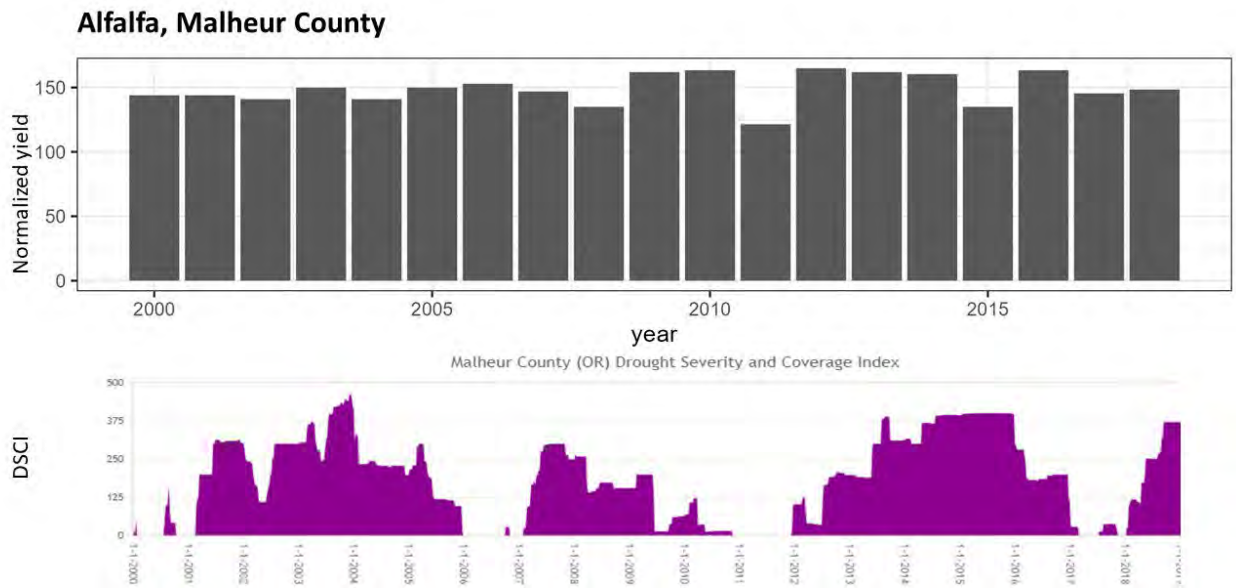


Figure 3.15. Normalized alfalfa yield and drought (DSCI) for Malheur County.

For each crop and each production practice in the data (irrigated, non-irrigated, all practices), we combined counties and years, made scatterplots (graphed the points), and fit regression lines to the data, with DSCI on the y axis and normalized yield on the x axis. A line with a negative slope – higher on the left than on the right – may indicate a negative impact of drought on crop yield. Figure 3.16 suggests that irrigated winter wheat, the orange line, may produce higher yields during drought, indicated by the positive slope. Meanwhile, non-irrigated wheat yield, the green line, is negatively associated with drought.

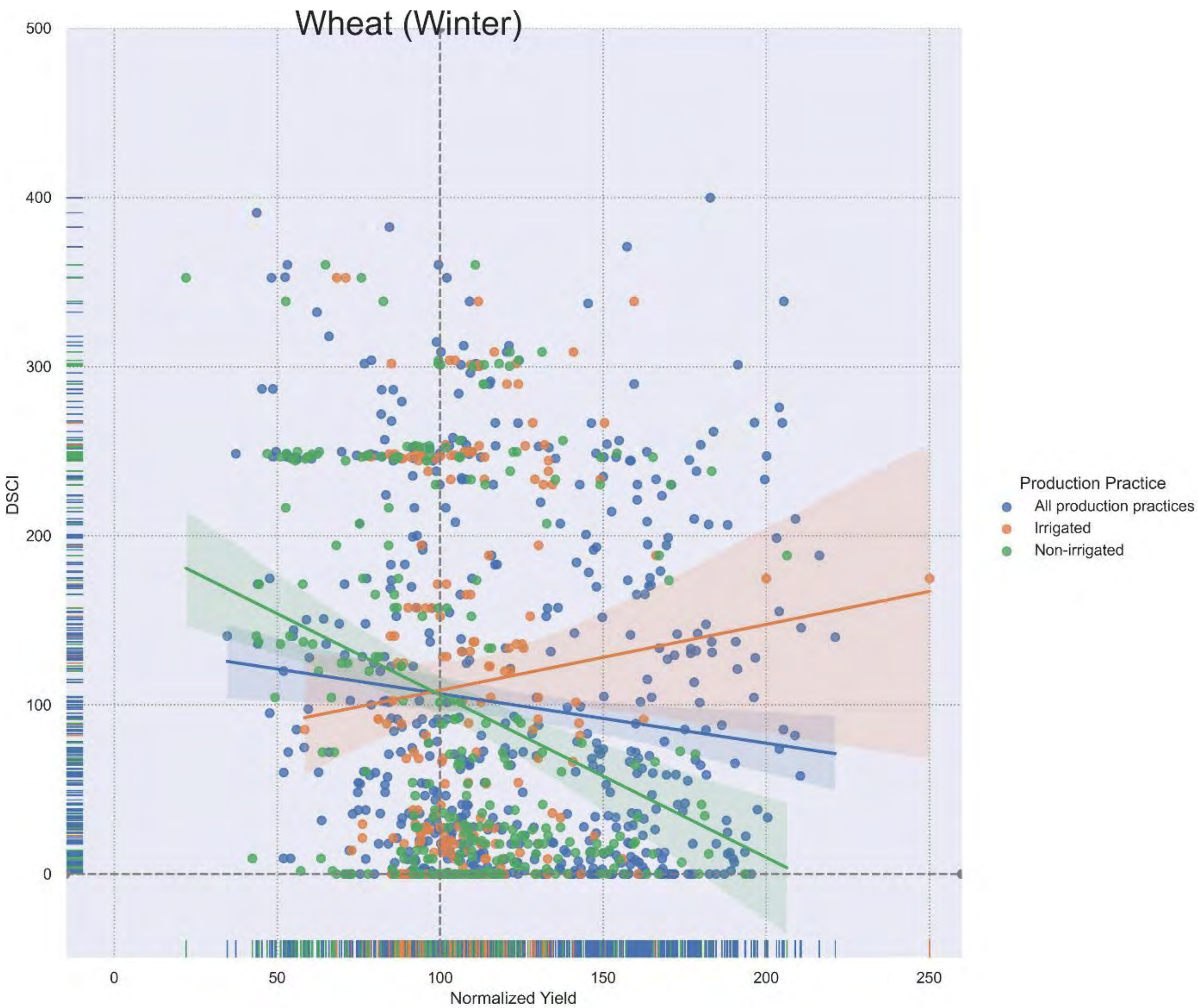


Figure 3.16. The relationship of drought (DSCI) on the y axis and normalized yield on the x axis. Each point represents yield for a county and year, with its placement determined by yield and DSCI. The regression lines help generalize the relationship between the two. Confidence intervals show how well the lines describe the relationship between DSCI and yield. Confidence intervals are represented by shading above and below lines.

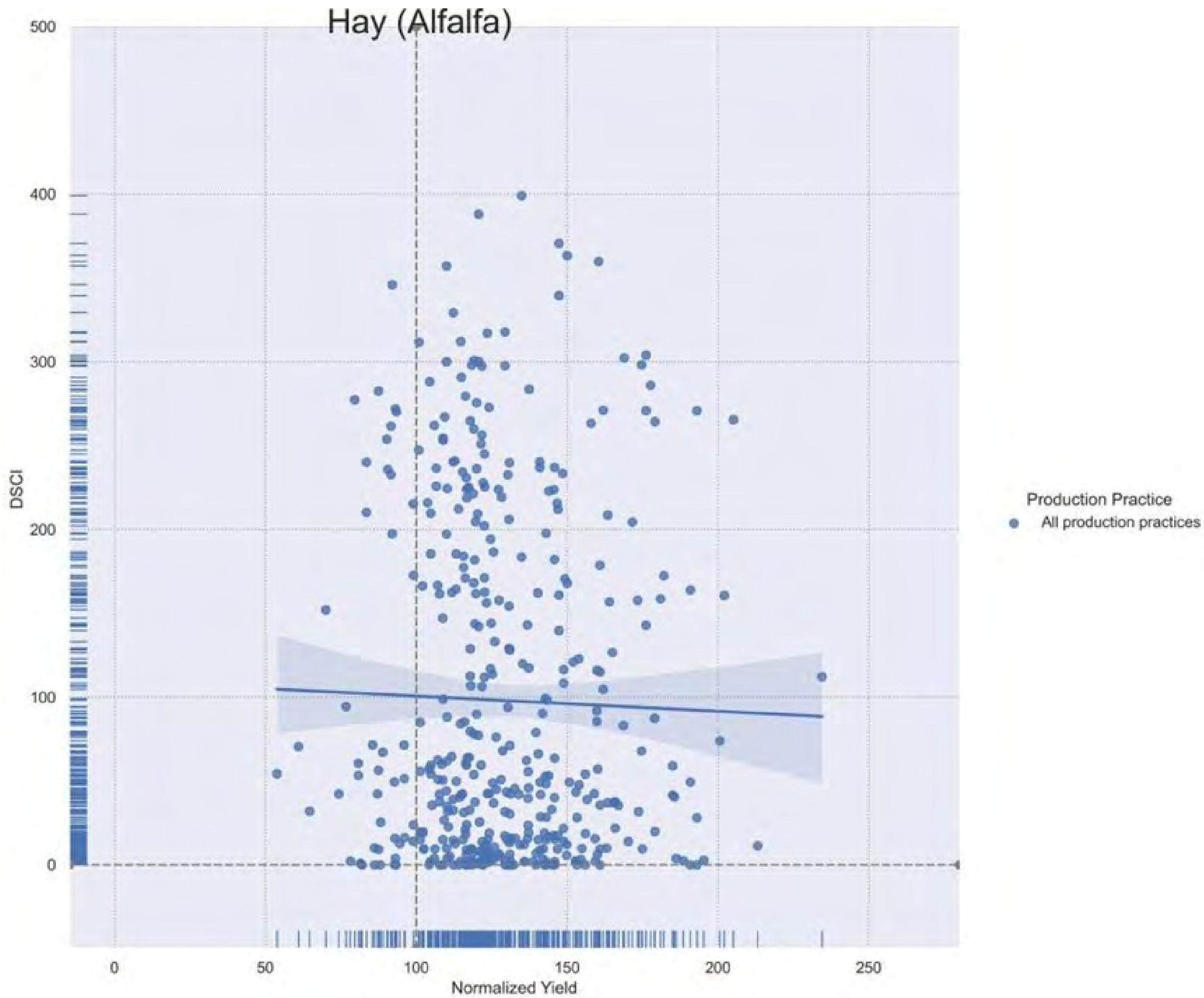


Figure 3.17. The relationship between drought (DSCI) on the y axis and normalized alfalfa yield on the x axis.

The comparison of DSCI and normalized yield for alfalfa, all production practices, shows a very slight negative effect of drought on yield, when all of the counties in the state are grouped onto a single chart (Figure 3.17).

Spatial differences in impact of drought on crop yield

To map spatial differences in the effects of drought, slopes for the relationship between DSCI and normalized yield were computed for each county and crop combination, then grouped into five classes: negative (worse in drought), positive (better in drought), having no relationship, not enough data, or no data.

Although the scatterplot graphing the relationship between drought and crop yield for alfalfa statewide does not show a distinct pattern, computing and mapping slopes for each county shows that the relationship between drought and alfalfa yield is positive in some counties and negative in others (Figure 3.18). This may be due to differences in where irrigation is available.

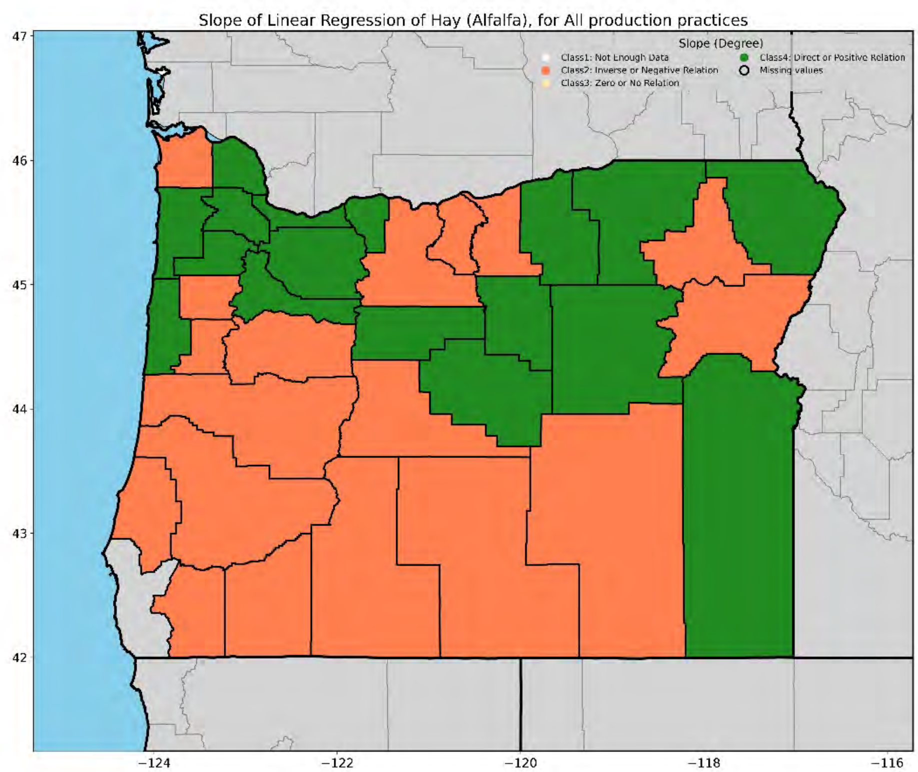


Figure 3.18. Reduced alfalfa yield associated with drought in counties that are orange and increased yield associated with drought in counties that are green.

Figure 3.19, showing a positive relationship between irrigated winter wheat and drought in all of the counties that had enough data for analysis, reinforces the idea that irrigated crops benefit from plenty of water and more sunny days during drought. In contrast, Figure 3.20 shows a negative relationship between drought and non-irrigated winter wheat. The difference in how drought affects irrigated and non-irrigated winter wheat suggests that irrigation is an effective strategy for coping with drought.

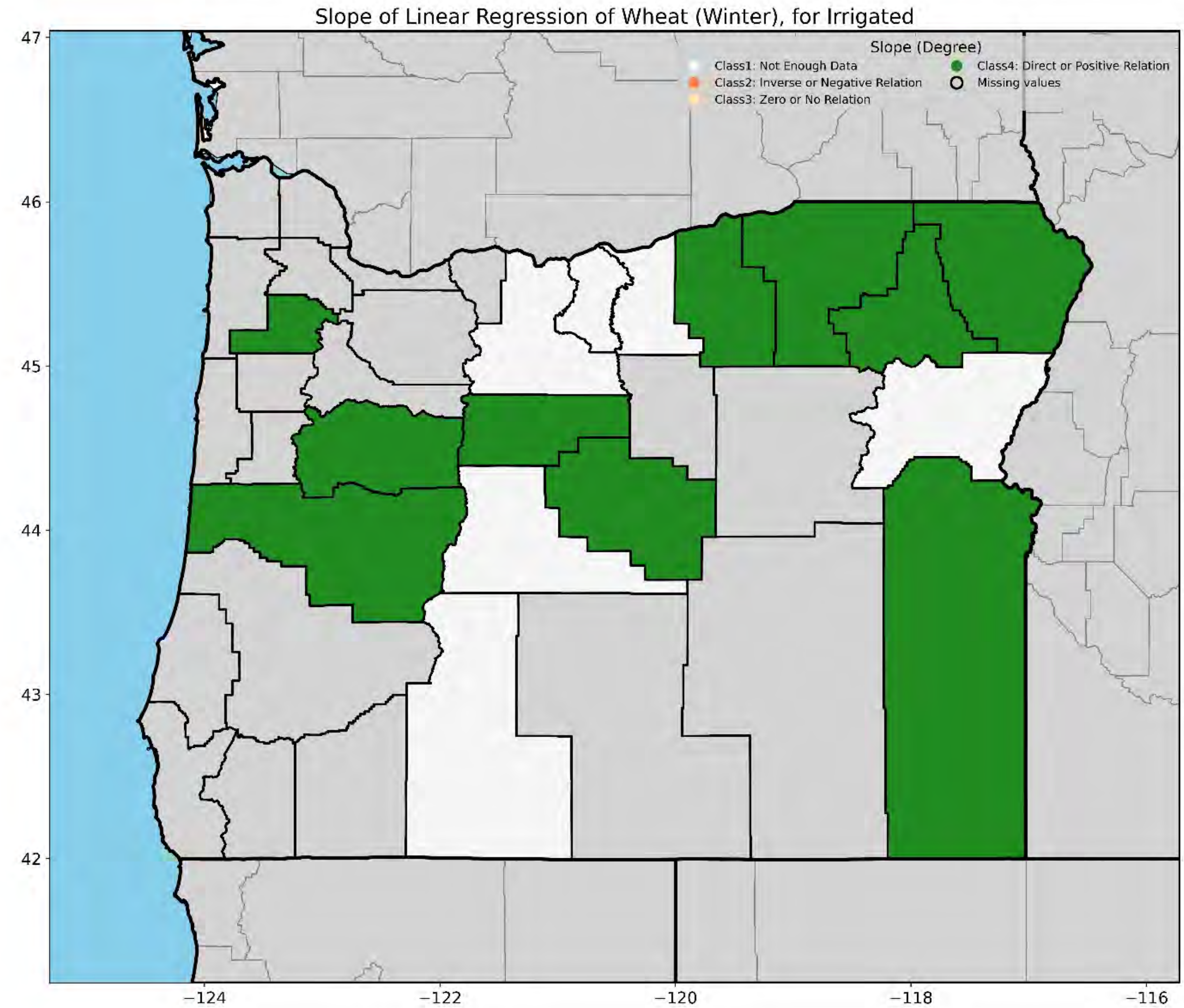


Figure 3.19. Positive relationship between irrigated winter wheat and drought.

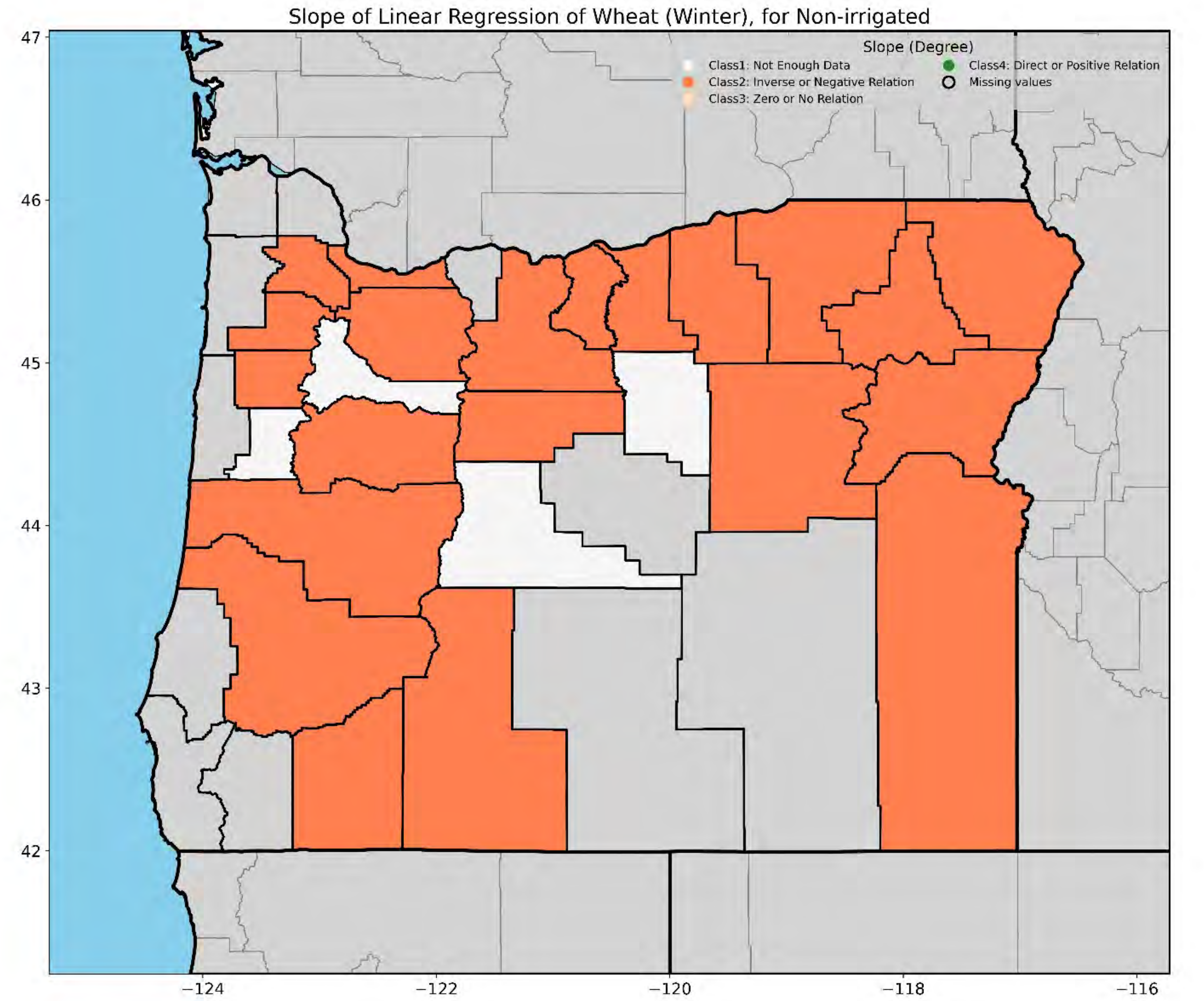


Figure 3.20. Negative relationship between drought and non-irrigated winter wheat.

In contrast, for spring wheat, drought has a negative relationship with both irrigated (Figure 3.21) and non-irrigated crops (Figure 3.22).

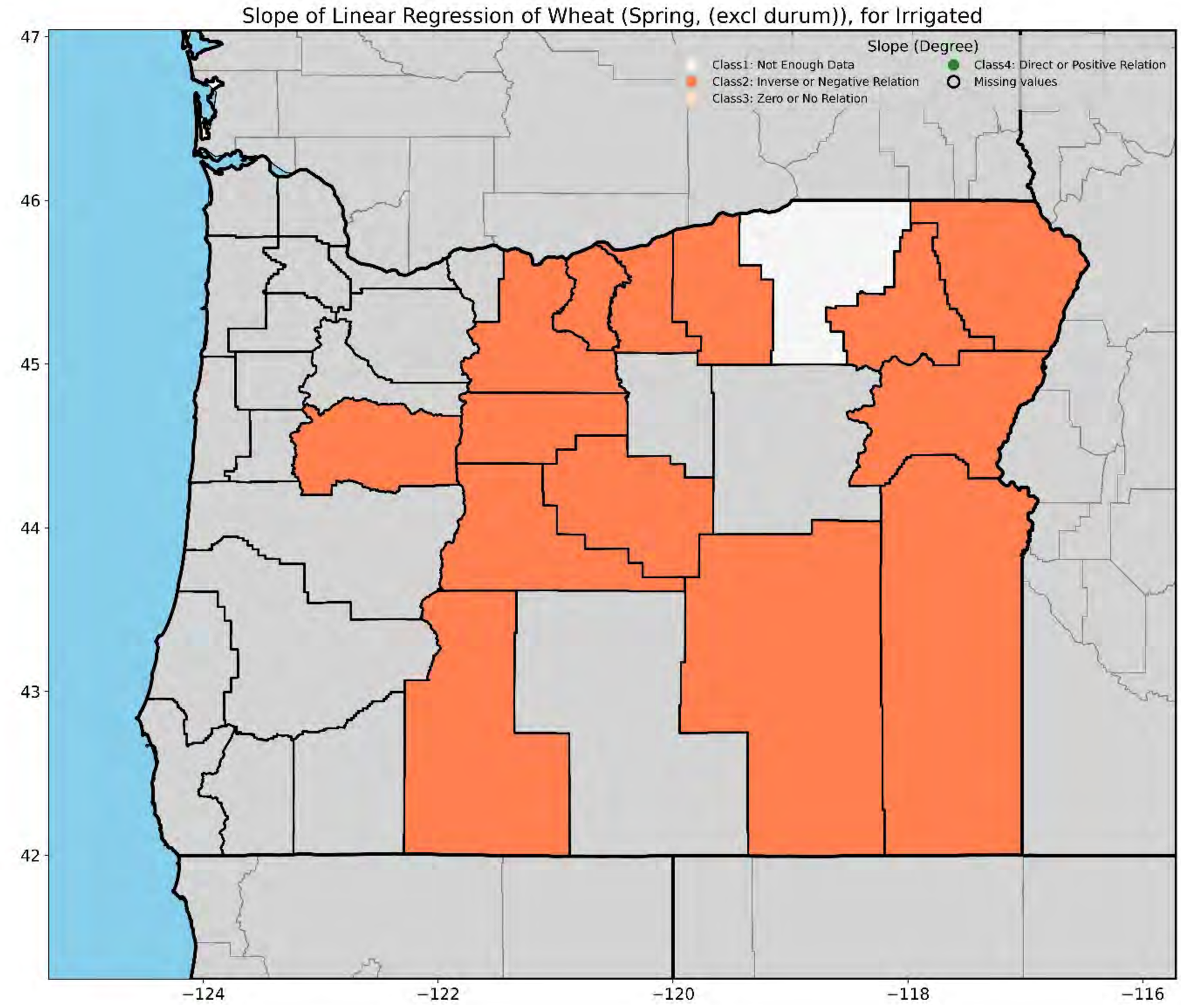


Figure 3.21. Drought has a negative effect on irrigated spring wheat in the counties with enough data to analyze.

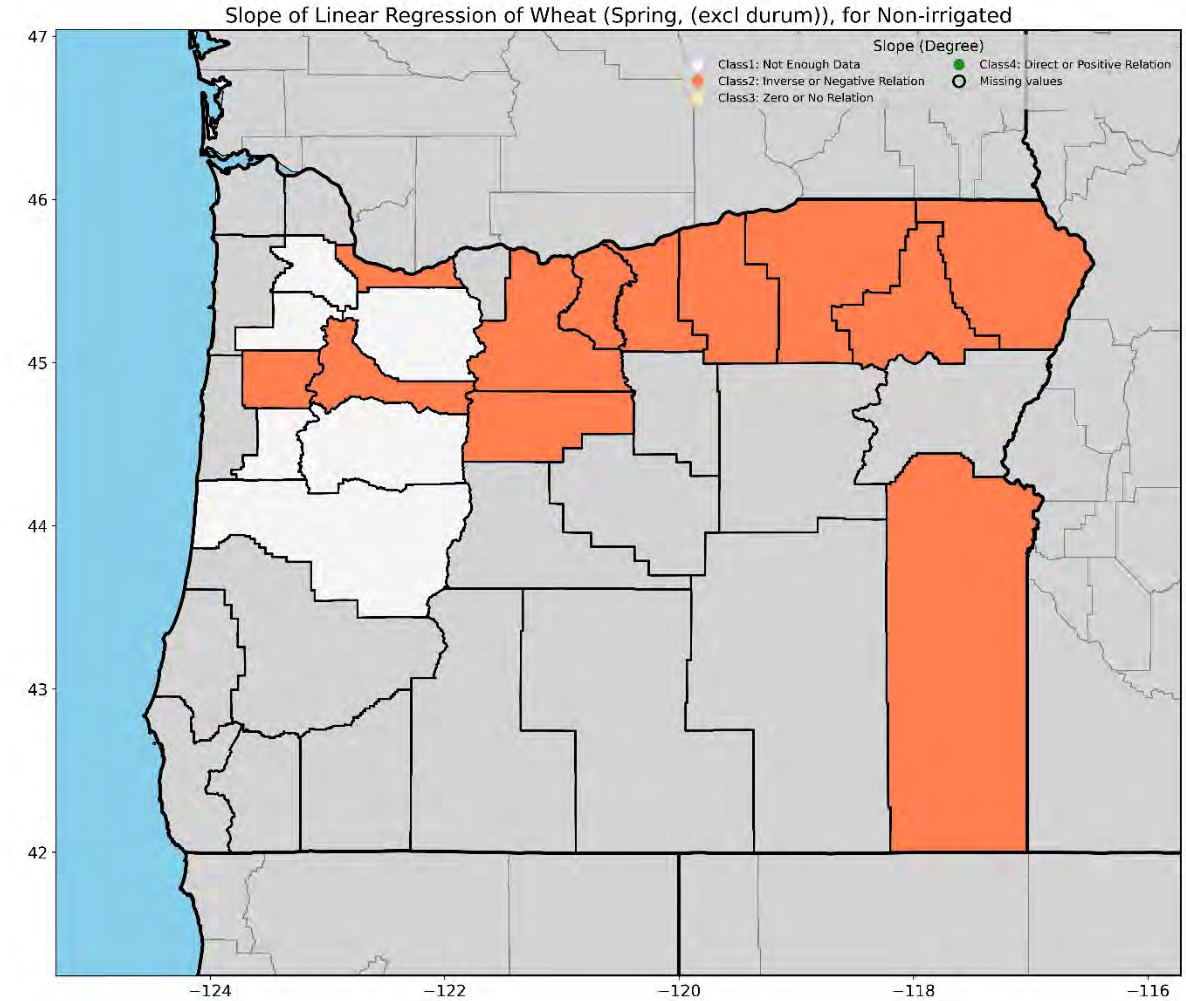


Figure 3.22. Drought has a negative impact on non-irrigated spring wheat, in the counties where there is enough data to analyze.

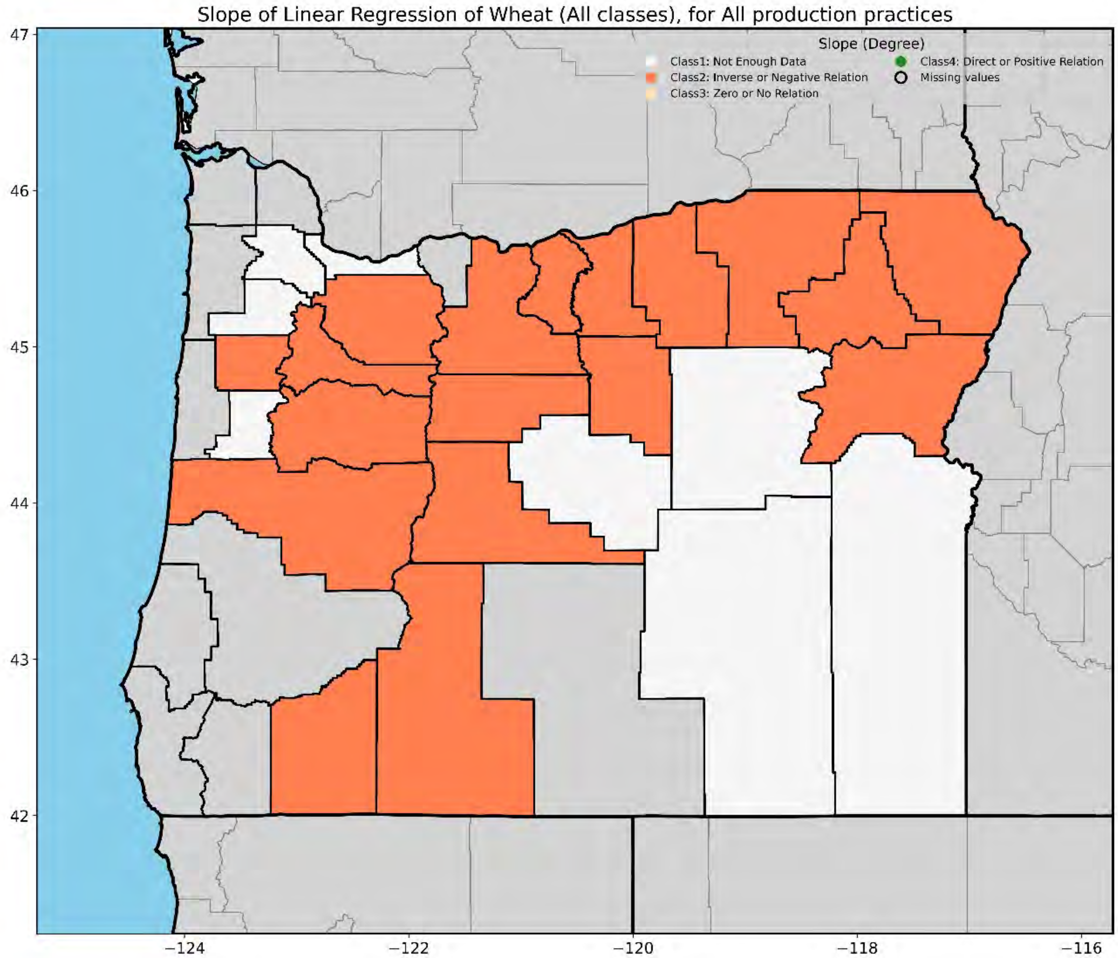


Figure 3.23. Negative relationship between wheat (all classes, all practices) and drought.

Figure 3.23 shows a negative relationship between drought and wheat when all types of wheat and all production practices are grouped together. It is included to illustrate the value of distinguishing between production practices, and for more direct comparison with RMA and CropScape data with all practices grouped together.

CropScape: Mapping Where Various Crops are Planted in Oregon

CropScape data is remotely sensed and provides an annual overview of the areas across the nation planted in each crop, beginning in 2007. Data for this report was downloaded from CropScape (https://nassgeodata.gmu.edu/CropScape/) and then pixels were translated into acres and percent of county area. CropScape accuracy varies across region, crop and year. A recent study found CropScape's average accuracy for all crops to be 90.3% (Lark et al. 2021). We mapped where 60 different crops were planted in Oregon, by county. For each crop, four maps were created: One set of maps showed the mean acres per county and percent area of county planted for all years (2007-2022). Figure 3.24 shows the mean acreage planted in wheat, by county, for 2007-2022, and Figure 3.25 shows the mean percent area planted in wheat, by county, 2007-2022.

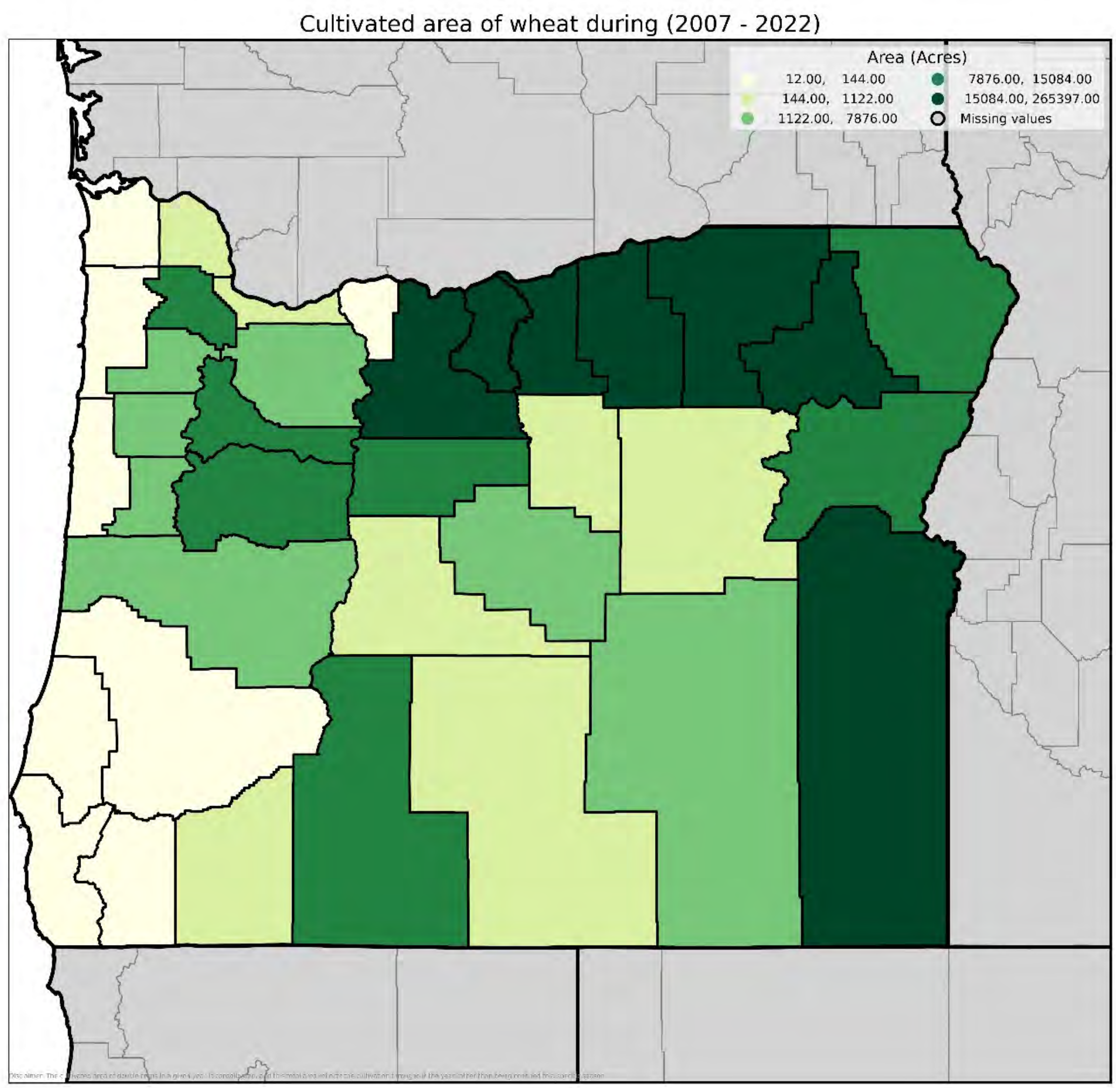


Figure 3.24. Ranges describing the mean acres within each county that were planted in wheat,

2007-2022, based on CropScape data.

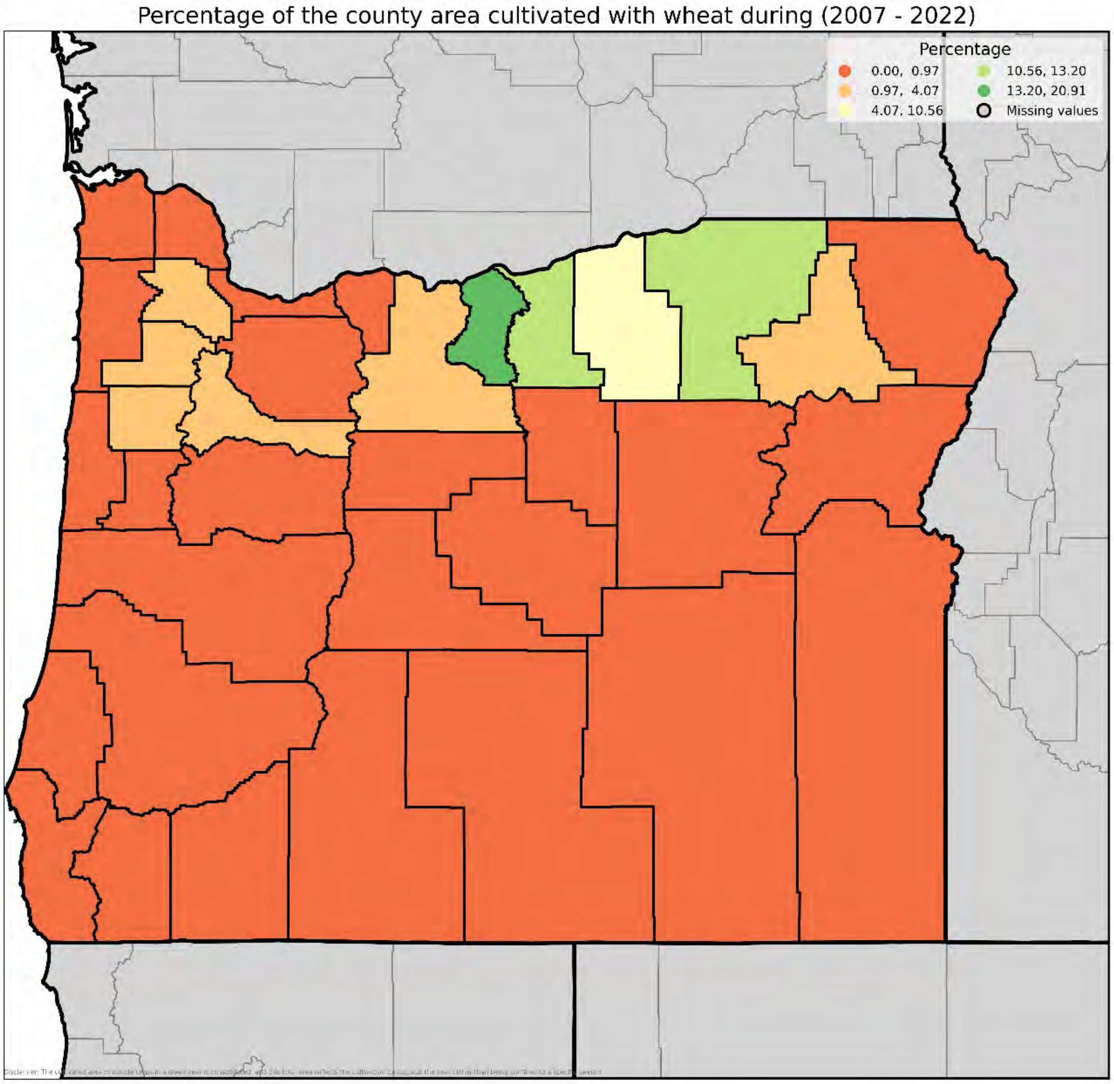


Figure 3.25. Ranges describing the mean percent area of each county that was planted in wheat, 2007-2022, based on CropScape data.

Another set of maps shows acres and percent of county area for each individual year. Figure 3.26 shows acres planted with alfalfa, by county, and Figure 3.27 shows percent of county area planted with alfalfa, both for 2022. They show that alfalfa is more widely grown in the eastern two-thirds of the state.

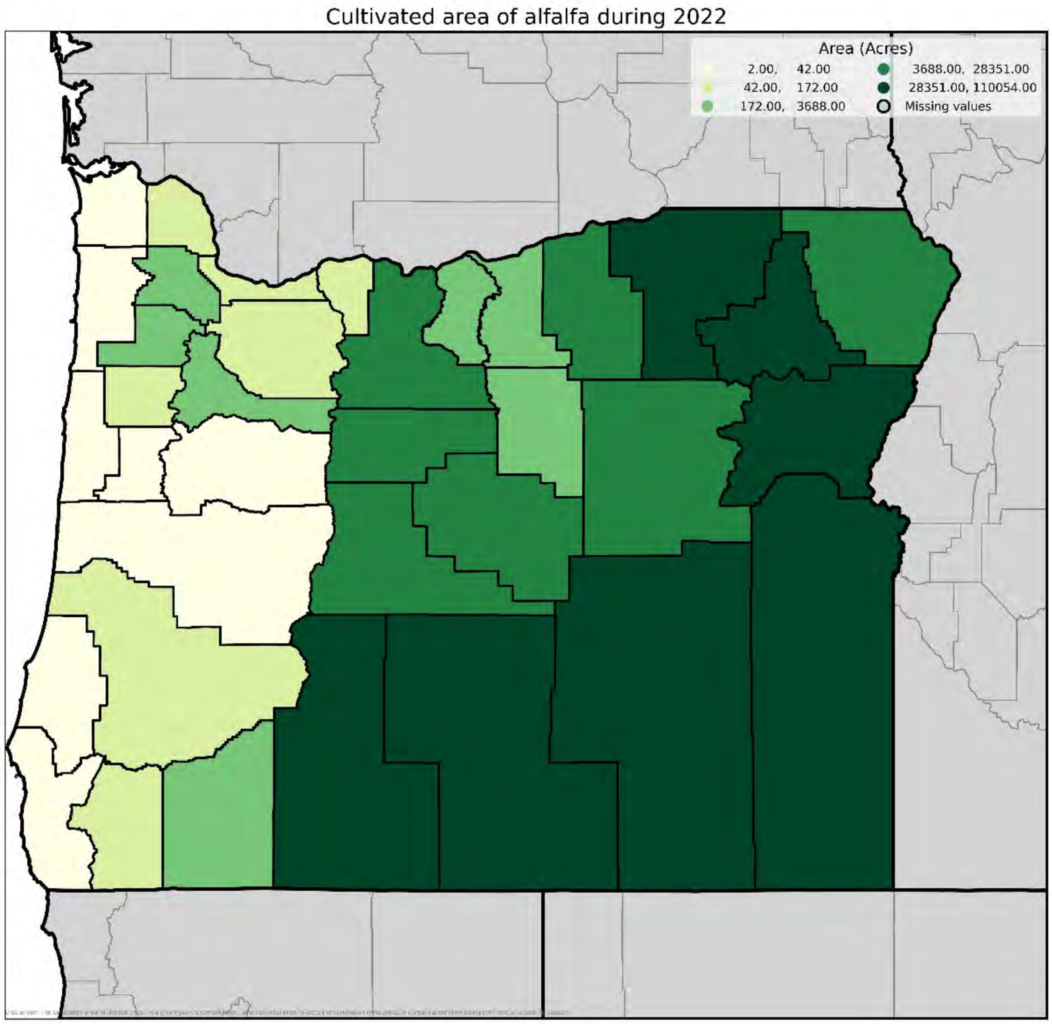


Figure 3.26. Acres planted in alfalfa by county in 2022, based on CropScape data.

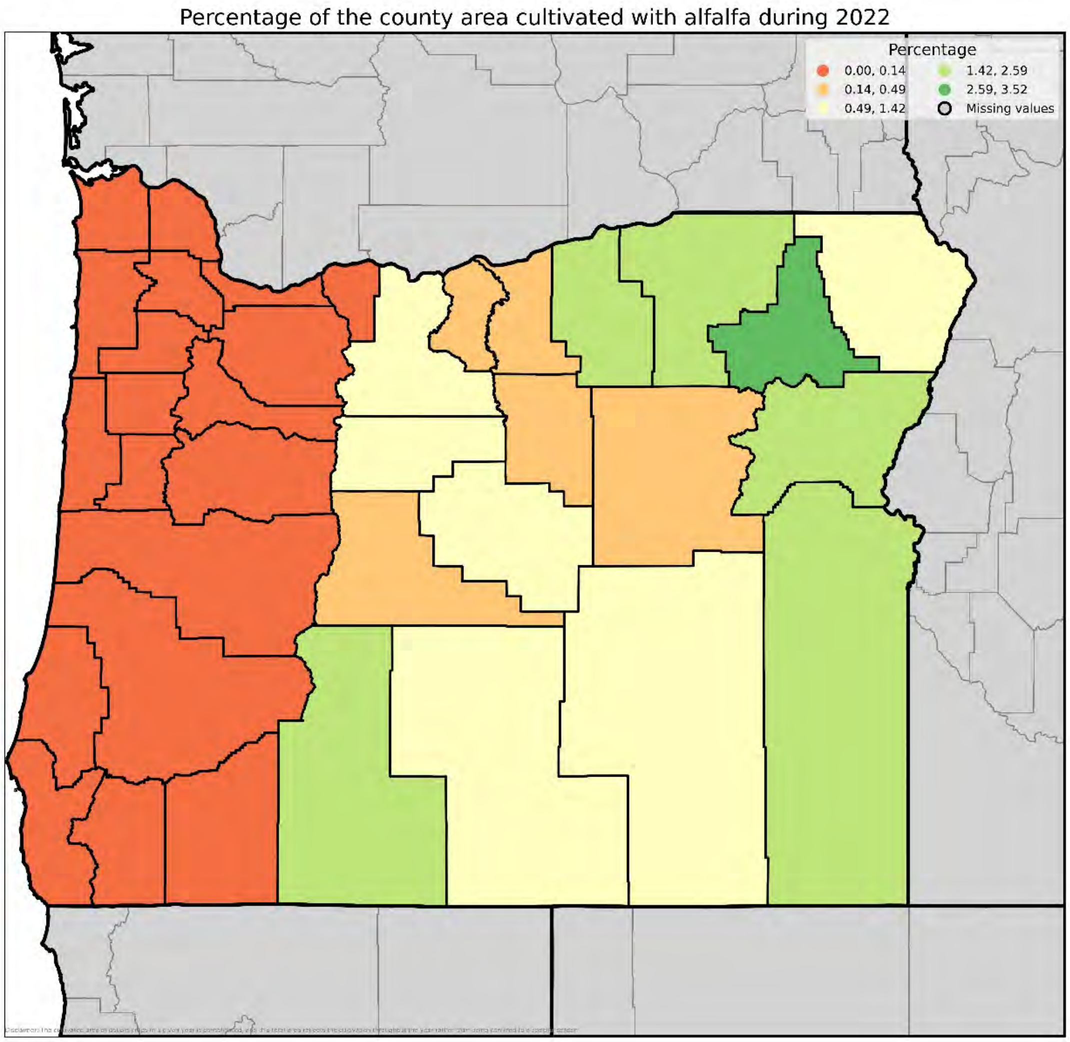


Figure 3.27. Acres planted in alfalfa as a percentage of county area in 2022, based on CropScape data.

The annual maps also included the number of acres and percentage of county area (Figure 3.28) for all crops combined to provide an overview of areas where land is more intensively cultivated. All maps for all crops and years were provided to the Oregon Department of Water Resources as zip files.

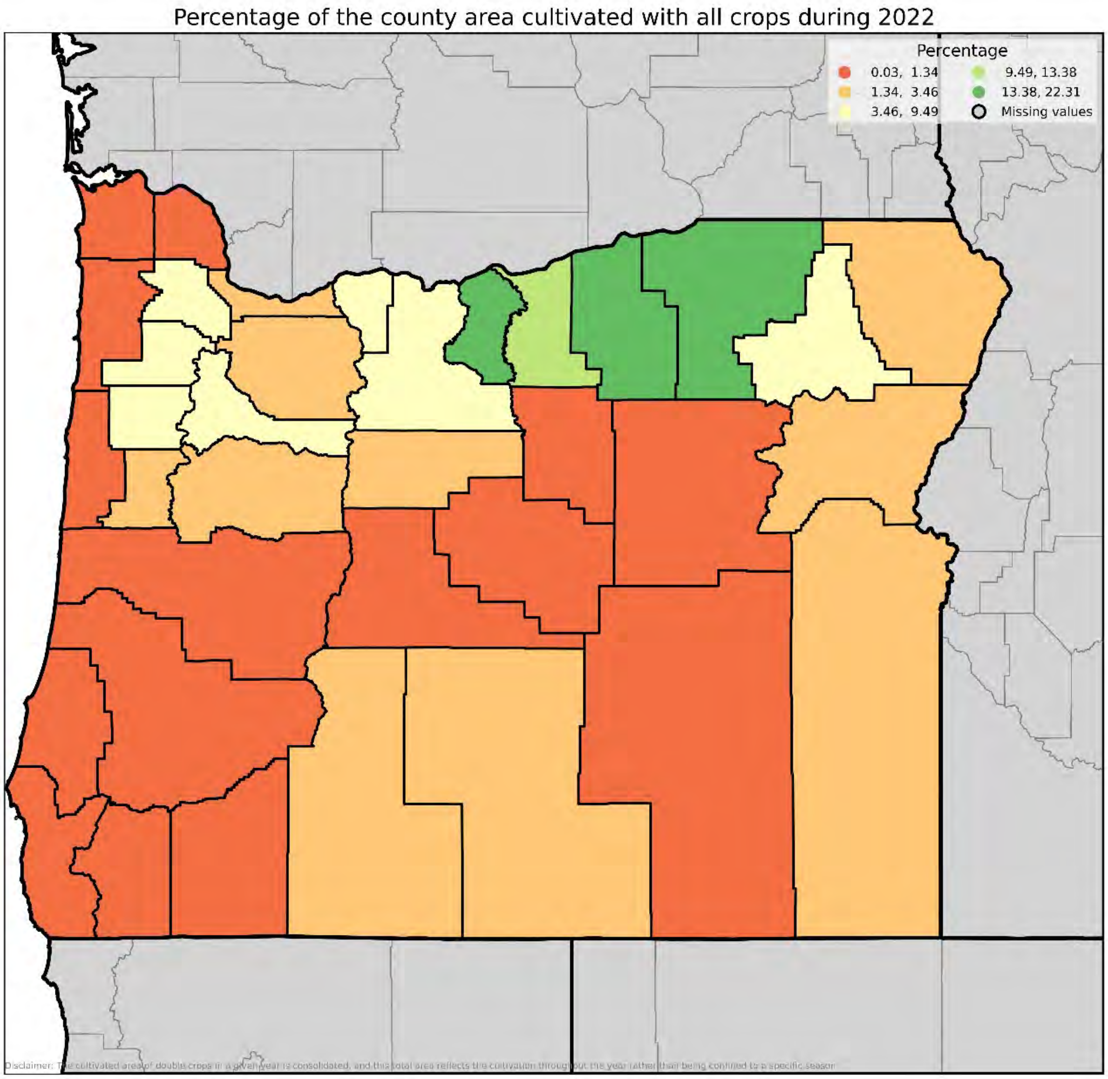


Figure 3.28. Percentage of each county that is cultivated with any crop in 2022, based on CropScape data.

Risk Management Agency Cause of Loss data

The USDA's Risk Management Agency Cause of Loss data records claims by county, year and cause of loss, including drought, for several key Oregon crops. The cause of loss data is particularly relevant for a drought vulnerability analysis because it identifies exactly which losses are due to drought or drought-related causes. A drawback in using RMA's Cause of Loss data to assess drought-related losses is that there are regional and individual differences in whether and how producers use insurance. To calculate all drought-related losses, in consultation with RMA insurance experts, we combined several related cause of loss categories, including drought, heat, hot wind, failure of irrigation including equipment, excess sun and a combination of program codes that designate forage-related losses. We then aggregated individual losses to county level. We created two maps for each crop, each year, showing differences between counties: One map showed a computed “loss-cost” variable (inflation adjusted indemnities/liabilities * 100) that describes how much was paid in claims as a percentage of how much was insured (Reyes and Elias 2019). The other map showed “Policies Indemnified,” the number of policies with claims paid. We also created tables with numeric values for all the combined data.

We also produced maps showing all years combined (2000-2022) for wheat, pasture-rangeland-forage, oats, grapes, cranberries, cherries, barley, apiculture, and all other crops, as well as other insured categories such as whole farm revenue protection and adjusted gross revenue-lite. We mapped loss-cost and claims for all crops combined, one year at a time, for the years 2000-2022.

Drought year vs normal year

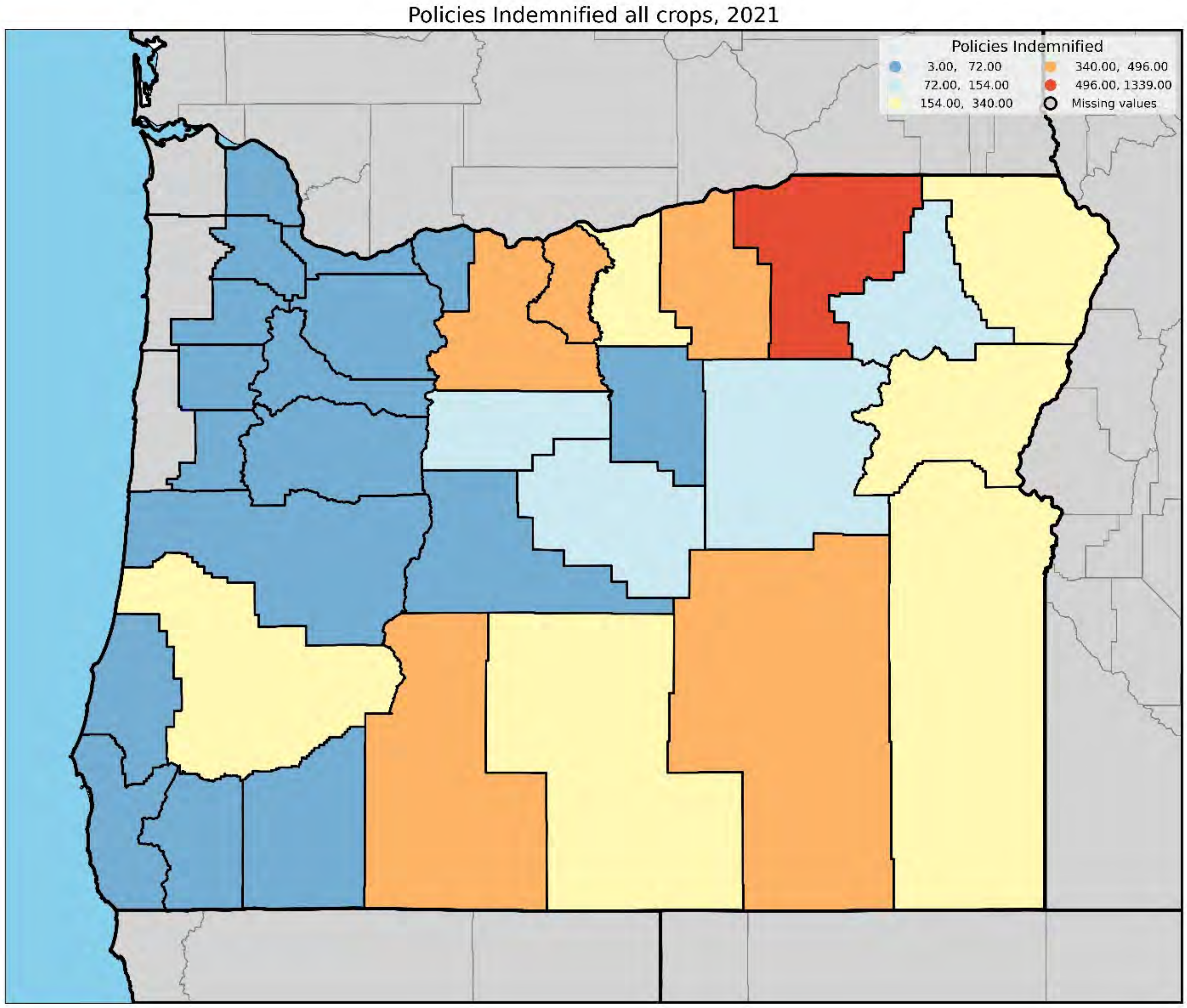


Figure 3.29. Areas where producers filed a total of 6,183 drought-related claims with the USDA's Risk Management Agency for all crops in 2021, a drought year.

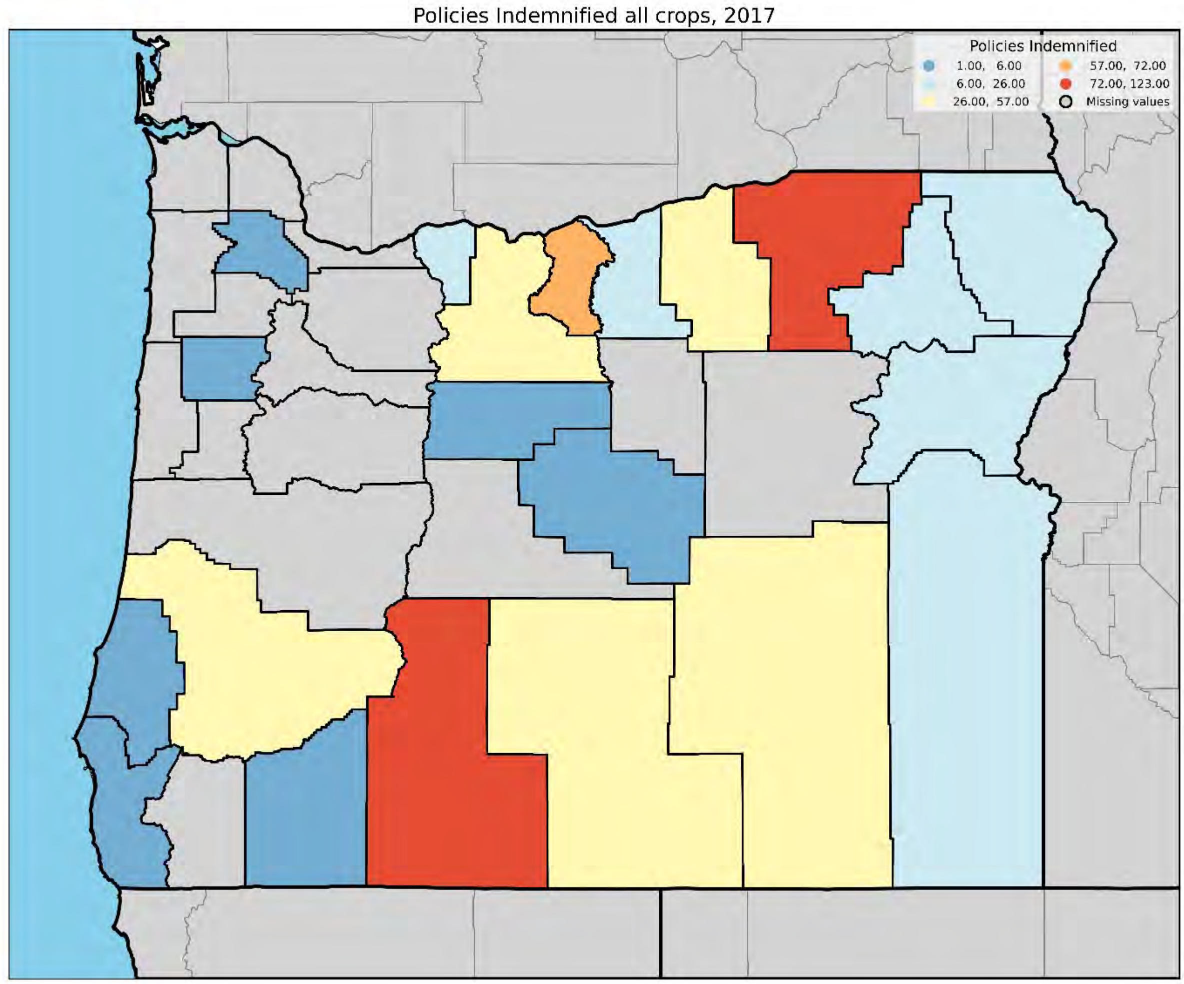


Figure 3.30. Areas where producers filed a total of 717 drought-related claims with the USDA's Risk Management Agency for all crops in 2017, a non-drought year.

In 2021, a drought year, all but the three northernmost coastal counties had drought-related claims filed (Figure 3.29). In contrast, fewer counties had drought-related claims filed in 2017, a non-drought year (Figure 3.30). The numbers of claims were much higher in the drought year, too: 6,183 statewide in 2021, compared with 717 in 2017. (Note: The scale varies from year to year on these maps due to the classification method used to categorize the data.)

Wheat

Figures 2.31 and 2.32 show where farmers planted wheat and where they filed claims on drought-related losses to wheat. Although Linn County had a high loss-cost ratio, it is based on only two claims in 23 years, reflecting many fewer policies sold in that county. (In looking for meaningful patterns, small numbers tend to produce more volatile results that are less indicative of a larger pattern.) Jefferson County had 84 claims. Umatilla County had the highest number of claims, at 5,684, and Morrow County had 2,902.

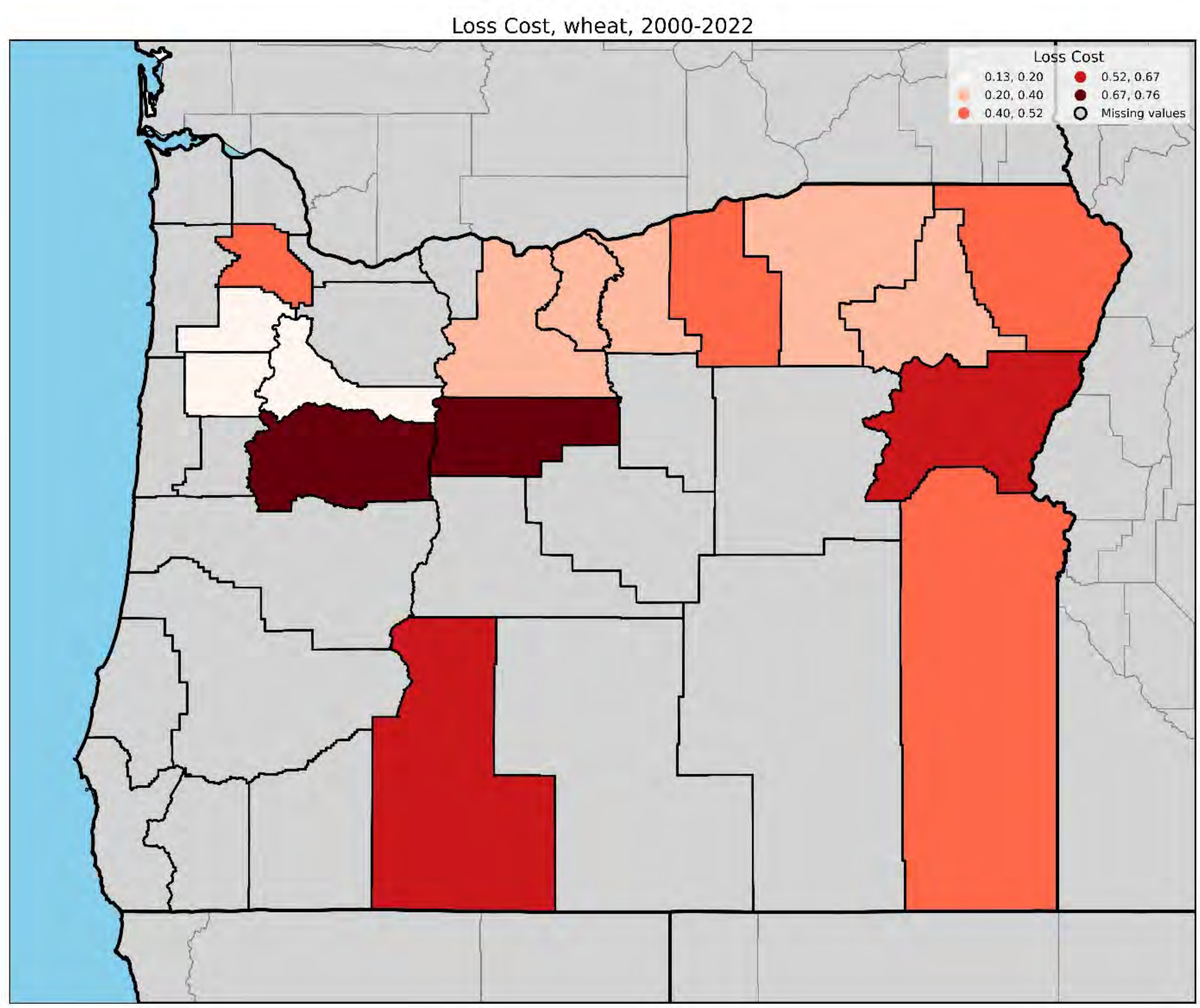


Figure 3.31. Loss-cost, the value of insurance claims paid as a percentage of the total amount insured, based on RMA's Cause of Loss data, for all categories of wheat, 2000-2022.

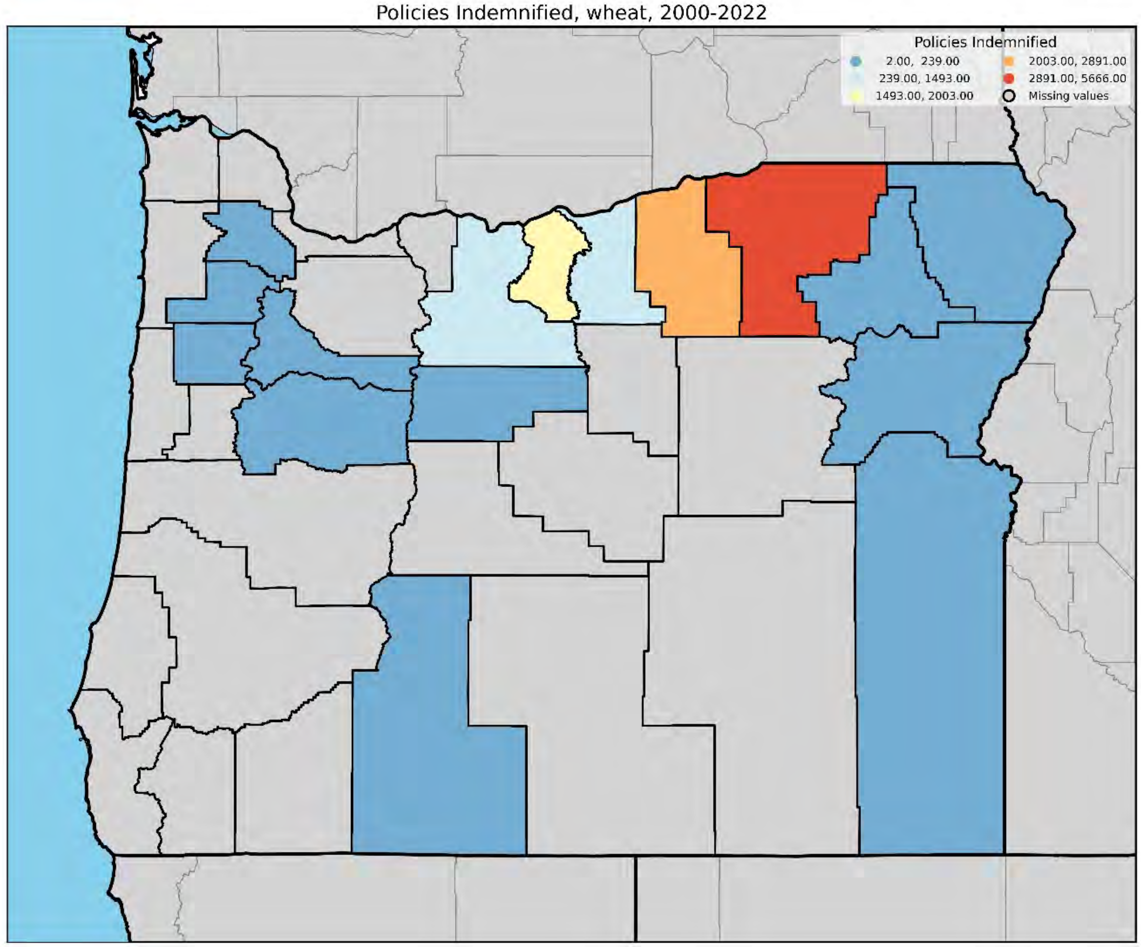


Figure 3.32. Number of policies where claims were paid in each county for wheat. Many more producers received payments in Umatilla and Morrow counties than in other counties, at least partly reflecting the greater numbers of policies sold (see "Policies Earning Premium" in associated data tables).

Pasture, Rangeland, Forage

For pasture, rangeland and forage, Figure 3.33 shows a higher loss-cost ratio in eastern counties, where numbers of policies are lower, and Figure 3.34 shows higher numbers of claims paid in southern and eastern counties.

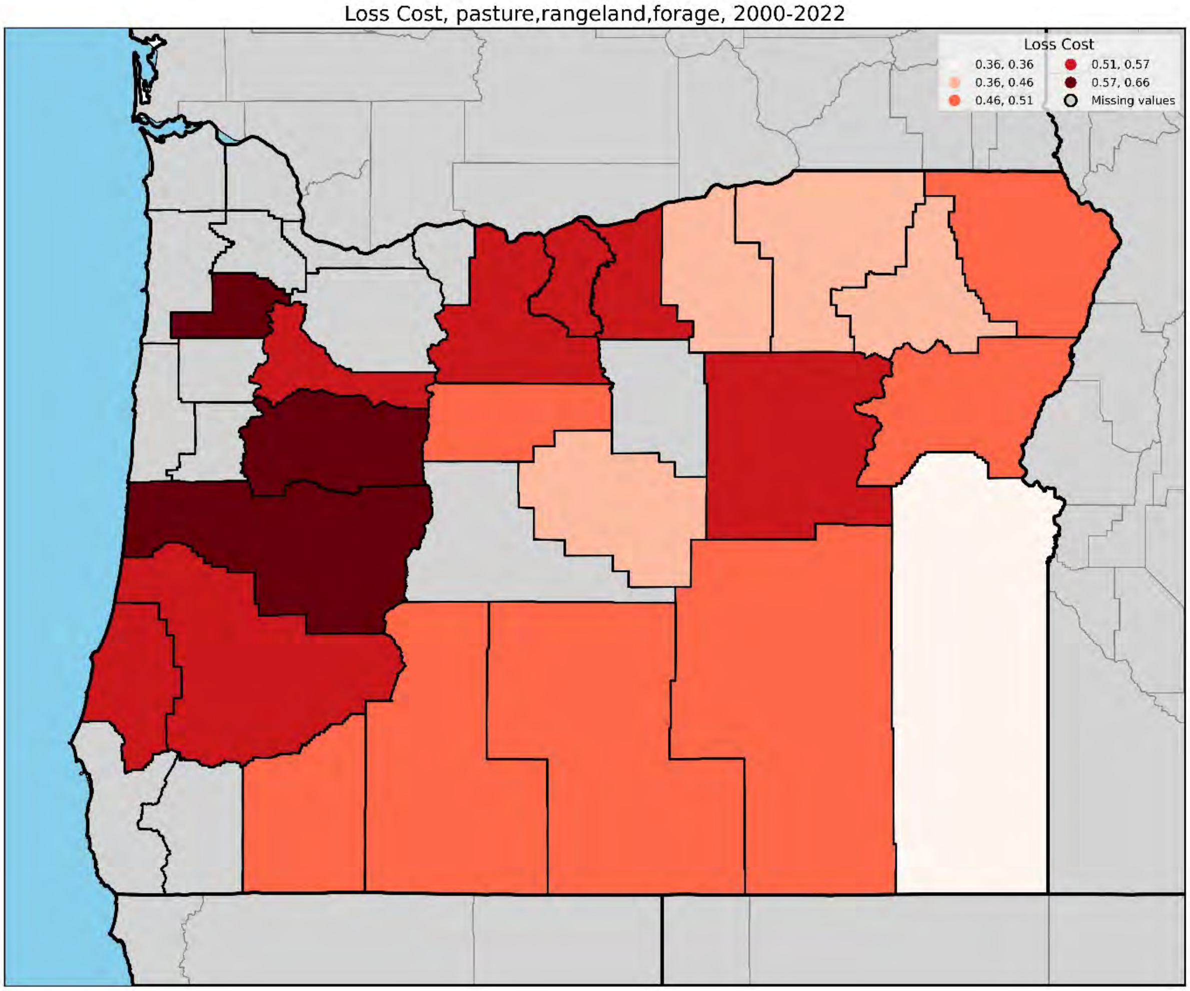


Figure 3.33. Loss-cost ratio for pasture, rangeland and forage, 2000-2022.

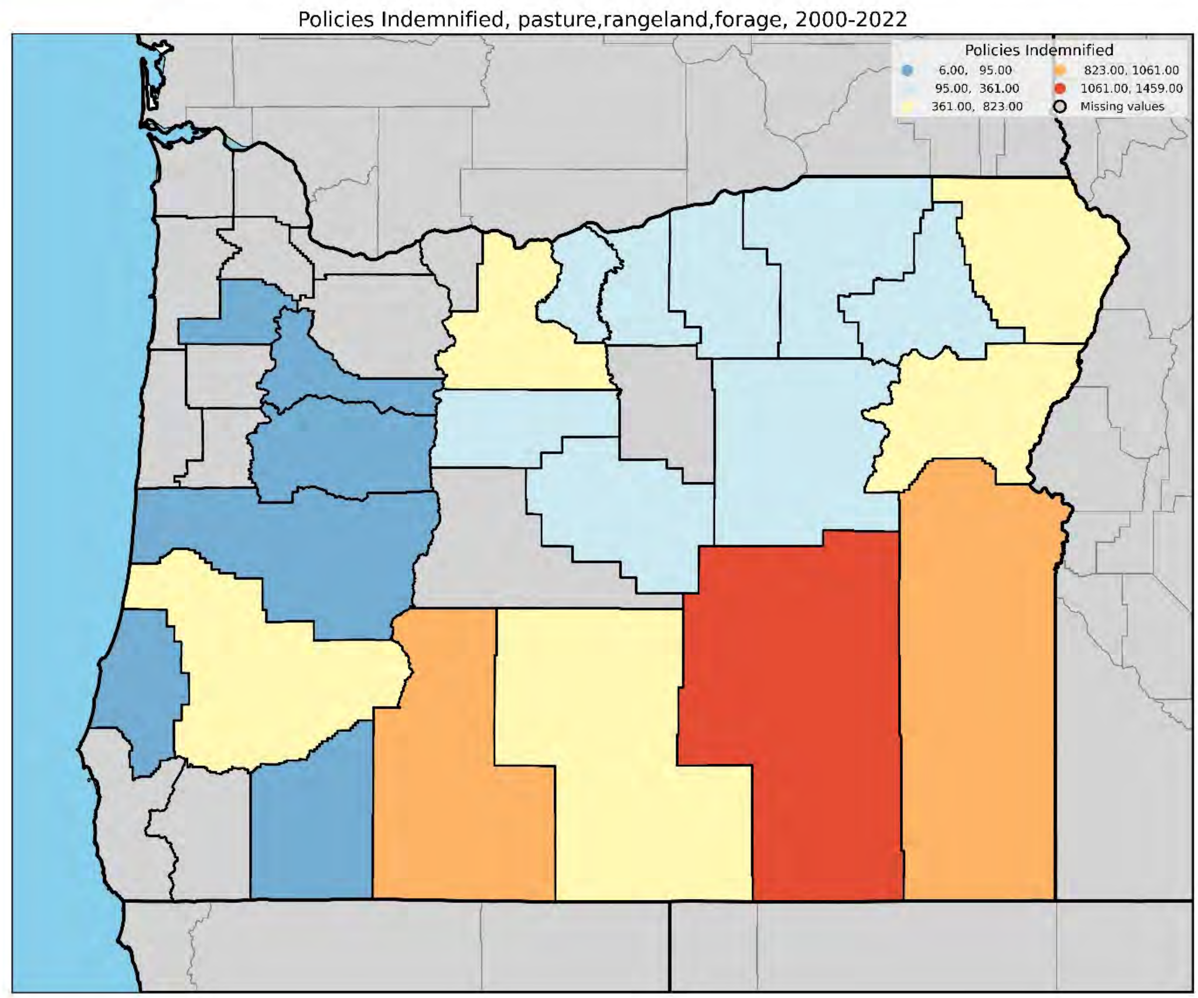


Figure 3.34. Areas where producers filed claims for pasture, rangeland and forage.

RMA data and maps

All maps and associated data tables described here have been provided to the Oregon Department of Water Resources as zip files. Others may benefit from data that is already aggregated to all drought-related causes by county and year, or want to map different variables from the dataset. Tables are either by year of loss (summarizing all crops) or by crop (summarizing all years). Tables include the county and FIPS code, policies earning premium, policies indemnified, net planted quantity, net endorsed acres, liability, total premium, determined quantity, indemnity, loss ratio, liability norm (inflation adjusted liabilities), total premium, indemnity, loss cost and loss ratio normalized (inflation adjusted). Definitions of each of these fields are available on RMA's website at https://www.rma.usda.gov/SummaryOfBusiness/StateCountyCrop as "Record layout."

Analysis of insurance use

Buying crop insurance is one of the main ways that agricultural producers reduce their vulnerability to drought. Producers' decisions to purchase insurance may reflect previous experience, judgments based on prevailing conditions at the start of the growing season, and sometimes local preferences. We compared CropScape and RMA's Summary of Business data for a high-level look at the relationship between where different crops are grown and where they are insured. These maps depict "hotspots," areas where crops are likely to be insured, on the red end of the spectrum, and "coldspots," areas where crops are less likely to be insured, on the blue end of the spectrum. For example, Figure 3.35 shows different rates of insurance uptake (decisions to purchase insurance) for wheat in 2022, with red showing higher levels of uptake and blue showing lower levels.

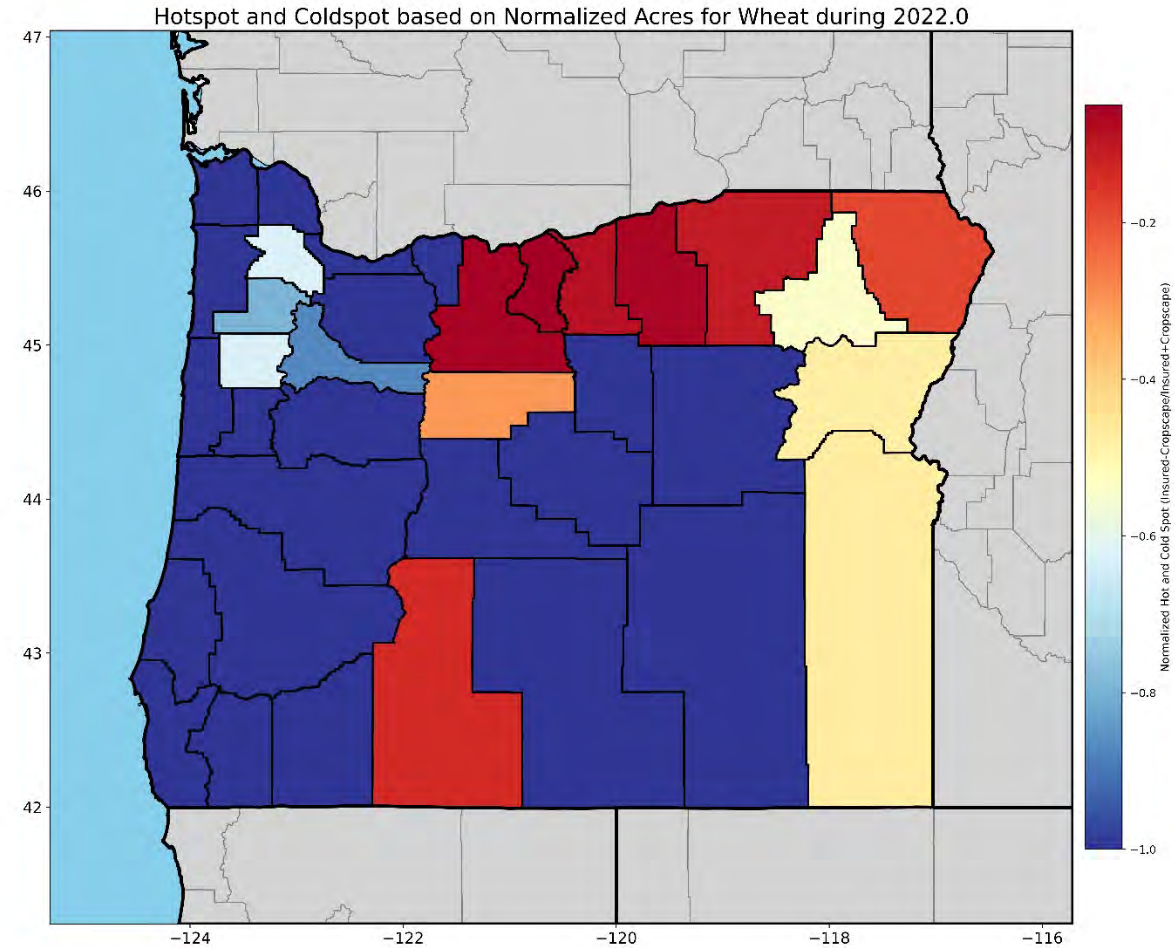


Figure 3.35. Normalized Insurance Index for wheat across Oregon in 2022, comparing where producers planted wheat, based on CropScape data, with where producers insured wheat, based on Risk Management Agency Cause of Loss data. Counties in the deepest shade of blue are where CropScape shows that wheat was grown but RMA's Summary of Business data does not show any insurance policies purchased.

CropScape data shows several counties where producers grow wheat but, according to RMA Summary of Business data, do not insure it. This difference merits further investigation into both the accuracy of the data, particularly CropScape, and producers' decision-making.

For those interested in the technical detail of the comparison, we calculated the maximum value of each crop area for each year and the previous four years, and joined CropScape data with RMA Summary of Business data based on year, crop and county. Then we computed a

Normalized Insured Index:

$$Normalized\ Insured\ Index = \frac{RMA\ Insured\ Acres - \ CropScape\ Acres}{RMA\ Insured\ Acres + CropScape\ Acres}$$

We mapped the Normalized Insured Index, visualized as hotspots and coldspots, for 20 crops for the years from 2012 through 2022. Due to differences in how crops are grouped and categorized in different datasets, the Normalized Insured Index was not computed for pasture, rangeland and forage or for alfalfa. All of the maps were provided in a zip file to Oregon Water Resources Department.

Convergence of evidence

A convergence of evidence methodology, comparing each of these different maps for a crop, may be informative. In all cases, maps should be interpreted with caution and in light of local knowledge and expertise. In the case of wheat, CropScape (Figure 3.36, top left) and other maps indicate that several counties along the state's northern border are main wheat production areas. Drought generally has a negative effect on yield (with the exception of irrigated winter wheat, noted above) in the counties where enough data exists to analyze (Figure 3.36, lower left). The number of claims paid was greatest in the counties on the northern border, suggesting more systematic and intensive cultivation (Figure 3.36, top right).

The map at bottom right in Figure 3.36, the Normalized Insured Index, further highlights county differences and spatial pattern in rates of cultivation and insurance. Exploration of coldspots, or areas where producers plant but do not insure different crops, could be informative. Qualitative research into producers' decision-making on planting and insurance could shed light on opportunities to tailor or market insurance products for different crops and regions. The accuracy level of CropScape data should be taken into account.

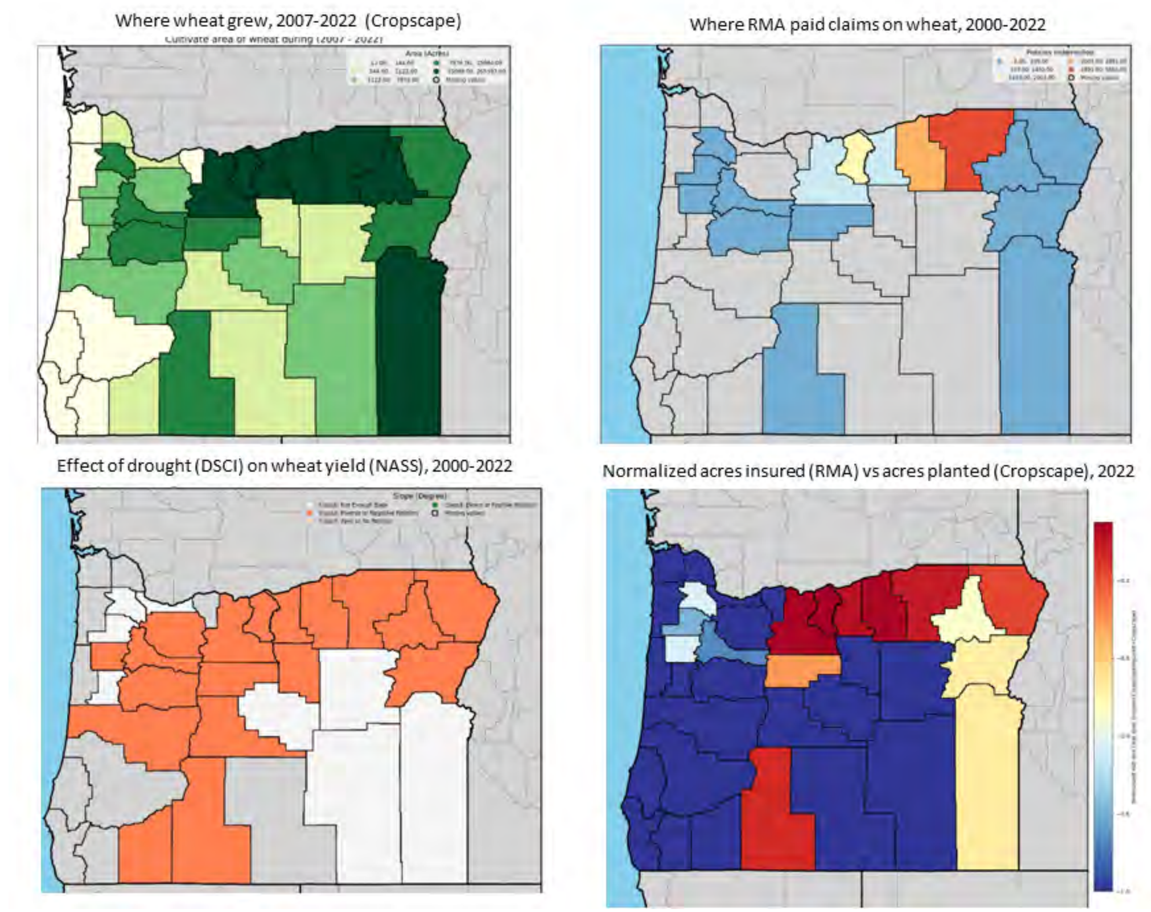


Figure 3.36. Comparison of where wheat was planted, 2007-2022, where claims were paid, 2000-2022, the effect of drought on yield, 2000-2022, and whether producers bought insurance in 2022.

A similar convergence of evidence approach is more complicated for forage, including alfalfa, because each of our data sources categorized forage crops differently (Figure 3.37). Due to differences in data categorization, we were not able to compute the Normalized Insured Index for alfalfa or forage crops, and the maps presented in Figure 3.37 should be taken as a very broad-brush overview. Further investigation may reveal opportunities to better align data.

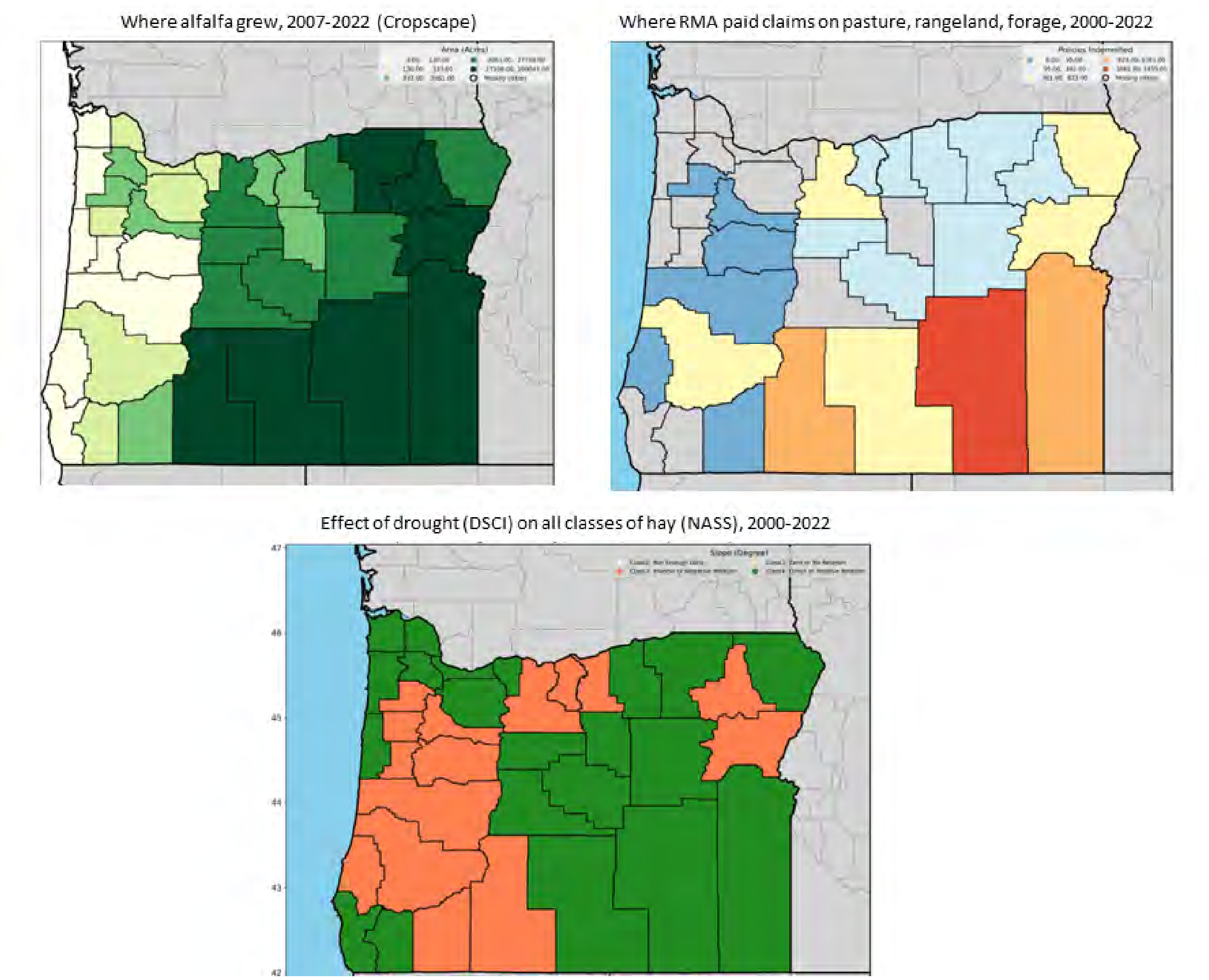


Figure 3.37. Compilation of forage-related maps from different data sources. The map at top left, from CropScape, shows where alfalfa grew, 2007-2022. The map at top right shows where RMA paid claims for pasture, rangeland or forage, 2000-2022. The map on the bottom shows counties in orange where drought (DSCI) reduced crop yield (NASS) and in green where drought increased yield.

Figure 3.37 suggests that alfalfa and other forage crops are most intensively cultivated in southeastern Oregon, based on where CropScape detected alfalfa (top left) and on where producers filed claims (top right). On the bottom, the analysis of where drought (DSCI) affects yield for all classes of hay (NASS) shows a positive effect in green for several central and eastern counties and a negative effect in orange for other counties, mostly in the west. It is likely that differences between types of forage crops and cultivation practices across the state, especially irrigation, account for varying responses to drought.

References

AgClassroom. A look at Oregon Agriculture. https://cdn.agclassroom.org/nat/data/stats/oregon.pdf Accessed January 29, 2024.

Albany Democrat-Herald. Grass seed farmers expect low yields due to drought - Albany Democrat-Herald (OR), July 13, 2015. http://democratherald.com/news/state-and-regional/grass-seed-farmers-expect-low-yields-due-to-drought/article_d76c43a4-91fd-5daa-9d5d-a4f83ddbb628.html.

Allen, Blake. Drought could mean fewer local sustainable products, Bend-area farmer says. KTVZ (OR), August 18, 2020. https://ktvz.com/news/2020/08/18/drought-could-mean-fewer-local-sustainable-products-bend-area-farmer-says/.

Alexander, Kurtis. In the Klamath Basin, drought forces hard choices. San Francisco Chronicle (CA), May 22, 2020. https://www.sfchronicle.com/environment/article/In-the-Klamath-Basin-drought-forces-hard-choices-15289697.php.

Ashland Daily Tidings. Drought declaration: A disaster on top of a disaster - Ashland Daily Tidings (OR), April 21, 2020 https://ashlandtidings.com/news/top-stories/drought-declaration-in-jackson-county-is-a-disaster-on-top-of-the-covid-19-disaster-oregon.

Ashland Daily Tidings. Pear growers beat some COVID-19 impacts - Ashland Daily Tidings (OR), May 4, 2020 https://ashlandtidings.com/news/top-stories/rogue-valley-pear-growers-beat-some-covid-19-impacts.

Azar, Kellee. Ongoing drought leads to concerns for Christmas trees across Oregon. KATU News (OR), November 23, 2018. https://katu.com/news/local/ongoing-drought-leads-to-concerns-for-christmas-trees-across-oregon

Barnard, Jeff. Klamath Irrigation Project facing another short year. Everett Herald (WA), April 9, 2014. https://www.heraldnet.com/news/klamath-irrigation-project-facing-another-short-year/

Barnard, Jeff. Farmers on Oregon-California border might get less water than they expect. Bend Bulletin (OR), April 9, 2015. https://www.bendbulletin.com/nation/farmers-on-oregon-california-border-might-get-less-water-than-they-expect/article_0be8407f-341d-5588-b89d-bd06138065e8.html

Bend Bulletin. Farmers struggle to survive water cuts. Bend Bulletin (OR), April 5, 2010. http://www.bendbulletin.com/apps/pbcs.dll/article?AID=/20100405/NEWS0107/4050327/1009/NEWS01&nav_category=NEWS01.

Bend Bulletin. Drought forces Klamath farmers to expand potato leases to new lands. Bend Bulletin (OR), May 13, 2010. http://www.bendbulletin.com/apps/pbcs.dll/article?AID=/20100513/NEWS0107/5130359/1009/NEWS01&nav_category=NEWS01

Bend Bulletin. Stakeholders tout Klamath basin deal. Bend Bulletin (OR), June 6, 2014. http://www.bendbulletin.com/localstate/2130711-153/stakeholders-tout-klamath-basin-deal?entryType=0.

Bradshaw, Bill. Grim harvest: Farmers get low yields after summer drought. Wallowa County Chieftain (OR), August 25, 2021. https://www.wallowa.com/news/grim-harvest-farmers-get-low-yields-after-summer-drought/article_8ad0c3a6-0461-11ec-a8a3-0f73812d597f.html.

Callahan, Mary. Drought losses mounting in Sonoma County agricultural sector. The Press Democrat (CA), June 3, 2021. https://www.pressdemocrat.com/article/news/drought-losses-mounting-in-sonoma-county-agricultural-sector/.

Cerullo, Mike. Oregon's drought could cause worldwide grass seed shortage. KEZI (OR), September 3, 2021. https://www.kezi.com/news/local/oregons-drought-could-cause-worldwide-grass-seed-shortage/article_db684f24-c46c-52c7-bdff- 72f729b2d90e.html.

Cerullo, Mike. Extreme drought leaves Christmas tree supply thin in future years. KEZI (OR), October 25, 2021. https://www.kezi.com/news/local/extreme-drought-leaves-christmas-tree-supply-thin-in-future-years/article_e7b1df22-ad54-5cf8-9aee-a660c0de1e99.html.

Chaney, Jason. County facing drought as irrigation season begins. Central Oregonian (OR), May 26, 2020. https://www.centraloregonian.com/news/county-facing-drought-as-irrigation-season-begins/article_5a95aef8-272f-59a5-9dd3- 3fd44b227f70.html.

Clarke, Ron. Dust a risk factor in calf pneumonia. Canadian Cattleman (Canada), December 21, 2021. https://www.canadiancattlemen.ca/vet-advice/dust-a-risk-factor-in-calf-pneumonia/

Cockle, Richard. Eastern Oregon ranchers work to hang on to cattle herds in wake of summer wildfires. OregonLive (OR), Oct 30, 2012. https://www.oregonlive.com/pacific-northwest-news/2012/10/eastern_oregon_ranchers_work_t.html.

Cockle, Richard. Oregon's high desert country, scorched by fire, now suffering from drought. OregonLive (OR), June 27, 2013. https://www.oregonlive.com/pacific-northwest-news/2013/06/oregons_high_desert_country_sc.html.

Darling, Dylan. Drought leaves Crooked River a trickle. Bend Bulletin (OR), August 28, 2015. https://www.bendbulletin.com/localstate/drought-leaves-crooked-river-a-trickle/article_ceaa2b23-c70d-547f-9b17-19ef3e5180df.html.

Dillemuth, Holly. Drought affects bull sale, but can't dampen mood. Klamath Falls Herald and News (OR), February 9, 2014. https://www.heraldandnews.com/email_blast/article_90140654-9149-11e3-a021-0019bb2963f4.html.

Dillemuth, Holly. $10.3 million in drought relief ok'd. Klamath Falls Herald and News (OR), May 8, 2018. https://www.heraldandnews.com/news/local_news/million-in-drought-relief-ok-d/article_84fa61b8-bd5d-5561-960a-b5a331413058.html.

Dinman, Emry. Ranchers, hay producers hit hard by drought and heat. Union-Bulletin (OR), July 28, 2021. https://www.union-bulletin.com/news/ranchers-hay-producers-hit-hard-by-drought-and-heat/article_a2b04970-ee80-11eb-953f-f3c8a67a6a4b.html.

Ditzler, Joseph. Crook county gets drought recommendation. Bend Bulletin (OR), March 11, 2014. https://www.bendbulletin.com/business/crook-county-gets-drought-recommendation/article_b2ccc1b4-42a0-594b-a7b1-a31daff3a935.html.

Ditzler, Joseph. Drought falls unevenly on Central Oregon farmers. Bend Bulletin (OR), July 26, 2015. https://www.bendbulletin.com/business/drought-falls-unevenly-on-central-oregon-farmers/article_1b1eba3b-fd9c-504a-97a9-ce406c77994c.html.

Dole, Bryce. Umatilla County moves to declare drought as officials raise concerns for agriculture. East Oregonian (OR), April 22, 2021. https://www.eastoregonian.com/townnews/agriculture/umatilla-county-moves-to-declare-drought-as-officials-raise-concerns-for-agriculture/article_b3862108-a2b7-11eb-a3be-a7068fcaea36.html

Dole, Bryce. Wheat farmers, experts look toward grim harvest as drought consumes Oregon. East Oregonian (OR), June 24, 2021. https://www.eastoregonian.com/news/local/wheat-farmers-experts-look-toward-grim-harvest-as-drought-consumes-oregon/article_0d02b70a-d459-11eb-b8fd- 37dcd07bd4b0.html.

Ellis, Sean. Dry, drier, driest. Capital Press (OR), December 11, 2014. https://www.capitalpress.com/dry-drier-driest/article_5bc1142d-631a-5e94-ad00-c2e6fd9d6de9.html.

Farm Service Agency. Disaster Designation Information. USDA, no date. https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/disaster-designation-information/index

Flaccus, Gillian. Water crisis "couldn't be worse" on Oregon-California border. Fox26 News (OR), May 24, 2021. https://kmph.com/amp/news/local/water-crisis-couldnt-be-worse-on-oregon-california-border.

Flaccus, Gillian. Farms, fish on dry California-Oregon border see scant water. Associated Press (NY), April 11, 2022. https://apnews.com/article/business-oregon-pacific-ocean-lakes-environment-d85af0d4dfa6458395bfdd89df66c7b6.

Floyd, Stephen. House committee approves Klamath Project water bill. Klamath Falls Herald and News (OR), February 20, 2018. https://www.heraldandnews.com/news/house-committee-approves-klamath-project-water-bill/article_a276adc4-45ca-5130-b2b2-eb66e2b5ef9c.html.

Floyd, Stephen. County to begin assessing drought properties. Klamath Falls Herald and News (OR), June 27, 2018. https://www.heraldandnews.com/news/county-to-begin-assessing-drought-properties/article_b76ea1bf-34d3-59b0-8dda-0b977d2438f1.html.

Gutierrez, Kassandra. Christmas tree growers in Oregon adjust after years of drought. KVAL (OR), October 10, 2019. https://kval.com/news/local/christmas-tree-growers-in-oregon-adjust-after-years-of-drought

Harbarger, Molly. Drought, early spring warmth force Oregon agriculture to prepare for tough year – or years. OregonLive (OR), March 29, 2015. https://www.oregonlive.com/business/2015/03/drought_early_spring_warmth_fo.html

Hottman, Sara. Thinking about Harvest. Klamath Falls Herald and News (OR), September 10, 2010. https://www.heraldandnews.com/news/article_412a6f12-b8ba- 11df-8c13-001cc4c002e0.html

House, Kelly. Feds declare drought emergency in 13 Oregon counties, releasing aid money. OregonLive (OR), March 20, 2015. https://www.oregonlive.com/environment/2015/03/feds_declare_drought_emergency.htm l

Houston, Will. Feds eye scaling back antiparasite Klamath dam releases. Eureka Times-Standard (CA), March 26, 2018. https://www.times-standard.com/2018/03/26/feds-eye-scaling-back-antiparasite-klamath-dam-releases/.

Jacoby, Jayson. Bog to bone-dry. Baker City Herald (OR), May 18, 2019. https://www.bakercityherald.com/news/local/bog-to-bone-dry/article_9f33af97-9f70- 54c0-8a72-ad2932206780.html.

Jacoby, Jayson, Ronald Bond, Bennett Hall. Drought steals pounds from cattle, dollars from ranchers. East Oregonian (OR), October 22, 2021. https://www.eastoregonian.com/townnews/zootechnics/drought-steals-pounds-from-cattle-dollars-from-ranchers/article_118068e4-27a7-11ec-adc7-8b00de9b9c33.html.

Jacoby, Jayson. Grasshopper infestation bad, horrid in parts of Eastern Oregon. Capital Press

(OR), July 21, 2023. https://www.capitalpress.com/state/oregon/grasshopper-infestation-bad-horrid-in-parts-of-e-oregon/article_7afd1434-7b34-5f79-9c5e- 2256e3a6cfda.html.

Jarrell, Lacey. Groundwater aquifers under stress. Klamath Falls Herald and News (OR), August 14, 2014. https://www.heraldandnews.com/news/local_news/groundwater-aquifers-under-stress/article_97ef294a-2379-11e4-bccd-0019bb2963f4.html

KEZI News. Dry Conditions Taking a Toll on Oregon Christmas Trees. KEZI-TV ABC 9 (OR), August 9, 2018. https://www.kezi.com/content/news/Drought-taking-a-toll-on-Oregon-Christmas-trees--490459111.html.

King, Anna. "This is not normal." Eastern Oregon ranchers struggle with deepening drought. KLCC Northwest Public Broadcasting (OR), June 18, 2018. https://www.klcc.org/2018-06-19/this-is-not-normal-eastern-oregon-ranchers-struggle-with-deepening-drought

King, Anna. "Somber harvest": Crops may fail, cattle sold as the Northwest descends into drought. Northwest News Network (OR), May 27, 2021. https://www.nwnewsnetwork.org/food-agriculture-and-animals/2021-05-27/somber-harvest-crops-may-fail-cattle-sold-as-the-northwest-descends-into-drought.

Klamath Falls Herald and News. Feds give Klamath $2 million in drought aid. Klamath Falls Herald and News (OR), April 30, 2010. http://www.heraldandnews.com/news/oregon/article_d6330819-0a34-5959-9245-0d6f7bb4d672.html

Klamath Falls Herald and News. Klamath declared disaster area. Klamath Falls Herald and News (OR), May 4, 2010. http://www.heraldandnews.com/breaking/article_506970e0-56e0-11df-abae-001cc4c002e0.html.

Klamath Falls Herald and News. Funds to help with idle acreage. Klamath Falls Herald and News (OR), May 5, 2010. http://www.heraldandnews.com/news/article_487ac078-579e-11df-8401-001cc4c03286.html.

Klamath Falls Herald and News. Growers scramble to find acreage to grow specialty potatoes. Klamath Falls Herald and News (OR), May 22, 2010. http://www.heraldandnews.com/article_3e15e812-6638-11df-b4a1-001cc4c002e0.html.

Klamath Falls Herald and News. Farmers, ranchers deal with the Basin's realities, and will survive. Klamath Falls Herald and News (OR), July 10, 2010. https://www.heraldandnews.com/viewpoints/article_f7e14428-8cb0-11df-8378-001cc4c002e0.html

Klamath Falls Herald and News. Drought funding clears House. Klamath Falls Herald and Falls (OR), July 28, 2010. http://www.heraldandnews.com/breaking/article_7c78b0a4-99f9-11df-8dc9-001cc4c03286.html.

Klamath Falls Herald and News. Klamath Project irrigation forecast worsening. Klamath Falls Herald and News (OR), May 22, 2012. http://www.heraldandnews.com/breaking/article_fd47b152-a434-11e1-b2e2-001a4bcf887a.html.

Klamath Falls Herald and News. Portland Christmas tree grower says drought hurt crop - Klamath Falls Herald and News (OR). Klamath Falls Herald and News (OR), November 26, 2018. https://www.heraldandnews.com/ap_news/oregon/portland-christmas-tree-grower-says-drought-hurt-crop/article_c7046d75-9f72-5209-97a4-6ae9a1b36704.html.

KOBI5 Newsroom Staff. Possible Christmas tree shortage due to drought. KOBI5 (OR), November 5, 2021. https://kobi5.com/news/local-news/possible-christmas-tree-shortage-due-to-drought-172538/.

Kohn, Michael. Reservoir depletion forces Madras farmers to leave fields fallow. Bend Bulletin (OR), September 8, 2019. https://www.bendbulletin.com/localstate/reservoir-depletion-forces-madras-farmers-to-leave-fields-fallow/article_bc3bfc3d-ccc5-57d4-b8dc-b2ae686a30a2.html.

Kohn, Michael. Drought may leave central Oregon irrigation districts out of water this year. Bend Bulletin (OR), June 16, 2020. https://www.bendbulletin.com/localstate/environment/drought-may-leave-central-oregon-irrigation-districts-out-of-water-this-year/article_2fed7002-ac46-11ea-b086-839c957969d9.html.

Kohn, Michael. Drought: North Unit Irrigation District dials back water allotments again. Bend Bulletin (OR), July 13, 2020. https://www.bendbulletin.com/localstate/drought-north-unit-irrigation-district-dials-back-water-allotments-again/article_77bf8476-c143-11ea-9be4-ff9827743006.html.

Kohn, Michael. Arnold Irrigation District shuts off water as drought persists. Bend Bulletin (OR), August 16, 2020. https://www.bendbulletin.com/localstate/environment/arnold-irrigation-district-shuts-off-water-as-drought-persists/article_2fb2571a-de87-11ea-aab0-032bafec3fb3.html.

Kohn, Michael. Low water supplies force Lone Pine Irrigation District to shut down. Bend Bulletin (OR), August 27, 2020. https://www.bendbulletin.com/localstate/low-water-supplies-force-lone-pine-irrigation-district-to-shut-down/article_fe85fd1e-e88a-11ea-aac4-afe6d3de25a2.html.

Kohn, Michael. With reservoir drained, Deschutes water flow in danger of decline. Bend Bulletin (OR), September 15, 2020. https://www.bendbulletin.com/localstate/with-reservoir-drained-deschutes-water-flow-in-danger-of-decline/article_95793242-f48c-11ea-81eb-0fc55fd5bf6f.html

Kohn, Michael. Drought stirs fear of Dust Bowl near Madras. Bend Bulletin (OR), October 8, 2020. https://www.bendbulletin.com/localstate/environment/drought-stirs-fears-of-dust-bowl-near-madras/article_9401244e-0830-11eb-9b85-bb6c43d37cf5.html.

Kohn, Michael. Reservoir levels, drought stir farmers' fear of harsh summer. Bend Bulletin (OR), May 15, 2021. https://www.bendbulletin.com/localstate/environment/reservoir-levels-drought-stir-farmers-fear-of-harsh-summer/article_09888590-b4cf-11eb-accc-f3d1fbe95566.html.

Kohn, Michael. Drought, hay shortages pushing Central Oregon cattle producers to brink. Capital Press (OR), August 19, 2021. https://www.capitalpress.com/ag_sectors/livestock/drought-hay-shortages-pushing-central-oregon-cattle-ranchers-to-brink/article_97992211-b746-5e29-b509- 5beb94d6463d.html.

Kohn, Michael. Farmers prep for another dry year as three Central Oregon counties declare drought. Bend Bulletin (OR), March 17, 2022. https://www.bendbulletin.com/localstate/farmers-prep-for-another-dry-year-as-three-central-oregon-counties-declare-drought/article_a1b50740-a57d-11ec-97b4-a7ead42fc623.html

Kohn, Michael. Wickiup Reservoir emptied for unprecedented third year in a row. Bend Bulletin (OR), October 14, 2022. https://www.bendbulletin.com/localstate/environment/wickiup-reservoir-emptied-for-an-unprecedented-third-year-in-a-row/article_805602a4-49ae-11ed-9770- cb97fb0d51cb.html.

Kohn, Michael. Four years of drought taking a toll on weary Central Oregon farmers. Bend

Bulletin (OR), February 7, 2023. https://www.bendbulletin.com/localstate/four-years-of-drought-taking-a-toll-on-weary-central-oregon-farmers/article_418230ec-a292-11ed-8e6b-236f42b55795.html.

Kohn, Michael. After a promising spring, drought again stalking Central Oregon farmers. Capital Press (OR), July 18, 2023. https://www.capitalpress.com/ag_sectors/water/after-a-promising-spring-drought-again-stalking-central-oregon-farmers/article_677245c7-5ed6-59a7-8b50-849102312491.html.

Lark, T.J., Schelly, I.H. and Gibbs, H.K. (2021). Accuracy, bias, and improvements in mapping crops and cropland across the United States using the USDA Cropland Data Layer. *Remote Sensing*, *13*(5), p.968. doi:10.3390/rs13050968

Learn, Scott. Kulongoski declares drought emergency for Klamath County. The Oregonian (OR), March 17, 2010. https://www.oregonlive.com/environment/2010/03/kulongoski_declares_drought_em.htm l.

Learn, Scott. Gov. Kitzhaber declares drought emergency in Klamath County. The Oregonian (OR), April 18, 2013. https://www.oregonlive.com/environment/2013/04/gov_kitzhaber_declares_drought.html

LeCroy, Holden. Farmers fear historically low water levels during drought emergency. KTVL (OR), April 8, 2021. https://ktvl.com/news/local/farmers-fear-for-historically-low-water-levels-during-drought-emergency.

Loew, Tracy. Gov. Brown declares drought emergency in two counties. Salem Statesman-Journal (OR), March 16, 2015. https://www.statesmanjournal.com/story/tech/science/environment/2015/03/16/two-oregon-counties-drought-emergency/24862085/

Loew, Tracy. Field burning starts early as heat hastens harvest. Salem Statesman-Journal (OR), July 8, 2015. https://www.statesmanjournal.com/story/tech/science/environment/2015/07/09/field-burning-starts-early-heat-hastens-harvest/29898005/.

Malheur Enterprise. Drought, hot weather produce new challenges for area ranchers. Malheur Enterprise (OR), August 18, 2021. https://www.malheurenterprise.com/2021/08/18/drought-hot-weather-produce-new-challenges-for-area-ranchers/.

McClain, Sierra Dawn. Sheep ranchers face hard decisions during drought. Capital Press (OR), June 24, 2021. https://www.capitalpress.com/ag_sectors/livestock/sheep-ranchers-face-hard-decisions-during-drought/article_8c2bf30a-d519-11eb-b5aa-630cf83d229d.html.

Medford Mail Tribune. Governor to sign Klamath drought declaration. Klamath Falls Herald and News (OR), March 9, 2010. http://www.mailtribune.com/apps/pbcs.dll/article?AID=/20100309/NEWS07/30903 39.

Medford Mail Tribune. Jackson County declares drought disaster. Medford Mail Tribune (OR), March 31, 2021. https://www.mailtribune.com/environment/2021/03/31/jackson-county-declares-drought-disaster/.

Medford Mail Tribune. Drought is killing pear industry. Medford Mail Tribune (OR), October 6, 2021. https://www.mailtribune.com/top- stories/2021/10/06/drought-is-killing-pear-industry/.

Mendez, Brisa. Concern grows for tree farmers as drought conditions affect Willamette Valley. KVAL (OR), August 16, 2021. https://kval.com/news/local/concern-grows-for-tree-farmers-as-drought-conditions-affect-willamette-valley.

Meyer, Larry. County court declares state of emergency. The Argus Observer, October 4, 2018. https://www.argusobserver.com/news/county-court-declares-state-of-emergency/article_36372e28-c7f3-11e8-940c-5f83d2775610.html

Morgan, Tyne. Drought and grasshoppers ravage fields in Northwest, some producers bale 10% of normal hay crop. AgWeb (PA), August 9, 2021. https://www.agweb.com/news/livestock/beef/drought-and-grasshoppers-ravage-fields-northwest-some-producers-bale-10-normal.

NASA Earth Observatory. Diminished Snow Pack in the Pacific Northwest. May 2015. https://earthobservatory.nasa.gov/images/85887/diminished-snow-pack-in-the-pacific-northwest

National Drought Mitigation Center (NDMC). Managing Drought Risk on the Ranch. No date. https://drought.unl.edu/ranchplan/

Natural Resources Conservation Service (NRCS). Oregon Basin Outlook Report. 2015. https://efotg.sc.egov.usda.gov/references/public/OR/WSOR_2015_Jun.pdf

Neumann, Erik. Feds cut water off to Klamath farmers for remainder of season. Oregon Public Broadcasting (OR), August 19, 2022. https://www.opb.org/article/2022/08/19/feds-cut-water-off-to-klamath-farmers-for-remainder-of-season/.

O'Conner, Samantha. Baker County commissioners declare drought emergency. Baker City Herald (OR), April 7, 2021. https://www.bakercityherald.com/news/local/baker-county-commissioners-declare-drought-emergency/article_51ee4f68-97dd-11eb-8bda-ff3e7cecbcd8.html.

Oregon Department of Agriculture. Oregon Agriculture Regions. September 2020. https://www.oregon.gov/oda/shared/Documents/Publications/Administration/ORGrowingRegions.pdf

Oregon Department of Agriculture. Oregon Agriculture Statistics and Directory 2022. www.oda/direct/AgStatsDirectory

Oregon Office of Emergency Management. Drought Annex: State of Oregon Emergency Operations Plan. January 2016. https://www.oregon.gov/owrd/WRDPublications1/2016ORDroughtAnnex.pdf

Oregon State University. "West Coast record low snowpack in 2015 influenced by high temperatures." Press release, October 31, 2016. https://today.oregonstate.edu/archives/2016/oct/study-west-coast-record-low-snowpack-2015-influenced-high-temperatures

Oregon Water Resources Department (OWRD). 2023 drought permits unlikely in Upper Klamath Basin. February 10, 2023. https://www.oregon.gov/owrd/newsroom/wrdnewsroom/23-02_DroughtPermitsInKlamathBasin.pdf

Oregon Water Resources Department. Public Declaration Status Report. No date. https://apps.wrd.state.or.us/apps/wr/wr_drought/declaration_status_report.aspx Accessed December 14, 2023

Owens, Holly. BOR to award tribal members drought funds. July 30, 2013. https://www.heraldandnews.com/breaking/article_7c59beae-f984-11e2-a385-0019bb2963f4.html

Parfitt, Jamie. Feds pledge $15 million toward drought relief for Klamath Basin growers. Newswatch 12 (OR), August 2, 2021. https://www.kdrv.com/news/local/feds-pledge-15-million-toward-drought-relief-for-klamath-basin-growers/article_34f3d995-ae1b-568a-

890b-2fe3d39a19a3.html.
Plaven, George. Klamath Project farmers, ranchers get 2018 irrigation plan. Everett Herald (WA), June 26, 2018. https://www.heraldnet.com/northwest/klamath-project-farmers-ranchers-get-2018-irrigation-plan/.
Plaven, George. Klamath Project irrigators say more drought relief needed after A Canal shutdown. Klamath Falls Herald and News (OR), May 27, 2021. https://www.heraldandnews.com/news/local_news/klamath-project-irrigators-say-more-drought-relief-needed-after-a-canal-shutdown/article_6e7ef01c-e3eb-5523-a09a-5135de06f42f.html.
Pope, Charles. Merkley, Wyden ask feds for rapid, coordinated effort in drought-stricken Klamath. The Oregonian (OR), March 9, 2010. https://www.oregonlive.com/politics/2010/03/merkley_wyden_ask_feds_for_rap.html.
Reyes, J.J. and Elias, E. (2019). Spatio-temporal variation of crop loss in the United States from 2001 to 2016. Environmental Research Letters, 14(7), p.074017. doi: 10.1088/1748-9326/ab1ac9
Roig, Suzanne. Hay farmers in Central Oregon face challenges from drought, water shortages. Bend Bulletin (OR), November 21, 2021. https://www.bendbulletin.com/business/hay-farmers-in-central-oregon-face-challenges-from-drought-water-shortages/article_6072cdf4-46fe-11ec-a3e8-1f5d563c643f.html.
Rush, Claire. “Biblical” insect swarms spur Eastern Oregon push to fight pests. Oregon Public Broadcasting (OR), June 28, 2022. https://www.opb.org/article/2022/06/27/biblical-insect-swarms-spur-oregon-push-to-fight-pests-farmers/
Sacramento Bee. Drought cuts water for Klamath Project irrigators. Sacramento Bee (CA), June 6, 2013. http://www.sacbee.com/2013/06/06/5477880/drought-cuts-water-for-klamath.html#mi_rss=Latest%20News.
Salem Statesman-Journal. Agencies prepare for intense Oregon wildfire season. Salem Statesman-Journal (OR), May 14, 2013. http://www.statesmanjournal.com/article/20130514/NEWS/305140010/Agencies-prepare-for-intense-Oregon-wildfire-season.
Salem Statesman-Journal. Counties to ask Gov. Kitzhaber to declare drought today. Salem Statesman-Journal (OR), February 6, 2014. http://www.statesmanjournal.com/article/20140206/NEWS/302060037/Counties-ask-Gov-Kitzhaber-declare-drought-today.
San Francisco Chronicle. Dry winter means tough times along the Klamath. San Francisco Chronicle (CA), March 21, 2012. http://www.sfgate.com/cgi-bin/article.cgi?f=/n/a/2012/03/21/state/n141330D19.DTL&type=newsbayarea.
Shinn, Troy. Mid-valley farms hit hard by drought and heat. Albany Democrat-Herald (OR), August 23, 2021. https://democratherald.com/news/local/mid-valley-farms-hit-hard-by-drought-and-heat/article_24af582f-8543-529f-8f06-0a8d22d2bfec.html.
Sinclair, Michelle, Claire Fryer, Clive JC Phillips. The benefits of improving animal welfare from the perspective of livestock stakeholders across Asia. March 28, 2019. Animals. https://doi.org/10.3390/ani9040123
Snavely, Brooke. Irrigation districts issue drought declaration request; earliest on record. Central Oregon Daily (OR), March 3, 2022. https://centraloregondaily.com/abysmal-snowpack-and-water-storage-prompts-drought-declaration-request/.
Snavely, Brooke. Crook County declares drought emergency for 4th consecutive year. Central

Oregon Daily (OR), January 12, 2023. https://centraloregondaily.com/weather-drought-crook-county-emergency/.
Sorte, Bruce, Jeffrey Reimer, Gordon Jones. Oregon Agriculture, Food, and Fiver: An Economic Analysis. Oregon State University College of Agricultural Sciences, August 2021. https://agsci.oregonstate.edu/sites/agscid7/files/main/about/oragecon_report_2021.pdf
Stiles, Greg. Drought puts burden on Oregon ranchers. Klamath Falls Herald and News (OR), August 23, 2018. https://www.heraldandnews.com/news/local_news/agriculture/drought-puts-burden-on-oregon-ranchers/article_5c73ce77-aca7-5b6b-8a68-3a7af66a48d1.html?block_id=1275156
Tipler, Samantha. No water, no food: Cattle moved from Modoc Point. Klamath Falls Herald and News (OR), August 12, 2013. https://www.heraldandnews.com/news/local_news/article_de7c8cec-03ca-11e3-ac5e-0019bb2963f4.html.
USDA National Agricultural Statistics Service, 2017 Census of Agriculture. Complete data available at www.nass.usda.gov/AgCensus.
Vaughn, Jane. Water managers could withhold Klamath County drought permits this year. Jefferson Public Radio (OR), February 10, 2023. https://www.ijpr.org/environment-energy-and-transportation/2023-02-10/water-managers-could-withhold-klamath-county-drought-permits-this-year.
Zukoff, Anthony. Grasshoppers increasing in western Kansas. Kansas State University Extension (KS), August 17, 2021. https://blogs.k-state.edu/kansasbugs/2021/08/17/grasshoppers-increasing-in-western-kansas/

Supplemental Files

Only a small portion of the maps and plots generated for this analysis are included in this document. But all have been provided to OWRD as zip files, as described below.

drought and yield.zip maps the slope of regression lines describing drought's effect on crop yield for wheat (winter, spring and all classes), sugarbeets, potatoes, oats, hay (alfalfa, all classes, and excluding alfalfa), corn and barley. Wheat folders include separate maps for all practices, irrigated and non-irrigated. In some cases maps mainly show counties for which there was some but not enough data to analyze.

cropscape.zip is grouped by year, 2007-2022, and "mean," summarizing all years. Each year and mean folder includes sub-folders for about 60 different crops. Each crop sub-folder includes maps showing the number of acres planted in that crop, by county, and the percentage of county area planted with that crop.

cause of loss.zip is grouped by year, 2002-2022, and by crop, for each of several major crops. Sub-folders include maps for loss-cost, a computed comparison of claims paid to amounts insured, and policies indemnified, as well as a table summarizing several variables by county, including both the ones mapped here and others that are part of the data. A particular benefit to other researchers is that the table combines several drought-related causes of loss: drought, heat, hot wind, failure of irrigation including equipment, excess sun and a combination of program codes that designate forage-related losses.

normalized insured index.zip is grouped by year, 2012-2022. Each year folder includes a sub-folder and map for about 20 different crops, comparing where crops were planted, according to CropScape, and where crops were insured, according to the USDA's Risk Management Agency Summary of Business data.

Chapter 4: Aquatic Recreation

Summary

Aquatic recreation opportunities such as boating are available throughout the State of Oregon and depend on sufficient water in reservoirs, rivers and lakes. Drought can lead to decreased visitor satisfaction, unsafe conditions and boat ramp closures. In this report, we identify parks and regions that have experienced recreational drought impacts in the past and may be more vulnerable to future impacts, analyze whether attendance at 62 Oregon state parks featuring aquatic recreation (swimming, paddling, and boating) is associated with drought, and interview park managers to gain further understanding of the impact of drought on recreation. Future research into this topic might include analysis of park revenue compared to drought metrics. We found that boating impacts were primarily recorded during two major drought periods: one from 2013 to 2015, and the other from 2020 to 2022. It is important to note that boating closures are relatively rare, especially in rivers, even when conditions are dangerous (Salem Statesman-Journal, personal communication). In many cases, warning signs are posted at locations with low water levels, but formal communication of conditions is not made. Thus, our report cannot be viewed as a comprehensive record of all instances where water bodies, especially rivers, were unsuitable for boating. Jackson County had the most impacts, with reports coming primarily from Howard Prairie Lake, Hyatt Reservoir and Emigrant Lake. Deschutes County had the second highest number of impacts, including stories from Wickiup Reservoir, Prineville Reservoir, and East Lake. Statistical analysis indicated that, overall, drought may have a positive effect on park attendance. Only four individual parks (Ben and Kay Dorris State Recreation Area – Lane County; Dexter State Recreation Site – Lane County; Ontario State Recreation Site – Malheur County; and Willamette River Greenway – Cloverdale access, Lane

County) showed a negative impact of drought on visitation. All of those parks are popular for boating, so visitors may be driven away when drought conditions inhibit the ability to launch and use watercraft. Park managers indicated that even parks that do not experience a decrease in visitation are still negatively impacted by drought. Visitor conflict was a key concern related to drought and managers stated that increased education for visitors regarding what to expect at parks during drought would be highly beneficial in reducing staff stress and turnover.

Introduction

Aquatic recreation in Oregon is not limited to the Pacific Coast: boating opportunities are available throughout the state. Over 40% of Oregonians visited lakes, reservoirs and rivers in 2017 (Bergerson 2018). Nearly $606 million was spent on inland beach visitation and $22 million on whitewater navigation in Oregon in 2020 (Mojica et al. 2021).

Recreational drought is defined by Jedd et al. (2019) as "a shortage of naturally available water needed for vegetation health and animal habitat, to support lake sports, to prevent permanent infrastructure damage, and to maintain visitor volumes for economic stability." A limitation of this definition may be its emphasis on "natural drought," given that many hydrologic systems are highly managed (Van Loon et al. 2016). These systems are typically used for many purposes, including water storage, maintaining flows for downstream habitat, power production, irrigation and more.

A park's vulnerability to the effects of drought depends in part on management of its water source. For instance, river rafting is one of the most-affected recreation industries during drought. In 2021, the Northwest Rafting Company in Oregon needed to cancel all but one of its 10 rafting trips on the Owyhee and Illinois rivers due to low water levels (Smith 2022). The stretches of the Owyhee and Illinois rivers that are popular for rafting do not benefit from stored water, making them particularly vulnerable to drought. The Rogue River, conversely, has multiple dams and reservoirs, making its rafting industry more resilient to drought.

Low water levels in Oregon's lakes, reservoirs and rivers can be devastating to the freshwater recreation industry due to low visitor satisfaction, boat ramp closures, angling restrictions and safety concerns. Visitation to reservoirs in the Willamette River Basin, for instance, tends to decline by 5-6% during droughts (Jaeger et al. 2017). One study projected that decreased visitation and recreational use in the Willamette River Basin would cause losses around $5 million per year in recreational benefits during the 2020s, and modeling by Oregon State University indicates that those losses may surpass $13 million by 2080 (Jaeger et al. 2017). These economic losses can be attributed to boat ramp closures, mud and reduced aesthetic value due to "bathtub rings" caused by low water levels. Boat ramps that do remain open during low-water conditions are often undeveloped and muddy, making them more inconvenient to access. Anecdotal evidence also suggests that boaters are adapting to chronically low water levels by purchasing smaller and/or nonmotorized watercraft that are more suited to conditions present in recent years (Oregon State Marine Board, personal communication).

Safety hazards may also be of higher concern during drought and at times prompt the closure of reservoirs and lakes for recreation. Cyanobacterial blooms can happen during normal conditions, but drought provides the ideal conditions for these microorganisms to flourish: water warms due to low volume and flow speed, and runoff from drought-hardened soil provides excessive amounts of nutrients needed for cyanobacteria to flourish (Lisboa et al. 2020). Some cyanobacterial blooms release toxic compounds that pose health risks to humans and pets. When discovered, affected waterbodies are closed for use. Between 2013 and 2023, the Oregon Health Authority issued 94 recreational waterbody closures due to cyanobacteria. The South Umpqua

River in Oregon, for instance, has been under a permanent recreational use advisory since 2018, when lethal anatoxin-a, produced by cyanobacteria, was found (Oregon Health Authority, n.d.). At the time of this report, there was limited flow and water temperature data to analyze the correlation between drought and cyanobacterial blooms in Oregon.

The Centers for Disease Control and Prevention website (CDC 2020) outlines other risks associated with freshwater recreation during drought. Parasites such as *Naegleria fowleri* also thrive in warm, slow-flowing water, as does *Culex pipiens*, the mosquito that carries West Nile Virus. Chemical and metal contaminants are also more concentrated in drought-impacted waterbodies, increasing the risk of exposure through ingestion, contact, or inhalation. Life-threatening injuries are also more likely with low water levels for diving, striking unseen objects while boating, and contact with dangerous debris that is normally covered by water.

This report aims to document and assess the impact of drought on water-based recreation in Oregon. We accomplish this by identifying parks and regions that have experienced recreational drought impacts in the past and may be more vulnerable to future impacts, analyzing whether park attendance is related to drought, and interviewing park managers to gain further understanding of the impact of drought on recreation.

Drought impacts to aquatic recreation reported by media

In this section we use DIR and media searches to identify parks and regions that have experienced recreational drought impacts in the recent past and may be more vulnerable to future impacts. Instances of boating closures that were attributed to drought came from the following sources: Oregon State Marine Board's Reported Access Closure Map (2020-2022); Oregon State Marine Board's Opportunities and Access Reports (May 2022 – present); impact reports (DIR); boat ramp availability data from Winberry, Prineville Reservoir, and Detroit Lake, provided by

OPRD; and additional media searches conducted using Google. We included hydrological data such as reservoir fill levels where available. It is important to note that boating closures are relatively rare, especially in rivers, even when conditions are dangerous (Salem Statesman-Journal, personal communication). In many cases, warning signs are posted at locations with low water levels, but formal communication of conditions is not made. Thus, our report cannot be viewed as a comprehensive record of all instances where water bodies, especially rivers, were unsuitable for boating.

Boating impacts were primarily recorded in the DIR in two major drought periods: 2013-2015 and 2020-2022. The two recorded impacts that happened in between came from Jackson County. Across all years, Jackson County (in the Cascades Mountains) had the most impacts, with reports coming primarily from Howard Prairie Lake and Hyatt Reservoir (Figure 4.1). Detroit Lake, Prineville Reservoir and Crump Lake were also identified as vulnerable water bodies for aquatic recreation.

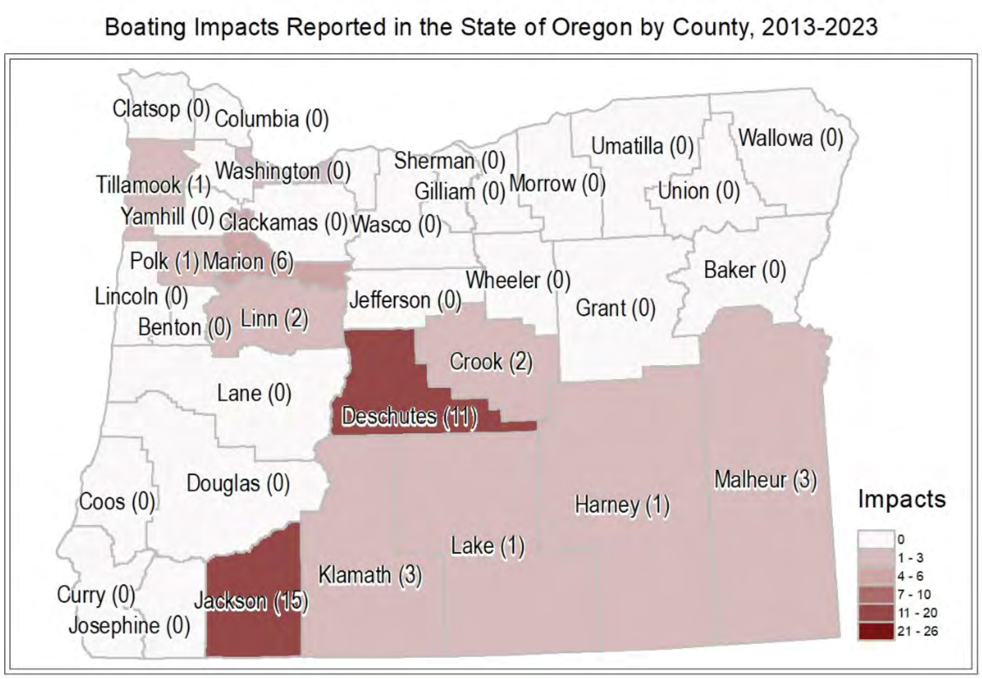


Figure 4.1. Boating impacts across the State of Oregon by county, 2013-2023.

2013-2015

Snowpack across the state of Oregon was at a record low during the 2013-2015 drought, leading to low reservoir levels during this time. In March 2015, the USDA reported that 45% of the long-term snow monitoring sites in Oregon had been at the lowest snow depth on record. Eight of those sites did not have snow as of March 1 for the first time on record. In Wasco County, SNOTEL sites peaked at 70-90% below typical peak snowpack during the 2014-2015 season, and those peaks occurred six to twelve weeks earlier than normal (Wasco County 2015). Similarly, the same year, snow water equivalent in the Rogue Basin was only 14% of average (Josephine County 2015). Impacts to boating occurred in Jackson County (Howard Prairie Lake, Hyatt Reservoir), the Detroit Lake (Linn/Marion counties), Crump Lake (Lake County), Prineville Reservoir (Crook County), and the Owyhee River (eastern Oregon) during this time.

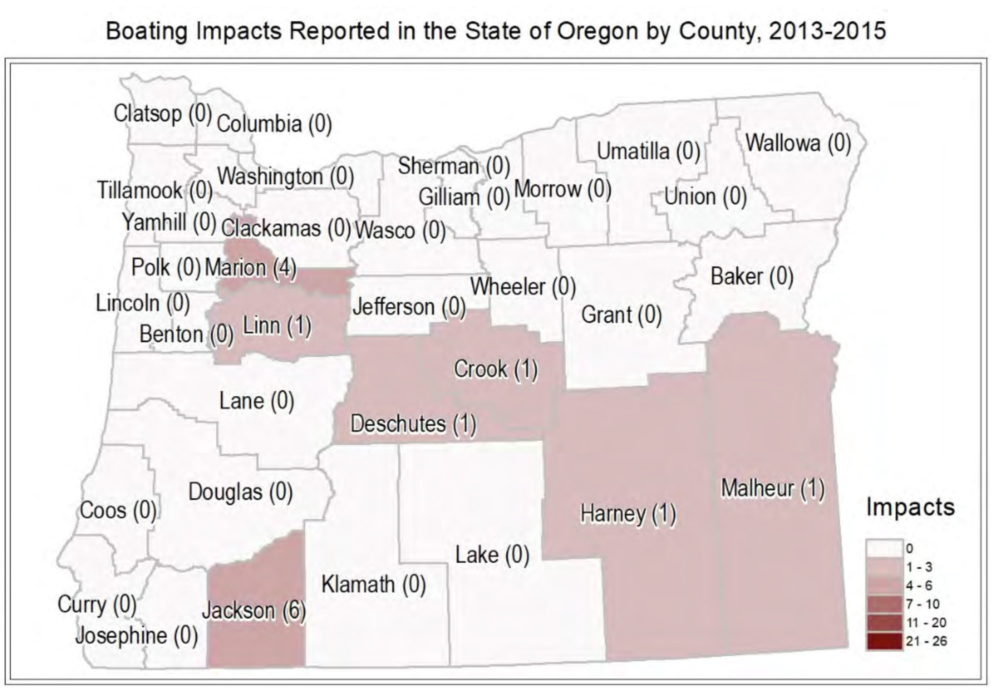


Figure 4.2. Boating impacts in the State of Oregon by county, 2013-2015.

2020-2023

Drought was widespread in Oregon between 2020 and 2023. Impacts to aquatic recreation during this time were reported in Jackson County (Howard Prairie Lake, Hyatt Reservoir, Emigrant Lake), Cascades (Fall Creek Lake, Detroit Lake, Wickiup Reservoir, Crescent Lake), Crump Lake (south-central Oregon), Prineville Reservoir, and Beulah Reservoir (eastern Oregon).

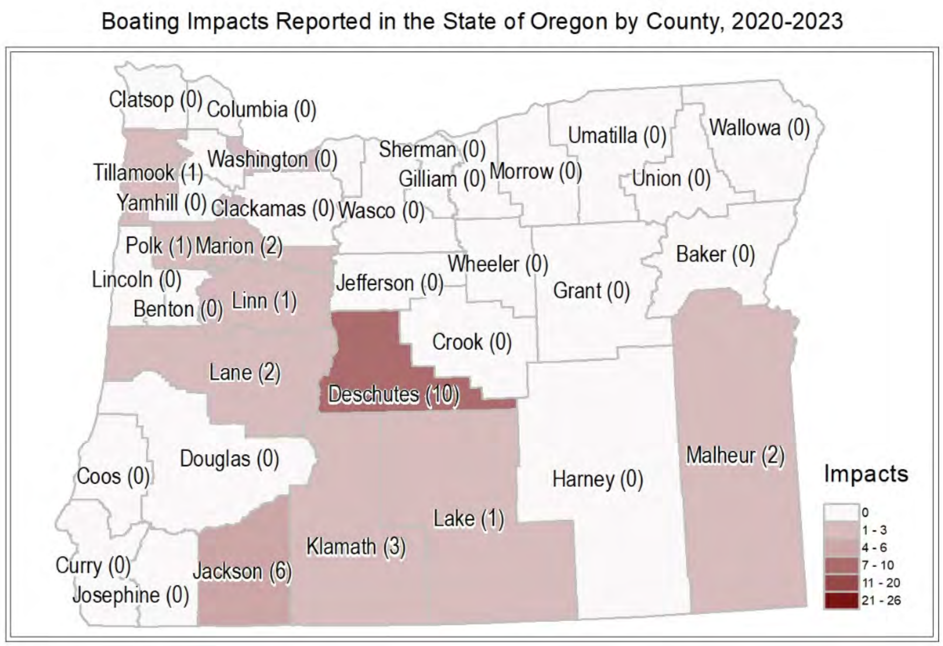


Figure 4.3. Boating impacts in the State of Oregon by county, 2020-2023.

Jackson County

Reservoirs in Jackson County made up the majority of boating impacts. Jackson County is located in the southwest region of Oregon within the Cascades Mountain Range. Several recreational water bodies are found in Jackson County. Howard Prairie Lake and Hyatt Reservoir were impacted by drought on multiple occasions during the study period of 2013-2023. Examination of the USDM time series (Figure 4.4) indicates that recent periods of drought occurred in Jackson County during 2014-2015, 2018-2019 and 2020-2022. Boating impacts in the county correspond with these time periods.

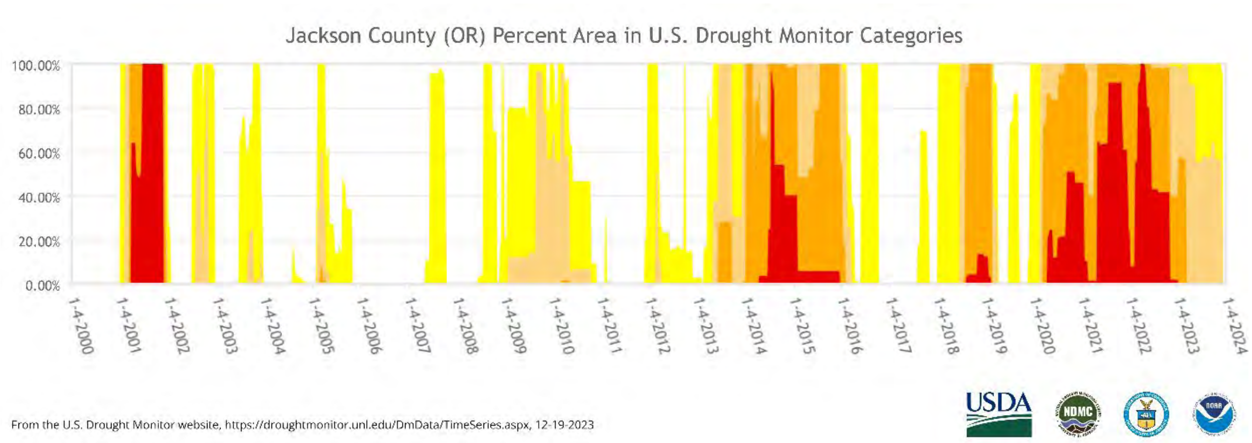


Figure 4.4. USDM drought time series for Jackson County, Oregon, 2000-2023.

Howard Prairie Lake is a 62,100 acre-foot reservoir on Beaver Creek, located about 18 miles east of Ashland, Oregon (USBR, https://www.usbr.gov/projects/index.php?id=124). The mountain lake hosts seven county parks, including the Howard Prairie Resort. There are multiple developed boat ramps at the lake, according to the Jackson County website (https://jacksoncountyor.gov/). Howard Prairie Lake experienced drought impacts in 2014, 2015, 2018, 2020 and 2021. These years align with low water levels exhibited in a hydrograph of Howard Prairie Lake (Figure 4.5).

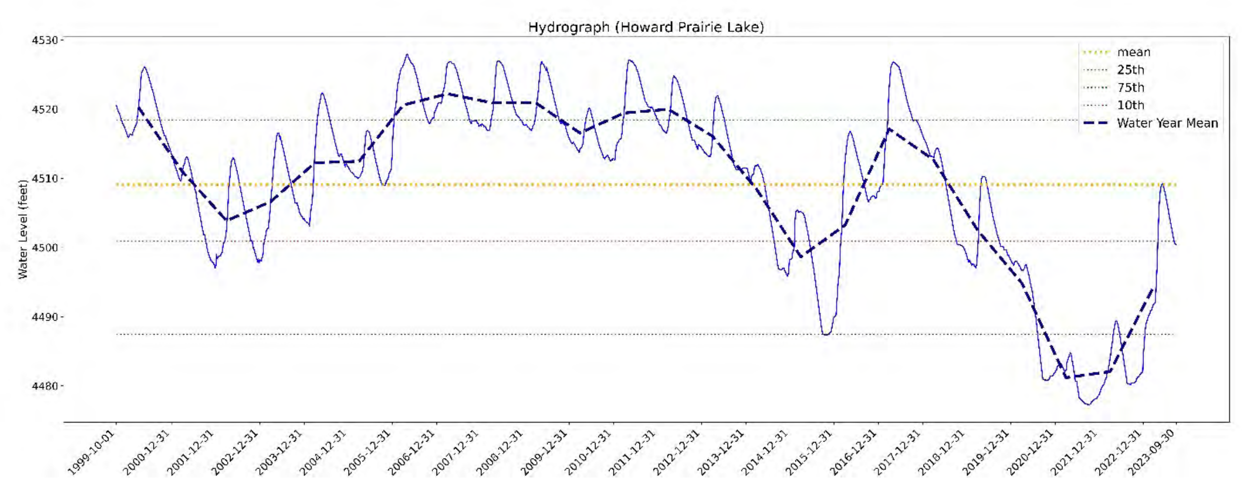


Figure 4.5. Hydrograph of Howard Prairie Lake, 1999-2023.

Hyatt Reservoir is only about three miles southeast of Howard Prairie Lake. The Hyatt Dam on Keene Creek creates the 16,200 acre-foot reservoir. Hyatt Reservoir was created for the storage of irrigation water, but boating is also popular from the reservoir's boat ramp and six miles of shoreline. Boating impacts occurred at Hyatt Reservoir in 2015, 2021 and 2022.

Low snowpack during the 2013-2015 drought caused correspondingly low reservoir levels during this period. Howard Prairie Lake closed its boat ramps early in both 2014 and 2015. In 2014, the resort on the lake was able to open two of its ramps. By August 2014, the lake was 26 feet below full pool (approximately 35% full; USGS Hydromet), and all boat ramps were closed (KOBI5 Newsroom Staff 2014).

Drought impacts were already felt by May in 2015, at which point Howard Prairie Lake was only at 54% of its average fill for that time of year (38% full; USGS Hydromet; Burns et al. 2015). The lake was too shallow for large boats at that time. The low water levels were attributed to low snowpack from the winter of 2014-2015. Basin snowpack in May 2015 was only 14% of average for that time. Hyatt Reservoir was only 42% full that month, creating problems for large boats.

Drought in Oregon was mostly absent or mild in 2016-2017, and only Jackson County appears in the media in 2018 with boating impacts. In September 2018, boat ramps closed early at Howard Prairie Lake due to low water levels (KOBI5 Newsroom Staff, Aug 31, 2018). According to USGS Hydromet, the lake was about 40.5% full when the boat ramps closed.

Widespread drought from 2020 to 2023 plagued boating in Jackson County. By June 2020, Howard Prairie Lake was only 26% full. All boat ramps at Howard Prairie Lake closed earlier than normal, in June, for the rest of the year due to drought (KOBI5 Newsroom Staff, June 9, 2020). Emigrant Lake, another popular reservoir located near Ashland, dropped to 41% in July 2020 (KOBI5 Newsroom Staff, July 24, 2020). Managers reported seeing an increase in confrontations with visitors due to long lines caused by low water levels and overcrowding (KOBI5 Newsroom Staff, June 9, 2020). By September 25 of that year, Emigrant Lake was only 3-4% full and all boat ramps were closed (KOBI5 Newsroom Staff Sept 25, 2020). It was still possible for visitors to carry a kayak or canoe to the lake to use at that time.

Reservoir levels were extremely low in Jackson County in August 2021. Emigrant Lake (3% full), Howard Prairie Lake (4% full) and Hyatt Reservoir (1% full) all closed boating due to historically low water levels (KOBI5 Newsroom Staff 2021). Drought conditions at Hyatt Reservoir impeded boating again in June 2022. Hyatt Reservoir was less than 21% full, so boat ramps were closed, but paddlers could still carry their boats down to the water (OSMB OAR 6/8/2022).

Other locations in Cascades Mountains

Detroit Lake (Linn/Marion counties), Fall Creek Lake (Lane County), Wickiup Reservoir (Deschutes County) and Crescent Lake (Klamath County) are other locations in the Cascades Mountains that have been affected by drought. Boating impacts were recorded at Detroit Lake in

2015 and 2021. Detroit Lake was affected by low snowpack in May 2015. Eight boat ramps in Detroit Lake were closed due to low water that month (Richard 2015). In September 2015, the county reported that businesses in the Detroit area had experienced 25-30% decreases compared to 2014, which were attributed to the impacts of drought (Marion County 2015).

Spring 2021 brought more drought and boating impacts to the Cascades. Cascara, Winberry and North Shore boat ramps in Fall Creek Lake (Lane County) closed in June 2021 due to the drought (Oregon State Parks Twitter 2021). In July 2021, Detroit Lake was below its average July fill level. An announcement stated that all moored boats at Detroit Lake Marina needed to be removed by July 11 due to the low water levels and damage caused by the 2020 wildfires (Abad 2021). Boat, kayak and paddleboard rentals would continue as long as water was under the docks.

Some of the boat ramps at North Wickiup (Deschutes County) and Crescent Lake (Klamath County) were never installed in 2022 due to low water levels (KTVZ News Sources 2022). As of April 5, 2023, Crescent Lake was only 10% full and developed boat ramps were still closed due to extremely low water (ODFW 2023).

Crump Lake

Crump Lake, in south-central Oregon (Lake County), is unique in this dataset in that it is not a managed park, but rather an undeveloped, natural water body on state-owned lands that is used for some recreational fishing, hiking and petroglyph viewing. The lake periodically dries out during extreme drought, revealing Native American artifacts such as arrowheads, gravesites and other archeological resources. When the lake bottom is dry, some visitors come to the site to illegally disturb the artifacts and potentially resell them, according to our interview with the Oregon Department of State Lands. The State of Oregon closed Crump Lake in 2014, 2021 and

2022 to prohibit these criminal activities. During the 2021 closure, the Burns Paiute Tribe reported spending, on average, $1,000 per day patrolling the lake (Cureton Cook 2023). Closures also inhibit access to public lands beyond the lake, per our interview with the Department of State Lands.

In 2023, the State Land Board proposed a new rule to restrict all public access to Crump Lake when lake levels become too low, to protect the cultural resources on the lake bottom (Oregon Department of State Lands, July 1, 2023). The rule was passed and became effective during October 2023. According to our interview with the Department of State Lands, the lake will automatically be closed to all public recreation once lake levels reach a specific minimum depth. Previously, enacting restrictions required additional steps that are now unnecessary under the new rule, expediting and simplifying the process.

Prineville Reservoir

Prineville Reservoir, in Crook County, is a 154,690 acre-foot water body on the Crooked River about 20 miles from the town of Prineville (https://www.usbr.gov/projects/index.php?id=45). There are two state parks on the reservoir, Prineville Reservoir State Park and Jasper Point State Park, which feature multiple boat ramps. Drought impacts to Prineville Reservoir occurred in 2015, 2020 and 2022, which aligns with examination of the USDM drought time series for Crook County (Figure 4.6).

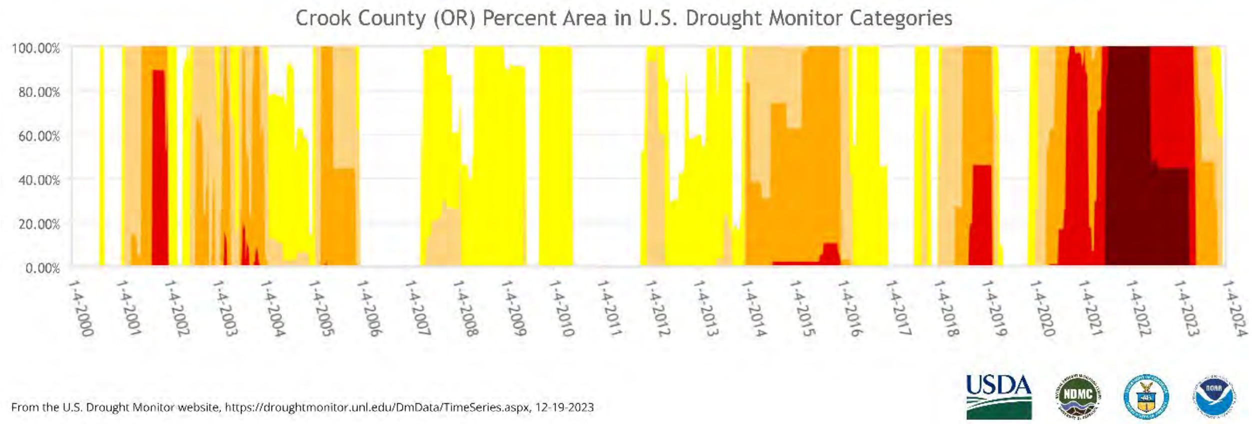


Figure 4.6. USDM drought time series for Crook County, 2000-2023.

A hydrograph of Prineville Reservoir indicates that low water levels align with drought periods. Recently, water levels dropped in the reservoir in 2015, 2018 and 2020-2023 (Figure 4.7).

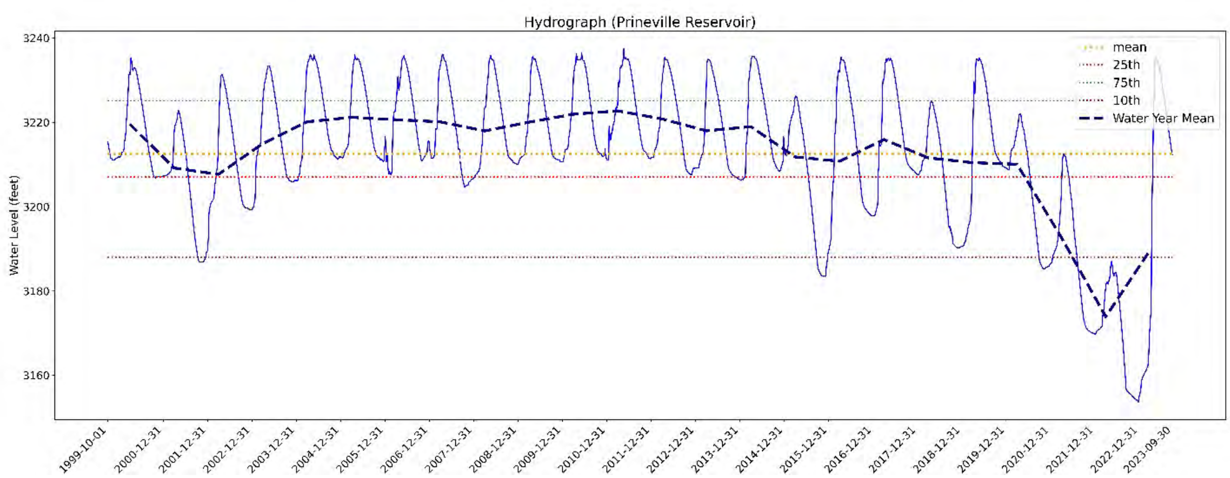


Figure 4.7. Hydrograph of Prineville Reservoir, 1999-2023.

Low snowpack during the winter of 2014-2015 meant that, in August 2015, Prineville Reservoir closed its boat ramps earlier than usual. The reservoir was 41% full at that time (Darling 2015). Low water levels at Prineville Reservoir caused problems again during the 2020-2022 drought, as well. Powderhouse Cove Boat Ramp closed in June 2020 (OSMB Reported

Access Closures Map), and the reservoir was only 40% full in July 2021, prompting the closure of Jasper Point and Powderhouse Cove boat ramps (Oregon Parks and Recreation Department 2021). At that time, it was still possible to launch small boats or use the one open lane of the main boat ramp.

In 2022, Prineville Reservoir's day-use ramp was initially closed from April 1 to May 8 (OSMB Reported Access Closures Map). According to USGS Hydromet, the reservoir was 26.8% full on April 1 and had only increased to 30% full by May 8, 2022. On May 31, 2022, the Prineville Reservoir day-use ramp closed for the rest of the year (OSMB Reported Access Closures Map). Prineville Reservoir was 29% full, which was its lowest level in 20 years for that time of year (USGS Hydromet; Carlton 2022). On July 1, 2022, Jasper Point and Powderhouse Cove boat ramps were closed for the year, as well (OSMB Reported Access Closures Map).

Eastern Oregon

There were scattered boating impacts in Eastern Oregon. Affected water bodies included the Owyhee River, Beulah Reservoir and Lake Owyhee. A period of drought lasting from 2013 to 2015 prevented a river outfitter from taking his dories into the canyonlands of eastern Oregon on springtime trips for three years due to low flows on the Owyhee River (Connelly 2016).

In June 2022, drought conditions at Beulah Reservoir impeded boating. Beulah Reservoir was 31% full, so boat ramps were closed, but paddlers could still carry their boats down to the water (OSMB OAR 6/29/2022). Gordon Gulch Day-Use Area at Lake Owyhee closed for the year in August 2022 when the reservoir was 23.6% full (OSMB Reported Access Closures Map).

References

Abad, J. Detroit Lake Marina to shut down for season. KOIN 6 News (OR). July 7, 2021. https://www.koin.com/news/oregon/detroit-lake-marina-to-shut-down-for-season/#:~:text=Damage%20from%20the%20devastating%20wildfires,%2C%20July%2011%2C%20officials%20said.

Bergerson, T. (2018). Oregon Park and Recreation Provider Survey. July 2018. Oregon Parks and Recreation Department. https://www.oregon.gov/oprd/PRP/Documents/SCORP-2018-Provider-Survey.pdf

Burns J., T. Schick, and J. Bernert. Drought conditions are sucking the fun out of northwest reservoirs. Oregon Public Broadcasting (OR). May 22, 2015. https://www.opb.org/news/article/drought-conditions-are-sucking-the-fun-out-of-northwest-reservoirs/

Carlton, J. Western lakes shrink from drought, and boat businesses struggle. Wall Street Journal, June 19, 2022. https://www.wsj.com/articles/western-lakes-shrink-from-drought- and-boat-businesses-struggle-11655631002

CDC. Health implications of drought. Centers for Disease Control and Prevention. January 16, 2020. https://www.cdc.gov/nceh/drought/implications.htm

Connelly, J. Ample mountain snowpacks are drowning the Northwest's drought. Seattle PI (WA). February 8, 2016. https://www.seattlepi.com/local/politics/article/Ample-mountain-snowpacks-promise-to-bury-6816360.php

Cureton Cook, E. Long-term rules limiting access to E. Oregon lake sought as worsening drought exposes Indigenous relics. Oregon Public Broadcasting (OR). February 8, 2023. https://www.klcc.org/environment/2023-02-08/long-term-rules-limiting-access-to-e-oregon-lake-sought-as-worsening-drought-exposes-indigenous-relics

Darling, D. Drought leaves Crooked River a trickle, Bend (OR) Bulletin, August 28, 2015. https://www.bendbulletin.com/localstate/drought-leaves-crooked-river-a-trickle/article_ceaa2b23-c70d-547f-9b17-19ef3e5180df.html

Jaeger, W., A.J. Plantinga, C. Langpap, D. Bigelow, and K. Moore (2017). Water, Economics, and Climate Change in the Willamette Basin, Oregon (Vol. EM 9157, p. 105).

Jedd, T.M., Bhattacharya, D., Pesek, C., and M.J. Hayes (2019). Drought impacts and management in prairie and sandhills state parks. Journal of Outdoor Recreation and Tourism 26:1–12. doi: 10.1016/j.jort.2019.02.003

Josephine County. Drought declaration. May 22, 2015. https://apps.wrd.state.or.us/apps/misc/vault/default.aspx?type=drought&county=JOSE&drought_year=2015

KOBI5 Newsroom Staff. Drought drying up business. KOBI-TV 5 (OR). Aug 20, 2014. https://kobi5.com/news/local-news/drought-drying-up-business-10855/

KOBI5 Newsroom Staff. Low water levels for Emigrant and Howard Prairie lake. KOBI-TV 5 (OR). Aug 31, 2018. https://kobi5.com/news/local-news/low-water-levels-for- emigrant-and-howard-prairie-lake-85020/

KOBI5 Newsroom Staff. Local lakes face consequences or dry conditions. KOBI-TV 5 (OR). June 9, 2020. https://kobi5.com/news/dry-conditions-local-lakes-130243/

KOBI5 Newsroom Staff. Jackson Co. warns water levels are extremely low. KOBI-TV 5 (OR). July 24, 2020. https://kobi5.com/news/local-news/jackson-co-warns-water-levels- are-extremely-low-133276/

KOBI5 Newsroom Staff. Water levels at Emigrant Lake, Howard Prairie “unusable,” park officials say. KOBI-TV 5 (OR). Sept 25, 2020. https://kobi5.com/news/water-levels-at-emigrant-lake-howard-prairie-unusable-park-officials-say-137593/

KOBI Newsroom Staff. Lakes on south end of Jackson Co. continue to experience low historically low water levels. KOBI-TV 5 (OR). Aug 24, 2021. https://kobi5.com/news/local-news/lakes-on-south-end-of-jackson-co-continue-to-experience-historically-low-levels-165509/

KTVZ News Sources. Low water levels mean some boat docks won’t be installed at East Lake, Crescent Lake, Wickiup Reservoir. KTVZ News (OR). June 3, 2022. https://ktvz.com/news/outdoors/2022/06/03/low-water-levels-mean-some-boat-docks-wont-be-installed-at-east-lake-crescent-lake-wickiup-reservoir/

Lisboa, M.S., R.L. Schneider, P.J. Sullivan, and M.T. Walter (2020). Drought and post-drought rain effect on stream phosphorus and other nutrient losses in the Northeastern USA. Journal of Hydrology: Regional Studies, Volume 28. https://doi.org/10.1016/j.ejrh.2020.100672

Marion County. Drought declaration. September 18, 2015. https://apps.wrd.state.or.us/apps/misc/vault/default.aspx?type=drought&county=MARI&drought_year=2015

Mojica, J., K. Cousins, and T. Madsen (2021). Economic Analysis of Outdoor Recreation in Oregon. 2021. Earth Economics. https://industry.traveloregon.com/resources/research/oregon- outdoor-recreation-economic-impact-study/

Oregon Department of State Lands. Crump Lake Reopens for Public Recreation. Oregon Department of State Lands. July 1, 2023. https://www.oregon.gov/dsl/News/Documents/NewsRelease_CrumpLakeReopeningJune2023.pdf

Oregon Health Authority. When in doubt, stay out! No date. https://www.oregon.gov/oha/ph/healthyenvironments/recreation/harmfulalgaeblooms/pages/index.aspx

Oregon Parks and Recreation Department. News Release. July 16, 2021. https://www.oregon.gov/oprd/AO/Documents/NEWS-2021-07-Prineville-Low-Water.pdf

Oregon State Marine Board. Opportunities and Access Report. June 1, 2022. https://www.oregon.gov/osmb/boater-info/Documents/OA%20Reports/OAR060122.pdf

Oregon State Marine Board. Opportunities and Access Report. June 8, 2022. https://www.oregon.gov/osmb/boater-info/Documents/OA%20Reports/OAR060822.pdf

Oregon State Marine Board. Opportunities and Access Report. June 29, 2022. https://www.oregon.gov/osmb/boater-info/Documents/OA%20Reports/OAR062922.pdf

Oregon State Marine Board Reported Access Closure Map. No date. https://geo.maps.arcgis.com/apps/dashboards/ad10caf7b3fd42bca1aeb8584d3736c0

Oregon State Parks [@ORStateParks]. “The Cascara, Winberry and North Shore boat ramps at Fall Creek State Recreation Site are closed because of the reservoir's low-water conditions. The Dexter Reservoir boat ramps at the Lowell and the Dexter state recreation sites are open.” [Tweet]. June 14, 2021. Retrieved from https://twitter.com/ORStateParks/status/1404462324757536769.

Richard, T. Detroit Lake poster child for Oregon drought, but boating goes on. Oregon Live (OR). July 31, 2015.

https://www.oregonlive.com/travel/2015/07/detroit_lake_poster_child_for.html
Smith, M. How drought affects local businesses on the water. February 7, 2022. KTVL10. Medford, OR. https://ktvl.com/news/local/how-drought-affects-local-businesses-on-the-water
Van Loon, A.F., K. Stahl, G. Di Baldassarre, J. Clark, S. Rangecroft, N. Wanders, T. Gleeson, AIJM, Van Dijk, L.M. Tallaksen, J. Hannaford, R. Uijlenhoet, A.J. Tueling, D.M. Hannah, J. Sheffield, M. Svoboda, B. Verbeiren, T. Wagener, and H.A.J. Van Lanen (2016). Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches. HESS, 20; 9, 3631-3650. https://hess.copernicus.org/articles/20/3631/2016/hess-20-3631-2016.html
Wasco County. Drought declaration. May 22, 2015. https://apps.wrd.state.or.us/apps/misc/vault/default.aspx?type=drought&county=WASC&drought_year=2015

The relationship between park attendance and drought

We also conducted statistical analysis of whether park attendance is associated with drought. In conversation with Oregon Parks and Recreation, we hypothesized that drought would negatively impact park attendance. To test this hypothesis, we analyzed the relationship between the Standardized Precipitation-Evapotranspiration Index (SPEI) and monthly attendance, 1989-2022, at 62 Oregon State Parks (Appendix A) with in-water recreational use such as boating or swimming.

The SPEI uses precipitation and temperature records to determine wetness or dryness relative to previous data and is a widely accepted way to describe drought. SPEI reflects the wetness or dryness of the preceding months on any timescale with the following guidelines: SPEI at one month reflects short-term precipitation and temperature trends that may immediately impact day-to-day decisions for recreationists. Generally speaking, SPEI values for three months or less may capture short-term drought or drought emergence. SPEI values for six months or fewer may show agricultural impacts. SPEI values for 12 months or longer may be associated with hydrological impacts of drought. “Water Year” SPEI is calculated for each month, year-to-date, back to the beginning of the current water year (starting October 1). For instance, the water year SPEI for November would be the 2-month SPEI for November. SPEI data by month and county was obtained from the Westwide Drought Tracker (Vicente-Serrano et al. 2010, Abatzoglou et al. 2017). An example of the 9-month SPEI for September 2021 shows how precipitation in the 9 months ending in September 2021 compared with the same period of time in previous years across the State of Oregon (Figure 4.8).

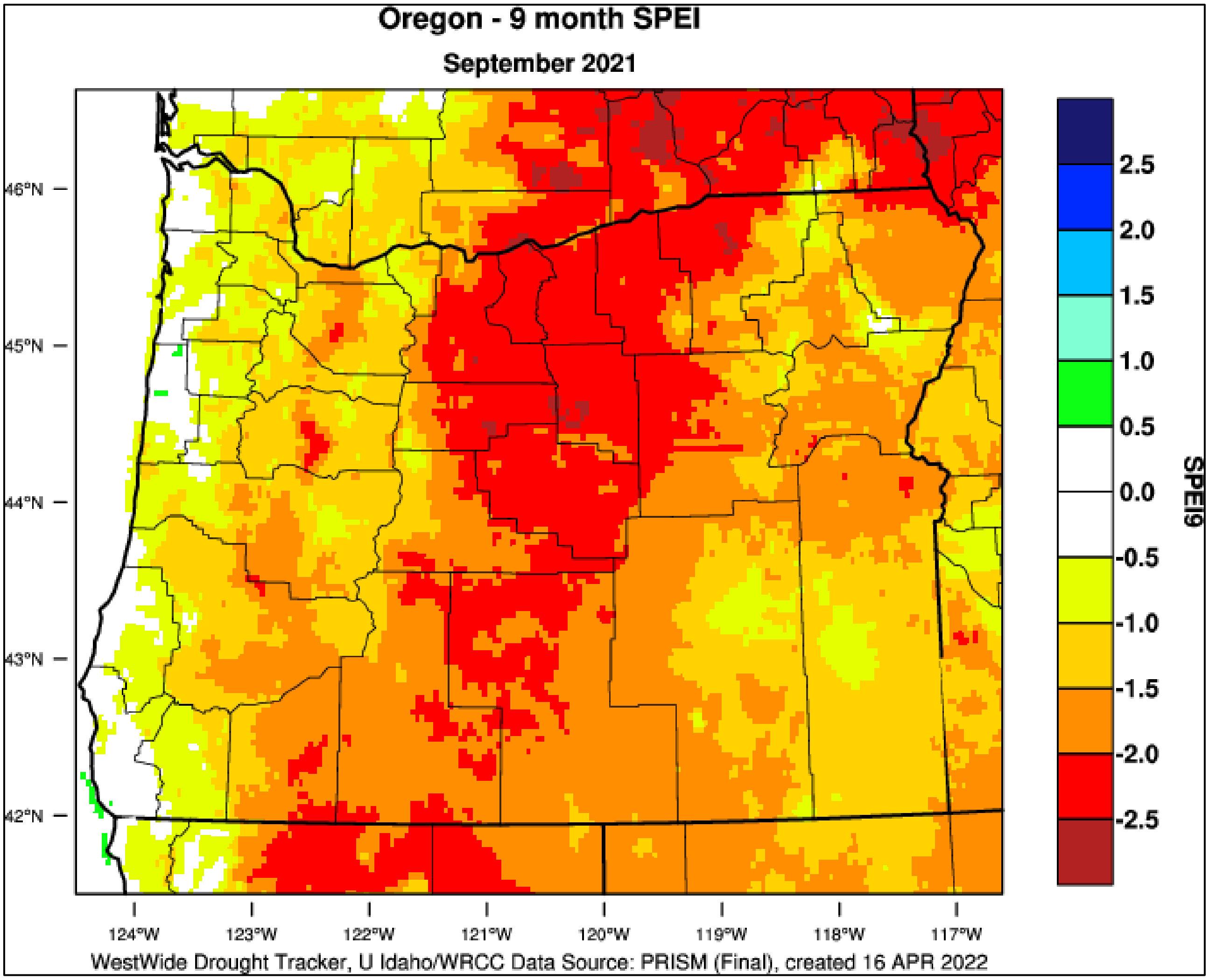


Figure 4.8. The 9-month SPEI for September 2021 shows how precipitation in the 9 months ending in September 2021 compared with the same period of time in previous years across the State of Oregon. Map courtesy of WestWideDroughtTracker, https://wrcc.dri.edu/wwdt

SPEI levels were categorized by severity for analysis (Table 4.1).

Dry or Wet Category	SPEI Range	Description
D23	Below -1.5	Severe drought
D12	>= -1.5 and < -1	Moderate drought
D01	>= -1 and < -0.5	Mild drought
Normal	>= -0.5 and < 0.5	Normal conditions
W01	>= 0.5 and < 1	Mildly wet
W12	>= 1 and < 1.5	Moderately wet

W23	>= 1.5	Very wet

Table 4.1. Categorization of SPEI levels for analysis.

Our statistical analysis compared “expected” numbers of visits with “observed” or actual visits. Expected visits are how many we would expect if visits were evenly distributed across months, regardless of wet or dry conditions, or whether visits are independent of the weather. To achieve this, we conducted a chi-square test of independence to determine whether the proportion of park visits in each SPEI category was equal to the proportion of months in each SPEI category, which would suggest that SPEI did not affect people’s decisions. If the proportion of visits in each category was significantly different from the proportion of months in each category, this would suggest that people modify their park use based on short- or longer-term weather conditions.

Bar plots were created to provide a simple visual comparison of expected and observed visits. Plots were created for the 62 state parks as a whole and for each individual park to see if the impact of drought on visitation varied. The data was then subset by climate division (https://psl.noaa.gov/data/usclimdivs/data/map.html) as well as their position east or west of the Cascades, and chi-square tests were run again to determine whether results were location-dependent.

Above-average precipitation (W01, W12 and W23) was generally associated with lower attendance than expected on the SPEI-1 scale. This pattern was exhibited across the parks when analyzed as a whole, in 24 individual parks, and in all climate divisions except the Southeast and Southwestern Valleys. Interviews with park managers indicate that visitation increases during warm, dry weather. Heavy rains can cause erosion, create mud, and wash out roads and campgrounds, as was seen at Prineville Reservoir in spring 2023 in Oregon.

On longer timescales, however, the relationship between SPEI and attendance was less clear. Examples of the bar plots are provided in the text to demonstrate how these analyses were conducted.

All parks

Visual analysis of the bar plots indicated differences between expected and observed numbers of visits (Table 4.2). A bar plot showing the expected versus observed visitation across all parks at SPEI-1 is included below as an example (Figure 4.9). These results indicated that the different levels of drought are associated with significant changes in attendance on all timescales. However, the relationship between drought and attendance was only clear on the SPEI-1, SPEI-3, and SPEI-WY timescales. The results on these timescales indicated that drought was associated with higher attendance than expected and wet conditions were associated with lower attendance than expected.

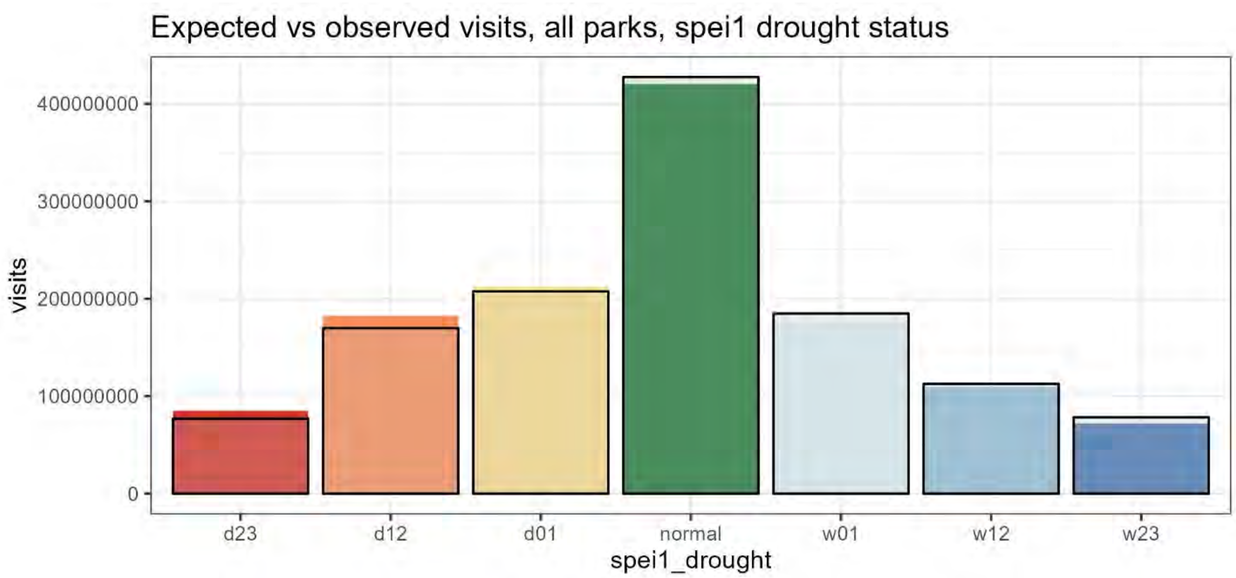


Figure 4.9. Expected versus observed visits across all parks on the SPEI-1 timescale.

On other timescales, the various categories were associated with higher and lower than expected attendance values in an unclear pattern. The SPEI-9 chart is included as an example, showing that attendance was above expected at the D23 drought level, below expected on the D12 and D01 levels, above expected during normal conditions, below expected again on the W01 and W12 levels, and equal to expected at W23. We consider this graph to show no clear pattern in the relationship between drought and attendance.

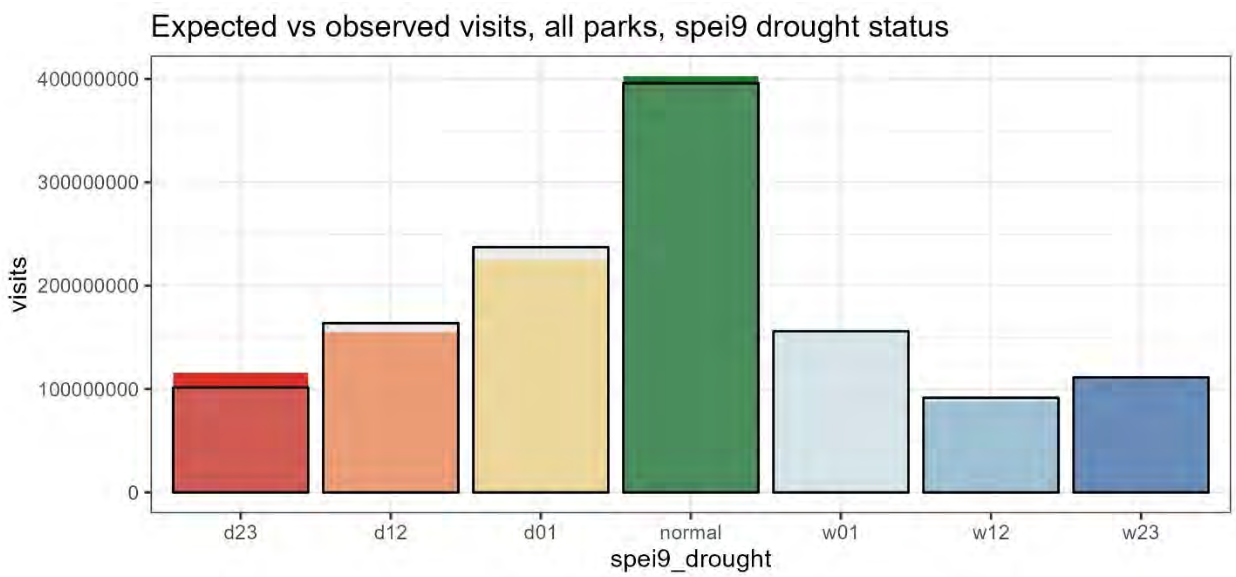


Figure 4.10. Expected versus observed visits across all parks on the SPEI-9 timescale.

	D23	D12	D01	Normal	W01	W12	W23
WY	H	H	E	E	L	L	E
SPEI-1	H	H	H	L	L	L	L
SPEI-3	H	E	H	L	L	E	E
SPEI-6	H	L	L	L	L	H	H
SPEI-9	H	L	L	H	L	H	H
SPEI-12	H	E	L	H	L	L	H

Table 4.2. Summary of observed relative to expected visitation across all parks during each drought level on various SPEI timelines. L = lower than expected, H = higher than expected, E = equal to expected.

To better understand why drought conditions are associated with higher attendance than expected, we compared attendance to precipitation and temperature separately. We used linear regression to determine the relationship between monthly average temperature and monthly total attendance at the state parks. Temperature was positively associated with attendance when the data was examined across all parks and seasons ($p < 0.05$; $R^2 = 0.098$; Figure 4.11). We then subset the data to determine the relationship between monthly average temperature and monthly attendance by season. The positive, but weak, relationship between temperature and attendance held true when examining each season individually across all parks. The relationship is weakest in the summer ($p < 0.05$, $R^2 = 0.003$). Summer temperatures in Oregon tend to be mild (in this dataset, minimum = 10.01°C, mean = 16.98°C, max = 25.46°C) and outdoor recreation is popular as children are out of school. It is possible that summer recreation in Oregon takes place at high rates regardless of differences in temperature.

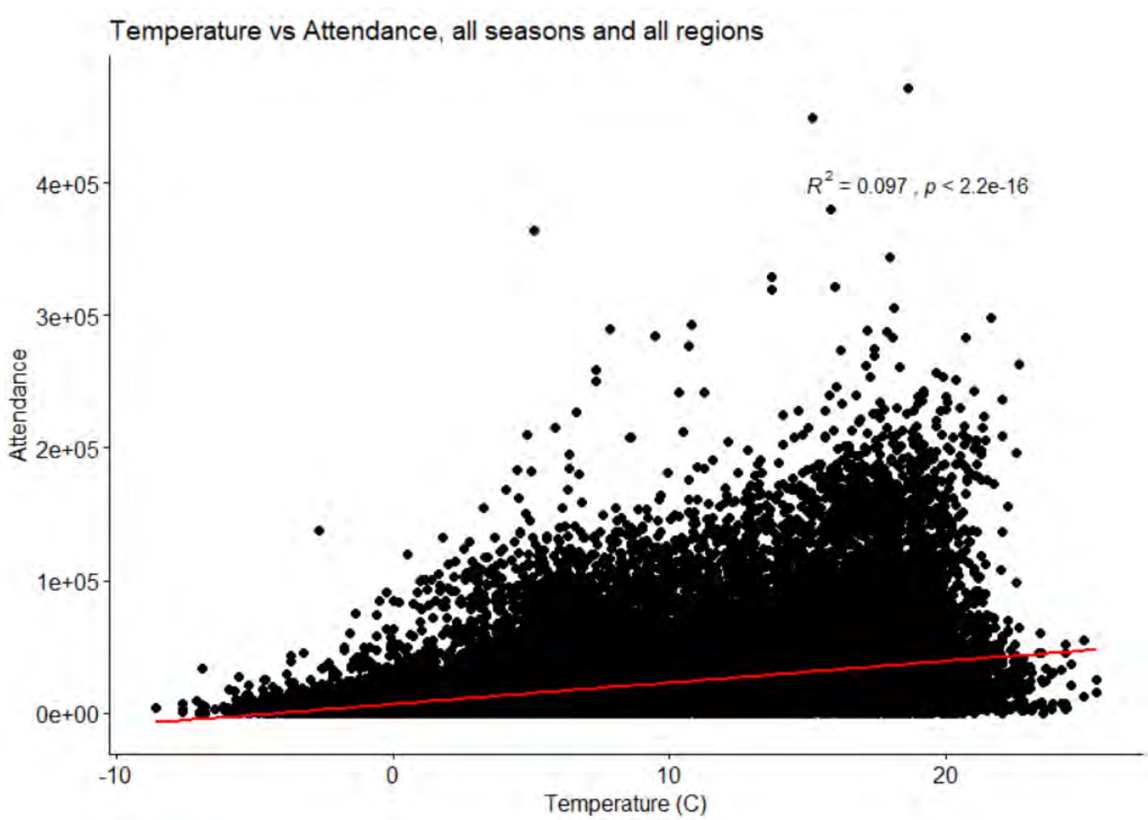


Figure 4.11. The relationship between temperature and park attendance during all seasons and

across all Oregon regions.

We also compared total precipitation (per month) and total attendance (per month) using linear regression to elucidate how precipitation may influence park attendance. Precipitation is negatively associated with attendance, when examined across all parks and seasons (linear regression, $p < 0.05$; $R^2 = 0.025$; Figure 4.12).

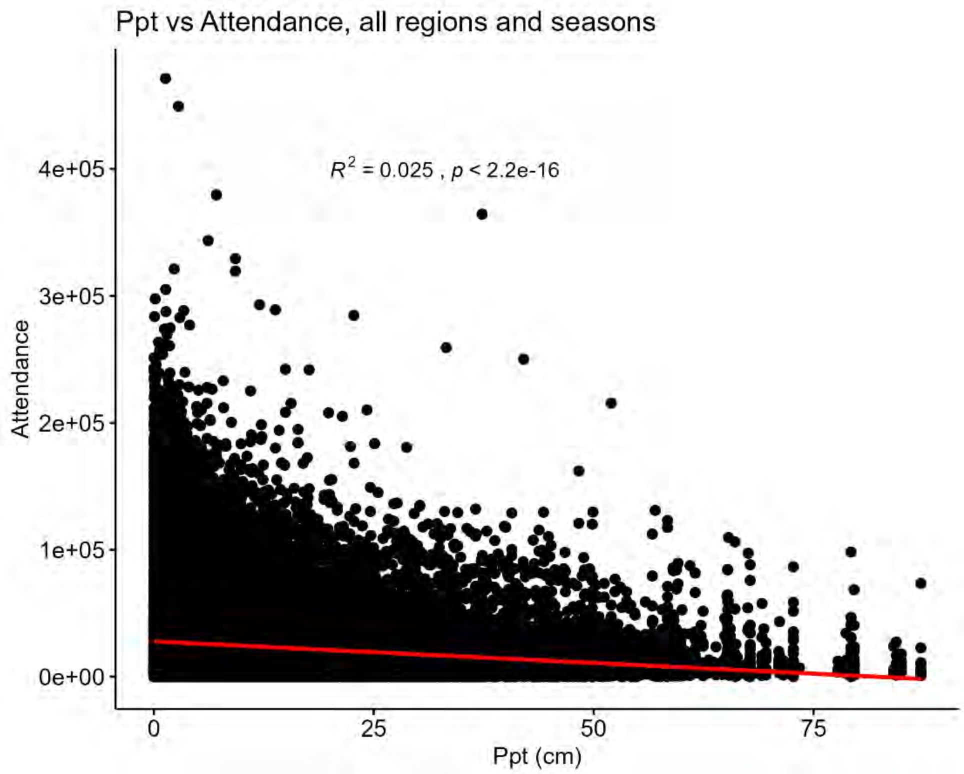


Figure 4.12. The relationship between precipitation and park attendance during all seasons and across all regions of Oregon.

Seasonal differences exist regarding the relationship between precipitation and attendance. Winter precipitation is positively but very weakly associated with attendance (linear regression, $p < 0.05$; $R^2 = 0.006$), while spring precipitation is not significantly related to attendance (linear regression, $p > 0.05$). Summer precipitation is negatively but weakly associated with attendance (linear regression, $p < 0.05$; $R^2 = 0.002$). Fall precipitation is also negatively but weakly associated with attendance (linear regression, $p < 0.05$; $R^2 = 0.006$).

We also considered the possibility that park attendance is increasing over time due to population growth, which coincides with increasing frequency of drought in Oregon. To test this, we performed linear regression comparing park attendance to state population. There was a significant positive relationship between attendance and population (linear regression, $p < 0.001$; $R^2 = 0.61$; Figure 4.13).

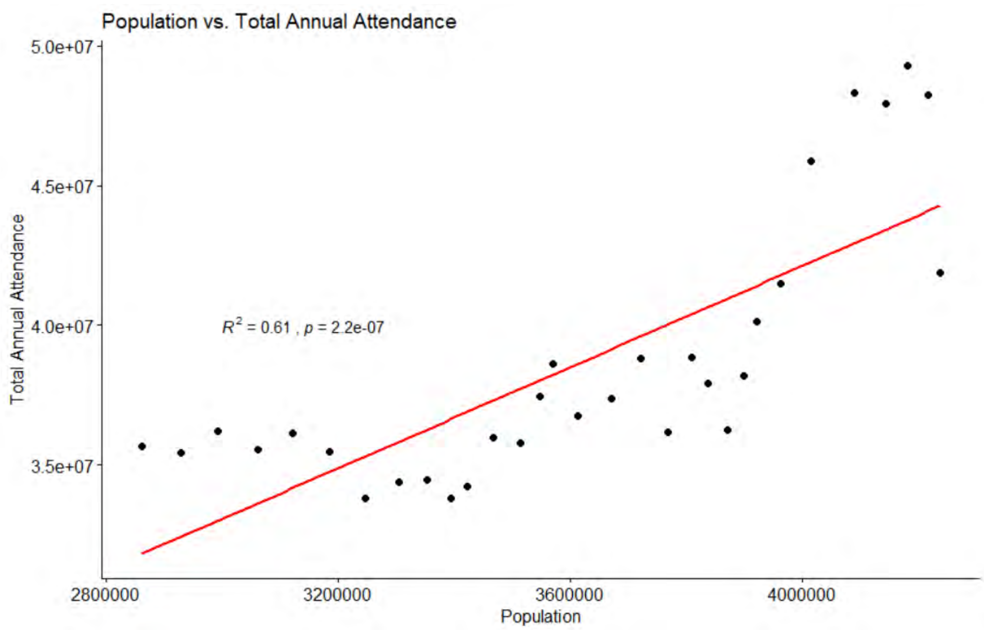


Figure 4.13. The relationship between park attendance and state population in Oregon.

East and west of the Cascades

Chi-square test of independence results and analysis of the associated bar graphs indicated that attendance is higher than expected during drought conditions on the SPEI-1 timescale for both sides of the Cascades, and on the SPEI-3 and SPEI-WY timescales west of the Cascades. Otherwise, the relationship between drought and attendance was unclear on both sides. Examples of the bar graphs on the SPEI-1 scale are included for each side of the Cascades (Figure 4.14, Figure 4.15).

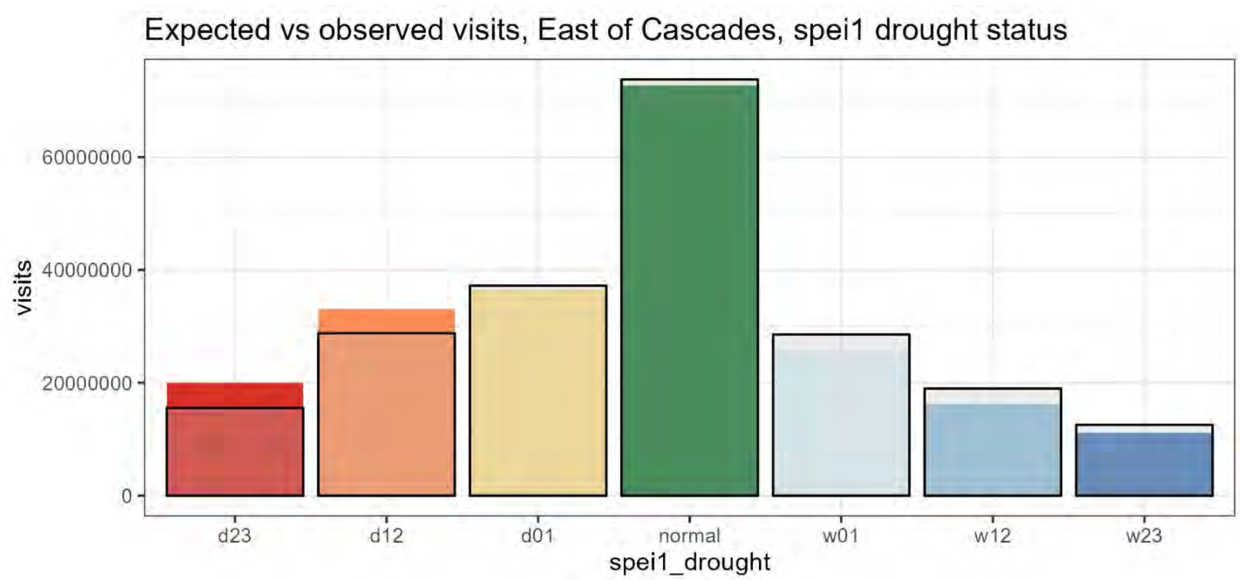
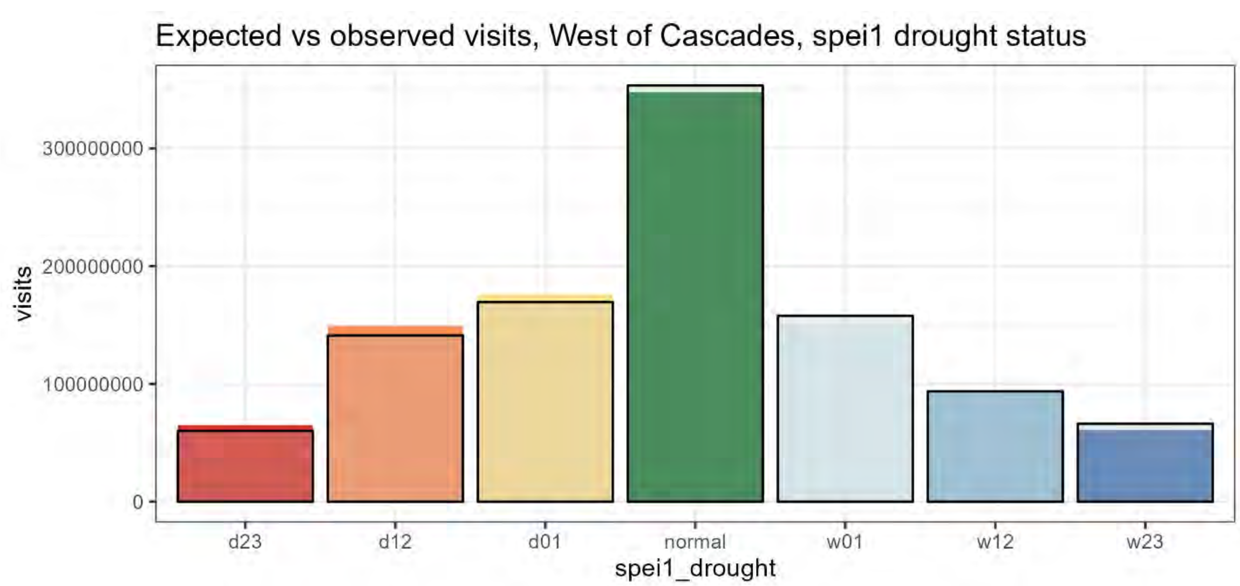
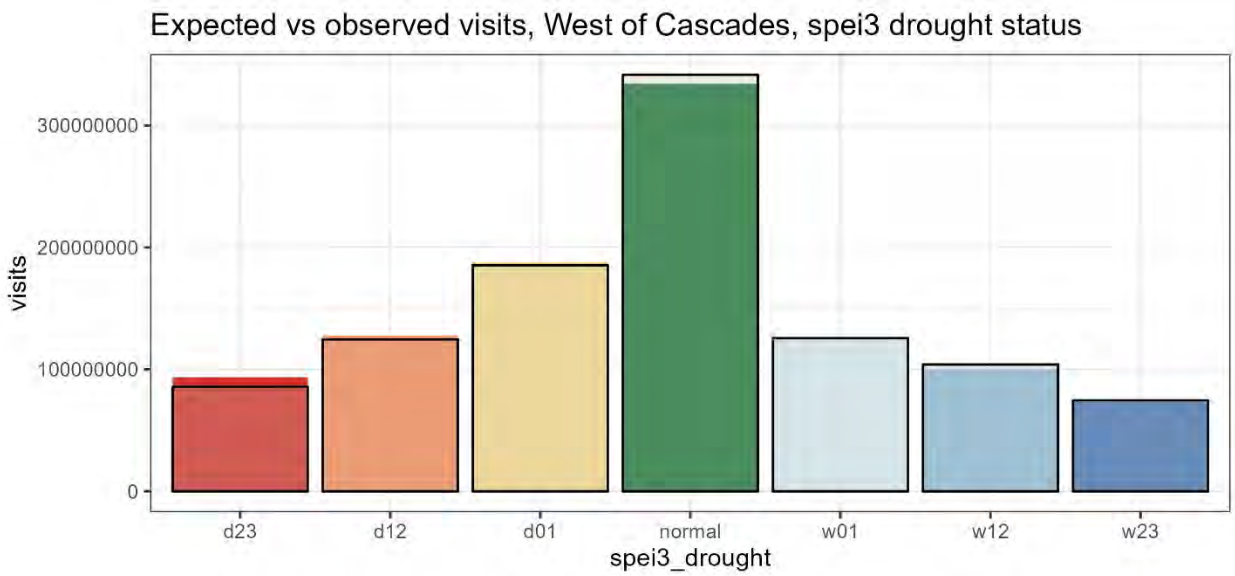


Figure 4.14. Bar plot of expected versus observed visits east of the Cascades on the SPEI-1 scale. Black lines indicate the expected visitation at each drought level. The colored fill represents the observed visitation at each drought level.





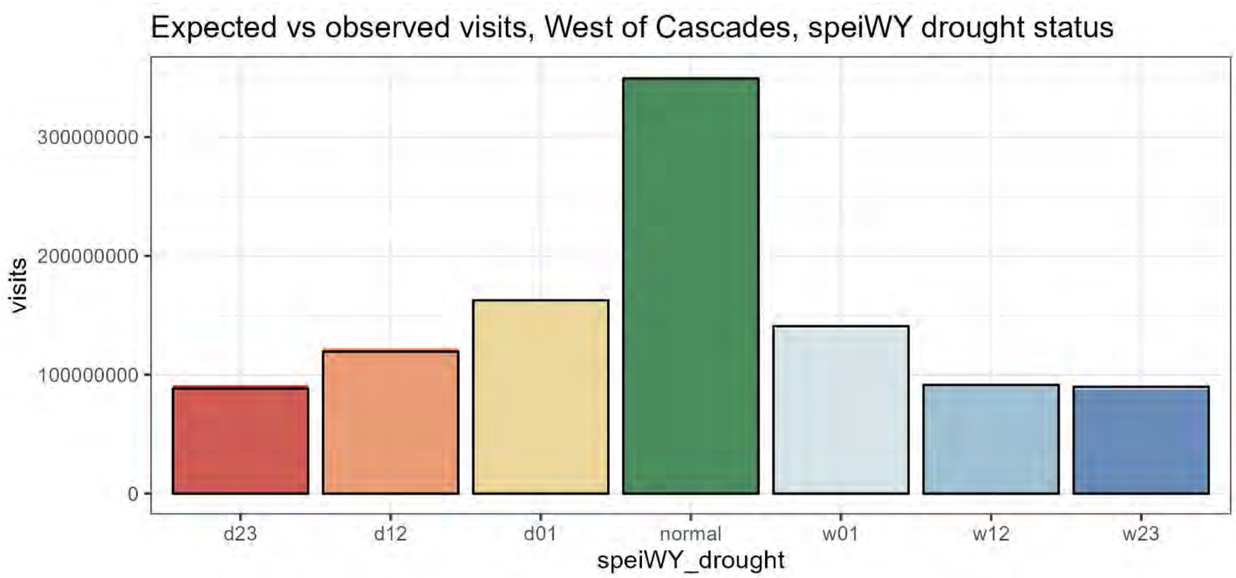


Figure 4.15. Bar plot of expected versus observed visits west of the Cascades on the SPEI-1, SPEI-3, and SPEI-WY timescales. Black lines indicate the expected visitation at each drought level. The colored fill represents the observed visitation at each drought level.

	D23	D12	D01	Normal	W01	W12	W23
SPI-1	H	H	L	L	L	L	L
SPEI-3	H	E	H	L	L	H	E
SPEI-6	H	H	L	L	L	H	H
SPEI-9	H	L	L	L	H	H	L
SPEI-12	H	E	H	L	L	E	L
SPEI-WY	H	H	H	L	L	H	L

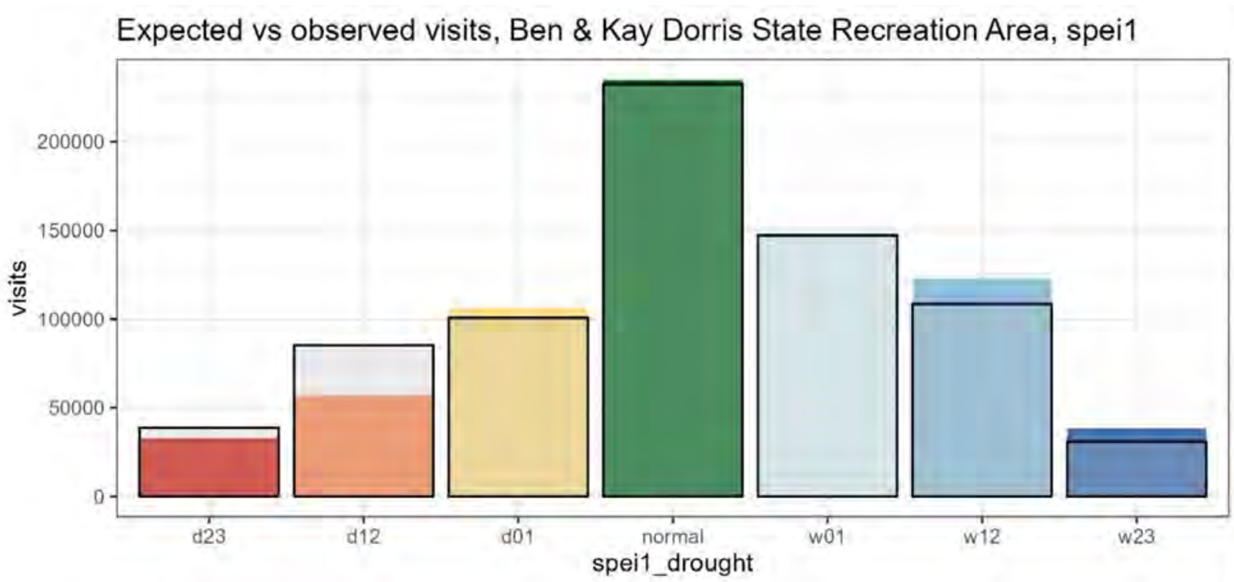
Table 4.3. Summary of observed relative to expected visitation east of the Cascades during each drought level on various SPEI timelines. L = lower than expected, H = higher than expected, E = equal to expected.

	D23	D12	D01	Normal	W01	W12	W23
SPEI-1	H	H	H	L	L	L	L
SPEI-3	H	H	H	L	L	L	E
SPEI-6	H	L	L	E	L	H	E
SPEI-9	H	L	L	H	L	L	E
SPEI-12	H	E	L	H	L	L	H
SPEI-WY	H	H	E	E	L	L	L

Table 4.4. Summary of observed relative to expected visitation west of the Cascades during each drought level on various SPEI timescales. L = Lower than expected, H = higher than expected, E = equal to expected.

Individual parks

Bar plots created for individual parks indicated that observed attendance was higher than expected during drought conditions at the various SPEI timescales across 56 of the 62 parks. Attendance at four parks was negatively affected by drought, meaning that observed attendance was lower than expected during D23, D12 and/or D01 on several (but not all) SPEI timescales. Above-average precipitation (W01-W23) was associated with higher attendance than expected at these locations, as well. The four parks were Ben and Kay Dorris State Recreation Area in Lane County, Joseph H. Stewart State Recreation Area in Jackson County, Unity Lake State Recreation Site in Baker County, and Willamette River Greenway – Cloverdale access, in Lane County. All four parks are popular for boating, so drought conditions may inhibit visitors' ability to launch and use watercraft.


Expected vs observed visits, Ben & Kay Dorris State Recreation Area, spei1
visits
200000
150000
100000
50000
0
d23
d12
d01
normal
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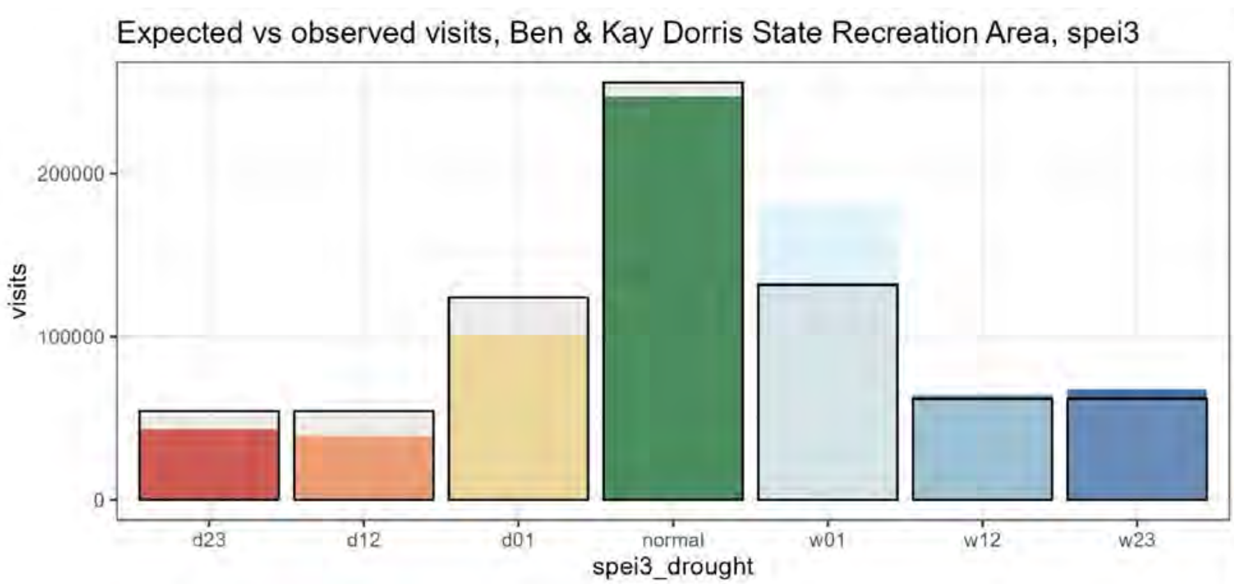
w23
spei1_drought


Expected vs observed visits, Ben & Kay Dorris State Recreation Area, spei3
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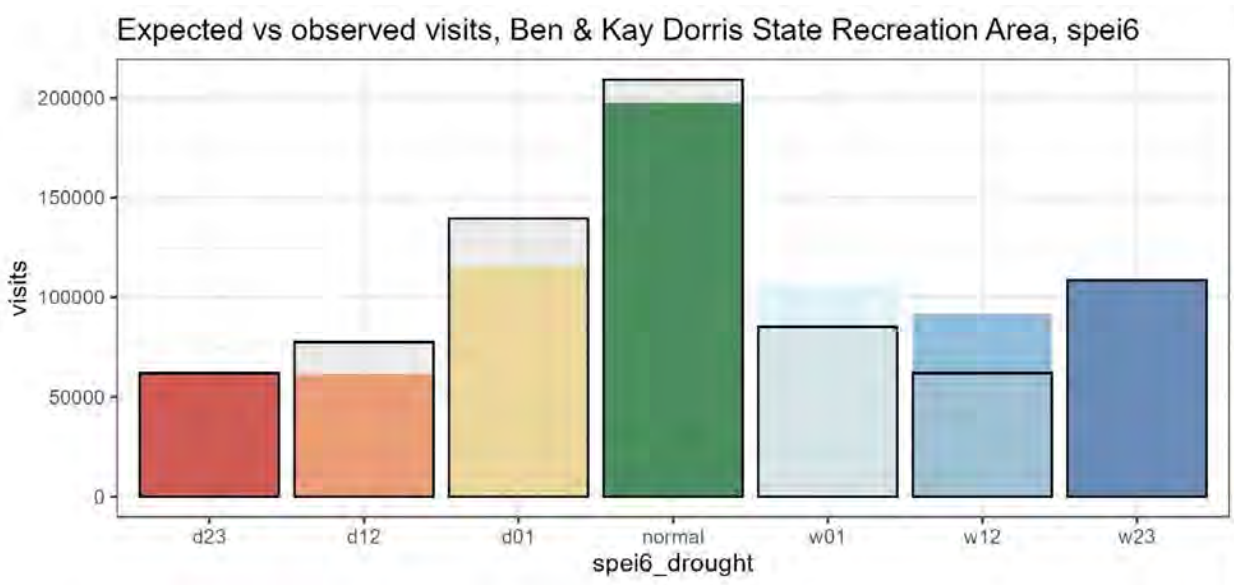
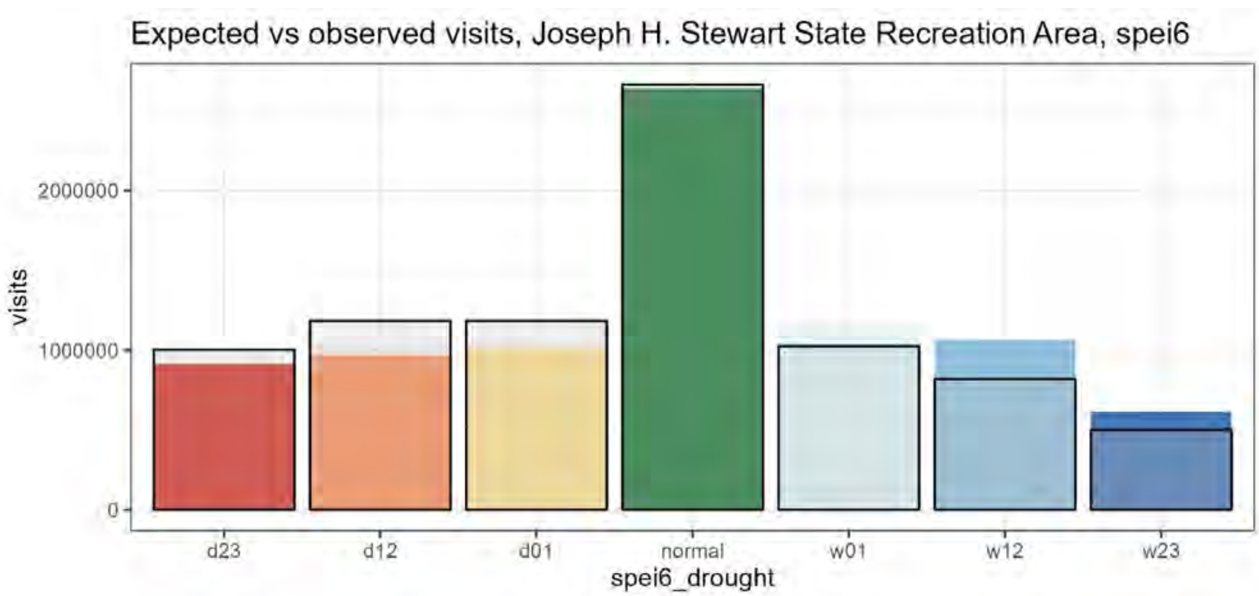


Figure 4.16. Bar plots of expected versus observed visits at Ben and Kay Dorris State Recreation Area on the SPEI-1, SPEI-3, and SPEI-6 timescales showing a positive effect of wet conditions on attendance. The pattern was unclear on the other timescales. Black lines indicate the expected visitation at each drought level. The colored fill represents the observed visitation at each drought level.



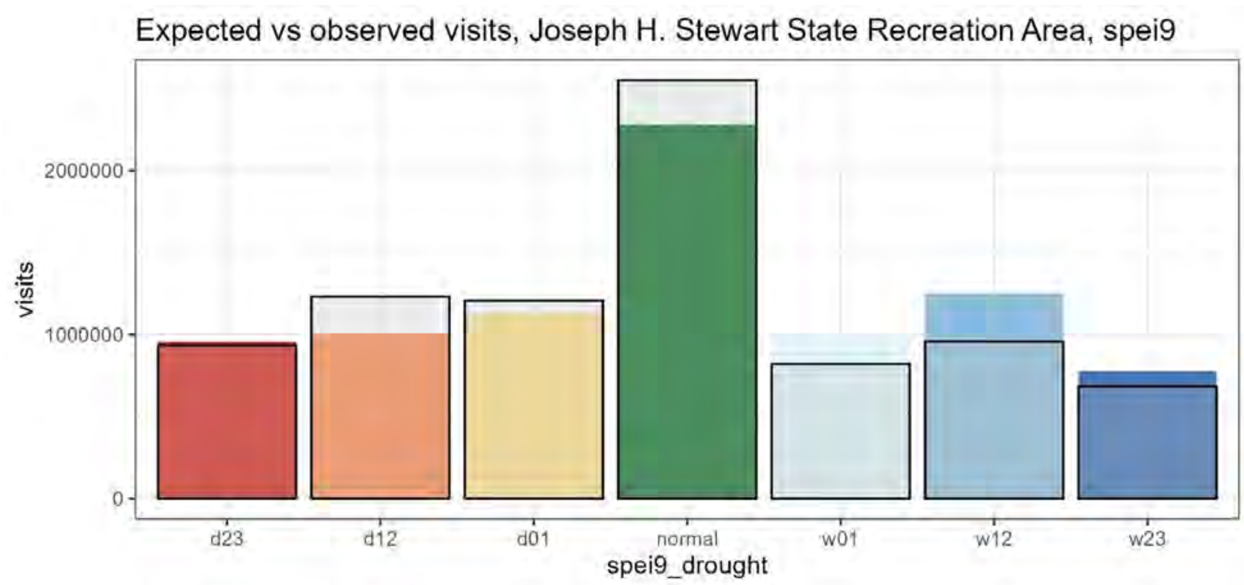


Figure 4.17. Bar plots of expected versus observed visits at Joseph H. Stewart State Recreation Area on the SPEI-6 and SPEI-9 timescales showing a positive effect of wet conditions on attendance. The pattern was unclear on the other timescales. Black lines indicate the expected visitation at each drought level. The colored fill represents the observed visitation at each drought level.

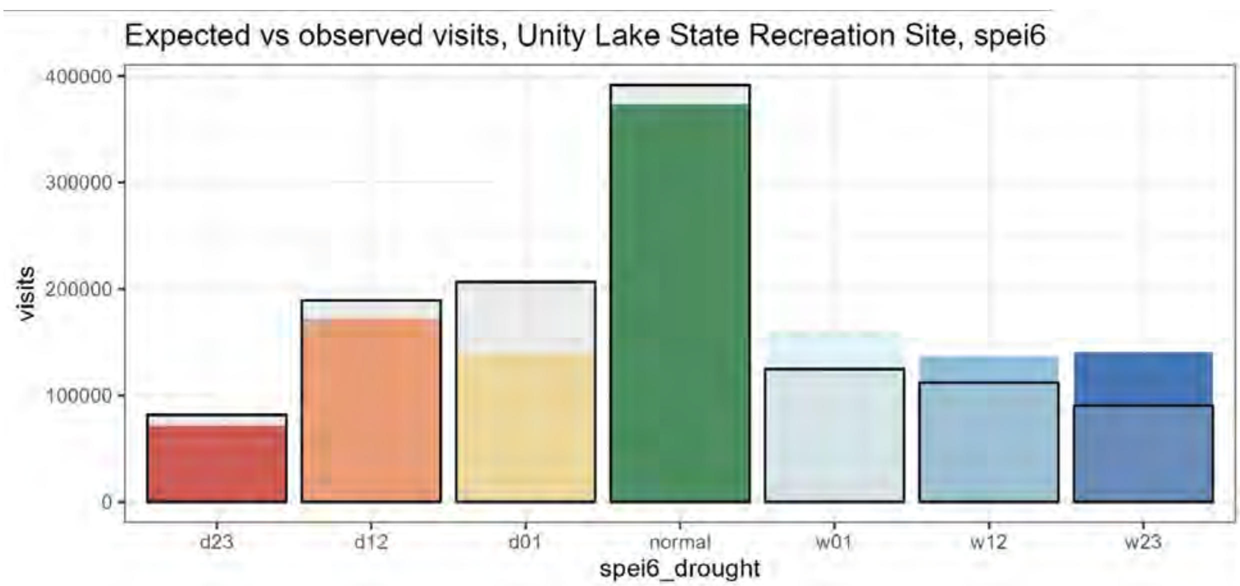


Figure 4.18. Bar plot of expected versus observed visits at Unity Lake State Recreation Area on the SPEI-6 timescale showing a positive effect of wet conditions on attendance. The pattern was unclear on the other timescales. Black lines indicate the expected visitation at each drought level. The colored fill represents the observed visitation at each drought level.

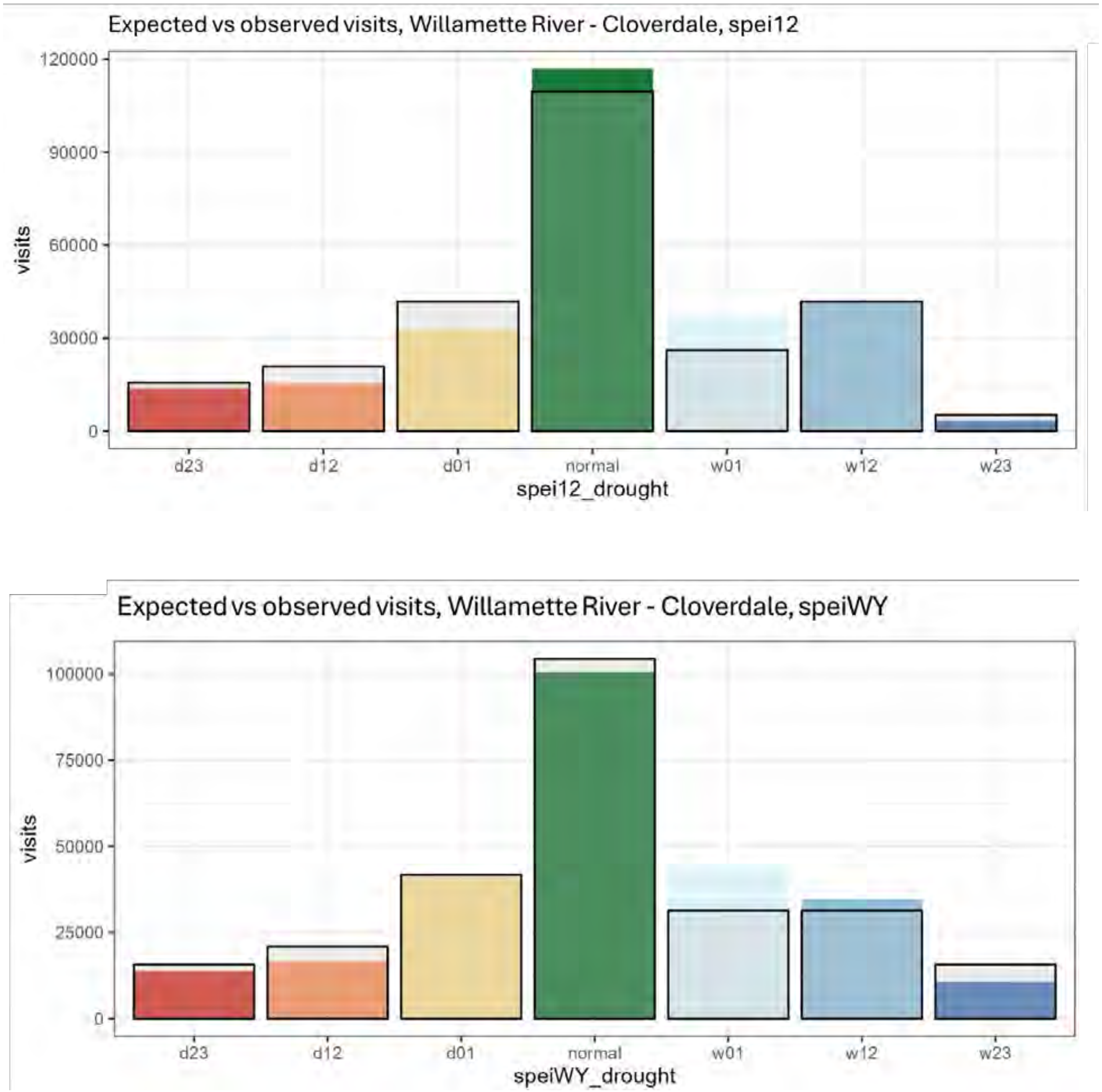


Figure 4.19. Bar plot of expected versus observed visits at the Willamette River Greenway – Cloverdale Access on the SPEI-12 and SPEI-WY timescales showing a positive effect of wet conditions on attendance. The pattern was unclear on the other timescales. Black lines indicate the expected visitation at each drought level. The colored fill represents the observed visitation at each drought level.

References

Abatzoglou, J.T., D.J. McEvoy, and K.T. Redmond (2017). The West Wide Drought Tracker: Drought Monitoring at Fine Spatial Scales. Bull. Amer. Meteor. Soc., 98, 1815–1820, https://doi.org/10.1175/BAMS-D-16-0193.1.

Vicente-Serrano, S.M., S. Beguería, and J.I. López-Moreno (2010). A multiscalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index. J. Climate, 23, 1696–1718, doi:10.1175/2009JCLI2909.1

Appendix

Appendix A. Parks with aquatic recreation that were used for analysis in this report.

Park	County	City
Alfred A. Loeb State Park	Curry	Brookings
Devil's Lake State Recreation Area	Lincoln	Lincoln City
Jessie M. Honeyman Memorial State Park	Lane	Florence
Umpqua State Scenic Corridor	Douglas	Reedsport
W. B. Nelson State Recreation Site	Lincoln	Waldport
William M. Tugman State Park	Coos	Florence
Cottonwood Canyon State Park	Gilliam	The Dalles
Deschutes River State Recreation Area	Sherman	The Dalles
Hat Rock State Park	Umatilla	Hermiston
J. S. Burres	Gilliam	Condon
Koberg Beach State Recreation Site	Hood River	Hood River
Mayer State Park	Wasco	The Dalles
Viento State Park	Hood River	Cascade Locks
Wyeth State Recreation Area	Hood River	Cascade Locks
Clyde Holliday State Recreation Site	Grant	Mount Vernon
Farewell Bend State Recreation Area	Baker	Huntington
Hilgard Junction State Park	Union	La Grande
Minam State Recreation Area	Wallowa	Minam
Unity Lake State Recreation Site	Baker	Unity
Wallowa Lake State Park	Wallowa	Joseph
Detroit Lake State Recreation Area	Marion	Detroit
Clarno State Park	Wheeler	Fossil
Collier Memorial State Park	Klamath	Chiloquin
Cove Palisades State Park	Jefferson	Culver
Jackson F. Kimball State Recreation Site	Klamath	Chiloquin
LaPine State Park	Deschutes	LaPine
Prineville Reservoir State Park	Crook	Prineville
Smith Rock State Park	Deschutes	Terrebonne
Tumalo State Park	Deschutes	Tumalo
Warm Springs State Recreation Site	Jefferson	Madras
Lake Owyhee State Park	Malheur	Adrian
Ontario State Recreation Site	Malheur	Ontario
Casey State Recreation Site	Jackson	Trail
Illinois River Forks State Park	Josephine	Cave Junction
Joseph H. Stewart State Recreation Area	Jackson	Medford
TouVelle State Recreation Site	Jackson	Central Point

Valley of the Rogue State Park	Jackson	Gold Hill
Ben & Kay Dorris State Recreation Area	Lane	Vida
Benson State Recreation Area	Multnomah	Cascade Locks
Dabney State Recreation Area	Multnomah	Corbett
Dexter State Recreation Site	Lane	Dexter
Elijah Bristow State Park	Lane	Dexter
Fall Creek State Recreation Area	Lane	Fall Creek
Jasper State Recreation Site	Lane	Pleasant Hill
Lewis and Clark State Recreation Site	Multnomah	Troutdale
Lowell State Recreation Site	Lane	Lowell
Luckiamute Landing State Natural Area	Polk	Albany
Milo McIver State Park	Clackamas	Estacada
Molalla River State Park	Clackamas	Canby
North Santiam State Recreation Area	Linn	Lyons
Rooster Rock State Park	Multnomah	Corbett
Willamette River Greenway- Brown's Landing	Lane	Tualatin
Willamette River Greenway- Christensen's Boat Ramp	Lane	Junction City
Willamette River Greenway- Cloverdale Access	Lane	Creswell
Willamette River Greenway- Darrow Bar Access	Polk	Keizer
Willamette River Greenway- Grand Island	Yamhill	Wheatland
Willamette River Greenway- Lincoln Access	Polk	Lincoln
Willamette River Greenway- Log Jam Access	Lane	Jasper
Willamette River Greenway- Lynx Hollow Access	Lane	Creswell
Willamette River Greenway- Marshall Island Access	Lane	Junction City
Willamette River Greenway- Pengra Access	Lane	Trent
Willamette River Greenway- Spring Valley Access	Polk	Keizer

Park manager interviews

In this section, we interview park managers to gain further understanding of the impact of drought on recreation. Interview requests were sent to managers whose parks experienced negative impacts of drought on attendance. Additional managers were contacted in an effort to achieve broad spatial distribution throughout the state of Oregon and incorporate parks where visitation was higher than expected during drought. Six park managers in charge of a total of 91 recreational areas were ultimately interviewed. Interviews provided information that media, scientific literature and park visitation data could not regarding the impact of drought on recreation in Oregon. Figure 4.16 depicts the spatial distribution of the parks with in-water recreation and whose managers were interviewed for this report.

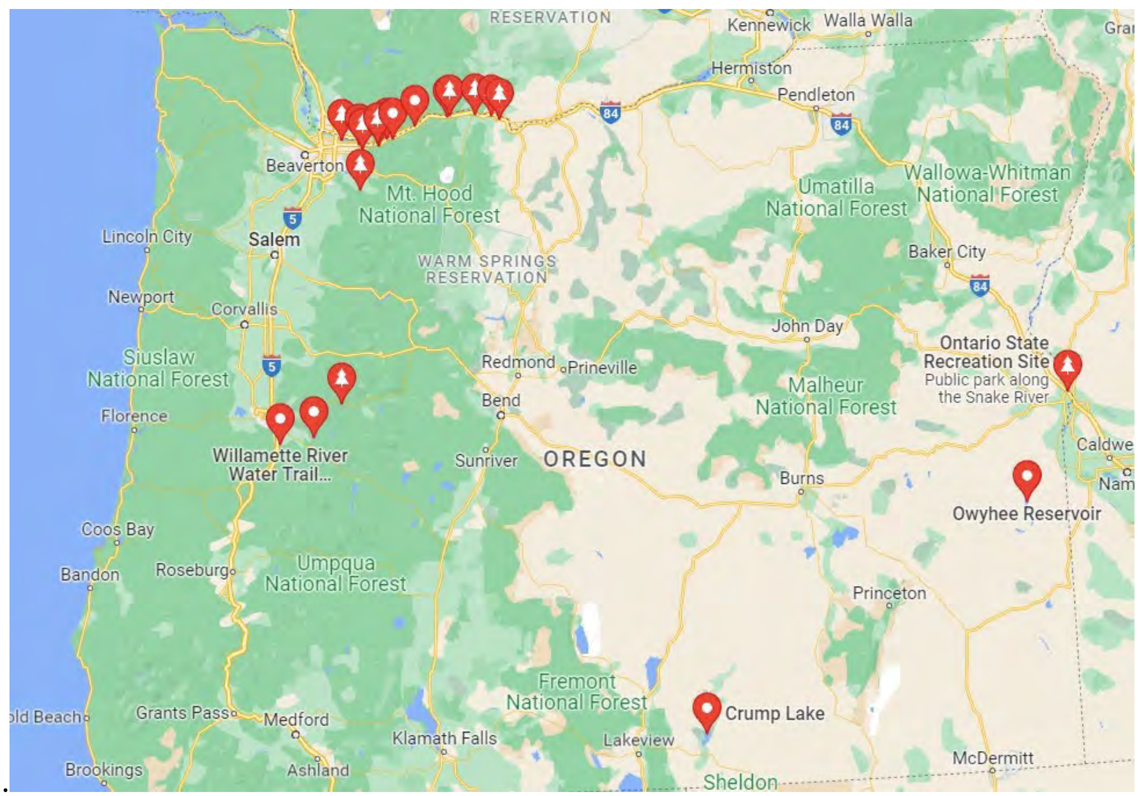


Figure 4.16. Spatial distribution of parks and management units interviewed.

The interview questions encompassed the following themes:

1. How do managers recognize drought?

2. What determines whether a park is impacted by drought?

3. Why do many parks experience an increase in attendance during drought?

4. What environmental impacts occur in the park during drought?

5. How are visitors, staff and management personnel affected during drought?

6. What actions are managers taking to address current drought and future vulnerability to drought?

How managers recognize drought

All park managers interviewed (from July to September 2023) stated that their parks and the surrounding regions were currently in a drought. They cited anecdotal evidence, visual assessment and precipitation records/forecasts as methods of determining whether drought was occurring. Dry vegetation was a common indicator of drought for the managers interviewed. Some managers also rely on Oregon Department of Forestry fire data, as fire and drought are correlated. One manager uses the U.S. Army Corps of Engineers website to look up reservoir levels. Several were not familiar with the NDMC's U.S. Drought Monitor but were interested in learning more about that tool.

Factors that influence the impact of drought on a park

Proximity to population centers: Parks near population centers tend to receive steady visitation regardless of drought conditions as they are convenient for large numbers of people to access.

Climate: Western Oregon receives more precipitation than the eastern and central parts of the state. Water levels in water bodies west of the Cascades tend to stay higher throughout the summer, even during drought conditions.

Water management: Water levels in water bodies that are heavily managed for purposes such as fish habitat and electric power can fluctuate greatly. The Columbia River is heavily influenced by water management. Effects of impoundment on recreation can vary, however. Recreation may increase on reservoirs during drought if the water levels are more stable than on rivers. At other times, reservoirs are drawn down to increase flow into rivers for salmon habitat, at which point boat ramps may not reach the water. Prineville Reservoir, for example, recently was required to increase its minimum outflow from 10cfs to 50cfs for fish habitat year-round.

Source of water: Parks that receive most of their water from precipitation can be more vulnerable to impacts of drought than those that rely on snowpack. Reservoirs within the Willamette Valley Project, for instance, rely heavily on precipitation. The McKenzie River, however, receives snowmelt from a large watershed and is not affected by drought as often.

Parks that do not see a decrease in visitation during drought

Drought can have a positive effect on visitation at some parks. At some parks, water levels stay relatively constant, or at least high enough that recreation isn't impacted. During droughts, visitors may overcrowd these locations as other parks are not accessible. Other parks' visitation levels are not affected by drought because they are close to population centers like Portland. Visitors may change their behavior within the park during droughts, such as using a different part of the water body.

Negative impacts, however, still plague parks that do not suffer decreased visitation during drought. These parks experience impacts related to decreased visitor satisfaction, ecological damage, and stress on staff and management. Activity restrictions, aesthetic impacts and overcrowding may have a negative effect on visitor satisfaction during droughts. Campfires are often banned during dry periods, which diminishes the camping experience for many recreationists. Inner tubes commonly pop on the rocky river bottom at Milo McIver State Park during low water conditions.

Most state-owned parks have stopped irrigating in recent decades to conserve groundwater, especially as droughts become longer and more common. Some managers have undertaken xeriscaping projects to replace non-native plants and turf with native vegetation, such as sagebrush, that uses less water. Park aesthetics are perceived as negatively impacted when dry grass, tree stress, and other vegetation changes are seen by visitors. Several of the managers interviewed regularly receive visitor complaints regarding dry vegetation.

Parks that maintain sufficient water levels during drought draw visitors looking for water recreation opportunities. These parks tend to become overcrowded, diminishing the experience for many recreationists who are seeking relaxation and solitude. There may be longer waits at boat ramps, less parking, excessive noise or a lack of space while boating, camping or otherwise using the park.

Oregon park managers have seen typical ecological impacts of drought occurring at their parks, regardless of whether their visitation numbers are affected. Several report seeing more wildlife, including large predators such as bears, coming into developed areas of their parks. They believe that wildlife may be running out of food and water in more distant reaches of the park due to drought and are coming closer to humans in search of sustenance. Other managers see reduced salmon returns during drought. Some reported increased frequency of cyanobacterial blooms, shorter wildflower bloom periods and vegetation going dormant early. Crowds also often cause compacted soil during times of high demand.

Staffing numbers generally stay constant during droughts, but duties and pressures on employees change. One park on the Clackamas River sees more emergency calls when water levels are low due to visitors getting stuck or injured on rivers that are too low for floating or boating. Multiple managers reported that they receive more complaints from visitors during droughts regarding overcrowding, aesthetics and their overall experience. One manager stated that the public at times expresses the belief that funds are being misused instead of managing the parks when vegetation goes dry. Another manager has noticed that visitors seem to consume more alcohol when they are unable to go boating, which the manager believes fuels more intense conflicts. The manager of one recreation area believes that greater public education of how drought impacts different regions of the state, cameras showing current water levels, and increased monitoring of park websites by visitors would help minimize conflicts and reshape visitor expectations. Pressure and complaints during drought periods appear to increase staff turnover, according to another manager.

Management units may shift staff between different park locations during drought. Parks with higher attendance may need additional employees to manage overcrowding. Drought conditions also necessitate performing maintenance tasks to minimize fire risks and informing visitors of limitations. Some parks mow grass to create fire breaks, and most post signs and updates on websites to notify visitors of water levels and other restrictions. They also may need to increase staffing to enforce rules and limitations imposed during drought. During slow periods, parks generally have deferred maintenance or temporary tasks that need to be completed. Vendors and concessions are likewise often mobile and can shift to different parks depending on how drought has impacted visitation.

Future vulnerability

Though several park managers do not currently see negative impacts of drought, nor do they expect to see them in the next 5-10 years, others have taken measures to reduce future vulnerability to drought. At some parks, managers have diversified activities available to ensure recreation opportunities when water levels are low. Some are considering improving camping facilities, adding birding trails, and hosting more events to bring visitors in year-round regardless of water levels. Another park recently received the first International Dark Sky designation of Oregon’s state parks. Staff have invested in interpretive programs for star gazing and have noticed an increase in visitors coming to the park for that purpose in the past few years.

Managers have prioritized decreasing water use in their parks to reduce future vulnerability to drought. One management unit recently invested $5,000 in xeriscaping in one park. That unit is also redesigning their park layouts, especially campgrounds, in an attempt to consolidate irrigation into small communal greenspaces for people to enjoy. At one park, the manager had decreased the amount of irrigated land by 20 acres. A goal in that park is to bring in native plants that support pollinators and provide aesthetic appeal, ecological benefits and water conservation.

Chapter 5: Recreational Fishing

Summary

Cold-water and warm-water fish alike are susceptible to declines in distribution, production, survival, abundance, growth and body condition due to drought-induced habitat degradation. In response to drought conditions, the Oregon Department of Fish and Wildlife (ODFW) may enact voluntary or legally enforced restrictions on angling to protect fish populations. This report records the impact of recent droughts on recreational fishing in Oregon and determines which locations have historically been affected by compiling reports from the DIR, media and academic literature. Recreational fishing impacts were recorded in nearly every county of the state and encompassed instances of habitat degradation, parasites and disease, and impaired spawning during droughts. Fish kills, fishing closures or restrictions, and reductions in fish distribution, abundance and survival also occurred. Two periods of drought were particularly hazardous for fish in Oregon: 2013-2015 (40 impacts) and 2020-2022 (66 impacts). Jackson County had the highest number of fish-related impacts reported (seven impacts), while Klamath and Deschutes counties each had six impacts. Review of DIR reports indicated that media attention to fish ecology is often tied to the ways humans are affected, such as through angling restrictions. Though angling restrictions are generally due to habitat degradation, fish disease outbreaks and other fish health concerns, they should not be interpreted as a comprehensive record of all the ways drought may affect fish in Oregon. Future analysis of the impact of drought on fishing and fish ecology would benefit from greater formal collaboration with tribal communities and the ODFW. Useful data would include comprehensive records of instances that angling restrictions were put into place (dates and locations) and the criteria used to determine when angling restrictions are necessary.

Introduction

Oregon's lakes, streams and reservoirs host a range of natural and stocked fish populations that draw locals and visitors alike for recreational angling. Salmon, bass, and multiple species of trout are the most popular game fish in Oregon (Oregon Department of Fish and Wildlife, n.d.). In addition to salmonids, several species of suckers and lamprey play critical roles in Native American culture, diet and medicine, making those fish of high importance as well (Castillo 2022 Ehrlich 2022). Low water levels and streamflow associated with drought commonly cause overall declines in fish distribution, production, survival, abundance, growth and body condition due to habitat fragmentation, water temperature increases, low dissolved oxygen concentrations and proliferation of diseases and toxins (VerWey et al. 2018).

A study by Oregon State University predicts that native cold-water species, especially juvenile Chinook salmon, will become substantially less abundant in the mainstem Willamette River if its water temperature increases by 2°C (Gregory 2015). Fish cannot physiologically thermoregulate and therefore rely on the ability to travel in search of suitable habitat as conditions degrade (Collingsworth et al. 2017). Salmon and trout thrive in cool water and can respond to early signs of drought by moving to deeper and/or cooler water at the onset of low-flow conditions if migration corridors remain suitable (Kahler et al. 2001, Dobos et al. 2016). Habitat fragmentation due to artificial barriers and low flows restricts movement, forcing salmonids and other species to stay in unfavorable conditions that induce physiological stress.

Fish with a higher relative tolerance to drought are primarily non-native warm-water species that prefer slow-moving or standing water. Bass, sunfish, crappie, channel catfish, bullheads, yellow perch and walleye (all of which are non-native to Oregon) fall into this category (Oregon Department of Fish and Wildlife, n.d.). While bass are a highly popular gamefish, other warmwater species are generally smaller and considered less desirable to recreational anglers. It is also important to note that even warmwater fish are susceptible to warm water temperatures around 30°C (Oregon Department of Fish and Wildlife, n.d.).

Lamprey have existed for hundreds of millions of years, indicating that they may be relatively resilient to climate change (Wang et al. 2021). However, lamprey physiology, reproduction and behavior are altered as water temperatures increase. For instance, Pacific lamprey and Western Brook lamprey larvae exhibit reductions in survival above 18°C (Meeuwig et al. 2005).

Drought conditions can increase the likelihood of cyanobacterial blooms (Lisboa et al. 2020). Some cyanobacteria species associated with blooms release toxic compounds that have severe short-term, chronic or deadly effects on fish (CDC 2022). Furthermore, cyanobacteria associated with harmful blooms have been identified as sources of antibiotic resistance genes (Wang et al. 2020). Antibiotic resistance genes found in cyanobacteria can be transmitted to other bacteria through horizontal gene transfer, jeopardizing the efficacy of antibiotic use in fish hatcheries (Wang et al. 2020; Schar et al. 2021).

Even cyanobacterial blooms that aren't labeled "harmful" cause problems for fish. Cyanobacteria float on the water surface and move through the water column, limiting visibility, blocking sunlight and clogging fish gills (USEPA 2022). Visual predators may have difficulty finding prey and aquatic plant growth may decrease under these conditions. As the cyanobacteria die, bacterial and fungal decomposition consumes dissolved oxygen, resulting in hypoxia, and may produce toxic methane and hydrogen sulfide (CDC 2022). These areas of low oxygen are called "dead zones" due to fatal impacts on fish and aquatic plants (Bailey et al. 2020). Dead zones are commonly associated with fish die-offs and can result in the complete elimination of all nearby aquatic life (USEPA 2022). Dead zones often appear off Oregon's coast during the summer (National Science Foundation, n.d.).

Low flow in drought-affected habitats also provides opportunities for piscine disease to spread, especially as fish begin to crowd together (Petty et al. 2022). Correspondence with the ODFW indicated that disease outbreaks in wild fish populations are not routinely tracked, but several instances arise in the media due to impacts on angling. In recent years, Oregon has experienced outbreaks of *Ceratonova shasta* in the Klamath River and *Cryptobia* on the north coast of Oregon. These diseases caused die-offs and limited reproduction in salmon and trout (Profita 2019; Smith 2021).

In response to drought conditions, the ODFW may enact voluntary or legally enforced restrictions on angling. Areas may be closed entirely or only during the hottest times of the day ("hoot owl rules") to reduce stress on fish. Correspondence with the ODFW found that water temperature criteria are used to determine when hoot owl rules are necessary, but information regarding what those criteria are was not provided. Conversely, in the most extreme situations, the ODFW may encourage anglers to take as many fish as possible, knowing that fish left in the water body will likely die.

Drought impacts to recreational fishing reported in media

This report records the impact of drought on recreational fishing in Oregon and determines which locations have historically been affected by compiling reports from the National Drought Mitigation Center's (NDMC) Drought Impact Reporter (DIR), media and academic literature. Note: the effects of drought often cover several counties. Each county is counted as a separate impact, even if the impact was reported from one news story.

Review of DIR reports indicated that media attention to fish ecology is often tied to the ways humans are affected, such as through angling restrictions. However, media reports help fill in data gaps: for instance, the ODFW does not track disease outbreaks in wild fish populations, per email communication with the organization. News reports serve to provide some record of wild fish disease, even though reporting is based on the effect on humans. There are also few follow-up reports to indicate when angling restrictions ended and whether predictions of impacts were realized. Though angling restrictions are generally due to habitat degradation, fish disease outbreaks and other fish health concerns, they should not be interpreted as a comprehensive record of all the ways drought may affect fish in Oregon. Future investigations into the effect of drought on fish in Oregon would benefit from increased collaboration with the ODFW. Useful data would include comprehensive records of instances that angling restrictions were put into place (dates and locations) and the criteria used to determine when angling restrictions are necessary.

Recreational fishing impacts were recorded in nearly every county of the state (Figure 5.1). Reports encompassed instances of Oregon fish experiencing habitat degradation, parasites and disease, and impaired spawning during droughts. Fish kills, fishing closures or restrictions, and reductions in fish distribution, abundance and survival also occurred. Two periods of drought were particularly hazardous for fish in Oregon: 2013-2015 (40 impacts) and 2020-2022 (66 impacts), with only 10 impacts being reported to DIR in between, all of which occurred from 2017 to 2019. Jackson County and the Klamath Basin stand out as particularly vulnerable to fishing-related drought impacts. Western Oregon also sustained several impacts, particularly during the 2013-2015 drought. Central Oregon and eastern Oregon were subject to fewer impacts than other parts of the state.

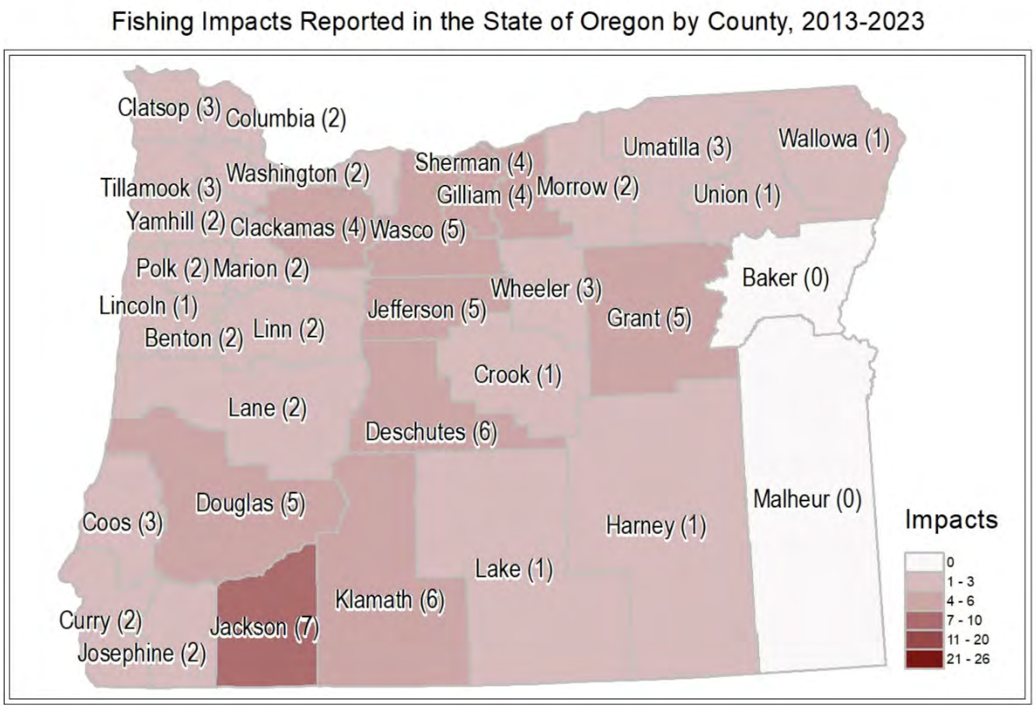


Figure 5.1. Impact reports on fish in Oregon by county, 2013-2023.

2013-2015

Between October 2013 and July 2015, 40 reports of fish habitat degradation and negative health impacts were recorded across Oregon (Figure 5.2). Several fish-related drought impacts pertained to large parts of the state. In July 2015, ODFW closed afternoon fishing on most rivers and creeks in the state due to low water levels and high water temperatures (Urness 2015). Fishing was completely closed on the lower Willamette, lower Clackamas and sections of the John Day River. Sturgeon mortality attributed to drought also caused managers to close sturgeon fishing in the Columbia River (Bonneville Dam to McNary Dam) beginning July 18, 2015.

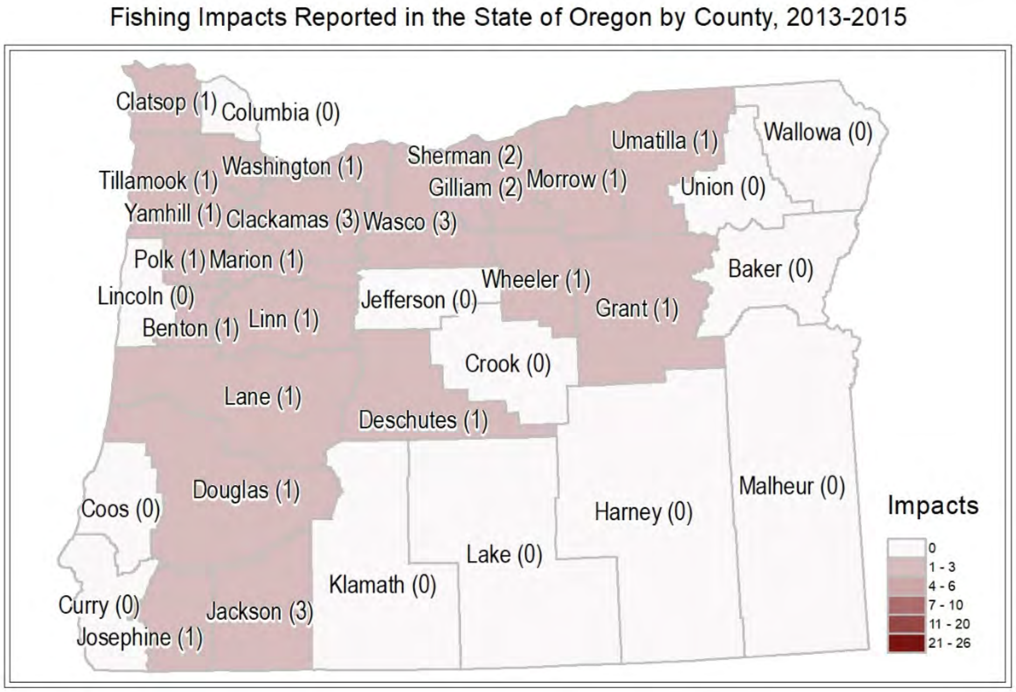


Figure 5.2. Impact reports on fishing in Oregon by county, 2013-2015.

2017-2019

Ten drought impacts related to fish were reported between 2017 and 2019 (Figure 5.3). Reports of fish impacts came from southern Oregon in 2017 and 2018. Coho salmon fishing for sport and commercial purposes was closed along the southern coast of Oregon in April 2017 (Associated Press 2017). The coho salmon closures were intended to allow salmon to spawn and recover from population declines due to drought and other challenges the previous few years. A similar widespread closure arose in December, when salmon fishing was closed on the northern coast of Oregon (Urness 2019). There had been a pre-spawn die-off of Chinook salmon near Tillamook in the Wilson, Nestucca and Kilchis rivers. The die-off was caused by a parasite called *cryptobia*, which had spread rapidly among salmon trapped in small pools due to drought.

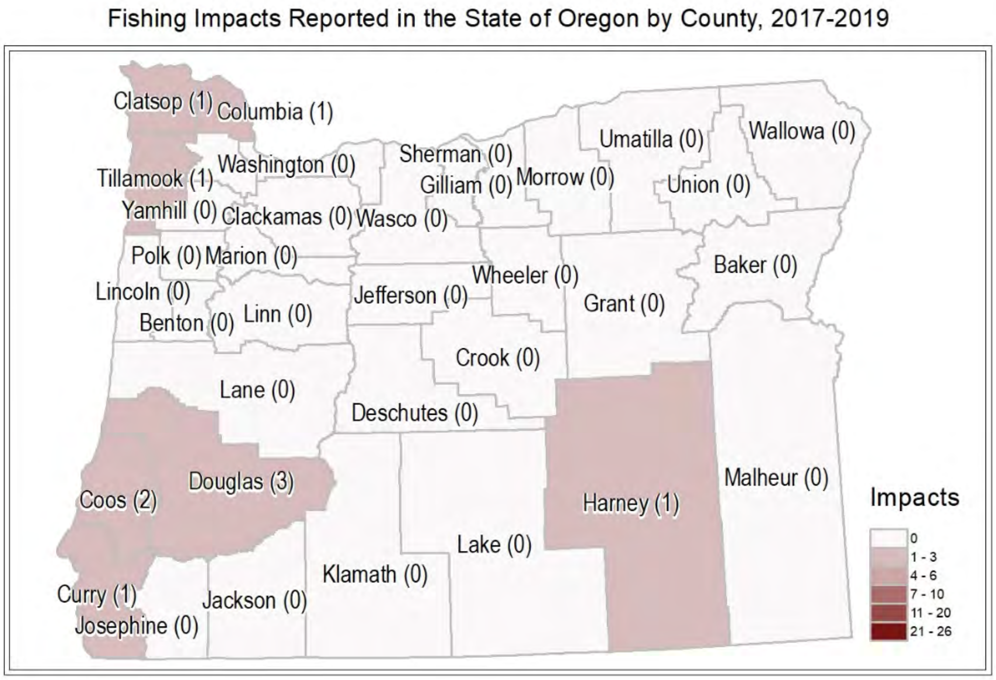


Figure 5.3. Impact reports on fishing in Oregon by county, 2017-2019.

2020-2022

Sixty-six reports of fish-related impacts were made over an extended period of drought between June 2020 and August 2022 (Figure 5.4). Emergency fishing restrictions were put in place across Oregon from July 1 through September 30, 2021, due to drought (USDM Status = D1-D4; KTVZ News Sources 2021). Impacted water bodies included: Deschutes River from the mouth to Sherars Falls, Nehalem River, Umpqua and North Umpqua rivers, portions of the Rogue and Illinois rivers, and Hyatt and Howard Prairie reservoirs.

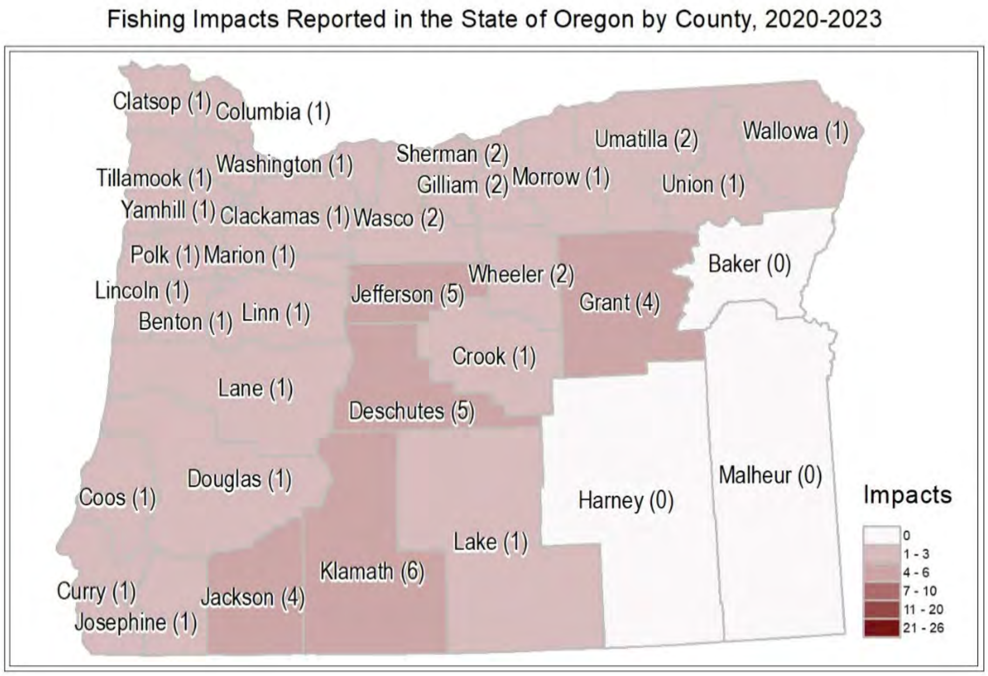


Figure 5.4. Impact reports on fishing in Oregon by county, 2020-2023.

Jackson County

In January 2014, Applegate Lake was at its lowest level since its construction in 1980, leaving Applegate River too dry for steelhead to move from the Rogue River into the Applegate River. Fishermen were concerned as the steelhead fishing season would end in March (Medford Mail, 2014). Jackson County was in the news again in June 2014, when low flow left thousands of juvenile chinook salmon and steelhead trapped in Bear Creek in downtown Medford, Oregon. The fish were stuck in oxygen-depleted pools of water measured at 70 degrees F. Volunteers and the ODFW were able to capture and transport several hundred fish upstream to better conditions (Freeman 2014).

Fishing limits and size restrictions were lifted at Howard Prairie Lake in June 2020. The lake was only 25% full and managers expected the fish to die in low water levels (Walgamott 2020). Later that year, steelhead and coho salmon had to be rescued from small pools created by low-flow conditions in the East Fork of Evans Creek in August 2020. Trapped fish were expected to die within a week without intervention. Local residents of the Rogue River Basin were asked to report stranded fish in need of rescue (Medford Mail, 2020).

Klamath Basin

Historically low spring and summer precipitation in 2021 (USDM Status = D4) caused widespread damage to steelhead, salmon and fish considered sacred by the Klamath Tribes (Cureton Cook 2021). Up to 70% of young salmon in the Klamath River began dying by May 4, 2021 (Smith 2021). The Yurok Tribal Fisheries Department reported that 97% of the salmon were infected with *C. shasta*, which worsens during drought conditions. Yurok Vice Chairman Frankie Joe Myers described juvenile fish die offs as “an absolute worst-case scenario” from a fish ecology perspective. Despite the massive amount of salmon deaths, the Bureau of Reclamation announced later in May 2021 that no water would be released into the Klamath River that year (USDM Status= D4; Schwartz 2021). Normally, incoming water would flush out salmon disease and support fish populations.

Though other parts of Oregon did not report fish impacts in 2022, the new year did not bring reprieve to the Klamath Basin (USDM Status = D4). On April 11, 2022, the Klamath Reclamation Project announced that salmon would receive about half of the normal amount of water that year as inflow to the Upper Klamath Lake was at a historic low (Flaccus 2022). The Bureau of Reclamation warned farmers and Tribes that conditions could worsen over the course of the year. By August 23, 2022, the Klamath Irrigation District was out of water (Associated Press, August 24, 2022).

Western Oregon

Low snowpack in the winter of 2014-2015 led to record low flow conditions throughout the Pacific Northwest. An academic study reviewed the effects of 2015's low snowpack-associated drought on coastal cutthroat trout (*Oncorhynchus klamath klamath*) in western Oregon (VerWey et al. 2018). The study evaluated the abundance, growth and movement patterns of coastal cutthroat trout in two reaches of an unnamed headwaters stream over a three-year period that spanned two years before and one year during a severe drought. The study found that the estimated abundance and total biomass of the trout declined during the drought compared to the two years prior. The fish also were less likely to move more than two meters from their release point during drought and only moved upstream to pools, while in non-drought years some fish moved to riffles. The study concluded that drought in the Pacific Northwest would likely reduce the abundance of fish in small headwater streams and increase the fish's use of pool habitats found in structurally complex streams.

Low water levels in the Willamette, Clackamas and Santiam rivers caused fatally high water temperatures, leading to deaths of pre-spawn fish in June 2015 (Miller, June 19, 2015). Drought conditions that month led the North Nehalem Hatchery (Tillamook County) and Trask River Hatchery (Clatsop County) to release fish earlier than planned (Miller, June 25, 2015). Conditions were poor both at the release sites and within the hatcheries. Some of the fish were already trapped in pools of water within weeks of release.

At the mouth of the Deschutes River in July 2015 (USDM Status = D3), around 50 sockeye salmon had died due to gill rot, a disease related to warm water associated with droughts (ODFW 2015). Many rivers in Oregon were above 70 degrees F (21 degrees C), creating dangerous conditions for salmon and trout survival. Low water levels and high temperatures were attributed in part to the warm, dry winter and resulting low snowpack. Fish biologists were concerned that at least half of the 500,000 sockeye salmon in the Columbia River Basin could be killed by the unusually warm water (Associated Press 2015).

Starting September 1, 2021, steelhead fishing was also closed in the lower Umatilla River and sections of the Deschutes and John Day Rivers (USDM Status = D3-D4; ODFW 2021). Returns of upriver steelhead from the Columbia Basin were the lowest since counts had begun in 1938 (ODFW 2021).

Central Oregon

Delayed rains in fall 2013 were associated with similarly delayed redd construction by Oregon coastal coho salmon, according to a study in the Smith River, central Oregon (Butler et al. 2021). Redds are depressions in the river bottom created by female salmon for laying eggs and are necessary for reproduction (Idaho Fish and Game 2023).

Wickiup Reservoir was at 1% capacity, a historical low, in September 2020 due to poor snowpack and long-term drought (Kohn, September 15, 2020). The Deschutes River was receiving no flow from the reservoir and was expected to decline rapidly (USDM Status = D3). By November 2020, Wickiup Reservoir (USDM Status = D3) was no longer suitable for the thousands of fish inhabiting it (Kohn, November 2, 2020). Wickiup Reservoir was similarly low in the following years: in July 2021, the reservoir reached 14% full and set a new record for the lowest fill level for that time of year (Goldwasser 2021). In 2022, the reservoir was drained to 3% by mid-October (Associated Press, October 14, 2022). The extremely low water levels were attributed in part to persistent drought in each of those years.

Eastern Oregon

Eastern Oregon experienced few fishing-related drought impacts, but several arose in 2018. In April 2018, low water levels in Mann Lake (Harney County) caused insufficient dissolved oxygen levels for fish (Plaven and Trainor 2018). Nearly all the Lahontan cutthroat trout in the lake had died, and the ODFW was uncertain it would be able to restock the fish for harvest that spring due to the low water levels. In fall of that year, Coho salmon spawning was delayed in Douglas County as low streamflow prevented the fish from swimming upstream (Harrell 2018).

References

Associated Press. Hot water kills half of Columbia River sockeye salmon. Oregon Live (OR), July 27, 2015. https://www.oregonlive.com/environment/2015/07/hot_water_killing_half_of_colu.html

Associated Press. Salmon fishing shut down for southern Oregon coast. Outdoor News (MN), April 14, 2017. https://www.outdoornews.com/2017/04/14/salmon-fishing-shut-southern-oregon-coast/

Associated Press. Water deliveries halted to farmers in Oregon, California. Associated Press News (NY), August 24, 2022. https://apnews.com/article/156lamat-lakes-california-156lamath-falls-dcfbed375dc879d83f3124c563ecb11c

Associated Press. Oregon reservoir emptied for an unprecedented 3rd year in a row. Seattle Times (WA), October 14, 2022. https://www.seattletimes.com/seattle-news/oregon-reservoir-emptied-for-unprecedented-3rd-year-in-a-row/

Bailey, A., L. Meyer, N. Pettingell, M. Macie, and J. Korstad (2020). Agricultural Practices Contributing to Aquatic Dead Zones. DOI: 10.1007/978-981-15-3372-3_17.

Butler, M.B., R.L. Flitcroft, and G. Giannico (2021). The relationship between hydroregime and coho salmon (Oncorhynchus kisutch) redd construction in the Smith River, Oregon. Ecology of Freshwater Fish 30(4), 519-530. https://doi.org/10.1111/eff.12601

Castillo, E. Klamath Tribes sue federal government over endangered fish. Oregon Public Broadcasting (OR), June 3, 2022. https://www.opb.org/article/2022/06/03/klamath-tribes-sue-federal-government-over-endangered-fish/

Collingsworth, P.D., D.B. Bunnell, M.W. Murray, et al. (2017). Climate change as a long-term stressor for the fisheries of the Laurentian Great Lakes of North America. Rev Fish Biol Fisheries 27, 363–391. https://doi.org/10.1007/s11160-017-9480-3

Cureton Cook, E. Fall rains can’t undo pains of drought in Oregon and Washington. Oregon Public Broadcasting (OR), November 18, 2021. https://www.opb.org/article/2021/11/18/fall-rains-cant-undo-pains-of-drought-in-oregon-and-washington/

Dobos, M.E., M.P. Corsi, D.J. Schill, J.M. Dupont, and M.C. Quist. (2016). Influences of summer water temperatures on the movement, distribution, and resource use of fluvial Westlope Cutthroat Trout in the South Fork Clearwater River Basin. North American Journal of Fisheries Management 36:549–567.

Ehrlich, A. Yakama, Warm Springs tribes celebrate lamprey harvest. Oregon Public Broadcasting (OR). August 1, 2022. https://www.opb.org/article/2022/08/01/yakama-warm-springs-tribes-celebrate-lamprey-harvest-willamette-oregon/

Freeman, M. A thirst for water. The Astorian (OR), June 8, 2014. https://www.dailyastorian.com/news/a-thirst-for-water/article_e1795c44-c6be-5270-

8170-839a2da40449.html
Goldwasser, Max. ‘Very bad news’: Wickiup Reservoir hits record-low level for this early in summer. KTVZ News (OR), July 9, 2021. https://ktvz.com/news/deschutes-county/2021/07/09/wickiup-reservoir-hits-record-low-water-levels-for-this-time-of-year/
Gregory, S. Fish and stream temperature. Oregon State University. 2015. https://inr.oregonstate.edu/book/export/html/1326.
Harrell, S. Despite rain, county remains in drought. The News Review (OR), November 25, 2018. https://www.nrtoday.com/news/despite-rain-county-remains-in-drought/article_4c007616-fac9-510f-8f5e-d765bce4741f.html
Howard, J. Drought and bullheads lift limits at two lakes. KDRV12 News, Jul 24, 2022. https://www.kdrv.com/news/drought-and-bullheads-lift-limits-at-two-lakes/article_bc7fe186-0b75-11ed-9937-b7297895b4c0.html.
Idaho Fish and Game. What is a redd? Salmon keep clearing out a “nest” for spawning. 2023. https://idfg.idaho.gov/article/what-redd-salmon-keep-cleaning-out-nest-spawning
Kahler, T.H., P. Roni, T.P. Quinn (2001). Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:1947–1956.
Kohn, M. With reservoir drained, Deschutes water flow in danger of decline. The Bulletin (OR), September 15, 2020. https://www.bendbulletin.com/localstate/with-reservoir-drained-deschutes-water-flow-in-danger-of-decline/article_95793242-f48c- 11ea-81eb-0fc55fd5bf6f.html
Kohn, M. Fish in peril after reservoir goes dry. The Bulletin (OR), November 2, 2020. https://www.bendbulletin.com/localstate/environment/fish-in-peril-after-reservoir-goes-dry/article_228127a6-1d57-11eb-8c9a-cfbbac8fe04d.html
KTVZ News Sources. ODFW: Emergency fishing regulations in response to drought to begin Wednesday. News Channel 21 (OR), June 30, 2021. https://ktvz.com/news/wildlife/2021/06/30/odfw-emergency-fishing-regulations-in-response-to-drought-to-begin-wednesday/
Lisboa, M.S., R.L. Schneider, P.J. Sullivan, and M.T. Walter (2020). Drought and post-drought rain effect on stream phosphorus and other nutrient losses in the Northeastern USA. Journal of Hydrology: Regional Studies, Volume 28. https://doi.org/10.1016/j.ejrh.2020.100672
Medford Mail (OR). Low and slow. January 24, 2014.
Medford Mail (OR). Rescue mission. August 22, 2020.
Meeuwig, M.H., J.M. Bayer, and J.G. Seelye (2005). Effects of temperature on the survival and development of early life stage Pacific and Western Brook Lampreys. Trans. Amer. Fish Soc. 134, 19-27.
Miller, H. Warm water blamed for pre-spawn Chinook salmon deaths. Statesman Journal (OR), June 19, 2015. https://www.statesmanjournal.com/story/news/2015/06/18/warm- water-blamed-pre-spawn-chinook-salmon-deaths/28944673/
Miller, H. Hatcheries releasing fish early because of drought. Statesman Journal (OR), June 25, 2015. https://www.statesmanjournal.com/story/news/2015/06/25/hatcheries- releasing-fish-early-drought/29316925/
National Science Foundation. New ways of taking the pulse of Oregon’s “dead zones”. No date. https://www.nsf.gov/news/special_reports/deadzones/glider.jsp
ODFW. 5 tips for fishing in hot water: warm water temps take a toll on fish. No date.

https://myodfw.com/articles/5-tips-fishing-hot-water

ODFW. Bacterial infection kills sockeye salmon in Deschutes River. ODFW News Releases (OR), July 8, 2015. https://www.dfw.state.or.us/news/2015/july/070815b.asp

ODFW. Emergency fishing closures begin Sept. 1 due to low steelhead returns. Argus Observer (OR), August 31, 2021. https://www.argusobserver.com/free_access/emergency-fishing-closures-begin-sept-1- due-to-low-steelhead-returns/article_5a01fc0a-09d3-11ec-bbdb-63088975a827.html

Petty, B.D., R. Francis-Floyd, and R.P.E. Yanong (2022). Bacterial diseases of fish. Merck Manual: Veterinary Manual. https://www.merckvetmanual.com/exotic-and-laboratory-animals/aquarium-fish/bacterial-diseases-of-fish

Plaven, G. and T. Trainor. Low water kills Oregon Lahontan cutthroat fishery. Klamath Herald News (OR), April 3, 2018. https://www.heraldandnews.com/news/local_news/low-water-kills-oregon-lahontan- cutthroat-fishery/article_f3a6813a-7374-51bd-9ccd-647b77e3fb9c.html

Profita, C. Salmon Die-Off Linked To Extremely Dry Conditions On Oregon’s North Coast. Oregon Public Broadcasting, Dec 13, 2019. https://www.opb.org/news/article/fall-chinook-die-off-parasite-oregon-north-coast/

Schar, D., C. Zhao, Y. Wang, D.G.J. Larsson, M. Gilbert, and T.P. Van Boeckel (2021). Twenty-year trends in antimicrobial resistance from aquaculture and fisheries in Asia. 2021. Nature Communications (12): 5384. https://www.nature.com/articles/s41467-021-25655-8

Schwartz, A. Reclamation says no water through A canal this year. Herald and News (OR), May 12, 2021. https://www.heraldandnews.com/news/local_news/reclamation- says-no-water-through-a-canal-this-year/article_0a694447-0b55-55df-9b74- 67f2d6cb7fea.html

Smith, A. Ongoing fish kill on the Klamath River is an “absolute worst-case scenario.” High Country News (CO), May 27, 2021. https://www.hcn.org/issues/53.7/indigenous- affairs-fish-ongoing-fish-kill-on-the-klamath-river-is-an-absolute-worst-case-scenario

Urness, Z. Afternoon fishing to be shut down on Oregon rivers. Statesman Journal (OR), July 16, 2015. https://www.statesmanjournal.com/story/news/2015/07/17/afternoon- fishing-shut-oregon-rivers/30253113/

Urness, Z. Salmon die-off expands, bringing total Chinook fishing closure on Oregon’s north coast. Statesman Journal (OR), December 13, 2019. https://www.statesmanjournal.com/story/news/2019/12/12/oregon-salmon-die-off-north-coast-fishing-wildlife-outdoors/4407552002/

VerWey, B.J., M.J. Kaylor, T.S. Garcia, and D.R. Warren (2018). Effects of a severe drought on summer abundance, growth, and movement of cutthroat trout in a Western Oregon headwater stream. Northwestern Naturalist 99(3):209-221.

Walgamott, A. With Howard Prairie Lake just 25% full, fishing limits lifted. Northwest Sportsman Magazine (WA), June 10, 2020. https://nwsportsmanmag.com/with-howard-prairie-lake-just-25-full-fishing-limits-lifted-to-encourage-harvest/

Wang, Z., Q. Chen, J. Zhang, T. Guan, Y. Chen, and W. Shi (2020). Critical roles of cyanobacteria as reservoir and source for antibiotic resistance genes. Environment International, Volume 144, https://doi.org/10.1016/j.envint.2020.106034.

Wang, C.J., J.M. Hudson, G. Lassalle, and T.A. Whitesel (2021). Impacts of a changing climate on native lamprey species: From physiology to ecosystem services. Journal of Great Lakes Research, Volume 47, Supplement 1, Page S186-S200.

Chapter 6: Waterfowl Viewing and Hunting

Summary

Oregon is a critical location for waterfowl due to its location along the Pacific Flyway. In this report, we document impacts of recent droughts on waterfowl in Oregon using the DIR, academic literature and correspondence with wildlife experts. The findings in this report should not be interpreted as a comprehensive analysis of all the ways drought may affect waterfowl and their habitats in Oregon, but rather an initial overview of locations and topics for further examination. Impacts on waterfowl included reduced visitation to wildlife refuges due to a lack of food and water, disease outbreaks attributed to crowding, and reports of reduced bird sightings. An extreme situation was encountered at the Lower Klamath Basin National Wildlife Refuge, where all hunting was closed for the September 2022 - March 2023 season. We found that the Klamath Basin National Wildlife Refuge Complex dominated instances of drought impacts on waterfowl. Lake Abert and the High Desert also emerged in our investigation as crucial waterfowl habitats vulnerable to drought. Future investigations into the effects of drought on waterfowl ecology, hunting and viewing in Oregon should include greater formal collaboration with the Oregon Department of Fish and Wildlife.

Introduction

Oregon provides critical habitat for many resident and migratory waterfowl populations that depend on wetlands, riparian areas and lakes as places to feed and rest. Birds often fly for an entire day before reaching the Klamath National Wildlife Refuges, which hosts up to 700,000 migratory birds in the fall (Neumann 2021). During drought years, birds have passed over the Refuges due to a lack of water and plants, putting themselves at risk of fatigue, starvation, disease, reproductive failure and predation (Alexander 2022). Bird hunting restrictions are rare but may be enacted in extreme situations. For example, the U.S. Fish and Wildlife Service closed the Lower Klamath Basin National Wildlife Refuge and neighboring Tule Lake National Wildlife Refuge to all bird hunting for the September 2022–March 2023 fall and winter seasons (Howard 2022). Drought conditions had led to a shortage of food, water and shelter for migratory water birds in the refuges, putting the bird populations in jeopardy (Howard 2022).

Crowding in wetlands due to limited water resources facilitates the spread of avian diseases such as avian influenza, avian botulism and avian cholera. Avian influenza is an ongoing catastrophe that killed around 52.7 million domestic and wild birds across the U.S. in 2022 (Chappell 2022). As of May 2023, Oregon has reported the fourth highest number of Highly Pathogenic Avian Influenza cases in wild birds (APHIS 2023). Popular hunting waterfowl such as American wigeons, American green-winged teal, Canada goose and mallards are among the most identified species in the current Highly Pathogenic Avian Influenza outbreak.

Drought impacts to waterfowl recorded in the media

This report records the impact of recent droughts on waterfowl in Oregon and determines which locations have been affected. We accomplish this by compiling reports from the National Drought Mitigation Center’s (NDMC) Drought Impact Reporter (DIR), media, academic literature and contact with Oregon wildlife experts and managers. We recommend greater formal collaboration with the Oregon Department of Fish and Wildlife for future assessments of the impact of drought on waterfowl. Drought affects waterfowl across the state, but impacts are particularly evident at the Klamath Basin National Wildlife Refuge Complex in Klamath County (Figure 6.1). Several other areas appear in the media, including Lake Abert, Oregon's High Desert and the Willamette Valley. Impacts were primarily seen during two periods of drought: 2012-2015 (Figure 6.2) and 2020-2022 (Figure 6.3).

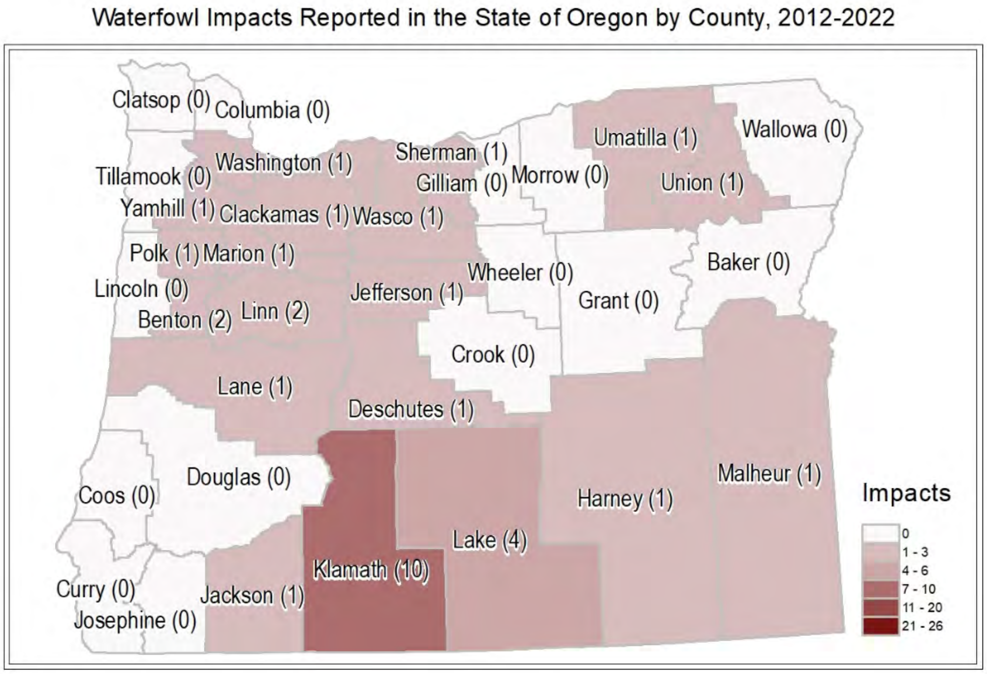


Figure 6.1. Impact reports on waterfowl in Oregon by county, 2012-2022.

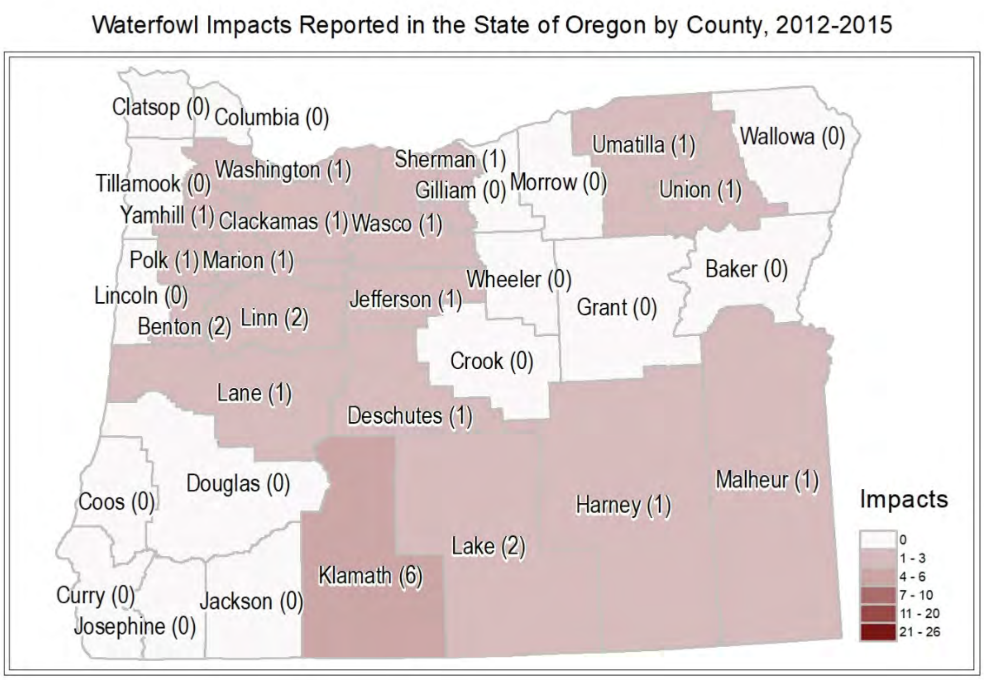


Figure 6.2. Impact reports on waterfowl in Oregon by county, 2012-2015.

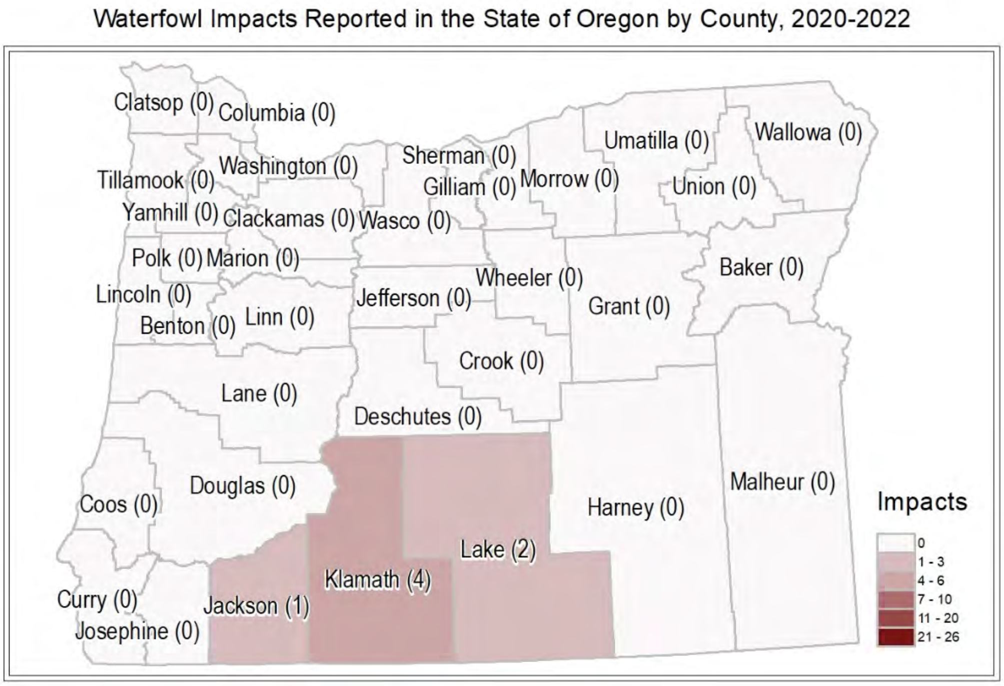


Figure 6.3. Impact reports on waterfowl in Oregon by county, 2020-2022.

Klamath Basin National Wildlife Refuge Complex

Klamath Basin National Wildlife Refuge Complex made up the majority of recorded impacts. Vast wetlands in the Klamath Basin of southern Oregon and northern California were host to migratory and resident birds before European settlement. Approximately 80% of birds on the Pacific Flyway pass through the Klamath Basin. Now, all but 25% of the wetland habitat has been drained and converted into agricultural lands. The Klamath Basin National Wildlife Refuge Complex was established in the early 20th century to preserve the remaining wetland habitat. The six wildlife refuges encompass approximately 200,000 acres: Lower Klamath Refuge (OR/CA), Upper Klamath Refuge (OR), Klamath Marsh Refuge (OR), Bear Valley Refuge (OR), Clear Lake Refuge (CA) and Tule Lake Refuge (CA). The refuges are highly dependent on the Bureau of Reclamation's Klamath Project for water, which is stretched thin between allocations for farmland, threatened and endangered fish, and the refuges.

Correspondence with officials with the U.S. Fish and Wildlife Service revealed that during droughts in the Klamath Refuges, managers see shifts in the timing of waterfowl life-cycle events such as nesting, hatching and molting—often 4-6 weeks earlier than during normal conditions. During severe droughts, birds pass over the Basin almost completely due to a lack of wetland habitat. Waterfowl sightings in the Klamath Refuges may decline to 95-98% below long-term averages during droughts.

A drought time series for the Klamath River Basin indicates widespread, severe (D2) to extreme (D3) drought with a short period of up to 20% of the basin in exceptional (D4) drought during 2013-2016, and another period of severe (D2) to extreme drought (D3) between 2018 and early 2019 (Figure 6.4). The drought from January 2020 to mid-2022 was noteworthy for its intensity and geographic spread, with much of the basin in extreme drought (D3) and a year of exceptional drought (D4) occurring in up to 30% of the basin. Impacts were reported for the Klamath Basin National Wildlife Refuges during the 2012-2013 drought and the 2020-2023 drought. It is important to note that drought is not the only factor impacting water management in the basin.

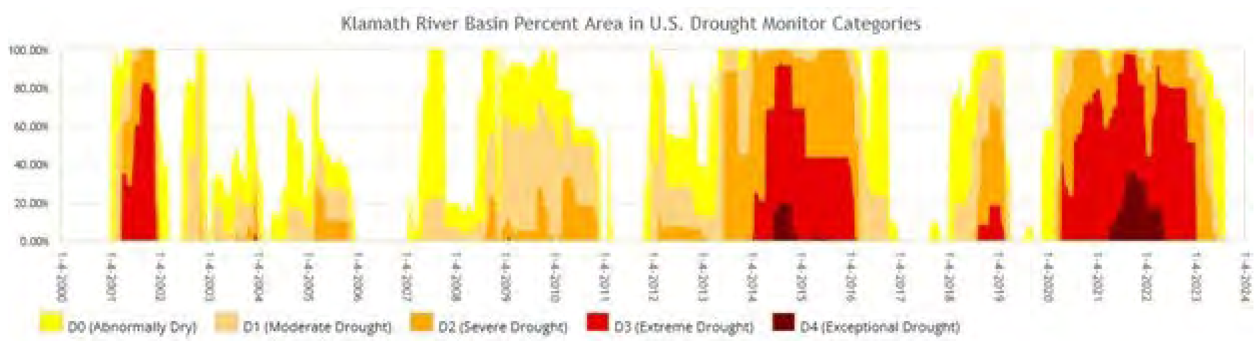


Figure 6.4. Drought time series for the Klamath River Basin.

Drought impacts are often specific to the Lower Klamath Basin Refuge and/or Tule Lake (California), but several impacts are recorded in the Drought Impact Reporter for the entire refuge complex during the extreme-exceptional drought of 2021 and 2022. The wildlife refuges in the Klamath Basin did not receive any water in 2021 (Flaccus 2021). In November 2021, it was reported that the Klamath Basin National Wildlife Refuge had been almost completely dry that year (Neumann 2021). Very few of the expected 700,000 migratory birds had stopped at the refuge complex.

Conditions did not improve much for the Klamath Refuges in 2022. Migratory ibis found dry conditions and a lack of food at Klamath Basin National Wildlife Refuge in October 2022 (USDM Status = D3; Alexander 2022). Wildlife experts expected other species migrating through the area to fare similarly, which could lead to starvation and fatigue in the birds.

The Lower Klamath Basin National Wildlife Refuge was specifically mentioned in several reports of drought impacts on waterfowl in Oregon. The Lower Klamath Refuge is considered one of the most important bird areas in Oregon, according to the National Audubon Society, owing to the number of birds that use its wetlands, agricultural lands, grasslands and sagebrush steppe habitats year-round (Trail 2022). The Lower Klamath Refuge hosts around 50% of all migratory birds along the Pacific Flyway year-round as well as during both the spring and fall migrations (USFWS n.d.). The 50,092-acre refuge is used by waterfowl for resting, feeding, nesting and raising young. Up to 1.8 million birds may use the refuge, which is fully dependent on the Bureau of Reclamation's Klamath Project for its water.

Waterfowl diseases were problematic in the Lower Klamath Refuge in 2012 and 2013. Drought was identified as a factor in the deaths of around 10,000 migrating waterfowl due to avian cholera in the Lower Klamath and Tule Lake national wildlife refuges in spring 2012 (Barnard 2012). The birds had been forced into closer conditions as the wetlands had shrunk to about half their normal size in the drought. The manager of the refuges expected around 15,000 more birds to die.

Another waterfowl disease outbreak occurred in the summer of 2013. As of July 2013, the refuge had not received water since March 2013 (Learn 2013). The refuge's marshes were drying earlier than they had in the past 70 years, leading to very few birds visiting the refuge that year. The Lower Klamath Refuge was nearly entirely dry as of August 31, 2013, forcing the birds to stop at Tule Lake. Around 9,000 ducks died at Tule Lake in August 2013 from avian botulism, again owing to overcrowding due to drought (Barnard 2013).

Drought conditions in the Lower Klamath were extreme in 2022. Lower Klamath and Tule Lake Wildlife Refuges closed all public waterfowl hunting for the 2022-2023 season (September 10–March 10) due to lasting drought (Howard 2022). Ducks Unlimited reported that only about 35% of the normal habitat was available for birds along the Pacific Flyway.

Lake Abert

Lake Abert, in southern Oregon, is another important waterfowl habitat. Lake Abert is a salt lake in the Great Basin that hosts migratory birds (Lane County Audubon Society 2022.). The lake is of great importance to the Pacific Flyway, providing an abundance of brine shrimp and flies for more than 80,000 birds including Wilson's phalaropes, American avocets, North American eared grebes, and snowy plover.

During droughts, salinity in the lake increases to the point that the shrimp and flies die off and the birds are left without a food source. Bird sightings may decline by nearly 82% at Lake Abert when water levels are low. Lake Abert has dried twice in recent history, in June 2014 and July 2021 (WaterWatch, n.d.). According to NASA's Earth Observatory, the lake was very close to drying in 2015 and 2022, as well (Voiland 2023).

High Desert

Oregon's High Desert was affected by drought in fall 2013. Chickahominy Reservoir, Malheur Lake, Warm Springs Reservoir and Goose Lake were expected to be dry or nearly dry for opening of hunting season in October 2013 (Monroe, September 12, 2013a). Ladd Marsh Wildlife Refuge, in the northeastern part of the state, similarly had few birds for hunting due to drought conditions (Monroe, September 12, 2013b). Drought impacts were apparent in the High Desert again in fall 2021. Only one colony of Franklin's gulls was sighted at Malheur National Wildlife Refuge in September 2021 due to lack of water and it was anticipated by some to be a bad breeding year (Brown 2021).

2020-2023 Highly Pathogenic Avian Influenza Outbreak

Preliminary investigation into Highly Pathogenic Avian Influenza (HPAI) in wild birds found no significant relationship between DSCI and the total number of cases in a county, or between DSCI and the number of cases per square mile in a county. Migratory birds tend to follow specific pathways where there are suitable resting spots, which are not evenly distributed throughout counties in Oregon. Inland birding areas noted by the Portland Audubon Society are primarily in the southern part of the state and the Willamette Valley. Counties with more than 10 cases of HPAI cluster around the Columbia River (Clatsop County – also on the Pacific Ocean, Columbia County, Morrow County; Multnomah County), known birding areas (Klamath Basin in Klamath County; Summer Lake and Lake Abert in Lane County) or along the Pacific Flyway (Willamette Valley: Lane County). Given birds' mobility, connecting drought in a particular location with increased incidence of HPAI would require a different research design, tracking infections and drought over space and time.

References

Alexander, K. Here's what it's like for migratory birds trying to fly south through California amid record drought. San Francisco Chronicle (CA), October 22, 2022. https://www.sfchronicle.com/bayarea/article/california-drought-bird-migration-17531568.php

Animal and Plant Health Inspection Service (APHIS). 2022-2023 Detections of Highly Pathogenic Avian Influenza. 2023. U.S. Department of Agriculture. https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/avian/avian-influenza/2022-hpai.

Barnard, J. Drought, cholera kill 10,000 birds at vital refuge. NBC News (NY), April 8, 2012. https://www.nbcnews.com/id/wbna46987169

Barnard, J. Drought a key factor in duck refuge die-off. The Spokesman Review (WA), August 31, 2013. https://www.spokesman.com/stories/2013/aug/31/drought-a-key-factor- in-duck-refuge-die-off/

Brown, L. The impact of drought is far reaching in Harney County. Burns Times-Herald (OR), September 22, 2021. https://www.btimesherald.com/2021/09/22/the-impact-of-the-drought-is-far-reaching-in-harney-county/

Chappell, B. (2022). What we know about the deadliest US bird flu outbreak in history. National Public Radio: All Things Considered, Dec 2, 2022. https://www.npr.org/2022/12/02/1140076426/what-we-know-about-the-deadliest-u-s-bird-flu-outbreak-in-history

Flaccus, G. Water crisis "couldn't be worse" on Oregon-California border. KMPH Fox 26 News (CA), May 4, 2021. https://kmph.com/news/local/water-crisis-couldnt-be- worse-on-oregon-california-border#

Howard, J. DroughtWatch: No hunting this fall and winter at two wildlife refuges. NewsWatch 12 ABC (OR), August 28, 2022. https://www.kdrv.com/news/droughtwatch- no-hunting-this-fall-winter-at-two-wildlife-refuges/article_9db8a180-26f9-11ed-883f-4b4ca3dc6c12.html

Lane County Audubon Society. Adequate water in Lake Abert is essential for more than 80,000 migratory birds. Lane County Audubon Society (OR), March 1, 2022. https://laneaudubon.org/adequate-water-in-lake-abert-is-essential-for-more-than-80000-migratory-birds/

Monroe, B. Hunting outlook for Oregon's High Desert Region. Oregon Live (OR), September 12, 2013a. https://www.oregonlive.com/sports/oregonian/bill_monroe/2013/09/high_desert.html

Monroe, B. Hunting outlook for Oregon's Northeast Region. Oregon Live (OR), September 12, 2013b. https://www.oregonlive.com/sports/oregonian/bill_monroe/2013/09/northeast.html

Neumann, E. Migrating birds skip dry Klamath refuges, disrupting annual migration. Oregon Public Broadcasting (OR), November 2, 2021. https://www.opb.org/article/2021/11/02/migrating-birds-skip-dry-klamath-refuges-disrupting-annual-migration/

Trail, P. The Klamath Basin's water crisis is a growing disaster for waterfowl. Audubon Society, March 11, 2022. https://www.audubon.org/news/the-klamath-basins-water- crisis-growing-disaster-waterfowl

USFWS. Lower Klamath National Wildlife Refuge. U.S. Fish and Wildlife Service, no date. https://www.fws.gov/refuge/lower-klamath/about-us
Voiland, A. Shrinking Lake Abert. NASA Earth Observatory, 2023. https://earthobservatory.nasa.gov/images/150891/shrinking-lake-abert#:~:text=The%20lake%20mostly%20dried%20up,for%20brine%20shrimp%20and%20flies.
WaterWatch. Lake Abert: A natural jewel in peril. WaterWatch.org (OR), no date https://waterwatch.org/programs/lake-abert/

OREGON DROUGHT VULNERABILITY ASSESSMENT: An Assessment of Oregon's Drought Policies

Prepared by the University of Oregon School of Law
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EXECUTIVE SUMMARY

This report is part of a four-part assessment of Oregon's drought vulnerability and provides an assessment of state drought policies.

Vulnerability to drought describes the propensity to be adversely impacted by drought, which describes an extended period of precipitation deficit that results in insufficient water to meet human and ecosystem needs. Vulnerability is influenced by the frequency of exposure to drought conditions and the likelihood that those conditions result in negative impacts and the ability to cope with or adapt to those conditions. Government policies impact how communities and natural systems experience drought and therefore play an important role in determining vulnerability.

This report provides a descriptive overview of state drought policies, identifies vulnerability gaps in how the State responds to and plans for drought, and highlights opportunities to enhance drought resilience.

Drought response measures address short-term impacts during drought. Oregon's response framework includes a suite of emergency and standing policies that help alleviate impacts during drought. Identified vulnerability gaps are:

- The need to improve coordination of state drought response actions.
- Information gaps around the efficacy of state emergency drought tools.
- Limited measures to address environmental impacts from drought.
- The lack of established funding programs to respond to drought impacts.

Drought planning measures are taken before drought onset to build institutional capacity to respond to drought and to limit drought impacts. Oregon has an emergency response plan and has incorporated drought resilience into statewide and local plans that address natural hazard mitigation, water and natural resources, and climate adaptation. Identified vulnerability gaps are:

- The need to strengthen state drought resilience planning.
- The need for improved evaluation of drought impacts and policies.
- The need to increase support for local drought planning.
- The need for planning to address ecosystem vulnerabilities.

Drought resilience measures increase the ability to absorb, cope with, and recover from drought. Measures that increase drought resilience are varied, reflecting the range of factors that impact drought risk and vulnerability. This report describes state resilience measures that improve water conservation, enhance water supply, support health ecosystems and natural lands, address cascading hazards, strengthen data and information, and fund resilience policies.

The aim of this report is to describe how the State manages drought and to evaluate how its policies impact vulnerability to drought. This report does not recommend specific measures to address vulnerabilities, but the information is intended to support the State in understanding how drought policies impact vulnerability and in identifying policy opportunities to build a more drought-resilient Oregon.

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INTRODUCTION

Role of Policy in Drought Vulnerability

Drought can be defined as an extended period of precipitation deficit that results in insufficient water to meet demands (O'Neill and Siler 2023). Vulnerability to drought describes the propensity to be negatively impacted by drought and is a function of the likelihood to be exposed to drought conditions (exposure), sensitivity to those conditions (sensitivity), and the ability to adapt to those conditions (adaptive capacity) (Engstrom 2020). The physical conditions that result in drought are only one component of determining vulnerability (Wilhite 2000). Impacts from drought are largely a function of social factors (Wilhite 2000), which influence the demands we place on water supply and our ability to cope with or adapt to water deficits. Changes in social factors will therefore change how vulnerable a community is to drought (Wilhite 2000).

Government policies, which include laws, regulations, investments, and programs, affect how communities and ecosystems are impacted by drought. Policies impact the physical and social conditions that influence vulnerability. For example, land use, water, and natural resources policies affect the types of land uses, health of natural landscapes, and water availability, all of which influence the type and extent of impacts from drought. Policies also frame how we build resilience to, prepare for, and respond to drought. This report refers to these types of policies collectively as "drought policies."

As a natural and recurring part of most climates, the primary focus of drought policies should be to reduce long-term risk. Drought policies should also be equitable in who they support and the impacts they address. The foundation of drought policies should be proactive planning for drought and the adoption of strategies to build resilience (WMA et al. 2014). While communities can reduce drought impacts through proactive risk reduction strategies, drought will still occur, and policies should incorporate response frameworks that provide tools to address impacts from drought conditions (Wilhite et al. 2014).

About this Report

This report provides an assessment of the impact of state drought policies on Oregon's drought vulnerability. The report includes an overview of state drought management frameworks and a discussion of gaps in those frameworks that increase vulnerability. The report is intended to help the State understand how existing policies impact vulnerability to drought and to identify actions to reduce vulnerability.

This report discusses three types of drought policies: drought response, drought planning, and drought resilience. They are defined in this report as:

- **Drought response describes interventions that address impacts during drought.** Examples of response policies include measures that address temporary water supply interruptions and emergency grants and loans to offset losses. Drought response measures are limited in their capacity to address long-term vulnerability to drought. Once drought conditions become an emergency, there are few management measures available to address impacts (Wilhite 2016). In addition, because these measures focus on alleviating short-term impacts during drought, they often inadvertently support the continuation of practices that reduce long-term resiliency (Wilhite 2016). However, through proactive planning, drought response policies can be structured to support long-term resilience goals.

- **Drought planning describes actions taken before drought to build institutional capacity to respond to drought and to limit drought impacts.** Planning recognizes drought as a natural feature of climate and prepares communities for periods of water shortage (WGA Drought Forum 2015; Wilhite et al. 2005). Drought planning may incorporate vulnerability assessments, contingency plans for emergency response, and plans that identify strategies to build resilience. Planning for drought response allows communities to develop an organized response strategy that is effective in addressing identified vulnerabilities, is consistent with long-term resilience goals, and is equitable in addressing impacts and providing relief. Resilience planning provides a framework to understand vulnerabilities and build a strategy to reduce risk from drought.
- **Drought resilience describes the ability to withstand and recover from drought conditions, reducing susceptibility to drought and lessening impacts when drought does occur.** In the context of drought, resilience is closely connected to mitigation planning and strategies, which identify measures to reduce impacts from drought before it occurs (Wilhite 2000). Examples of drought resilience measures include water conservation, water supply enhancements, infrastructure improvements, education programs, and streamflow and ecosystem restoration. Proactive strategies that build resilience to drought through mitigation and preparedness should be the foundation of drought policies (Wilhite 2016).

While all levels of government play a role in managing drought, this report focuses on assessing state drought management. States have primary authority for water allocation and have regulatory authority over many of the natural resources and sectors impacted by drought. State agencies contribute to the collection, collation, and dissemination of data and information that supports drought preparedness and response. State requirements and programs direct and support local planning and the adoption of drought mitigation measures. State agencies may also own and manage land and facilities and play an important role in conserving and curtailing water use and implementing measures to reduce drought impacts.

Oregon's drought policies have historically focused on its operational response to drought emergencies, including a drought response plan and authorities to manage drought impacts. The State has more recently invested in enhancing its mitigation planning and policies to build drought resilience. These investments have largely occurred in response to notable droughts, which highlighted the State's vulnerabilities.

Report Organization

This report is organized into three sections:

- **Section I** provides a detailed description of the State's drought response and planning frameworks.

- **Section II** identifies gaps in the State's response and planning frameworks that increase vulnerability to drought. Gaps were identified through findings in state plans and prior assessments and literature on best practices. The report highlights model approaches from other states that could help address the identified gaps. The report does not recommend specific policy actions but is intended to support the State in identifying policy approaches to reduce drought vulnerability.
- **Section III** provides an overview of the State's drought resilience policies. The section describes key types of drought resilience strategies, provides examples of policies that implement those strategies, and highlights state policies that support drought resilience. Given the range of measures that can support drought resilience, the report does not comprehensively describe all state policies that impact resilience or identify gaps for each type of policy.

Four technical appendices supplement this report: Appendix A identifies drought management roles at a local, Tribal, state, and federal level; Appendix B describes state plans, strategies, and audits that address drought; Appendix C summarizes state laws, regulations, and policies that support drought response and resilience; and Appendix D provides an inventory of recent state investments that support drought response, planning, and resilience.

SECTION I: DROUGHT RESPONSE AND PLANNING

The following describes the State's drought response and planning frameworks. This overview is intended to provide an understanding of current state management frameworks and to inform future policy development and drought planning.

The State's drought response framework includes a suite of emergency and standing policies that address impacts from severe water shortages. The State's drought planning has addressed both emergency response and resilience. The State maintains an emergency operations plan for drought. Drought resilience planning is incorporated into several statewide and local plans addressing natural hazards, water resources, water supply, and climate adaptation.

Drought Response

Drought emergency response policies encompass measures that address drought conditions once they have occurred. These policies primarily focus on alleviating short-term impacts from acute water shortage. The state framework for responding to drought is provided in the Drought Annex to the State of Oregon's Emergency Operations Plan (OEM 2016) and is based on several assumptions:

- Drought and changes in climate are likely to reduce water supply and have ecological and socio-economic consequences.
- Drought is normal and reoccurring, but impacts vary by region.
- Local jurisdictions have initial responsibility for responding to drought conditions and state assistance should be leveraged to supplement local response when necessary.
- In responding to drought, local jurisdictions should consult with water suppliers and utilize all water management tools available.

The following provides an overview of the State's drought management framework and describes government response roles, the framework for monitoring and identifying drought, and policies and funding leveraged during drought emergencies.

Government Response Roles

All levels of government play a role in managing drought. Oregon's drought response framework is premised on local governments playing the primary role in responding to local drought conditions. Local governments track and communicate local drought conditions, provide information about drought resources and best practices, implement water conservation and curtailment plans, deploy local resources, issue drought state of emergencies, and request state drought declarations and other emergency relief when needed.

The State supports local drought response by monitoring and tracking statewide drought conditions in coordination with federal agencies, communicating drought conditions, implementing water management measures, and coordinating emergency assistance. The Governor, with guidance from state agencies, responds to local requests for assistance by issuing drought emergency declarations, which trigger state drought emergency authorities (ORS 536.740). If severe water shortages persist, the Governor may issue emergency declarations, which activate state financial and capacity assistance (ORS 401.165). State agencies also track the impact of drought on resources and programs and implement regulatory and management measures to address those impacts.

The federal government is a critical partner for the State in monitoring and tracking drought conditions. Federal agencies also administer drought relief programs, which remain the State's primary source of emergency drought relief funding. Federal disaster relief programs include emergency loans, grants, repayment relief, and insurance to address drought impacts to agricultural producers.[1] The availability of federal drought disaster relief is primarily triggered by a disaster designation issued by the Secretary of Agriculture. Drought disaster designations are largely automatic based on the drought intensity on the U.S. Drought Monitor. Lastly, federal agencies implement management measures to respond to drought on federally owned lands and water supply facilities.

As independent sovereigns, Tribes have primary authority for responding to, planning for, and building resilience to drought on Tribal lands. Tribes may request federal and state support in responding to drought.

Appendix A describes the roles of government entities in drought response.

Drought Monitoring and Communication of Drought Conditions

Droughts are typically slow to onset, which can challenge the identification of drought conditions and delay the deployment of resources to address drought impacts. Oregon's drought

[1] USDA Farm Service Agency, Disaster Assistance Programs, https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/index

response framework incorporates monitoring and communication strategies to support early identification and messaging of drought.

The State coordinates drought monitoring through two inter-agency committees. The Drought Readiness Council reviews local requests for assistance and makes recommendations to the Governor on county requests for state drought declarations. The Council also serves as a forum for agencies to share information about observed impacts and response measures. Council membership includes state agencies representing the range of sectors impacted by drought.

The Water Supply Availability Committee monitors water supplies and drought indices and provides information about the status of drought in counties to support the Drought Readiness Council in assessing requests for drought declarations. The Committee's membership includes state and federal agencies with a role in monitoring drought indices. The Committee meets monthly to evaluate conditions related to snowpack, precipitation, streamflow, temperature, reservoir level, and flood and fire risk.

The Oregon Water Resources Department (OWRD) is the lead agency for communicating about drought. It produces the Oregon Water Conditions Report, which compiles statewide information on drought indices and conditions. The OWRD also maintains the primary state drought website,[2] which provides information on drought indices, including state and federal data on streamflow, temperature and precipitation outlooks and reservoir storage. The website also includes data on drought declarations issued and emergency water rights applications. Lastly, the OWRD maintains a suite of information resources to support drought response, including information on the State's drought response framework, state and federal assistance programs, potential drought impacts, prior droughts, water conservation, and factsheets on conserving water in various sectors.[3]

In addition to monitoring drought conditions, during drought emergencies state agencies also collect and disseminate information on drought impacts, emergency closures or restrictions, best practices, and health advisories. Examples include:

- The Oregon Department of Fish and Wildlife (ODFW) maintains a drought toolkit,[4] which provides information on how drought impacts fish and wildlife and best practices to protect fish and wildlife during drought. The ODFW publishes a weekly Recreation Report, which provides information on water conditions, and issues advisories about angling and hunting closures and other regulatory changes.
- The Oregon Health Authority (OHA) maintains a drought website,[5] which provides information to help communities address public health and drinking water impacts, including water hauling guidelines, fish advisories, and domestic well safety.

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[2] Oregon Water Resources Department, Drought, https://www.oregon.gov/owrd/programs/climate/droughtwatch/Pages/default.aspx.

[3] Factsheets address producers (updated 2015), municipal water systems (updated 2015), inside the home (updated 2015), outside the home (updated 2015), and energy and fish (updated 2005).

[4] Oregon Department of Fish and Wildlife, Statewide impacts of drought on fish and wildlife, https://myodfw.com/articles/impact-drought-fish-and-wildlife.

[5] Oregon Health Authority, Drought in Oregon, https://www.oregon.gov/oha/ph/preparedness/prepare/pages/preparefordrought.aspx.

- The Oregon Department of Agriculture (ODA) maintains a website with information on drought and disaster resources for producers.[6]
- The Oregon Department of Environmental Quality (ODEQ) maintains resources for wastewater dischargers on best practices during drought and conducts direct outreach to pollution dischargers when drought declarations are issued with information on meeting permit requirements during drought.
- The Oregon Department of Forestry (ODF) maintains information about the impacts of drought on forest health and wildfire.
- The Oregon Department of State Lands (ODSL) issues information about closures on state-owned lands due to drought conditions.[7]
- The Oregon Parks and Recreation Department (OPRD) issues news releases about drought related impacts to park facilities, park closures, and fire bans.
- The Oregon Department of Emergency Management (OEM) provides updates to local emergency managers.

Drought Response Authorities

The State utilizes a suite of management authorities to respond during drought conditions. These include authorities that are triggered by drought as well as standing authorities that support drought response. Appendix C provides an inventory of the state drought policies.

(a) Drought emergency authorities

The State has a suite of management authorities that are triggered by drought conditions. These include authority to issue drought declarations (ORS 536.740), emergency water management tools (ORS 536.710 through .780), and standing authorities that authorize actions to address drought conditions.

(i) State drought declaration

The Legislature has recognized that drought conditions causing a "lack of water resources" may result in an emergency that threatens the public's "health, safety, and welfare" (ORS 536.710). The Governor may issue a drought declaration when a severe water shortage creates "a need . . . for statewide coordination of water resource conservation measures by municipal and other political subdivisions" (ORS 536.740). Tribes and counties may request the Governor issue a drought declaration.

A county's request for a drought declaration is made to the Drought Readiness Council, which evaluates the request in coordination with the Water Supply Availability Committee and provides a recommendation to the Governor. Guidance from the Council directs the county to declare a local emergency prior to requesting a state declaration and to include in the request information about observed impacts, actions taken at the local level, and the need for state support. Drought declarations are issued through executive order and typically extend until the

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[6] Oregon Department of Agriculture, Drought and Disaster Resources, https://www.oregon.gov/oda/agriculture/Pages/DroughtDisaster.aspx.
[7] See e.g., Oregon Department of State Lands, E-News Jan. 26, 2015, https://www.oregon.gov/dsl/News/Documents/20150126Closure.pdf.

end of the calendar year. The Council has developed a template request for a state drought declaration.[8]

The operative effect of a drought declaration is to trigger emergency water management tools, which support water users in accessing back-up water supplies and authorizes the State to require water conservation and curtailment. Drought declarations may also include directives to state agencies to coordinate response measures. Functionally, drought declarations can also help raise public awareness about drought conditions, which supports local communities in implementing measures to mitigate drought conditions.

(ii) Water management tools

A state drought declaration triggers a suite of emergency authorities that address water supply shortages through water conservation, facilitating access to back-up water supplies, and managing water to protect priority uses (ORS 536.710 through .780). The drought tools generally authorize temporary changes through expedited or simplified administrative processes during the term of a drought declaration.

Water Conservation: During a drought declaration, the Water Resources Commission is authorized to require state agencies and political subdivisions to develop water conservation and curtailment plans, and the Governor may require the implementation and enforcement of curtailment plans (ORS 536.720, .780). Conservation plans identify long-term measures to reduce water use. Curtailment plans identify emergency measures to reduce water use during times of shortage.

Water Access: A drought declaration authorizes the Water Resources Commission to make available water management tools to temporarily facilitate access to water (ORS 536.720). While the water code provides the OWRD with authorities that support management of water during periods of water shortage, the administrative timelines for implementing many of these tools make them misaligned with emergency response. The drought emergency tools streamline or shorten administrative processes for existing water right holders to access water from different sources or points of diversion or to use water for different purposes or on different lands. Similarly, the tools reduce regulatory burdens to lease water instream.

Specific tools include authorizing new temporary water uses, transferring existing water uses to a different source, point of diversion or type or place of use, instream leases, the substitution of groundwater for a surface water source, and an exchange of water. The OWRD has established a reduced fee schedule for the use of emergency water rights tools.

In addition, the emergency tools allow the Water Resources Commission, local governments, public corporations, and water rights holders to enter into contractual agreements to use water pursuant to another water right or permit during a drought. Water obtained under a "Special Option" agreement may be used for both instream and out-of-stream uses. These agreements provide a mechanism to build resilience into water supply by proactively planning for water shortage.

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[8] Drought Guidance Memo and Template, Oregon Drought Readiness Council (Jan. 2021), https://www.oregon.gov/owrd/programs/climate/droughtwatch/Documents/Drought_Guidance_and_Template.pdf.

Water Use Management: The emergency drought rules authorize the Water Resources Commission to establish a preference for human consumption and stock watering uses without respect to a water right's priority date (ORS 536.750).

(b) Drought specific authorities in standing policies

A few standing policies incorporate specific authorizations to address drought conditions. Examples include:

- Nonuse of a water right during years when there is a drought declaration within the county where the water right is used does not count for purposes of forfeiture (ORS 540.610(4)).
- The ODF may extend the time to allow for reforestation during drought (OAR 629-610-0400).

(c) Standing authorities

The State largely relies on existing authorities and programs to respond during drought emergencies. These authorities do not target drought but provide management tools that assist in addressing drought impacts. Examples include:

- The OWRD has numerous existing authorities that support water management during periods of water scarcity. Examples of key policies include the authority to regulate water use in order of priority during times of shortage (ORS 540.145), the Pilot Project for Irrigation District Temporary Transfers allows pilot project participants to temporarily change the place of use of water rights for one irrigation season without filing a water right transfer application (Sec. 23, ch. 705, Oregon Laws 2003; SB 130 (2021)), and authorization of split-season leasing, which allows irrigators to lease water instream for a portion of a growing season (ORS 537.348(3)).
- The ODFW's regulatory programs for managing fish and wildlife provide tools to manage resources during drought including authority to adopt angling rules to address species or stock depletion or decline or to prevent waste (OAR 635-011-0050(2)(a)(b)), to modify hatchery programs to adjust the timing and location of release of fish to address emergency conditions (OAR 635-007-0545(19)(c)), and to close lands to public entry (OAR 635-008-0050(1)).
- Under ODEQ rules, exceedances of temperature criteria are not considered permit violations when they occur during periods of extremely low stream flows—when the flow is less than the lowest 7-day average flow that occurs on average once every 10 years (OAR 340-041-0028(12)(d)). In addition, ODEQ may exercise its enforcement discretion and elect to not assess civil penalties for water quality standard violations during periods of drought.
- The ODSL has authority to close public lands for public use to address an emergency or to protect resources (OAR 141-088-0004).
- The OPRD has authority to restrict access to and uses of parks to protect public health and safety or park resources (OAR 736-010-0020(10)).

- The Governor has authority to declare a state of emergency if drought conditions become life-threatening or cannot be managed locally (ORS 401.165). An emergency declaration allows the State to deploy resources including people and equipment.

Funding

Funding can be an important component of drought response, providing a mechanism to address drought impacts and offset losses resulting from drought (relief funding). Federal funding continues to be the primary source of relief funding to address drought impacts in Oregon. Federal emergency designations automatically make available low-interest emergency loans for agricultural producers. Federal grants are also available to help communities recover from emergencies that threaten water supply.

The State has two permanent programs that, although they are not directly focused on drought, can, in a limited sense, help respond to drought. The State Preparedness and Incident Response Equipment Grant Program (SPIRE) provides equipment to local governments for emergency preparedness.[9] The program includes mobile water tankers that can support drinking water access during drought. The Water Well Abandonment, Repair and Replacement Fund (WARRF), provides grants to households to repair, replace, or abandon domestic wells (ORS 537.766, .767). The Legislature prioritized expenditures under the current appropriation to address drought and fire impacts.

Other state drought disaster relief funding has been temporary and established in reaction to ongoing drought emergencies. In 2021, the Legislature appropriated over $61.5 million in forgivable loans and grants to offset losses from drought incurred by agricultural producers and workers and outdoor recreation outfitters and guides. Emergency relief funding included $40 million to the Oregon Department of Agriculture for the Oregon Drought and Disaster Assistance Program (ODAP), which provided forgivable loans for farmers and ranchers that lost income in 2021 due to drought (SB 892, SB 5561 § 5 (2021 2nd Special Session)); $1.5 million to the Oregon Community Food Systems Network to provide grants to small-scale farmers who did not qualify for relief under the ODAP (SB 5561 § 15 (2021 2nd Special Session)); $10 million to the Oregon Worker Relief Coalition for direct payments to agricultural workers who missed work due to heat or smoke (SB 5561 § 14 (2021 2nd Special Session)); and $10 million to the Oregon Tourism Commission to provide grants to outdoor recreation outfitters and guides impacted by drought or wildfire (SB 5561 § 30 (2021 2nd Special Session)).

The Legislature has also made significant recent investments that support drought and water supply resiliency. These investments are discussed as a resiliency measure in Section III.

Drought Planning

Planning is a key mechanism for building institutional capacity and readiness for drought and can support both drought response and resilience (Jedd and Smith 2022). Several types of plans can integrate drought, including emergency operations plans, hazard mitigation plans, water resources plans, climate adaptation plans, and water supply plans.

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[9] State Preparedness and Incident Response Equipment (SPIRE) Grant Program, Oregon Department of Emergency Management, https://spire-geo.hub.arcgis.com.

The State's drought planning has historically focused on operational planning for drought emergency response. The statewide plan for drought response is an annex to the state emergency operations plan. Local water supply curtailment plans and emergency operations plans also address drought response.

The State's drought resilience planning is integrated into several statewide plans that address natural hazard mitigation, water and natural resources, and climate adaptation. Local natural hazard mitigation plans, water resources plans, and water supply plans also include strategies to build drought resilience.

State Planning

The following describes statewide plans that address drought response (the Drought Annex) and drought mitigation (the multi-hazard mitigation plan, the climate adaptation plan, the water resources strategy, and individual natural resource plans). Appendix B describes key plans and reports and identifies strategies and recommendations in those plans that address drought.

(a) Drought Annex to the State of Oregon Emergency Operations Plan

Oregon's only stand-alone drought plan is the Drought Annex to the State of Oregon Emergency Operations Plan, which identifies the operational procedures and policies for responding to drought conditions (OEM 2016). The plan was first adopted in 1988 and subsequently updated in 1991, 1993, 2001, 2002, and 2016. The plan defines and describes the indices for tracking drought, government response roles, information gathering and communication strategies, and management tools and resources to address drought impacts. The Drought Annex does not address drought mitigation nor recovery.

(b) Natural Hazards Mitigation Plan

The Natural Hazards Mitigation Plan (NHMP) is the principal state mitigation plan for natural hazards. Drought is one of 11 statewide natural hazards and the NHMP identifies drought as a hazard for every region and as a hazard whose exposure risk will increase across the state due to climate change. Identified impacts from drought include public health, infrastructure, economy, and the environment. The 2020 NHMP identifies three drought-specific mitigation actions: develop a methodology to assess drought vulnerability, complete an assessment of drought vulnerabilities, and document the economic, social, cultural, and environmental impacts of drought (NHMP, Action Items 46, 47, and 48). Several of the mitigation tools that address general hazard preparedness also support drought preparedness. For example, interconnection of public water systems can build resilience into community water supply, expanding the stream gaging network can help forecast drought and monitor drought impacts, and pursuing funding for vulnerability and risk assessments can support preparedness (NHMP, Action Items 133, 135, and 40).

(c) Climate Change Adaptation Framework

The 2021 Climate Change Adaptation Framework serves as a framework for interagency action to adapt to, mitigate, and respond to anticipated climate change effects (DLCD 2021). The plan recognizes climate change will likely increase both the length and severity of drought and that drought will continue to impact the economy, natural world, built environment, and public health. Specific areas of impact highlighted in the framework include fisheries, farming and ranching, increased wildfires, energy systems, mental health, dehydration, toxic exposures, and diminished living conditions. The plan identifies actions to increase the State's adaptive capacity to climate change. While only one adaptation strategy directly addresses drought, several strategies address water supply and security, public health, and ecological resilience, all of which can reduce long-term drought risk.

(d) Integrated Water Resources Strategy

The Integrated Water Resources Strategy (IWRS) is an interagency framework to better understand and meet instream and out-of-stream needs (ORS 536.220(3)). The IWRS provides information on Oregon's water resources, water needs, and pressures that will affect water resources and needs. The IWRS identifies critical issues and offers recommended actions to better understand and manage water resources, meet our water needs, and address identified pressures.

In response to the 2015 drought, the Governor directed the OWRD to address drought in the IWRS, and in 2023, the Legislature codified the requirement that the IWRS consider "water-related natural hazards" and other climate change risks (HB 2010 §§ 15, 16 (2023)). The IWRS will be updated in 2024 and subsequently updated every 8 years.

The 2017 IWRS addresses drought as a natural hazard that will likely become more severe and frequent with climate change and recommends that the State "Plan and Prepare for Drought" (IWRS, Recommended Action 5.5A). Example actions to implement the recommendation include improving the frequency of drought projections and long-term forecasting, assessing community and ecosystem vulnerability to drought, documenting impacts, and improving the drought toolbox through education, planning, and additional voluntary tools to restore streamflow.

(e) Natural resource planning

Individual natural resource plans can support drought preparedness by identifying strategies to address drought impacts, such as water scarcity, on the subject resources. While most plans do not directly address drought, their strategies often support long-term drought resilience. For example, the Oregon Conservation Strategy, the statewide plan for conserving fish and wildlife, considers drought as part of water quality and quantity and climate change challenges.[10] Key strategies to meet these conservation challenges include maintaining and restoring streamflow, enhancing aquifer recharge, monitoring watershed function and establishing thresholds for when conservation action may be needed, increasing information on the impacts of climate change on ecosystems, and minimizing climate threats by building resiliency into ecosystems.

State Support for Local Drought Planning

The impact of drought is highly dependent on local conditions, making local preparedness critical to reducing statewide drought risk. The extent of local drought planning varies across the state but has included both planning for drought response and resilience. Local planning for

[10] Oregon Conservation Strategy, Oregon Department of Fish and Wildlife, https://www.oregonconservationstrategy.org.

drought response primarily focuses on addressing water supply disruptions and has been integrated into local emergency operations plans and water supply plans, including emergency preparedness plans and water use curtailment plans. Local planning for drought mitigation has been incorporated into water resources plans, water supply plans, local hazard mitigation plans, and drought plans. The State supports these preparedness actions through its place-based integrated water resources planning program, planning requirements for water suppliers, and providing resources and capacity support.

(a) Emergency operations plans

The OEM maintains resources to support the development of local emergency operations plans.[11] Local emergency operations plans identify the management actions taken in response to emergency events. Some local emergency response plans include a drought annex that coordinates response actions during drought.

The OEM and the OWRD have also developed guidance for local water supply emergency planning.[12]

(b) Place-Based Planning

The State funds and provides technical assistance to place-based planning efforts, which help communities plan to meet current and future water needs. Established in 2015, the Legislature permanently authorized the program in 2023 and appropriated $2 million for planning grants (HB 2010 §§ 15, 16, 44 (2023)). Draft guidance adopted for the pilot program identified climate change and drought as conditions for planning groups to consider and recommended that final plans include an assessment of drought impacts (OWRD 2015a). The three completed plans identify drought as a natural hazard and include strategies to mitigate drought vulnerability.

(c) Water supply planning

The State supports water supply planning through regulatory requirements and by providing capacity and information resources. Water supply plans help water suppliers understand and plan for water needs, identify opportunities to reduce water use, and plan for emergencies. Given the nexus between water supply and drought, these plans are closely interrelated with drought planning. Key water supply plans that support drought include:

- The OHA requires all community water systems to maintain an emergency response plan (OAR 333-061-0064). Emergency response plans for community water systems serving populations over 3,300 must include an assessment of risks from natural hazards and identify measures to reduce risk and respond during emergencies. Measures must include identifying alternative sources of water and provisions for water rationing and providing water in emergencies.

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[11] Oregon Department of Emergency Management, Hazards and Preparedness, https://www.oregon.gov/oem/hazardsprep/Pages/Hazards-in-Oregon.aspx.

[12] Oregon Department of Emergency Management, Local Water Supply Emergency Planning Guidance (Feb. 2, 2023), https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/PREPAREDNESS/Documents/local-water-supply-emerg-planning.pdf.

- Water Management and Conservation Plan (WCMP) requirements guide municipal and agricultural water suppliers to develop and implement strategies to reduce long-term water use and ensure a sustainable water supply. The OWRD conditions the issuance of new municipal water right permits and permit extensions on the completion of WMCPs (ORS 537.230(3)(b), .630(3)(b); OAR 690-410-0060; OAR Ch. 690 Div. 86; OAR 690-315-0090). Agricultural water suppliers are required to develop WMCPs as a condition of eligibility for certain water rights tools (ORS 540.572; OAR Ch. 690 Div. 86). Both municipal and agricultural WMCPs must (a) describe the system, including water supply needs, current water use, and system losses, (b) identify how the supplier will meet expected future water supply needs, (c) identify water conservation strategies to increase water efficiency, and (d) assess the system's ability to maintain service during water shortage and develop a plan to curtail water use.
- During drought, the Governor and the Water Resources Commission may require state agencies and political subdivisions to develop conservation and curtailment plans (ORS 536.780). An emergency water use permit issued to a state agency or political subdivision must include a requirement for the development and submission of a water conservation and curtailment plan (OAR 690-019-0040(6)). The OWRD may also condition other emergency drought permits on the implementation of water conservation or curtailment measures (OAR 690-019-0040(5)(f)).

State agencies provide resources to support water supply planning efforts. The OWRD provides resources for municipal and agricultural water providers to support the development of water management and conservation plans, including guidebooks (OWRD 2015b; OWRC 2007) and plan templates.[13] The OWRD also maintains model curtailment measures for municipal water providers (OWRD 2005). There is no dedicated state funding program for water supply planning, though funding may be available through other grant or loan programs.

The OHA provides resources for drinking water systems to support emergency response planning. Resources include guidance and templates[14] and funding for circuit riders to provide free on-site technical assistance to small water systems, which can include development of emergency response and water management plans.[15] The ODEQ's Drinking Water Program provides information and technical assistance to public water systems in developing plans to protect water sources; funding to support source water protection planning is available through the Drinking Water Source Protection Fund.[16]

(d) Local hazard plans

The State provides limited support for local natural hazard mitigation planning. Natural hazard mitigation plans are a precondition to receive federal disaster mitigation funding and there are no

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[13] Oregon Water Resources Department, Water Management and Conservation Planning, https://www.oregon.gov/owrd/programs/planning/wmcp/pages/default.aspx.
[14] Oregon Health Authority, Emergency Response Planning, https://www.oregon.gov/oha/ph/healthyenvironments/drinkingwater/preparedness/pages/emergency.aspx.
[15] Oregon Health Authority, Circuit Rider Program, https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/OPERATIONS/Pages/circuitrider.aspx.
[16] Oregon Health Authority, Drinking Water Source Protection Projects, https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/DRINKINGWATER/SRF/Pages/spf.aspx.

state requirements to develop plans. The DLCD assists communities in preparing local natural hazard mitigation plans by providing data and subject matter expertise. The DLCD also has limited funding available to support local planning through its Technical Assistance Grants Program. In addition, the statewide NHMP serves as a blueprint for the development of local plans. While the statewide NHMP identifies drought as a risk for all Oregon counties, not all local NHMPs address drought as a risk. Furthermore, not all plans that do discuss drought as a risk identify mitigation strategies for drought.

(e) Drought plans

The State has supported the development of local drought plans, which help communities build resilience to drought. State agencies (ODA, ODEQ, and ODF) participated in the development of the North Santiam Watershed Drought Contingency Plan, which serves as a plan to monitor, respond to, and mitigate drought in the watershed.[17] The plan was partially funded through a grant from the Bureau of Reclamation's WaterSMART program.

State agencies (ODA, ODEQ, ODF, OWEB, and OWRD) supported the development of a long-range drought mitigation plan to address drought and build resiliency to water scarcity in Jefferson County.[18] Plan development was led by the Jefferson County Soil and Water Conservation District, which convened the Jefferson County Agricultural Drought Resiliency Group, consisting of over 60 participants representing producers, regional nonprofits, extensions staff, and state and federal agencies. The workgroup identified tools to improve drought resiliency, including barriers to implementation, potential benefits, and implementation pathways. The planning effort was partially funded through legislative appropriations made as part of the 2021 legislative session to respond to drought in Jefferson County (SB 5561 §20 (2023)).

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is developing a drought early warning system and drought contingency plan to better understand drought risk, identify drought conditions, and prepare for and mitigate drought. The project includes the development of regional drought indices for First Foods. The project received federal funding through the National Integrated Drought Information System (NIDIS) through the Coping with Drought Competition: Building Tribal Drought Resilience.

Assessment of Drought Impacts and Drought Management Frameworks

Evaluating drought impacts and response measures provides data and information that can assist in understanding drought trends and vulnerabilities, direct resources to address impacts, improve drought response, and identify and prioritize preparedness and resilience actions.

[17] North Santiam Watershed Drought Contingency Plan (July 17, 2017), http://northsantiam.org/wp-content/uploads/NorthSantiamDCP_FINAL_forBOR_July25_2017.pdf.
[18] Jefferson County SWCD, Managing for Drought, https://www.jeffswcd.org/drought-resiliancy-group-mtgs.

(a) Drought impacts

The State does not have a formalized process for collecting and documenting data on drought impacts either during or following drought.[19] To report drought impacts, the State directs the public to the National Drought Impacts Reporter, which collects drought impacts nationally. Where state agencies collect data on drought impacts, it is through existing agency programs or on an ad hoc basis. For example, as part of existing programs, the ODFW collects data on streamflow and temperature and the OWRD collects information on dry wells. While these programs capture data about drought impacts, the information is disaggregated. During drought, agencies informally share identified drought impacts as part of their participation on the Drought Readiness Council, but this information is not memorialized in a form that readily supports future drought planning or assessments.

The State has documented drought impacts following individual drought events. Following statewide droughts in 2015 and 2018, the State commissioned studies to assess drought impacts (BeCraft, 2017).[20] In 2021, the Legislature funded the OWRD to contract for this statewide vulnerability assessment and funded the Klamath Tribes to study the impact of drought and wildfire on aquatic resources in Klamath Lake and Sprague River tributaries (SB 5561 §§ 18, 13 (2021)). In 2023, the Oregon State University Extension Service completed a statewide assessment of farmer and rancher drought and heat management practices and needs to support those practices (Dinsdale, 2023). The report utilized funding provided in the 2021 legislative session to the Oregon State University Extension Service to provide technical assistance to farmers and ranchers (SB 5561 § 17 (2021)). In 2023, the Legislature funded the Oregon State University Extension Service and the Oregon State University Agricultural Experiment Station to prepare an annual report for the Legislative Assembly describing climate-related impacts, including drought, on agricultural producers and identifying recommendations to build resiliency (HB 2010 § 14 (2023)). Lastly, the Oregon Health Authority has assessed public health drought impacts as part of its annual report on the impact of climate hazards on public health.[21]

(b) Drought management measures

The State generally has no formal process to collect data on the types or efficacy of management measures used during drought. The only state agency that formally collects data on management measures is OWRD, which maintains information on drought declarations and the use of drought water rights tools.

State planning documents generally have periodic review requirements that provide a process to update drought management frameworks and policy recommendations. However, drought-specific components to these plans are not always updated. For example, the State of Oregon

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[19] Drought impacts are collected as part of the Pacific Northwest Water Year Impacts Assessment, which assess yearly drought impacts in Oregon, Washington, and Idaho (Bumbaco 2023). The Assessment has been completed in 2020, 2021, and 2022. In Oregon, the report is supported by the Oregon Climate Service and Oregon Climate Change Research Institute.

[20] Oregon Water Resources Department, Oregon 2018 Drought Impact Stories, https://aquadoc.typepad.com/files/learning_from_oregons_2015_drought_23june2017.pdf.

[21] Oregon Health Authority, Climate and Health in Oregon Profile Report, https://www.oregon.gov/oha/ph/healthyenvironments/climatechange/pages/profile-report.aspx (reports have been issued for 2014, 2020, and 2021-2022), https://www.oregon.gov/oha/ph/healthyenvironments/climatechange/pages/profile-report.aspx.

Emergency Management Operations Plan is required to be periodically updated, but the Drought Annex has generally not been updated as part of those processes.

Following the notable statewide drought in 2015, the State engaged in several efforts to evaluate and update its drought planning and policies, including updating the Drought Annex and addressing drought in the IWRS. In addition, the Legislature established a Taskforce on Drought Emergency Response to assess the State's drought response tools and recommend actions to address gaps (HB 4113 (2016)). The Task Force members approved 13 recommendations and highlighted a suite of other tools that could improve drought preparedness and response.

Section II: Gaps in Drought Response and Planning

The following identifies gaps in the State's drought response and planning frameworks that increase drought vulnerability. These findings are informed by prior reports that evaluated state water and drought management policies,[22] state agency staff observations, and literature on drought management best practices. For each identified gap, the report highlights model approaches from other states. The report does not provide specific recommendations on policy approaches but is intended to support the State in identifying solutions to reduce its drought vulnerability.

Drought Response

This assessment identified four key gaps in the State's drought response framework:

- The need to improve coordination of state drought response actions.
- Information gaps around the efficacy of state emergency drought tools.
- Limited measures to address environmental impacts from drought.
- The lack of established funding programs to respond to drought impacts.

Drought policies should focus on building long-term resilience and reducing overall risk. However, even with strong mitigation policies, drought will still occur, and drought response policies provide an important safety net to minimize and alleviate impacts. Thoughtfully designed drought response policies can increase the effectiveness of state response and support long-term resilience.

Gap: The need to improve coordination of state drought response actions.

A key element of effective drought response is the implementation of timely management actions. However, several characteristics of drought can obscure its severity, which can delay and complicate response measures. Unlike most natural hazards, drought often develops slowly over time, has a diffuse range of impacts, and persists for extended periods with no clear beginning or end point (Wilhite and Vanyarkho 2000).

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[22] Reports reviewed for this assessment include the Report of the Task Force on Drought Emergency Response (2016), the Secretary of State Advisory Report: State Leadership Must Take Action to Protect Water Security for All Oregonians (2023), Learning from Oregon's 2015 Drought: A Review of Documents Conditions, Impacts, and Response Strategies, and Beating the Heat: A Statewide Assessment of Drought and Heat Mitigation Practices (and Needs) with Oregon Farmers and Ranchers (2023).

To support timely response actions, drought frameworks often incorporate monitoring to track drought conditions and use indicators or indices[23] to understand the extent and severity of drought. These measures are then paired with frameworks to proactively identify and coordinate response actions based on drought conditions. For example, many plans utilize drought triggers, which are threshold values tied to drought indicators or indices that activate recommended management measures. Triggers are often further organized into drought stages, which describe a spectrum of drought severity.

Oregon's drought response framework incorporates measures that support the early identification of drought conditions. The Water Supply Availability Committee meets monthly to assess and track a variety of drought indicators. The OWRD uses information developed by the Committee and the U.S. Drought Monitor to communicate the extent and severity of drought through its biweekly water conditions report. These existing frameworks help develop and share information to support early response action.

However, the State does not have a framework that coordinates state response either before or during drought conditions to ensure that the information is translated into action. Agency staff have identified a need for improved coordination of state drought response measures to support early and proactive decision making.

While local governments lead in responding to local drought conditions, many state agencies play a role in responding to drought. These actions are largely taken as part of existing programs and, in most cases, the type and timing of response actions is determined by the individual agency and is frequently ad hoc. An exception is the State's drought emergency water management tools, which are triggered by drought declarations.

The State also has no formal mechanism to coordinate response across agencies. During drought, the Drought Readiness Council informally provides a forum for agencies to share observed impacts and management responses. However, the Council's formal function is to review local requests for a drought declaration.

Frameworks that coordinate drought response have several benefits. Coordinating management measures ahead of drought conditions can improve both the speed and efficacy of response. It can also support more strategic responses that can build preparedness for increasing drought severity. For example, management measures during early stages of drought can include actions to prepare for more severe conditions, such as assessing resource needs or proactive outreach to vulnerable water systems. These frameworks can also support local drought response. Improving the timeliness and efficacy of State drought response, can help ensure timely delivery of information and resources.

Models of frameworks that support coordinated and timely drought response include the adoption of triggers and drought stages with corresponding management measures, establishing

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[23] Drought indicators are physical variables that are used to identify drought conditions, for example, precipitation, streamflow, soil moisture level, and temperature. Indices assimilate drought indicators to determine severity, examples include the Standardized Precipitation Index (SPI), the Palmer Drought Severity Index (PDS), and the U.S. Drought Monitor (USDM).

task forces to address specific types of drought impacts, and establishing a body to coordinate drought response actions.

Models: Frameworks for Coordinating Drought Response

Washington's drought plan adopts two tiers of drought response—advisory and emergency. The stages are triggered by hydrologic conditions and social hardship factors.[24] Each stage has specific recommended mobilization and communications actions. For example, the advisory stage precedes drought and is triggered when "conditions indicate a cause for caution, the need for preparation, and mobilizing resources." During this stage, state agencies are directed to convene the drought communication coordination team, issue advisories for drought effected areas, and highlight successful projects that support drought resilience. Mobilization and preparation actions include planning for temporary staff reassignment, assessing the adequacy of contingency funding, and proactively identifying and communicating with vulnerable water systems about drought risk. The state's drought plan also includes detailed management actions for high priority sectors including agriculture, energy, fisheries, wildlife, public water supplies, and recreation.

Colorado's drought plan divides its drought response into four phases (normal conditions, phase I, II, and III) that are triggered based on indicators and impacts.[25] For each phase, the plan identifies a corresponding set of recommended actions. During normal conditions, the plan calls for the monthly monitoring of drought conditions, implementation of mitigation actions, and plan review and assessment of prior drought response. Phase I, II and III trigger specific communications actions, assessments of the need for additional resources, and activation of drought taskforces. The response framework also specifies actions taken as drought conditions recede, which include implementing recovery actions and issuing final reports from activated taskforces outlining drought impacts and applied management measures.

Colorado administers drought response through a Drought Task Force and five specialized Impact Task Forces (water availability, agriculture, municipal water, wildlife, and energy). For each task force, the plan identifies criteria for activation, required tasks and impact assessments, and data sources. Task force membership includes state and federal agencies, local government entities, and stakeholders.

Gap: Information gaps around the efficacy of state emergency drought tools.

The State's emergency drought water management tools are a principal component of its drought response toolkit. The tools have been substantively unchanged since 2001. While the intention of the tools is to facilitate water access during drought, their efficacy in addressing water supply shortages has been limited and, in some cases, may not align with long-term resiliency. The 2016 Task Force on Drought Emergency Response recommended OWRD review the emergency

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[24] Washington State Drought Contingency Plan, Department of Ecology (Sept. 2018), https://apps.ecology.wa.gov/publications/documents/1811005.pdf.

[25] Colorado Drought Mitigation and Response Plan, Colorado Water Conservation Board, Department of Natural Resources (Aug. 2018), https://drought.unl.edu/archive/plans/drought/state/CO_2018.pdf.

drought water management tools to understand how they are being utilized, their short and long-term impacts, and opportunities to improve the use of underutilized tools (Task Force, Recommendation C).

Within the management tools available during drought, only two types have been used consistently and the use of those tools has been concentrated in certain counties, even during periods of widespread drought. The tools consistently used are applications for emergency water use (replacing water that is temporarily unavailable) and transfers (changing the type of use, where the water is used, and the location of where the water is diverted). The State has used its authority to give preference to human and stock watering uses four times (2013, 2014, 2015, and 2018), all in Klamath County. Drought instream flow leases, water exchanges, substitutions of water, and option agreements have not been utilized in recent years.

The State has largely not used its authority to direct local water conservation; however, during drought emergencies in 2015 and 2021, the Governor issued executive orders directing state agencies to curtail non-essential water use at state-owned and managed facilities, to encourage public water conservation, and to update and enhance state drought planning (EO No. 15-09, EO No. 21-20).

Year	Drought Declarations	# of Counties where Water Right Tools Used	Drought Emergency Use Permit Applications Filed	Drought Emergency Transfer Applications Filed	Counties with largest percentage of applications filed
2023	12	5	13	2	40% Jackson 26% Crook
2022	17	11	30	18	37% Jackson 25% Klamath
2021	26	14	66	29	55% Klamath 12% Jackson
2020	17	3	49	6	92% Klamath 3% Jackson 3% Josephine
2018	11	2	40	4	97% Klamath 1% Grant
2015	36	11	65	25	44% Klamath 20% Malheur

More research is needed to understand the reasons the various drought tools are not being utilized. Some reasons may include: (a) because counties are not timely in requesting drought declarations, which are necessary to trigger the availability of drought tools, (b) because they are not effective in addressing drought impacts, (c) because they are only effective when a true emergency exists thus the need for their use is limited, (d) because some have unintended consequences such as disrupting the system of prior appropriation for water distribution, (e) because of the investment necessary to utilize the tools, or (f) because there is a lack of awareness about the tools.

More research is also needed to understand the impact of these tools on water security and long-term resilience. For example, emergency use permits to use groundwater have been a frequent mechanism to augment surface water shortages during drought. However, this approach is premised on the assumption that interceding wet years will offset groundwater declines caused by increased pumping during drought periods. The predicted increase in the frequency and severity of drought, including more common multi-year droughts, may undermine these assumptions.

Finally, additional research is also needed to understand the tools' equity impacts. For example, additional groundwater pumping during drought can intensify groundwater declines, which can impact domestic well users. Drying domestic wells can disproportionately impact low-income households and renters. In addition, emergency water use may impact streamflow, which can affect cultural uses that are tied to water.

Investing in a more comprehensive review of the emergency drought water management tools would help identify opportunities to improve the efficacy of the tools to address water shortage for both instream and out-of-stream uses, to support long-term resilience, and to be more equitable in who they benefit and burden. Opportunities could include changing the types of tools offered, modifying the impacts the tools can be used to address, and investments in state agency capacity to increase the use of existing tools.

Model: Drought Water Management Tools

The Washington Legislature recently modified the Department of Ecology's authorities to manage water during drought. Changes include:
- Requires Ecology to prioritize addressing certain types of impacts (irrigated crops, fisheries, and small water systems) when issuing emergency water withdrawals (RCW 43.83B. 410(1)(a)).
- Requires Ecology to consult with federally recognized Tribes prior to issuing a drought declaration and approving an emergency withdrawal (RCW 43.83B.405(2)(b), .410(1)(c)).
- Directs Ecology to begin a pilot program to explore the use of long-term water rights leases for use during drought conditions that would address drought impacts to public health and safety, drinking water, agriculture, and fish and wildlife (RCW 43.83B.450).

Gap: Limited measures to address environmental impacts from drought.

Drought has significant environmental impacts affecting fish, wildlife, and plant communities. Freshwater ecosystems are particularly vulnerable to drought—reduced water availability lowers streamflow, which in turn elevates stream temperature and dissolved oxygen levels, concentrates pollutant loads, and reduces habitat connectivity (Vose et. al. 2016). Inadequate water supply also reduces water and food availability for wildlife, and reduces soil moisture, which exacerbates tree and vegetation mortality and increases fire risk (Vose et al. 2016). Despite the significant ecological impacts from drought, drought policies have historically focused on alleviating human impacts (Crausbay et al. 2017). Particularly during drought emergencies, this can result in ecosystem impacts being deprioritized.

Oregon has limited regulatory tools to address environmental impacts during drought. To protect streamflow, the state emergency drought water management tools authorize an expedited process to lease water rights instream, which shortens the usual administrative timelines. Conceptually, this provides a framework to quickly shift existing uses to respond to low flow conditions. However, the tool has been used infrequently, if at all. Existing instream water rights can provide important resiliency during drought but do not provide flexibility to respond to drought impacts as they arise. Instream water rights can also have limited impact because many—particularly on the eastern side of the state—have more junior priority dates that will not be regulated in favor of in times of water shortage. Finally, even where instream water rights exist, many allow for the subordination of instream flows in favor of domestic and livestock water rights.

Voluntary agreements with water rights holders are a nonregulatory approach that has been utilized in Oregon to enhance streamflow and could be leveraged as a tool to provide flow during drought conditions. The Fifteenmile Action to Stabilize Temperature (FAST) program, which addressed temperature concerns in Fifteenmile Creek, a tributary to the Columbia River, provides a model for this type of approach.[26] Under the FAST program, irrigators who have voluntarily enrolled in the program agree to reduce water diversions when stream temperature exceeds a defined threshold. During low-flow conditions, the enrolled irrigator is contacted to shut off diversions and compensated for leaving water instream. Having a preexisting agreement allows the program to respond quickly and effectively in times of water shortage. In addition, because the voluntary agreement is established prior to drought conditions, it can leverage funding sources whose grant timelines make them impracticable as a resource during drought.

If this model is considered for replication elsewhere, it is important to understand that since the program does not officially lease water instream through the State, the water cannot be protected from diversion by watermasters at the OWRD. A potential solution within existing authorities could be to enter a Special Option Agreement under the OWRD's drought management tools, though more analysis would be necessary to determine the feasibility for this type of program (OAR 690-019-0080).

The ODFW's rules and policies do not incorporate specific drought response triggers or management actions that can help identify and respond quickly to drought impacts. During drought conditions, ODFW relies on its general authority to regulate the timing, location, and catch limit for fishing and hunting to adopt emergency regulations to protect species. It also relies on its authority to adjust hatchery programs to respond to drought conditions.

The need to enhance the tools available to address environmental impacts from drought was highlighted by the 2016 Task Force on Drought Emergency Response and in the 2017 IWRS. The Task Force recommended several measures to address instream flows during drought, including assessing management options to use stored water to meet instream needs, developing funding to support emergency access to water to meet instream needs, evaluating emergency instream flow transfer tools, and developing additional mechanisms to support voluntary streamflow augmentation (Task Force, Recommendation B, C, and L). The 2017 IWRS recommends developing additional voluntary streamflow restoration measures and installing additional stream gages to measure instream flows (IWRS, Recommendation 5.5A).

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[26] Fifteenmile Action to Stabilize Temperature, The Freshwater Trust (2014), https://www.thefreshwatertrust.org/case-study/fifteenmile-action-to-stabilize-temperature/.

Models to address environmental impacts during drought include enhancing tools to support streamflow augmentation during drought, developing specific drought response protocols or plans to coordinate management actions to address environmental impacts, and increasing funding to support state response measures.

Models: Environmental Response Frameworks

Montana utilizes both regulatory and nonregulatory tools to respond to environmental impacts during drought. Montana has supported the development of local drought management plans for individual rivers.[27] These plans set up frameworks to encourage voluntary measures to augment streamflow and protect fisheries during drought. Components of the plans include communication frameworks to educate and notify parties about drought conditions and identification of triggers for voluntary water conservation efforts and angling restrictions. The state supports these plans by providing information about drought conditions, providing technical support, and communicating regulatory restrictions. State policy also allows locally developed plans to supersede state regulatory criteria for river closures.

Montana's administrative rules outline the conditions under which the state may consider angling closures, which include physical conditions (flow, temperature, dissolved oxygen) and drought status, and when the department may reopen waters following a closure (MAR 12.5.507, .508). Montana Department of Fish, Wildlife, and Parks has also adopted a policy that guides how Montana will respond during drought to protect fisheries.

California uses both regulatory and nonregulatory approaches to address impacts to fish and wildlife during drought. The state has adopted temporary emergency minimum flow requirements for individual rivers and prohibits diversions that interfere with those minimum flow levels.[28] California also supports voluntary streamflow augmentation efforts. The California Department of Fish and Wildlife partners with the National Oceanic and Atmospheric Administration (NOAA) to implement the Voluntary Drought Initiative, which works with landowners in areas with endangered and threatened species to voluntarily augment streamflow, reduce water use, improve groundwater recharge, and facilitate monitoring and species relocation. Funding has been available to support voluntary flow augmentation activities.[29]

During drought, California conducts monitoring surveys to identify fisheries impacts and prioritize management actions in locations where fisheries are the most vulnerable to drought

[27] Montana Department of Fish, Wildlife, and Parks Drought, Response and Management Plans, https://fwp.mt.gov/conservation/fisheries-management/water-management/drought.
[28] See e.g., Establishment of Minimum Instream Flow Requirements, Curtailment Authority, and Information Order Authority in Klamath Watershed, State Water Board Resolution No. 2022-0025 (June 21, 2022), https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2022/rs2022-0025.pdf.
[29] California Department of Fish and Wildlife, Voluntary Drought Initiative, https://wildlife.ca.gov/Drought/Voluntary-Drought-Initiative#:~:text=The%20California%20Voluntary%20Drought%20Initiative,help%20reduce%20the%20effects%20of.

stressors, including relocating fish when habitat conditions threaten species survival.[30] The California Department of Fish and Wildlife has standing authority to rescue fish and is working with federal and nonprofit partners to map cold water refugia that can be used as translocation sites.[31]

Colorado's drought plan identifies specific actions to protect fish and wildlife during drought.[32] These include activating the Wildlife Impact Drought Taskforce, which is responsible for tracking drought impacts to fish and wildlife, identifying forest areas impacted by drought, recommending measures to prevent and mitigate wildlife loss, communicating information about drought impacts, and evaluating the impact of state water rights on reservoirs, streams, and hatcheries.

Washington has several programs that address fish and wildlife impacts during drought. The Department of Ecology has used standing authority to lease water to augment streamflow during drought (RCW 90.42.080). For example, during a notable drought in 2001, Ecology purchased 21 water rights leases that maintained streamflow in important fish-bearing streams. In 2020, the legislature directed Ecology to initiate a pilot program for long-term water lease agreements that can maintain streamflow during drought (RCW 43.83B.450). In addition, projects that "mitigate the impacts of waters supply shortages on fish and wildlife" are eligible to receive grant funds that address drought emergencies (RCW 43.83B.415).

Gap: The lack of established funding programs to respond to drought impacts.

Drought emergency funding can provide a mechanism to help respond to and recover from drought. While communities should work towards building resilience and reducing the need for emergency response, drought emergencies will still arise, and funding can be an important component of effective response (Knutson et al. 1998). Funding to support drought response can include programmatic funding to support drought response measures as well as grants and loans to alleviate and offset drought impacts.

To be most effective, drought funding should provide short-term relief and support long-term resilience. Establishing funding programs prior to drought emergencies provides opportunity to structure funding to be accessible when needed and to be deliberate in the form of relief so that it is equitable, addresses both instream and out-of-stream impacts, and is consistent with long-term drought resilience.

Oregon does not have a long history with drought specific funding programs. In recent years, Oregon's limited drought relief funding has been temporary and provided in response to discrete drought emergencies, which has created delays in delivery of funding resources. The programs have required legislative action to establish and capitalize, and agency or partner capacity to

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[30] California Department of Fish and Wildlife, Drought Related Actions, https://wildlife.ca.gov/Drought#570783377-fish-rescue-and-stressor-monitoring.
[31] CalTrout, Native Rainbow Trout Refugia Mapping, https://caltrout.org/projects/native-rainbow-trout-refugia-mapping.
[32] Colorado Drought Mitigation and Response Plan, Colorado Water Conservation Board, Department of Natural Resources (Aug. 2018), https://drought.unl.edu/archive/plans/drought/state/CO_2018.pdf.

stand up the new program. For example, in response to notable drought in 2021, the Legislature created the Oregon Disaster Assistance Program at the Oregon Department of Agriculture to provide relief to producers. While the funding filled an important gap in federal relief, because it was a new program its deployment was impeded by the need to set up administrative frameworks.[33] The State's emergency funding resources have primarily addressed economic impacts on agricultural producers and workers, with limited relief for other sectors.

While the State has provided ad hoc relief in response to discrete droughts, the lack of a permanent funding source is a gap in its drought policies. The 2016 Task Force on Drought Emergency Response recommended the State "look at establishing a drought emergency fund for instream and out-of-stream needs" (Task Force, Recommendation C).

Developing a drought response fund prior to drought emergencies can provide opportunity to identify where funding is needed to support response measures (e.g., water supply, environmental impacts, and agency capacity), facilitate development of funding that works synergistically with long-term resilience goals, and address inequities in the types of impacts and communities that receive funding.

Models of permanent drought response funding programs include stand-alone programs, the use of general disaster relief funding programs, drought response funding programs housed within standing grant programs that also address drought preparedness and mitigation activities, and permanent programs that are capitalized only during drought emergency.

Models: Drought Response Funding Programs

Washington's drought plan identifies a need for predictable and timely drought contingency funding for both drought resilience and response.[34] In 2023, the state legislature established the state emergency fund, which provides funding during a declared drought emergency to address hardship caused by water unavailability (RCW 43.83B.435). The legislation directs the state treasurer to automatically transfer monies necessary to capitalize the fund to $3 million upon the declaration of a drought (HB 1138 (2023)). Washington's drought plan also directs agencies to estimate funding needs for drought response during drought advisories, providing time for the state to allocate necessary funding resources before a drought emergency arises.

Colorado established the Agricultural Emergency Drought Response Program, which provides up to $1 million in grants and loans for water augmentation projects that address drought.[35] The fund is only available following a federal or state emergency declaration due to drought

[33] Aileen Hymas, Oregon farmers now applying for last year's drought assistance, tool late for some (May 20, 2022), https://ktvl.com/news/local/oregon-disaster-assistance-program-department-agriculture-drought-assistance-releif-farmers-fund-; see also, Pat Kruis, Drought relief pays the water bill for Jefferson County irrigators, The Madras Pioneer (March 9, 2022), https://www.madraspioneer.com/news/drought-relief-pays-the-water-bill-for-jefferson-county-irrigators/article_16206964-bb8d-5ce8-9305-4cb3de05579e.html.
[34] Drought Contingency Plan, Washington Department of Ecology, (2018), https://apps.ecology.wa.gov/publications/documents/1811005.pdf.
[35] Colorado Water Conservation Board, Agricultural Emergency Drought Response Program, https://cwcb.colorado.gov/funding/agricultural-emergency-drought-response-program.

conditions. The Flood and Drought Emergency Fund is an as-needed program for drought response.[36]

Maine established the Farmer Drought Relief Grant Program in 2022 to provide grants to address drought impacts on farmers (MRS 220-A). Eligible uses include to assist farmers in accessing new sources of irrigation water to alleviate crop losses.

Drought Planning

This assessment identified several gaps in the State's drought planning frameworks:

- The need to strengthen state drought resilience planning.
- The need for improved evaluation of drought impacts and policies.
- The need to increase support for local drought planning.
- The need for planning to address ecosystem vulnerabilities.

Gap: The need to strengthen state drought resilience planning.

Planning is a key component of building drought resilient communities. Drought plans provide a framework to understand drought risk, develop actions to build resilience, and identify implementation strategies (Wilhite et al. 2000; Knutson et al. 1998).

Drought planning in Oregon has been integrated into numerous statewide, Tribal, and local plans. For example, the Drought Annex identifies the framework for drought response. The statewide NHMP provides an assessment of drought risk and identifies strategies to reduce risk from drought. The IWRS provides strategies to achieve long-term water resilience. A variety of local plans identify local drought risk and resilience strategies.

While these plans individually address components of drought planning, no plan serves as a statewide framework to build drought resilience. The 2017 IWRS highlighted the benefits of drought planning for building resilience and the 2020 NHMP identified several opportunities to strengthen hazard and drought planning (IWRS; NHMP, 2020, Action Item 10, 18, 46 and 47).

Enhancing the State's drought planning would provide a structure to coordinate and integrate information from existing planning efforts. It would also provide a framework to consolidate other plans, reports, and assessments that support drought resilience.

Enhanced planning would provide a structure to strengthen mitigation strategies and support implementation. While many existing many state plans identify strategies that can help reduce drought risk, these strategies are not organized in way that supports prioritization. Enhanced planning would also provide an opportunity to integrate Tribal cultural values into state drought resiliency planning, which was highlighted as important by the Tribal Water Task Force convened in 2022.

[36] Colorado Water Conservation Board, Flood & Drought Response Fund, https://cwcb.colorado.gov/funding/flood-drought-response-fund.

An enhanced drought plan can also support local drought resilience by increasing public awareness of drought risk and providing guidance on drought strategies to improve resilience. It can also serve as a structure to integrate information about Tribal and local drought planning, which can help identify where state policies and funding could fill gaps and accelerate implementation of mitigation strategies.

Models of drought plans from other states include developing a drought specific annex to the statewide multi-hazard mitigation plan.[37] These states utilize the existing hazard mitigation planning process as the framework to develop specific drought mitigation plans that guide the development and implementation of resiliency strategies. Utilizing an existing planning framework may reduce administrative burdens. Other states have developed stand-alone drought plans.[38] States have also established central bodies to coordinate drought resilience planning.

Models: Drought Mitigation Plans

South Dakota's Drought Mitigation Plan is a hazard-specific annex to the statewide hazard mitigation plan, which provides enhanced detail to support intergovernmental and stakeholder coordination to support drought mitigation.[39] The plan includes an assessment of six sector-specific vulnerabilities: agriculture, health and socioeconomic, tourism, water resources, wildland fire, and wildlife.

The mitigation strategy includes state objectives for long-term resilience, an assessment of the state's current mitigation capacity, and identification of mitigation actions and implementation strategies. The mitigation plan identifies five resilience goals: improve water availability monitoring and drought impact assessments, increase public awareness and education, enhance mechanisms to respond to water supply shortage, reduce water demand and encourage water conservation, and reduce drought impacts. Proposed mitigation actions were developed and ranked for each goal. The state maintains a separate drought emergency plan that guides response during drought conditions.

Colorado's Drought Mitigation and Response Plan is a drought-specific annex to the state's natural hazard mitigation plan and includes a risk assessment and mitigation strategy. The mitigation strategy includes an assessment of current state mitigation capacities, which incorporates a review of state statutes, rules, regulations, and policies that address drought. The mitigation strategy identifies proposed mitigation actions and their potential benefits, progress towards actions and funding opportunities. State-developed resiliency criteria[40] are used to rank proposed mitigation actions for implementation. The plan integrates local drought planning efforts by cataloguing where local planning efforts have occurred and identifying drought mitigation actions from local and regional hazard plans. These efforts help identify gaps in local

[37] Examples include Colorado and South Dakota.
[38] Examples include Montana, Washington, Connecticut, Missouri, Kentucky, and New Mexico.
[39] South Dakota Drought Mitigation Plan, South Dakota Drought Task Force (Nov. 2015), https://dps.sd.gov/application/files/5615/0161/4504/2015-SD-Drought-Mitigation-Plan_LR.pdf.
[40] Resiliency criteria considers co-benefits, addressing high-risk areas, economic benefit/cost, social equity, technical soundness, innovation, adaptive capacity, harmonize with existing activity, long-term/lasting impact.

drought planning and help target drought resilience funding and state capacity to support implementation. The drought plan includes several annexes and appendices, which incorporate relevant drought planning documents, examples include the drought response plan, an assessment of potential impacts of climate change on drought risk, and drought monitoring indices.

Missouri maintains a stand-alone Drought Mitigation and Response Plan, which incorporates a description of the state's drought history, assessment of past and potential future impacts, drought response plan, and mitigation plan.[41] The plan builds on state water resources and multi-hazard mitigation planning. The mitigation component includes an assessment of existing mitigation capabilities, including funding, agency roles and local capacity, and identifies preparedness and long-term resilience actions.

Gap: The need for improved evaluation of drought impacts and policies.

The evaluation of drought impacts and policies is a key component of drought preparedness (Wilhite 1991). Formalized post-drought assessments ensure that data about drought conditions, drought impacts, areas of system resilience, and the efficacy of drought coping measures are captured. Periodic review and update of drought frameworks helps ensure that lessons learned are integrated into state drought policies so that they remain effective in building drought resilience. Without formalized processes, preparedness efforts can wane after drought conditions subside, resulting in planning efforts being unfinished or abandoned (Jedd and Smith 2022).

Oregon does not have a formalized process for collecting and reviewing drought impacts. While data collected through existing programs captures drought impacts, this information largely remains disaggregated. Drought impact assessments that have occurred have been ad hoc. Further, there is no formal process to integrate findings or recommendations into the State's drought policies or programs.

The 2016 Task Force on Drought Emergency Response recognized the importance of tracking drought impacts to improve the efficacy of state drought policies and recommended the State provide resources to assess "drought impacts, risks, and vulnerabilities on instream and out-of-stream sectors" (Task Force, Recommendation B). Similarly, the 2017 IWRS recommends the State document the "economic, social and environmental impacts of drought" and where, when, and how often they occur (IWRS, Recommendation 5.5A). The 2020 NHMP also identified the development of a process to continually update the plan as a mitigation action item (NHMP, Action Item 12). Agency staff have identified the lack of a framework and resources to assess drought impacts as a gap in the State's drought policies[42] and highlighted the importance of memorializing agency actions taken to address drought and their efficacy.[43]

The lack of a coordinated framework to assess drought impacts and to evaluate and update drought policies continues to present a gap in the State's drought preparedness. This gap includes

[41] Missouri Drought Response and Mitigation Plan, Missouri Department of Natural Resources (2023), https://dnr.mo.gov/document-search/missouri-drought-mitigation-response-plan-2023.
[42] Minutes of the November 2017 Drought Readiness Council.
[43] Minutes of the May 2016 Drought Readiness Council.

funding to support the collection of data and plan updates.[44] Models from other states that support the evaluation of drought impacts and drought response measures include formalizing requirements to complete post-drought assessments and for periodic plan updates.

Models: Plan Update and Impact Assessment Frameworks

South Dakota's Drought Mitigation Plan is updated every five years in coordination with the multi-hazard mitigation plan. In addition, the state drought task force meets annually to review progress in implementing recommended mitigation actions and any drought impacts and response measures taken.[45] Progress is tracked in the plan.

Colorado's drought plan is comprehensively updated every five years in coordination with the multi-hazard mitigation plan.[46] Colorado's drought response framework integrates impact assessments following drought. The drought taskforce meets yearly to review lessons learned from drought response, to monitor progress on mitigation goals, and to review the response plan. The plan is updated as needed to integrate findings. The plan also calls for the state to test a minimum of every five years the response framework to ensure plan users are aware of plan processes and their roles.

Montana's draft drought plan requires several levels of periodic review including an annual review to ensure the plan reflects current response measures and monitoring procedures, a biennial review to integrate legislative changes, and a five-year in-depth review and evaluation incorporating stakeholder input.[47] The plan also requires post-drought evaluations of impacts and assessments of drought response measures.

Gap: The need to increase support for local planning.

Local drought planning is an important component of reducing community vulnerability (Haigh et al. 2022). Drought impacts vary based on local characteristics and local planning can identify place-based vulnerabilities and strategies to reduce risk. Local drought planning is also important to help governments and communities prepare to respond to drought.

Despite its importance, many local jurisdictions have not planned for drought. A 2018 national survey of local planners on drought planning identified several barriers to planning, including funding, capacity, and lack of political will (APA 2018). State support has also been identified as an important factor in local drought planning; community drought planning is more widely adopted where there are state requirements or support (Haigh et al. 2022).

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[44] Agency staff have identified post drought assessments of impacts and response approaches as helpful but noted a lack of capacity to complete such assessments. Minutes of the Oct. 2016 and April 2018 Drought Readiness Council.

[45] South Dakota Drought Mitigation Plan, South Dakota Drought Task Force (Nov. 2015), https://dps.sd.gov/application/files/5615/0161/4504/2015-SD-Drought-Mitigation-Plan_LR.pdf.

[46] Colorado Drought Mitigation and Response Plan, Colorado Water Conservation Board, Department of Natural Resources (Aug. 2018), https://drought.unl.edu/archive/plans/drought/state/CO_2018.pdf.

[47] Montana Drought Management Plan, Public Comment Draft, Department of Natural Resources (June 2023), https://repos.dnrc.mt.gov/esri/hub/drought/PDFs/Draft-Montana-Drought-Management-Plan.pdf.

Local drought planning in Oregon remains inconsistent. State regulatory frameworks for water system planning do not require planning for water shortage (OAR 333-016-0060(5)). Requirements for municipal and agricultural water providers to develop Water Conservation and Management Plans are triggered by water rights permitting processes, which do not impact all water providers (ORS 537.211, 540.572). Emergency response plans, which are required for all public water systems, have not been fully leveraged as a tool for addressing drought. The OHA is currently revising emergency planning guidance to better incorporate drought and water supply shortage. Local comprehensive plans have generally not addressed drought. Goal 11 requires public facilities planning for long-term water supply needs but does not address planning for water shortage or water conservation. Goal 7 requires comprehensive plans to address natural hazards but does not require consideration of drought risk.

The State has historically provided limited resources to support locally led water planning efforts. Data about water remains a planning gap. The State-Supported Regional Water Planning and Management Workgroup identified a need to increase state capacity and resources to collect and compile water data.[48] The 2021 Tribal Water Task Force identified a lack of adequate data as a barrier to water decision making and planning.[49]

The State also has limited funding to support local water planning. Recent legislative investments have expanded state agency capacity to support planning, including making permanent the place-based planning program, funding the Oregon Association of Water Utilities to conduct an assessment of small community water system needs and to provide technical assistance capacity, and funding the Oregon State University Extension Service to develop a technical assistance center for agricultural users (HB 2010 §§ 15-16, 24, 26, 12-14, 56 (2023)). These programs have the potential to build local capacity for drought planning, however, additional funding gaps remain. For example, the State continues to lack a funding resource to support local drought contingency planning, which could help communities leverage federal resources.

Additional state support to enhance local drought planning has been consistently recognized as a need. The 2016 Task Force on Drought Emergency Response recommended the development of funding resources to support local planning, including the development of local hazard mitigation plans and water supply planning for small community systems and irrigation districts (Task Force, Recommendation F). The Task Force also identified a need to provide technical assistance to small water systems to support drought planning (Task Force, Recommendation H). The 2017 IWRS recommends the State invest in local and regional water planning efforts, including hazard mitigation plans and water management and conservation plans (IWRS, Recommendation 13.C). Several of the 2020 NHMP actions address a need for additional

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[48] Report of the Work Group on State-Supported Regional Water Planning and Management, House Bill 5066 (2021), https://www.oregon.gov/owrd/Documents/HB%205006%20Work%20Group_FINAL%20REPORT.docx%20(2)%20(2).pdf.

[49] Tribal Water Task Force Summary Report, https://www.oregon.gov/owrd/WRDReports/Tribal%20Water%20Task%20Force%20Summary%20Report_Final%2002.02.2023.pdf.

information on community vulnerability to support local response (NHMP, Action Items 46 and 47). Agency staff also identified local planning as a key component of drought preparedness.[50]

Models from other states that support local drought planning include comprehensive regulatory requirements for water supply and drought planning, state funding for water resources and drought planning, increased capacity for technical support and resources, and improved data and information.

Models: State Support for Local Planning

Washington's Drought Planning and Preparedness Grant program authorizes Department of Ecology to provide grants for the development of local drought preparedness plans. In 2024, Ecology is offering $1.8 million in planning grants as part of a pilot program.[51] Eligible entities include Tribes, county and city government agencies, public utility districts, water and sewer districts, conservation districts, irrigation districts, port districts, and watershed management partnership.

California uses a suite of regulatory requirements, funding, data, and technical support to build local drought preparedness. The state recently passed legislation to improve drought preparedness at the local level through water shortage and drought resilience and response planning requirements for counties and small water suppliers (SB 552 (2021)). Counties are required to prepare drought plans that describe drought and water shortage risks and short- and long-term solutions for small water systems and domestic well users. Counties are also required to establish a standing drought task force to support small water systems and privately supplied water users. Small water suppliers are subject to varying planning requirements based on size. This legislation builds on existing requirements for urban water suppliers and large agricultural water suppliers (SB 606 (2016)).

The state supports planning with funding and technical resources. Counties may request up to $125,000 for planning efforts and direct technical assistance. The state maintains a water shortage vulnerability tool that provides information on physical and social vulnerabilities of small water systems and domestic wells.[52]

Colorado requires all water providers that sell over 2,000 acre-feet per year to have a water efficiency plan, which identifies opportunities to extend existing water supply through water use savings or water reuse (CRS 37-60-126). Water providers are also required to annually report water use and efficiency data to the state (CRS 37-60-126). State guidance recognizes efficiency planning as an important component of increasing drought resiliency.

[50] Minutes of the November 2017 Drought Readiness Council.
[51] Washington Department of Ecology, Drought Planning and Preparedness Grants, https://ecology.wa.gov/about-us/payments-contracts-grants/grants-loans/find-a-grant-or-loan/drought-planning-and-preparedness-grants.
[52] California, Drought & Water Shortage Vulnerability Explorer, https://water.ca.gov/Programs/Water-Use-And-Efficiency/SB-552/SB-552-Tool.

The Colorado Water Conservation Board provides technical and funding support for water conservation and drought planning, including maintaining a guide on drought management planning for water providers.[53] The Water Efficiency Grant Program previously provided targeted funding to support water efficiency and drought planning (HB05-1254 (2005)). The state drought plan integrates information on local drought plans and provides resources on state support for local plan development.

In 2021, the Colorado Legislature created the Agricultural Drought and Climate Resilience Office in the Department of Agriculture to provide nonregulatory and voluntary support for producers to mitigate, prepare for, and respond to drought and climate change (HB21-1242). The state-funded Drought Plan Program, housed at the Colorado State University Extension program, provides farmers and ranchers individualized support for development of drought conservation and contingency plans, and plan implementation.[54] Participants receive a $500 incentive for developing a plan and $1,000 for plan implementation.

Gap: The need for planning to address ecosystem vulnerabilities.

Research is increasingly demonstrating the significant and often long-term ecological impacts of drought as well as the connection between ecosystem and human resilience (Crausbay et al. 2017; Raheem et al. 2019). However, ecological impacts have historically received limited attention in drought planning efforts, which have primarily been human-centric (Crausbay et al. 2017). In addition, when plans have addressed ecosystem impacts, they commonly focus only fish and fish habitat (Raheem et at. 2019).

Planning for ecosystem resilience to water shortages helps reduce environmental impacts when drought does occur. As with other drought impacts, increasing preparedness and resilience provides greater benefits than response-focused approaches. However, ecosystems may particularly benefit from these measures. Legal frameworks and drought policies often provide limited tools to address environmental water shortages. Further, during drought emergencies, management measures can prioritize mitigating human impacts, often to the detriment of already stressed ecosystems. Finally, many ecosystems are already degraded and have insufficient water during critical periods, making them less resilient to further stressors.

Oregon's ecosystems face each of these challenges, which heightens the State's vulnerability to drought. The State needs to further assess ecosystem drought vulnerabilities and impacts. In addition, the State has not developed a framework to build ecosystem resilience to drought or a plan for managing ecosystem impacts during drought. Recent funding has supported agency capacity to increase data on groundwater, streamflow, temperature and refugia habitat, which can support drought response and mitigation planning. However, the information has not yet been integrated in a way that can identify high priority drought resilience actions and response management measures.

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[53] *See e.g.*, Colorado Conservation Board and Department of Natural Resources, Drought Management Planning: A Guide for Water Providers (June 2020), https://dnrweblink.state.co.us/CWCB/0/edoc/213920/2020DroughtPlanGuidance.pdf.

[54] Colorado State University Extension, Colorado Agricultural Drought Advisors, https://droughtadvisors.org/drought-plan-program/.

The 2016 Task Force on Drought Emergency Response identified a need to better understand the impacts of drought on instream uses and to identify ecosystem drought vulnerabilities (Task Force, Recommendation B). The 2017 IWRS recommends the study of long-term demands for instream needs, including considerations of species, water quality and quantity, and long-term climate projections (IWRS, Recommended Action 3.A). The 2020 NHMP also identifies the need for additional information on ecosystem impacts from drought (NHMP, Action Items 47 and 48).

Enhancing planning to address ecosystem impacts during drought can improve the State's toolbox to protect ecosystem functions during periods of critical water shortage. Planning can identify ecosystems vulnerable to drought, proactively coordinate response measures, and identify and prioritize strategies to build system resilience. Models from other states that support preparedness for ecological drought include completing ecosystem vulnerability assessments at the state and watershed scale, incorporating ecosystem resilience into statewide drought planning, and developing drought contingency plans for individual watersheds.

Model: Ecological Drought Planning

Montana has supported the development of several watershed-scale drought plans that build preparedness to address ecosystem impacts during drought.[55] These include drought response plans which identify strategies to respond to ecological drought. The plans generally rely on a communications strategy and voluntary measures to augment streamflow and angling restrictions to protect fish. Local watershed organizations have also developed local drought resilience plans. These plans identify local watershed conditions, drought vulnerabilities, and strategies to build resilience and reduce drought risk.[56]

Montana's drought vulnerability assessment addresses ecological vulnerabilities, and its draft drought plan identifies response and resilience measures to mitigate impacts (Walker et al. 2023).[57] Montana is also participating in the development of tools to better monitor drought impacts on cold-water fisheries and to support decision making to address ecological drought.

SECTION III: DROUGHT RESILIENCE

Drought resilience is the ability to absorb, cope with, and recover from drought. As a normal feature of climate, the conditions that result in drought cannot be avoided but the impacts can be

[55] Montana Department of Fish, Wildlife & Parks, Drought Response and Management Plans, https://fwp.mt.gov/conservation/fisheries-management/water-management/drought.
[56] Examples include the Jefferson River Watershed Drought Resilience Plan and Big Hole River Watershed Drought Resilience Plan. Drought Resilience Plan, Jefferson River Watershed Council (Sept. 2019), https://jeffersonriverwc.com/fish/uploads/2019/11/2019_DroughtResilience_JRWC.pdf; Big Hole Watershed Drought Resilience Plan, Big Hole Watershed Committee (Dec. 2019), https://bhwc.org/montana/uploads/2020/08/2019-Big-Hole-Watershed-Drought-Resilience-Plan.pdf.
[57] Montana Drought Management Plan, Public Comment Draft (June 2023), https://repos.dnrc.mt.gov/esri/hub/drought/PDFs/Draft-Montana-Drought-Management-Plan.pdf

minimized. Drought resilience policies increase the threshold of human and natural systems to withstand water deficits.

A wide range of policies influence how resilient a community is to drought. The impacts a community experiences from drought are determined by the interface between the physical conditions that cause drought and the demands placed on water supply (Wilhite 2000). Policies that increase resilience address the physical and social conditions that determine capacity to absorb water deficits (Wilhite 2000). These include policies that support sustainable management of water resources, restore and protect ecosystems and natural lands, and address social impacts from drought, including health and safety. Policies that build resilience also typically have a range of co-benefits, which can amplify their impact—such as ecosystem restoration, climate change resilience, and reducing water insecurity.

The aim of this section is to (1) describe key types of strategies that build drought resilient communities, (2) provide examples of policies that implement those strategies, and (3) highlight state policies that support drought resilience. Given the breadth of policies that can support drought resilience, this section does not comprehensively describe or evaluate all related state policies. This section is supported by Appendix C, which identifies many of the state policies that support drought resiliency.

Drought Resilience Policies

Oregon has implemented numerous strategies that support drought resilience. These include strategies that build capacity to support decision making, improve water security, address ecosystem health, and support public health. The IWRS serves as the primary state strategy for sustainable water management and identifies many of the state actions that support water security and drought resilience. The State has also recently increased investments to support water security. While many of the drought-specific investments were temporary, they provide a model for future funding.

This section describes five types of drought resilience strategies and highlights state policy approaches in each:

- Water conservation strategies reduce the amount of water needed to meet demand through increased efficiency and reductions in waste.
- Water supply strategies develop additional water supplies by changing how and where water is used, capturing and storing water, and improving the quality of water.
- Healthy ecosystem strategies build the resilience of natural systems, which reduce the vulnerability of both humans and ecosystems to drought.
- Cascading hazard strategies reduce the compounding impact of drought on the likelihood and severity of other natural hazards, including wildfire, flooding, and extreme heat.
- Data and analysis strategies support the collection, analysis, and use of data to inform decision making to build drought resilience.
- Funding strategies use investments to support the adoption and implementation of drought resilience measures.

Water Conservation

Water conservation policies improve the efficiency of water use and eliminate waste to reduce the amount of water needed to meet demands. Water conservation extends the uses a water supply can serve and increases thresholds to periods of water shortage. These policies also reduce the burden on water resources and natural systems and, with proactive policy choices, can keep more water in rivers and streams.

Water conservation policies include measures that improve water use and distribution efficiency and support demand reduction. Policy strategies can include behavioral changes, regulation, data collection, land management practices, and infrastructure investments. Long-term water conservation policies build more sustainable water management. In contrast, short-term water conservation policies address acute water shortages through behavioral and regulatory measures to temporarily curtail water use.

Water conservation strategies include:

- Municipal water conservation planning, actions, and data collection. These policies require or incentivize water providers to understand existing water use (e.g., through audits and metering) and identify and implement measures to increase efficiency and reduce demand. Washington and Nevada provide examples of comprehensive water conservation planning and efficiency requirements. Washington requires all entities that supply water for municipal purposes to comply with water use efficiency rules (RCW 246-290-800). These include conservation planning and metering requirements. Washington also sets a standard of no more than 10% water loss. Nevada requires all water suppliers with over 15 connections to develop conservation plans and to complete and report the results of a water loss audit (NRS 540.121 through .151; AB 163 (2019)).
- Municipal indoor water efficiency standards. These policies set requirements for the efficiency of indoor fixtures. For example, Nevada requires local government building codes to require water fixtures in new construction to meet WaterSense standards (AB 163 (2019)).
- Municipal outdoor water efficiency. These policies require and incentivize the use of less water intense landscaping. For example, Colorado, Nevada, and California have established programs to reduce outdoor water use. Colorado established a turf replacement fund to support the removal of non-essential turf (HB 1151 (2021)). Nevada restricts the use of Colorado River water to irrigate nonfunctional grass in areas not zoned for single-family use (AB 356 (2021)). California requires local governments to adopt minimum landscape efficiency standards (CCR Title 23 § 490).
- Agricultural water use efficiency. These strategies support improvements in agricultural water use efficiency including in water distribution and on-farm systems. Strategies include funding for infrastructure improvements, land use changes and restoration (e.g., retiring marginally productive lands), and policy changes to remove regulatory barriers that disincentivize conserving water.
- Public education. These programs provide water users with information and resources to reduce water use. Examples include the production of factsheets and guides, the installation of smart meters, and efficiency checkups.
- Soil health. Healthy soils infiltrate and retain more water—reducing the amount of irrigated water needed for crops. California's Healthy Soils Program provides grants for

implementation of land use practices that improve soil health.[58] The Washington Department of Agriculture is a partner in the Washington Soil Health Initiative, which promotes the adoption of soil health practices.[59] Grants from the state's Sustainable Farms and Fields (SFF) Program can fund soil health projects.

Water conservation is a stated priority in Oregon's water policies and the State has adopted to varying degrees many of the water conservation strategies outlined above.[60] These include statutory provisions that require and incentivize water conservation planning and practices for certain municipal and agricultural water providers, prohibit waste, and remove barriers to water conservation by water right holders. The state plumbing code establishes minimum water efficiency standards for fixtures. These regulatory policies are complemented by investments in public education programs and grant and loan programs that support adoption of water conservation practices. The following are examples of state water conservation policies:

Municipal Water Conservation. The Water Conservation and Management Planning program is the State's primary mechanism for advancing municipal water conservation. As a condition of new water rights permits and permit extensions, municipal water suppliers must develop and implement water conservation plans (ORS 537.211). Required conservation measures include water audits, system metering, a rate structure based in part on water use, leak detection program at the supplier's facilities, and a public education program (OAR Ch. 690 Div. 086). Larger municipal water suppliers must consider enhanced conservation measures, including reducing system leakage to 10%, establishing technical and financial assistance programs to reduce customer demand, addressing inefficient fixtures, adopting payment structures to support conservation, and providing reuse and recycling opportunities (OAR 690-086-0150(6)). Not all municipal water providers are subject to program requirements.

Agricultural Water Conservation Programs. The State has several programs that support agricultural water conservation. The State incentivizes agricultural water suppliers to develop water conservation plans by making plan development a condition of using water rights tools that allow for the transfer of water between district patrons (ORS 540.572). The Conserved Water Program allows a water right holder who implements a water conservation project to retain a portion of the water conserved for use on additional lands (ORS 537.455 through .500). The remaining portion of conserved water is retained instream.

The State also incentivizes water conservation practices by providing grants for infrastructure improvements that increase efficiency of distribution and on-farm irrigation systems. The Water Project Grants and Loans program can fund projects that increase efficiency of water distribution and delivery systems (ORS 541.656 et seq). The Legislature recently allocated $500,000 to OWRD for grants for projects that improve water use efficiency of irrigation systems (HB 5030 § 10 (2023)). The Legislature has also provided cost-share funding for the enrollment of lands in

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[58] Healthy Soils Program, California Department of Food and Agriculture, https://www.cdfa.ca.gov/oefi/healthysoils/.
[59] Washington Soil Health Initiative, https://washingtonsoilhealthinitiative.com.
[60] The Alliance for Water Efficiency ranked Oregon 12th nationally in its 2022 U.S. State Policy Scorecard for Water Efficiency and Sustainability, which considered state policies that support water conservation, efficiency, and sustainability (Alliance for Water Efficiency 2022).

Harney County in the Conservation Reserve Enhancement Program, which pays producers to retire marginal lands and voluntarily cancel associated groundwater rights (SB 5545 POP 112 (2021)).

Adoption of agricultural water conservation practices in Oregon is voluntary. State policies rely on regulatory and financial incentives to accelerate the adoption of water efficiency and conservation techniques to reduce water use.

Water Supply

Water supply policies develop additional water supplies. In contrast to water conservation, these policies do not focus on increasing water supply through reductions in water use but instead extend existing water supply or develop new sources of supply. Water is a finite resource, so water supply augmentation generally involves changing how and where water is used, capturing and storing water, and improving the quality of water.

Strategies to augment water supply include both regulatory and nonregulatory measures that facilitate access to new sources of water. Importantly, because many of these strategies require new uses of water, implementation frequently requires identifying and removing embedded policy barriers.

Water supply strategies include:

- Water reuse. Water reuse refers to practices that reclaim water and treat it for another beneficial purpose.
- Aquifer recharge. Aquifer recharge refers to practices that increase the amount of water that enters an aquifer through injection or natural infiltration. These practices increase groundwater supplies, may reduce reliance on built storage infrastructure (e.g., reservoirs), and provide a mechanism to augment natural storage.
- Rainwater harvesting. Rainwater harvesting involves the capture and use of rainwater from an impervious surface. These policies remove legal barriers to rainwater harvesting and may be paired with incentives to support installation of rainwater harvesting infrastructure. Several states have adopted programs to encourage the adoption of rainwater harvesting. Texas requires rainwater harvesting to be incorporated into new state buildings (Texas Government Code § 447.004(c)(8)). It also prohibits homeowners associations from prohibiting rainwater harvesting installations and provides a tax incentive for the purchase of rainwater harvesting equipment (Texas Property Code § 202.007, Texas Local Government Code § 580.004). Washington requires counties to reduce stormwater fees by 10% for commercial buildings with rainwater catchment systems and allows counties to reduce stormwater fees for other types of buildings that incorporate rainwater catchment systems (RCW 36.89.080).
- Land use policies. How we use and develop land directly impacts water supply. Land use policies that address water supply may include requirements for new growth to demonstrate adequate water supply to meet expected demands. Policies may also require local governments to better integrate land use and water planning. Land use policies can support the use of nature-based solutions, including by preserving natural landscapes and supporting the integration of nature-based solutions in buildings and urban settings.

- Infrastructure. Infrastructure can increase water supply by providing access to new water supplies and facilitating the movement and storage of water. For example, building interties between municipal water providers can extend water supply.
- Appropriation and transfers. In some cases, water may still be available for appropriation. More commonly, water transfers provide a tool to change how water is being used to support new uses.
- Nature-based solutions. Natural landscapes help augment water supply by capturing and storing water. Nature-based solutions may incorporate preservation of natural landscapes as well as constructed infrastructure that relies on natural functions. For example, nature-based solutions such as permeable pavement and bioswales capture stormwater runoff and return it to the land. Healthy natural landscapes slow water, which allows for greater infiltration into aquifers and moderates streamflow. California has defined watersheds as an integral component of the state's water infrastructure, which allows ecosystem and restoration projects to qualify for infrastructure funding (AB 2480 (2016)). In 2023, California amended its definition of natural infrastructure to include "aquifers," allowing aquifer recharge projects to access state infrastructure funding (SB 122 § 23 (2023)).

Oregon has adopted a variety of policies to expand its water supply. State regulatory frameworks authorize water reuse, aquifer recharge, and rainwater harvesting. Building code provisions permit the construction of rain catchment systems and the use of graywater. State funding programs support implementation of water storage solutions including both built and natural infrastructure. The following are examples of state water supply policies:

Water Reuse. Oregon has authorized water reuse since the 1990s and ODEQ implements a statewide program to encourage reuse practices. The State allows water reuse for graywater (domestic wastewater), recycled water (treated wastewater from municipal systems) and industrial wastewater. The primary use of reclaimed water is for non-potable uses; however, the State has approved one direct potable reuse project. In 2023, the Legislature directed ODEQ and OWRD to identify barriers to implementation of water reuse projects and to provide recommendations on how to expand water reuse projects (HB 2010 §§ 22-23, 57-60 (2023)).

Aquifer Recharge. Oregon administers two permit programs for underground storage. The Artificial Groundwater Recharge program was established in 1961, which permits the appropriation of water for storage underground through land application and well injection (ORS 537.135). The Aquifer Storage and Recovery program was established in 1995, which permits the injection of water underground for storage and later use (ORS 537.531 through .534). While permit requirements vary, both programs require an initial testing phase to understand impacts on groundwater. In 2023, the Legislature created a statewide Aquifer Recharge Due Diligence Grant Program to offset testing and due diligence costs for aquifer recharge projects (HB 2010 §28-34, 47, 55 (2023)). OWRD has assessed the geologic suitability of underground storage in the state.

Green Infrastructure. Oregon supports natural infrastructure solutions through grant and loan programs. The Clean Water State Revolving Fund maintains a set aside reserve to fund green infrastructure projects (OAR 340-054-0036). Natural infrastructure projects are also eligible for some Business Oregon infrastructure funding programs (see e.g., OAR 12-042-0020). In 2023, the Legislature established the Drinking Water Source Protection Grant Fund, which will fund land conservation projects to protect drinking water (HB 2010 § 2-4 (2023)).

Rainwater Harvesting. Oregon has approved the use of rainwater harvesting systems for potable and non-potable purposes and exempts rainwater harvested from impervious surfaces from water permit requirements (ORS 537.141(1)(h); Oregon Plumbing Code Ch. 16). These policies remove key regulatory barriers to rainwater harvesting. However, state policies do not incorporate incentives that encourage and support the use of rainwater harvesting.

Feasibility Study Grants and Water Project Grants and Loans. OWRD administers Feasibility Study Grants and the Water Project Grants and Loans program, which provide funding for water reuse, conservation, and storage (including both above- and below-ground) projects. Feasibility Study Grants provide funding to assess whether and how a project should be implemented (OAR Ch. 690 Div. 600). The program has awarded more than $9 million in grants. The Water Project Grants and Loans program funds project implementation (ORS 541.656 et seq). Projects must demonstrate an economic, environmental, and social or cultural benefit. Increased resiliency to climate change, which includes decreased risks from drought, is a qualifying environmental benefit. The program has awarded more than $50 million in grants.

Healthy Ecosystems and Natural Lands

Oregon's drought vulnerability is directly tied to the health of its ecosystems. Healthy ecosystems are less susceptible to drought conditions and are more able to cope with periods of water scarcity. Healthy natural lands and waters also increase water security for human resilience. Natural lands capture and hold water and release it more slowly over time, which can reduce impacts from periods of water shortage.

Strategies that support ecological health and reduce both human and ecosystem vulnerability to drought include:

- Instream flow. The restoration and protection of streamflow increases the health of ecosystems and makes them more resilient to drought.
- Fish passage. Water scarcity during drought can reduce available habitat. When habitat is further limited by fish passage barriers, fish can be stranded. Policies that direct removal of fish passage barriers increase the resilience of species by allowing fish to access refugia.
- Conservation of natural lands. Land conservation protects natural lands from development, which helps protect ecosystem functions that are essential for drought resilience.
- Forest health. Drought causes injury and stress in trees from water depletions, increases susceptibility of trees to pests, and increases the severity and intensity of fires (Vose 2020). Forest management practices that build healthy forests can reduce vulnerability to drought.

Oregon has a variety of policies that support ecosystem resilience. These include policies that protect and restore instream habitat, regulatory requirements for fish passage, data collection about habitat conditions, funding for voluntary conservation and restoration, and regulations that protect water quality. The following are examples of state policies that support healthy ecosystems and natural lands:

Instream habitat. Oregon has numerous programs that help protect and restore instream habitat and increase the resilience of freshwater ecosystems to drought. The instream water rights program protects streamflow through the establishment of instream water rights by (1) establishing new instream water rights at the request of the ODFW, ODEQ, and ODSL, (2) converting existing uses to instream uses, and (3) converting administratively protected streamflow to instream water rights (ORS 537.332 through .360).

ODFW is authorized to apply for instream water rights for fish and wildlife purposes and has a "long-term goal . . . to obtain an instream water right on every waterway exhibiting fish and wildlife values" (ORS 537.446; OAR 635-400-0005). Increased funding has allowed ODFW to reestablish and expand its instream flow program, including to develop a statewide strategy to protect instream flows in watersheds with the greatest need (see e.g., SB 5509 POP 107 (2023)). The Legislature has also made investments to support fish passage restoration including through adding ODFW capacity and grant funding for fish passage projects (see e.g., HB 5202 § 401 (2022); HB 5030 §3 (2023); and SB 5509 POP 119 (2023)).

ODFW has increased its capacity to collect data related to drought and instream habitat. Legislative investments in 2021 and 2022 supported installation of real-time discharge and temperature gauges at priority locations to improve information on drought impacts and direct response measures (HB 5202 § 403 (2022)). This funding is also supporting identification of cold water refugia areas that can help species adapt to drought and climate change.

OWEB administers the Water Acquisition Grant Program, which funds acquisition of an interest in water to protect instream flow (ORS 541.956). Grant funds can be used to lease water instream, to permanently transfer water instream, to pay costs to implement a water conservation project that will protect conserved water instream, and for legal agreements to reduce water diversions to maintain instream flow. In 2022, the Legislature allocated $10 million to OWEB for water acquisition grants (HB 5202 § 304 (2022)).

Beavers. ODFW has developed a 3-year action plan to accelerate restoration of beaver habitat in Oregon (ODFW 2023). The plan calls for ODFW to improve understanding of current beaver populations and habitat needs, to restore beaver habitat, to improve beaver coexistence strategies, and increase public awareness of the benefits of beavers. Beaver dams and channels help intercept and slow water, which helps water soak into soil and increases the water storage capacity of landscapes.

Forest health. ODF monitors the impact of drought conditions on forest health and has developed information on drought stress in conifers and recommendations to promote drought resiliency in trees.[61] Drought was discussed as a stressor for forest health in the 2022 Forest Health Highlights in Oregon (Buhl et al. 2022).

Cascading Hazards

Drought can increase the likelihood and severity of other natural hazards, including wildfire, flooding, and extreme heat (APA 2019). Reduced precipitation and soil moisture associated with drought increases the amount of dry or dead vegetation, which serve as fuel for fires and makes

[61] Oregon Department of Forestry, Drought Stress in Conifers (Oct. 2023), https://www.oregon.gov/odf/Documents/forestbenefits/Drought.pdf.

them more combustible. Dry soils associated with drought are less able to absorb water, increasing flood risk. Reduced water availability from drought reduces evapotranspiration and increases surface temperature. Extreme heat in turn increases evapotranspiration, which further reduces moisture levels worsening drought. Policies that reduce risks from these hazards also reduce the likelihood that drought will cause cascading impacts.

Hazard planning, land use laws, and natural resources policies all help reduce impacts from cascading hazards. In 2021, the Legislature invested $220 million to help Oregon create fire-adapted communities, improve fire response, and build resilient landscapes (SB 762 (2021)). As part of that effort, ODF is leading the development of a 20-Year Landscape Resiliency Strategy that will serve as a plan to prioritize restoration activities to address fire risk and build healthy landscapes. There is opportunity to address water in the strategy as an integral part of resilient landscapes.

To reduce impacts of extreme heat, the State has adopted regulatory requirements and funding programs to protect workers, increase access to portable cooling devices, and provide aid to agricultural workers impacted by heat (see e.g., OAR 4437-002-0156, -1131; SB 1536 (2022); SB 5506 § 309 (2023)).

Data and Analysis

Data and analysis are the foundation of policies that support drought resilience. They are critical for understanding drought risk and impacts, which is necessary to identify effective mitigation measures. Information is also necessary to build natural and human systems that are resilient to drought. Sustainable water management requires understanding where, when and in what quantity water is available, the condition of water resources, and water use. Information about streamflow, temperature, habitat fragmentation, and soil health are all necessary to adopt policies that build resilient ecosystems. To inform decision-making, data should be complete and in a useable form.

Strategies that support collection, analysis, and use of data include:

- Funding. Investments in capacity and equipment to collect data.
- Data accessibility. Data platforms that are aggregated to support public access and use.
- Water measuring and reporting. Water use data is essential for sustainable water management. Strategies to increase water use data include reporting requirements and funding for measuring equipment. For example, California requires most water users that divert over 10 acre-feet per year to measure and report diversions (CCR 23 §§ 931 through 938). Washington requires most surface water right holders to measure water use and authorizes measuring as a condition of groundwater permits (RCW 90.03.360, 90.44.450). To support water management, Texas requires all water users to annually report water use (Texas Water Code § 11.031). The Texas rule exempts domestic and stock watering uses.

Data collection and analysis is a core agency function related to water and natural resources management. Oregon also supports water data through regulatory requirements for water measuring and reporting. Examples of state policies that support the collection, analysis, and sharing of data include:

Water measuring and reporting. OWRD has a variety of authorities that support water use measuring and reporting. OWRD may require water measuring and reporting as a condition of new water rights permits (see e.g., ORS 537.211) and in certain administratively designated areas (see e.g., ORS 540.435), and must require it as a permit condition for some types of water use (see e.g., ORS 537.147(4)(b)). Certain types of government entities are required to report water use (ORS 537.099). Water projects funded through the Water Project Grants and Loans program are required to measure and report water use (ORS 541.692(3)). In 2023, the Legislature authorized OWRD to require reporting of water use where it requires measuring (HB 2010 § 26 (2023)). OWRD estimates that around 17% of water rights in the state are required to measure and report water use (OWRD 2022).

The Water Measurement and Cost Share Program provides grants to offset 75% of the cost to voluntarily install a water measuring device (ORS 536.021). In 2021, the Legislature allocated $1 million to support cost-share under the program (HB 5506 § 252 (2023)).

Oregon Water Data Portal. The Oregon Water Data Portal is an interagency initiative to improve data and information about water resources and infrastructure. The portal will integrate water data from across agencies and improve accessibility of information. In 2023, the Legislature provided additional funding to support continued development of the portal (HB 5018 (2023)).

Water data investments. Oregon has made a suite of investments in building data that can support drought-related decision making, including for producing groundwater budgets for all major hydrologic basins and expanding baseline water level and water use data collection (HB 2018 (2021)), expanding temperature and streamflow monitoring (HB 5006 § 251 (2021); HB 5202 § 403 (2022); SB 5009 (2023)), and updating water availability modeling (HB 5043 (2023)). Investments in baseline water level data are providing capacity to develop statewide evapotranspiration datasets.

Funding

Funding is a critical component of developing and implementing policies that build drought resilience. Investments that support resilience include adding government capacity to implement programs and authorities and funding grant and loan programs that incentivize and accelerate adoption of resilience practices.

The establishment of a dedicated funding program to support drought resilience projects can help accelerate the implementation of drought resilience measures. For example, in 2020 the Washington Legislature recognized resiliency and preparedness measures as important components of effective drought response and directed the Department of Ecology to support water users in adopting measures to improve resilience. Washington's Drought Preparedness Fund can support projects that build drought resiliency, including water storage, source substitution, development of alternative backup supplies, conservation and efficiency projects, promotion of reclaimed water use, and development of local drought contingency plans (RCW 43.83B.414). In 2021, Arizona established the drought mitigation revolving fund, which provides grants and loans to water supply and conservation projects that support long-term water security (ARS Title 49 Art. 8).

Many of the ways Oregon funds drought resilience are highlighted above. These include funding for agency capacity and resources that support data collection and program implementation. Funding also capitalizes grant and loan programs that incentivize and support the adoption of resilience actions, including water conservation and efficiency practices. Between 2021 and 2023, the Legislature made a suite of investments in water security that support drought resilience. Investments funded term-limited programs to address drought impacts, added capacity to existing programs, and capitalized new programs. For example, in 2021 the Legislature made a suite of investments that supported the adoption of water conservation practices by producers impacted by drought (SB 5561 §§ 17-23 (2021)), capitalized the new Water Well Abandonment, Repair, and Replacement Fund, which helps domestic well users remediate water well issues (SB 5561 § 12a (2021)), and enhanced funding for the Water Grants and Loans program (HB 5006 § 232 (2021)). In 2022, the Legislature added capacity to existing grant programs that build ecosystem resilience, including grants for fish passage and streamflow restoration (HB 5202 §§ 304, 399 (2022)). In 2023, the Legislature invested over $100 million in water resilience, including grant funding for irrigation modernization, fish passage, land conservation to protect drinking water sources, and aquifer storage and recovery projects (SB 5506 §§ 228, 185 (2023), HB 2010 §§ 1, 28-34, 47, 55 (2023)). The Legislature also invested in the capacity of technical assistance partners to support the adoption of water resilience practices by producers and water utilities (see e.g., SB 5506 § 87 (2023); HB 2010 §§ 12-14, 24 (2023)). Appendix D provides an inventory of water security legislative investments made between 2021 and 2023.

Literature Cited

BeCraft, R. 2017. Learning from Oregon's 2015 Drought: A Review of Documented Conditions, Impacts, and Response Strategy. https://aquadoc.typepad.com/files/learning_from_oregons_2015_drought_23june2017.pdf.

Buhl C., G. Ritokova, W. Williams, H. Stevens, D. Shaw, K. Ripley, D. DePinte. 2022. Forest Health Highlights in Oregon. Oregon Department of Forestry, U.S. Forest Service, Oregon State University. https://www.oregon.gov/odf/forestbenefits/Documents/odf-usfs--2022-forest-health-highlights.pdf.

Bumbaco, K.A., C.L. Raymond, L.W. O'Neill, A. Mehta, D.J. Hoekema. 2023. 2022 Pacific Northwest Water Year Impacts Assessment. A collaboration between the Office of the Washington State Climatologist, Climate Impacts Group, Oregon State Climatologist, Idaho Department of Water Resources, and NOAA National Integrated Drought Information System. https://www.drought.gov/sites/default/files/2023-03/NIDIS_PNW_Water_2022.pdf.

Crausbay, S. D., A.R. Ramirez, S.L. Carter et. al. 2017. Defining Ecological Drought for the Twenty-First Century. Bulletin of the American Meteorological Society. https://doi.org/10.1175/BAMS-D-16-0292.1

Dinsdale, B. 2023. A Statewide Drought and Heat Needs Assessment with Oregon Farmers, Oregon State University Extension Service. https://extension.oregonstate.edu/sites/default/files/2023-06/Drought%20and%20Heat%2 0Final%20Report_6_16_23.pdf.

Department of Land Conservation and Development (NHMP). 2020. Oregon Natural Hazards Mitigation Plan. https://www.oregon.gov/LCD/HAZ/docs/2015ORNHMP/201ORNHMPApproved/Approved_2015ORNHMP.pdf.

Department of Land Conservation and Development (DLCD). 2021. State Agency Climate Change Adaptation Framework. www.oregon.gov/lcd/CL/Documents/2021_CLIMATE_CHANGE_ADAPTATION_FR AMEWORKandBlueprint.pdf.

Drought Planning in the Multihazards Context Survey Report. 2018. American Planning Association. https://planning-org-uploaded-media.s3.amazonaws.com/document/Drought-Planning-Survey-Report-Final.pdf.

Engstrom, J., J. Keighobad, H. Moradkhani. 2020. Drought Vulnerability in the United States: An Integrated Assessment Water 12(7), 2033. DOI: https://doi.org/10.3390/w12072033.

Falling Dominos: A Planners Guide to Drought and Cascading Hazards. 2019. American Planning Association. https://planning-org-uploadedmedia.s3.amazonaws.com/

publication/download_pdf/Falling-Dominoes-Planners-Guide-to-Drought-and-Cascading-Impacts.pdf.

Haigh, T., E. Wickham, S. Hamlin, C. Knutson. 2022. Planning Strategies and Barriers to Achieving Local Drought Preparedness, Journal of the American Planning Association. DOI: 10.1080/01944363.2022.2071324.

Jedd, T., K.H. Smith. 2022. Drought Stricken U.S. states have more comprehensive water-related hazard planning. University of Nebraska. DOI: https://doi.org/10.21203/rs.3.rs-2093032/v1.

Knutson, C., M. Hayes, T. Phillips. 1998. "How to Reduce Drought Risk." Drought Mitigation Center Faculty Publications. https://digitalcommons.unl.edu/droughtfacpub/168.

Mucken, A., B. Bateman (Eds). 2017. Oregon's 2017 Integrated Water Resources Strategy. Oregon Water Resources Department. Salem, OR. https://www.oregon.gov/owrd /WRDPublications1/2017_IWRS_Final.pdf.

Office of Emergency Management (OEM). 2016. Drought Annex to the State Emergency Operations Plan. https://www.oregon.gov/owrd/WRDPublications1 /2016ORDroughtAnnex.pdf.

Oregon Department of Fish and Wildlife (ODFW). 2023. 3-Year Plan for Beaver Modified Landscapes Aug. 2022-2025. https://www.dfw.state.or.us/wildlife/living_with/docs/ ODFW_3YBeaverModLandscapesActionPlan_Final_20230616.pdf.

O'Neill, L., N. Siler. 2023. Drought. Pgs. 52-59 in Fleishman, E., editor. Sixth Oregon Climate Assessment. Oregon Climate Change Research Institute, Oregon State University, Corvallis, Oregon. DOI: 10.5399/osu/1161.

Oregon Water Resources Congress. 2007. Agricultural Water Management and Conservation Planning: A Guidebook for Oregon Irrigation Districts and Other Agricultural Water Suppliers. https://www.oregon.gov/owrd/WRDPublications1/ag_wmcp_guide.pdf.

Oregon Water Resources Department (OWRD). 2015a. Draft Guidelines: A Tool for Conducting Place-Based Integrated Water Resources Planning in Oregon, https://www.oregon.gov /owrd/WRDPublications1/2015_February_Draft_Place_Based_Guidelines.pdf.

Oregon Water Resources Department (OWRD). 2015b. Water Management and Conservation Plan: A Guidebook for Oregon Municipal Water Suppliers. https://www.oregon.gov/owrd/WRDPublications1/wmcp_guidebook.pdf.

Oregon Water Resources Department (OWRD). 2022. Legislative Report Water Use Measurement and Reporting. https://www.oregon.gov/owrd/WRDReports/OWRD_ 2022_LegislativeReport_WaterUse_Measurement_Reporting.pdf.

Rahem, N., A.E. Cravens, M. Cross, S. Crausbay, A. Ramirez, J. McEvay, D. Zoanni, D. Bathke, M. Hayes, S. Carter, M. Rubenstein, A. Schwend, K. Hall, P. Suberu. 2019. Planning for ecological drought: Integrating ecosystem services and vulnerability assessment. WIREs. DOI: https://doi.org/10.1002/wat2.1352.

Report of the Task Force on Drought Emergency Response (Task Force). 2016. State of Oregon. https://www.oregon.gov/owrd/WRDReports/DO_Drought_Emergency_Response_Task_Force_Report_11_1_2016.pdf.

U.S. State Policy Scorecard for Water Efficiency and Sustainability. 2022. Alliance for Water Efficiency. https://www.allianceforwaterefficiency.org/sites/default/files/assets/AWE%202022%20Scorecard%20Full%20Report.pdf.

Vose, J. M., J. S. Clark, C. H. Luce, T. Patel-Waynand. 2016. Effects of drought on forests and rangelands in the United States: A comprehensive science synthesis. U.S. Department of Agriculture General Tech. Rep. WO-93b. www.fs.fed.us/sites/default/files/DROUGHT_book-web-1-11-16.pdf.

Walker, C., E. Berglund, W. Grinnel, and K. Jones, Montana Drought Vulnerability Assessment. 2023. https://repos.dnrc.mt.gov/esri/hub/drought/PDFs/Appendix-C-Drought-Vulnerability-Assessment-report.pdf.

Western Governors' Association. 2015. Western Governor's Drought Forum, Special Report https://westgov.org/images/files/FINAL_Drought_Forum_June_2015.pdf.

Wilhite, D.A. 1991. Drought Planning: A Process for State Government, University of Nebraska, Drought Mitigation Center. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1023&context=droughtfacpub.

Wilhite, D. A. 2000. Drought as a natural hazard: Concepts and definitions. In D. A. Wilhite (Ed.), Drought: A global assessment (Vol. I), pp. 3-18. Lincoln, NE: University of Nebraska, Drought Mitigation Center Faculty Publications. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1068&context=droughtfacp.

Wilhite, D.A. 2016. Drought-Management Policies and Preparedness Plans: Changing the Paradigm from Crisis to Risk Management, Land Restoration, Ch. 7.1, 443-462. DOI: http://dx.doi.org/10.1016/B978-0-12-801231-4.00007-0.

Wilhite D.A., M.J. Hayes, C. Knutson, K.H. Smith. 2000. Planning for drought: Moving from crisis to risk management. JAWRA J Am Water Resource Association 36(4):697–710. DOI: http://dx.doi.org/10.1111/j.1752-1688.2000.tb04299.x.

Wilhite, D.A, M. Hayes, and C. Knutson. 2005. Drought Preparedness Planning: Building Institutional Capacity. In Wilhite D.A. (ed.) Drought and Water Crises: Science, Technology, and Management Issues. pp. 93–135. CRC Press. Boca Raton, FL.

Wilhite, D.A., M.V.K. Sivakumar, and R. Pulwarty. 2014. Managing drought risk in a changing climate: The role of national drought policy. Weather and Climate Extremes. DOI: http://dx.doi.org/10.1016/j.wace.2014.01.002.

Wilhite, D. A. and O.V. Vanyarkho. 2000. Drought: Pervasive Impacts of a Creeping Phenomenon. *Drought: A Global Assessment*, Vol. I, edited by Donald A. Wilhite, chap. 18, pp. 245–255. http://digitalcommons.unl.edu/droughtfacpub/71.

Appendix A: Drought Management Roles

Local Government	- Request Drought Declarations. - Assess drought conditions. - Adopt municipal codes addressing water conservation and curtailment. - Develop local hazard mitigation plans. - Lead provision of emergency water supply.
Tribal Government	- Issue emergency declarations. - Monitor and assess drought conditions. - Adopt tribal codes to address water use, conservation, and curtailment. - Develop drought plans.
Governor	- Issue Drought Declarations. - Issue Emergency Declarations. - Direct agency response to drought emergency. - Order implementation of curtailment plans.
Office of Emergency Management	- Co-chairs Drought Readiness Council and sits on Water Supply Availability Committee. - Reviews requests for emergency declaration and advises Governor. - Advises Governor on requests for federal emergency declaration.
Oregon Water Resources Department and/or Water Resources Commission	- Co-chair Drought Readiness Council and Chair Water Supply Availability Committee. - Direct and support the development of water conservation and curtailment plans. - Administer drought emergency water right tools and curtailments. - Lead drought communication. - Maintain data on use of drought emergency tools and drought declarations. - Administers funding programs for water resources planning, water project grants and loans, and water well abandonment repair and replacement.
Oregon Department of Environmental Quality	- Sits on Drought Readiness Council. - Advises on water and air quality impacts during drought. - Communicates with permit holders about best practices during drought. - Monitoring groundwater wells for water quality. - Recommend instream flows to protect water quality. - Administer Clean Water State Revolving Fund.
Oregon Health Authority	- Sits on Drought Readiness Council. - Provides information on drought and public health. - Advises on domestic water supply issues. - Provides information on harmful algal blooms and water contamination concerns. - Issues fish consumption guidelines and advisories. - Reviews water supplier emergency operations plans.
Oregon Department of Forestry	- Sits on Water Supply Availability Committee.

	- Monitors forest fire risk and administers forest closures and fire bans. - Administers state fire response.
Oregon Department of Agriculture	- Sits on Drought Readiness Council and Water Supply Availability Committee. - Coordinates with USDA to monitor drought impacts on agriculture and to implement drought relief programs. - Maintains information on drought resources for producers.
Oregon Department of Energy	- Sits on Drought Readiness Council. - Monitors impact of drought on power generation.
Oregon Department of Fish and Wildlife	- Sits on Drought Readiness Council. - Administers changes to fishing regulations to address drought impacts including to minimize stress, mortality & adverse harvest. - Public education on drought impacts on fish and wildlife and ways to minimize human and wildlife conflicts. - Communicate drought impacts and best practices. - Manage invasive species. - Manage ODFW facilities to reduce impacts.
Oregon Watershed Enhancement Board	- Administer a variety of grant programs that support drought resilience including grant programs for watershed restoration and protection, streamflow restoration, drinking water source protection, and the Oregon Conservation Reserve Enhancement Program.
Department of Land Conservation and Development	- Develop Hazard Mitigation Plan and Climate Adaptation Plan. - Administers Oregon's statewide planning goals. - Oversees the development of public facilities plan. - Support development of local hazard mitigation plans.
Oregon Department of Parks and Recreation	- Manages park access changes and closures.
United States Department of Agriculture	- Administers disaster relief programs for producers - Secretary of Agriculture issues Secretarial disaster declarations to authorize federal assistance for drought response.
National Oceanic and Atmospheric Administration	- Tracks and reports drought conditions. - Serves on Water Supply Availability Committee.
United States Geological Society	- Serves on Water Supply Availability Committee. - Measures streamflow and groundwater.
Unites States Bureau of Reclamation	- Serves on Water Supply Availability Committee. - Provides information on reservoir levels. - Manages reservoirs. - Administers WaterSMART Grants that promote irrigation efficiency.
United States Army Corps of Engineers	- Serves on Water Supply Availability Committee. - Manage reservoirs and USACE managed facilities.

Appendix B: State Plans, Strategies, and Assessments

Report	Recommendations/Strategies
Oregon's Integrated Water Resources Strategy (2017). The IWRS is an inter-agency strategy to understand and meet Oregon's water resources. The Strategy is grounded in understanding the state's water resources—water needs, demands, and pressures—and builds on that baseline information to recommends actions better manage water to meet the state's water needs and prepare for present and predicted pressures. The 2017 IWRS incorporated drought as a water management pressure for the first time and recommended the state plan and prepare for drought resiliency.	5.5A Plan and prepare for drought resiliency. Example implementation actions are: - Assess and assist those communities and ecosystems most vulnerable to drought. - Develop the appropriate set of indicators that signal and forecast different stages of drought. Document economic, social, and environmental impacts of drought, including the frequency, distribution, intensity, and duration. - Prepare for, respond to, and mitigate for the impacts of drought. - Improve the drought toolbox through education and outreach, drought contingency plans, more efficient water distribution systems, and additional voluntary measures to improve streamflow. A variety of other recommended actions support drought response and adaption, including addressing the need for data, water conservation, water storage, water reuse, and watershed health.
Climate Adaptation Plan (2021). The adaptation plan identifies state vulnerabilities to climate change and recommends a suite of actions to help the state prepare for and respond to projected challenges. While focused on climate change, drought is considered within the document as a climate risk. Drought is specifically identified as a vulnerability to the state's economy, ecosystems, built infrastructure, and public health.	- Develop state leadership framework to guide adaptation development. - Integrate DEI best practices into climate adaptation. - Create climate change vulnerability and social resiliency assessment; integrate into plans and create key indicators to update vulnerability. - Improve interagency coordination and information sharing (including investment based on social vulnerability indicators). - Integrate climate response across agency programs. - Conduct soil health studies. - Support research into forest and land management. - Invest in protection, restoration, and enhancement of areas for fisheries. - Enhance water security of instream and consumptive uses. - Reduce wildfire risk. - Design and build resilient water projects. - Work with partner agencies on policies to improve and protect air quality and water security. - Resource Oregon's public health system to address new and emerging health threats caused by climate change. - Recognize, collaborate, and consult with Tribal governments. - Broadly identify cultural resources at risk. - Identify impacted communities. - Build capacity of community-based organizations and create more opportunities to participate in decision making. - Review the statewide land use planning program.
Natural Hazard Mitigation Plan (2020). The NHMP is the state plan for identifying and characterizing the natural hazards impacting the state, the vulnerabilities of the state to those hazards, and strategies to mitigate risk. The NHMP identifies drought as one of 11 natural hazards impacting the state and	1. Update hazard probabilities for all natural hazards. 2. Establish an online platform for sharing mitigation actions from state, local and tribal plans. 13. Request the Legislature to fund State Disaster Loan and Grant Account to support emergency relief following disaster declaration. 18. Complete mitigation policy legislative needs assessment. 22. Provide technical assistance to "most vulnerable" jurisdiction to undertake resilience activities for the hazards to which they are most vulnerable. 34. Establish a multi-agency Climate Change Adaptation Leadership Structure.

recommends actions to reduce vulnerabilities to drought.	37. Establish funding for climate change adaptation activities. 40. Pursue funding for developing data to support assessments of probability, vulnerability, risk for drought and other natural disasters. 46 & 47. Develop and implement improved methodology for gathering data and identifying communities most vulnerable to drought and related impacts. 48. Document economic, social, cultural, and environmental impacts of drought. 108, 109 & 110. Refinement of state hazard identification; assessment exposure, vulnerability, and losses; and prioritization of risks and communities. 123. Support Interagency Workgroup on Climate Impacts and Impacted Communities. 127. Develop materials and opportunities to learn about the impact of climate change on natural hazards. 135. Expand the state's stream gage network and seek funding to operate and maintain the network.
Report of the Task Force on Drought Emergency Response (2016). Established by the Legislature in 2016, the task force was directed to evaluate the state's current drought response framework and provide recommendations that would help the state improve drought response. The task force identified 13 recommendations related to data collection, risks, vulnerabilities and impacts, and preparedness, response, and mitigation.	- Increase data to support water use, management, conservation, and drought identification. - Provide resources to assess drought impacts, risks, vulnerabilities and instream and out-of-stream needs. - Review drought declaration process and response tools for effectiveness. - Establish drought emergency fund. - Add OWRD capacity for community outreach around water management tools, water conservation, and drought. - Establish fund to support community drought planning. - Add capacity to watermasters to better administer water distribution tools. - Support small water systems in preparing for drought. - Evaluate barriers to accessing infrastructure programs and funding and add capacity to support communities in accessing funding. - Evaluate stored water management frameworks to understand flexibility to meet future water needs. - Adopt measures to promote water conservation and efficiency. - Explore voluntary programs to protect streamflow during drought. - Encourage water reuse activities.
Secretary of State Audit Oregon Water Resources Department: Enhancing Sustainability Efforts and Agency Planning Needed to Better Address Oregon's Water Supply Needs (2016). The audit report assesses the department's approach to water supply management and recommends actions to increase sustainability of water supply. The report identifies gaps in the department's water management approach and recommends actions to increase sustainability of water supply. While drought is not a focus of the audit report, increased sustainability of water supply has a direct nexus to drought resilience.	- Better balance agency efforts on issuing water rights and programs to restore and protect streamflows and watershed. - Increase and modernize efforts to manage groundwater. - Increase data collection, analysis, and availability. - Ensure sufficient staff to regulate water use. - Adopt a long-term agency plan. - Educate the public on water use and water laws and the Legislature on agency needs. - Establish a process to integrate staff feedback on processes and programs.

Advisory Report: State Leadership Must Take Action to Perfect Water Security for All Oregonians (2023). The advisory report is directed to state leadership and identifies gaps in Oregon's water governance that result in water insecurity and inequity; drought is identified as one of the significant water governance concerns prompting the report. The advisory report provides recommendations to improve the state's approach to water governance.	- Sustain legislative commitment and develop shared priorities to guide Oregon in making holistic and inclusive water decisions promoting water security. – Connect a regional planning system with an integrated state water plan to guide water decisions and policy development. - Take steps to balance interests and address high-priority water security needs by increasing public engagement in state and regional water management decisions. - Enhance public awareness and understanding of the state's urgent water challenges. - Explore opportunities to prioritize water security and equity more clearly in state policy, such as enshrining the human right to water in law and other policy changes that could expand protections for community and ecosystem health. - Improve water data to help Oregon agencies and communities better understand statewide and regional water needs and support strategic decision-making.

Appendix C: State Policies

Drought response policies

State Policy[*]	Impact	Nexus[**]
ORS 536.710	Recognizes severe water shortage as an emergency.	WS
ORS 536.740	Authorizes Governor to declare a drought when there is a severe water shortage causing a need for statewide coordination and sets duration of drought declarations authorities.	WS C E
ORS 401.165	Authorizes Governor to issue an emergency declaration	WS
ORS 536.720	Authorizes Governor to order state agencies and political subdivisions to implement and enforce water conservation and curtailment plans.	C WS
ORS 536.750	Drought emergency tools: - Issue temporary permit for use of water - Allow temporary change in type or manner of use - Allow for exchange of water sources - Allow for use of supplemental water right - Grant a preference for human consumption of livestock use	WS C E
OAR 690-019-0100, -0105	Sets fees for drought water management tools and authorizes Oregon Water Resources Department (OWRD) to refund fees.	WS
ORS 536.770	Authorizes the purchase of an option agreement to be used during periods of drought declaration for different uses than allowed in the permit or water right.	WS
ORS 536.780	During drought declaration, authorizes the Commission to require agencies or political subdivisions to file conservation and curtailment plans to reduce water use, to take actions to either promote or effect conservation and reuse of water. The Commission to develop plans if political subdivision or entity does not do so.	C
OAR 690-019-0058	Authorizes expedited process for temporary leasing water instream during a declared drought.	E
ORS 540.145	Authorizes OWRD to regulate off users in order of priority and provides enforcement authority.	C WS
ORS 540.610(4)	Establishes that nonuse of water during a declared drought does not count toward period nonuse for determining forfeiture.	C WS
ORS 94.779	Prohibits homeowner associations from enforcing irrigation requirements when Governor or OWRD finds there or is likely to be severe and continuing drought or where the municipality has adopted an ordinance requiring conservation or curtailment of water.	C
OAR 461-145-0100	Excludes federal drought relief from determination of income for purposes of state income or benefit eligibility.	F
OAR 340-041-0028(12)(d)	Excepts exceedances of temperate criteria or natural conditions during low flow conditions that are the lowest 7-day average flow that occurs once every 10 years.	E
OAR 736-010-0020(10)	Oregon Parks and Recreation Department has authority to restrict access to and uses of parks to protect public health and safety or park resources.	PH
ORS 477.505, .510, .512	Authorizes state forester to designate a fire season when fire hazards exist and prohibits certain activities during fire season	WF

[*] Where applicable, this chart identifies relevant statutory authorities. There are also often administrative rules that implement the statutory authorities.
[**] (F) Funding, (C) Conservation, (WS) Water Supply, (E) Environmental, (D) Data, (PH) Public Health, (WF) Wildfire, (P) Planning.

State Policy*	Impact	Nexus**
ORS 527.745 OAR 629-610-0040	Allows for extension of time to meet reforestation obligations during drought.	E
ORS 273.500 OAR 141-088-004	Authorizes Oregon Department of State Lands to close public lands for public use to address emergency or protect resources.	E PH

Policies that support drought resilience

State Policy*	Impact	Response	Mitigation	Nexus**
HB 2929 (2023)	Authorizes OWRD to seek a temporary or permanent injunctive relief when it believes a person is engaging in or about to engage in an activity that will violate water law.	X		C
ORS 448.131 OAR 333-061-0061 and -0064	Directs Oregon Health Authority to prescribe standards for operation of water systems to secure safe drinking water. Requirements include installation of meters at service connections; all water suppliers to have an emergency operations plan and water suppliers over 3,300 connections to have risk and resilience plan; develop water master plans.		X	C WS
Executive Order 20-04 (March 9, 2020)	Directing agencies to reduce greenhouse gas emissions and prepare for effects of climate change.		X	C WS
ORS 537.211	Establishes requirement for municipal water management and conservation plans.		X	C P
ORS 540.572	Establishes requirements for agricultural water management and conservation plans.			
ORS 541.561	Establishes the water conservation, reuse, and storage grant program ("Feasibility Study Grants") that provides funding to evaluate feasibility of water conservation, reuse, or storage projects.			C F
ORS 541.651-696	Water Project Grants and Loans fund conservation, reuse, above-ground storage, below-ground storage, streamflow protection or restoration, water distribution, conveyance or delivery systems, and other water resource development projects that result in economic, environmental, and community benefits.			F C
ORS 537.455 through .500	Establishes the Conserved Water Program, which allows water rights holders to increase water efficiency and to use 75% of conserved water for other use with 25% dedicated to instream uses.			C WS
ORS 537.131, .132, 540.510	Allows for use of reclaimed water without a permit in certain circumstances.			WS
ORS 537.141, .545	Authorizes reuse of surface water and groundwater for agricultural use without a permit.			WS

* Where applicable, this chart identifies relevant statutory authorities. There are also often administrative rules that implement the statutory authorities.
** (F) Funding, (C) Conservation, (WS) Water Supply, (E) Environmental, (D) Data, (PH) Public Health, (WF) Wildfire, (P) Planning.

State Policy*	Impact	Response	Mitigation	Nexus**
ORS 540.610(2)(h), (i)	Exempting from forfeiture the period when water right holder was using reclaimed and reused water for irrigation.		X	C
OAR 690-410-0600	Sets statewide policy to eliminate waste and promote efficient use of water and directs adoption of programs to eliminate waste; recognizes collection of data on water use—including measuring flow at points of diversion—and distribution of information essential to manage waters for public welfare, safety, and health; and directs commission to support public education of water conservation.		X	C WS
ORS 540.310	Provides authority to require measuring devices when necessary for regulation or management purposes.		X	C D
ORS 536.021	Establishes Water Measurement Cost Share Program Revolving Fund, which provides funding to offset costs to install water measuring devices.		X	C D
ORS 540.631	Makes it unlawful to waste water.		X	C
ORS 537.099	Requires governmental entities that hold water rights to submit an annual water use report.		X	C D
ORS 536.410	Provides commission authority to withdraw unappropriated water from appropriation.		X	C WS
ORS468B.050, .053	Sets requirement for water quality permits and alternatives to water quality permits (e.g., reclaimed water).		X	C
ORS 468B.015	Establishes a policy to conserve waters of the state through innovative uses including reuse of water and wastes.		X	C WS
ORS 540.435	Authorizes the installation of a measuring device and reporting in serious water management problem.		X	C D
ORS 447.145 ORS 455.610(4)	Sets maximum water use amount for new fixtures in construction, reconstruction, alteration, and repair of buildings; applies water conservation standards to low-rise residential dwellings.		X	C
ORS 537.747 through .765	Establishes rules for well constructor license and well construction standards.		X	PH C
ORS 537.766, .767	Establishes Water Well Abandonment Repair and Replacement Fund, which provides funding to repair, replace or abandon wells used for domestic purposes to address water quality and quantity issues and natural disaster impacts. (*Initial funding prioritized drought and wildfire impacted wells.)	X	X	PH
OAR 690-215-0005	Requires landowners to maintain water supply wells in a manner that is not a health threat or wastes groundwater.		X	PH
ORS 537.775	Authorizes Oregon Water Resources Commission to order the discontinuation of a well that is causing waste or adversely impacting water supply or public health.		X	PH C
HB 3092 (2021)	Establishes a grant program to replace, repair, or abandon domestic wells in Harney County.			F PH

State Policy*	Impact	Response	Mitigation	Nexus**
ORS 285B.560 through .599	Establishes a Water and Wastewater financing program to drinking water and wastewater projects owned or operated by a municipal entity.		X	F
OAR 333-061-0057	Establishes Voluntary Drinking Water Protection Program for water systems to plan to protect their drinking water source water.		X	F PH
ORS 285A.213	Safe Drinking Water Revolving Loan Fund provides low-interest loans for drinking water infrastructure and can support green and natural infrastructure projects.		X	F PH E C
ORS 468.427 through .440	The Clean Water State Revolving Fund provides low-interest loans for water infrastructure projects and can support green and natural infrastructure projects.		X	PH F E C
ORS 448.268	Authorizes the designation of an Area of Groundwater Concern in areas of contaminated groundwater that serve as a public water supply.		X	PH
ORS 468B.180 through .188	Authorizes designation of a groundwater management area where elevated levels of contaminants exist.		X	PH E
OAR 333-061-0510 through .580	Establishes rules for the testing, reporting, and public notification of cyanotoxins.	X	X	PH
ORS 468B.190	Direct Oregon Department of Environmental Quality (ODEQ) and Oregon State University, in cooperation with OWRD, to conduct ongoing statewide monitoring of quality of groundwater in the state.		X	
ORS 537.332 through .360	Establishes state's instream water rights program. Includes: permanent transfers, temporary transfers, conversion of minimum perennial streamflows, and split-season leases.	X	X	E
ORS 543A.305	Establishes procedures to convert hydroelectric water rights to instream use.		X	E
ORS 541.932(9)	Establishes Water Acquisition Grant program, which funds acquisition of water rights to support instream uses.		X	E
ORS 541.932(9)	Establishes Land Acquisition Grant program, which funds acquisition of land for watershed protection		X	E
ORS 536.235 OAR Ch. 690 Div. 76	Establishes minimum perennial streamflow program which established minimum flow requirements for waters.		X	E
ORS 509.580 through .645 OAR 635 Div. 412	Establishes Oregon Department of Fish and Wildlife (ODFW) fish passage policy, which includes prioritization for climate change including streamflow and temperature impacts.		X	E
OAR Ch. 635 Div. 415	Establishes a policy to require habitat mitigation when development will impact fish and wildlife habitat.		X	E
OAR Ch. 635 Div. 400	Setting process for ODFW instream flow applications and review of instream transfer applications.		X	E
OAR 340 Div. 56	Framework for ODEQ to apply for instream water rights to protect water quality.		X	E
OAR Ch. 635, Div. 11	Establish ODFW authority to set fishing regulations. Drought regulated actions include stocking changes, early release of hatchery fish, emergency closures,	X		E

State Policy*	Impact	Response	Mitigation	Nexus**
	and removal of bag limits to allow harvest of fish that may die in low water.			
HB 3293 (2021)	Authorizes agencies to use existing water project funding and capacity—projects addressing watershed health and conservation, water supply and water treatment—to support local governments and community group in developing community engagement plans.		X	F P E
HB 2018 (2021)	Directs OWRD to contract with USGS for groundwater studies and funds studies.		X	D F E
HB 2010 (2021)	Authorizes OWRD to require water users to report water use where water measuring is required.		X	D
ORS 537.147	Requires OWRD to condition permits to use stored water to require a measuring device at each point of diversion.		X	D C
ORS 537.780	The OWRC may enforce uniform standards for measuring and report groundwater withdrawals.		X	D
ORS 536.220 through .350	Establishes state basin program, which directs OWRC to study and develop plans for water basins.		X	C D E
ORS 536.220	Directs OWRD to develop the IWRS, which must address natural hazards.		X	P
Goal 11 OAR Ch. 660 Div. 11	Requires cities with populations over 2,500 to create a public facilities plan, which includes water service. Restricts city's ability to plan for services outside of the urban growth boundary.		X	WS P
ORS 536.241	Sets legislative policy that continued water availability is essential to the health and safety of Oregonians and that water should be managed to ensure a safe supply.		X	WS
ORS 308A.743	Provides that specially assessed irrigated farmland may not be disqualified from special assessment if landowner has active instream lease for water rights appurtenant to such irrigated farmland and farmland is being used according to accepted farming practices that are mode of operation customarily utilized in conjunction with farm use.		X	C
Building code requirements to demonstrate water supply availability	Counties may require evidence of a potable water supply for new construction. Typically requires connection to municipal or pump test and water quality test.		X	WS
SB 391 (2021)	Prohibits construction of accessory dwelling units in an area restricted for groundwater use if the dwelling will use well water.		X	C E
ORS 536.238	Sets state policy on multipurpose water storage facilities.		X	WS
ORS 537. 531 through .534	Identifies aquifer storage and recovery as a beneficial use and provides for standards for ASR program.		X	WS
ORS 537.135	Requires permit for aquifer recharge.		X	WS
OAR Ch. 690 Div. 350	Establishes program for ASR and aquifer recharge.		X	WS

State Policy*	Impact	Response	Mitigation	Nexus**
ORS 537.110	Establishes that all water within the state from all sources belongs to the public.		X	WS
ORS 537.730 through .742	Designation of critical groundwater areas that allow for curtailment of groundwater rights.		X	WS E
ORS 537.730	Designation of Groundwater Limited Area that allows for the restriction in the uses permitted in the area.		X	W
HB 2010 (2023)	Directs Oregon State University to establish a program to support agricultural producers in deploying new water management techniques and provide technical assistance and information around drought and climate resilience.		X	WS E C
ORS 537.141(1)(h)	Exempts collection and use of rainwater from water right permitting requirements, when collected from an impervious surface.		X	WS
Oregon Plumbing Code Ch. 16	Provides the requirements for installation, construction, alteration, and repair for rainwater catchments.		X	WS
ORS 537.990; 537.992	Establishes commission authority to assess criminal and civil penalties for violations of the groundwater code.		X	WS
ORS 537.143	Authorizes OWRD to issue a limited license for short-term forestland or rangeland management activities.		X	WS
ORS 477.490	Directs identification of land within the Wildland Urban Interface and development of a wildfire risk map.		X	E WF
ORS 477.503	Directs state forester to take steps to reduce fire risk through landscape resiliency and reductions in fuel loads.		X	WF E
ORS 477.698 OAR 629-048-0020	Directs state forester to develop permit program for prescribed fire.		X	WF E
ORS 477.748	Establishes small forestland grant program to support landscape resiliency to reduce fire risks.		X	F WF

Appendix D: Legislative Investments

Legislation	Impact *Funding targeting drought is highlighted in blue*	Relief	Resilience
HB 5006 § 125 (2021)	$5 million to address fish passage and fish screen projects.		X
HB 5006 § 232 (2021)	$30 million to the Water Supply Development Account for Water Projects Grants and Loans.		X
HB 5006 § 235 (2021)	$500,000 for Feasibility Study Grants to pay costs of feasibility planning studies for developing water conservation, reuse, or storage projects.		X
HB 5506 § 248 (2021)	$500,000 for local governments to implement fish passage requirements as part of dam upgrades.		X
HB 5006 § 240 (2021)	$450,000 to support the Integrated Water Resources Strategy update.		X
HB 5006 § 246 (2021)	$2 million deposit into the Water Well Abandonment, Repair, and Replacement Fund.	X	X
HB 5006 § 251 (2021)	$3 million to purchase groundwater and surface water collection equipment.		X
HB 5006 § 252 (2021)	$1 million for cost-share to install measuring devices.		X
HB 3092 (2021)	$500,000 to the Harney Valley Domestic Well Remediation Fund.		X
SB 892 (2021)	Established the temporary Oregon Agricultural Disaster Relief Fund a forgivable loan program for agricultural products to address 2021 drought.	X	
HB 2145 (2021)	$675,415 to establish the Water Well Abandonment, Repair, and Replacement Fund.		X
HB 5545 (2021)	$500,000 for Harney Conservation Reserve Enhancement Program.		X
SB 5561 § 11 (2021)	$4 million to Klamath Project Drought Response Agency.	X	
SB 5561 § 12a	$3.75 million for the Water Well Abandonment, Repair and Replacement Fund.		X
SB 5561 § 15 (2021)	$1.5 million for the Oregon Community Food Systems Network to provide grants to small-scale farmers impacted by drought, heat, or wildfire.	X	
SB 5561 § 17 (2023)	$1.5 million to Oregon State University Extension Service to provide technical assistance to farmers on accessing federal and state assistance, drought-resistant crops, and soil health.		X
SB 5561 § 18 (2021)	$300,00 for a drought vulnerability assessment		X
SB 5561 § 19 (2021)	$1.627 million for Irrigation Modernization Grant program funds projects that upgrade irrigation works to conserve water.	X	X
SB 5561 § 19a (2021)	$2 million to support irrigation modernization in North Unit Irrigation District.	X	X

SB 5561 § 20 (2021)	$1 million for Jefferson County Drought Resilience Grants to fund drought assessment and planning efforts and a water management transaction program activities that reallocates water as a drought response tool.	X	X
SB 5561 § 21 (2021)	$3 million for Klamath Off-Channel Livestock Watering Grants funds livestock watering wells and facilities.	X	X
SB 5561 § 22 (2021)	$1 million for Klamath County Drought Resilience grants (ended up in two programs TA & Stakeholder support and on-the-ground water conservation and drought resilience actions).	X	X
SB 5561 § 23 (2021)	$3 million for Jefferson County Soil and Water Conservation District Soil Conservation Grants funds projects that address soil degradation and erosion.	X	X
HB 5202 § 304 (2022)	$10 million to OWEB for water rights acquisition grant program.		X
HB 5202 § 399 (2022)	$8 million to ODFW for Fish Screening and Passage Grant Program.		X
HB 5202 § 401 (2022)	$5 million for grants through Oregon Conservation and Recreation Fund.		X
HB 5202 § 403 (2022)	$2.6 million to ODFW for activities that improve drought resiliency, including cold water refugia desktop analysis, river temperature and stream flow monitoring, and instream flow contested cases.		X
HB 2010 §§ 24, 46 (2023)	$1 million to Oregon Association of Water Utilities to assess vulnerability of small water systems and provide technical assistance to support drought readiness.		X
HB 2010 § 1, 4, 40, 52 and HB 5030 (2023)	Establishes the Community Drinking Water Enhancement and Protection Fund & $5 million in funding		X
HB 2010 §§ 12-14, 56 (2023)	~$3 million to Oregon State University for statewide agricultural water management technical assistance program.		X
HB 2010 §§ 15-16 (2023)	$2 million for establishment of place-based integrated water resource planning fund.		X
HB 2010 §§ 22-23 (2023)	$100,000 to direct ODEQ and OWRD to develop recommendation to expand water reuse or recycled water programs and projects.		X
HB 2010 §§ 28-34, 47, 55 (2023)	$3 million to establish an aquifer recharge and aquifer storage and recovery due diligence grant.		X
HB 2010 §§ 35-39, 48-50 (2023)	Establishes a program for Western Juniper removal.		X
SB 5506 § 58 (2023)	$500,000 to University of Oregon's Just Futures Institute to research and address water needs of environmental justice communities and to provide capacity grants for environmental justice communities to engage on water issues.		X
SB 5506 § 71 (2023)	$1.2 million for Morrow and Umatilla Drought Relief Aquifer Recharge and Aquifer Storage and Recovery Project.		X
SB 5506 § 87 (2023)	$1.6 million to Oregon Association of Water Utilities to build water system training center.		X

SB 5506 § 87(1) (2023)	$2.65 million to Oregon Community Food Systems Network for grants to small producers for drought resilience and adaptation.		X
SB 5506 § 87(3) (2023)	$1.5 million to Oregon Community Food Systems Network to support food hubs and drought resilience.		X
SB 5506 § 185 (2023)	$8.75 million to ODFW for fish passage projects.		X
SB 5506 § 226 (2023)	$100,000 for Portland State University to facilitate a Tribal/State Water Task Force.		X
SB 5506 § 228 HB 5030 § 10 (2023)	$50 million to OWRD for irrigation modernization grants.		X
SB 5506 § 309 (2023)	$2 million to the Oregon Worker Relief Climate Change fund to provide aid to agricultural works impacts by heat or smoke.	X	X
SB 5506 §§ 72, 73 (2023)	$2 million for Oregon Farmers Market Association to support food system resiliency to mitigate drought impacts.	X	X
SB 5509 (2023)	$1 million to Oregon Conservation and Recreation Fund for drought related projects.		X

DROUGHT ASSESSMENT: WATER JUSTICE CONSIDERATIONS[1]

Abstract

Environmental justice communities face unique and often unaddressed vulnerabilities to drought.[2] Building on the State of Oregon's 2016 Drought Taskforce Report, 2016 Secretary of State Audit, 2017 Emergency Operations Plan, the 2017 Integrated Water Resources Strategy, the 2020 Natural Hazards Mitigation Plan, the 2021 Climate Adaptation Framework, the 2023 Secretary of State's Advisory Report on Water Security, the 2023 Bipartisan Drought Relief and Water Security package (BiDRAWS), and findings from the Oregon Water Futures Collaborative (OWF) - and its Water Justice Framework, this assessment lays out a number of issues to consider during droughts to properly serve environmental justice communities. OWF's community engagement documents the needs and expertise of specific environmental justice communities - low income, rural, coastal, Native, Indigenous Latin American, Latinx, Black, Asian American, Pacific Islander, Middle Eastern, and African. Legislative action in 2021, 2022, and 2023 has intentionally addressed some of the challenges these communities face, and yet more remains to be done for deeper engagement with the state's most vulnerable communities as droughts exacerbated by climate change transform the weather and landscapes of the region for generations to come.

Introduction

As droughts are becoming a regular occurrence, they are impacting the ecosystems that sustain the habitats of many species, as well as groundwater and municipal water systems. As an initiative that has engaged tribal leaders, community-based organizations, environmental organizations, state agencies, legislators, and university-based researchers in one-on-one and group conversations since 2020, the Oregon Water Futures Collaborative (OWF) has helped shaped the 2023 Secretary of State's Advisory Report on Oregon Water Security, as well as legislative action in 2021, 2022, and 2023 ("Advisory Report" 2023, p 15). OWF's reports and Water Justice Framework provide first-hand stories and documentation of people's everyday experiences with water resources, and policy recommendations emerging from low income, rural, coastal, Native, Indigenous Latin American, Latinx, Black, Asian American, Pacific Islander, Middle Eastern, and African communities whose experiences and expertise have historically been underrepresented in decision making relevant to drought prevention, mitigation and relief in the state (Brown, et al; Dalgaard 2022, p 6; Reyes-Santos et al. 2021).

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[1] Co-authored by Alaí Reyes-Santos, Michelle Smith, Sophie Silva, and Isaac Stone at University of Oregon's Environmental and Natural Resources Law Center. Special thanks to Ira Cuello (PCUN), Lynny Brown (Willamette Partnership), Cheyenne Holliday (Verde) and Reyna Lopez (PCUN) for sharing resources relevant to this assessment.

[2] The term environmental justice communities has been defined by the Oregon Department of State Lands and the Oregon Legislature: "In 2022, the Oregon Legislature passed HB 4077 which expanded the definition of "environmental justice communities" to broadly include communities of color, communities experiencing lower incomes, communities experiencing health inequities, tribal communities, rural communities, remote communities, coastal communities, communities with limited infrastructure and other communities traditionally underrepresented in public processes and adversely harmed by environmental and health hazards, including seniors, youth, and persons with disabilities." https://www.oregon.gov/dsl/about/pages/ej.aspx

Oregon Water Justice Framework and Drought Management

In 2022, Oregon Water Futures articulated a Water Justice Framework drawing from its two years of community engagement. The Framework includes policy recommendations around the following themes: (1) Indigenous Water Justice Leadership, (2) Renter's Rights, (3) Water Access and Affordability, (4) Natural and Built Infrastructure for Clean Water, (5) Emergency Preparedness, and (6) Community Empowerment (Brown et al 2022; Dalgaard 2022). These six themes serve to organize a series of water justice considerations pertinent to drought management "uplifting priorities, issues, and knowledge from communities that have traditionally been left out of water policy decisions" (Brown et al 2022).

(1) Indigenous Water Justice Leadership

Throughout OWF's community engagement, participants articulated their desire for Indigenous water justice leadership. Centering Indigenous water leadership in drought prevention, mitigation, and relief efforts honors the ecological knowledge held by Oregon's tribal communities and citizens of tribal nations since time immemorial, while also making room for the ways in which Indigenous peoples who have relocated here from the U.S. and other countries bring with them significant water stewardship practices (Dalgaard 2022; Reyes-Santos et al. 2021). Integrating Indigenous water justice leadership into state decision-making process, according to interviewees, would enable the state to more effectively engage the unique vulnerabilities that Native communities face, and the solutions they mobilize, when water resources are compromised. Community engagement suggests that Indigenous water leadership can be mobilized to address drought impacts by supporting: a Tribal Water Justice Task Force with impact on decision making processes relevant to drought; projects that further enable Indigenous food sovereignty among Oregon's tribes and Indigenous immigrant communities; increased co-management of natural resources with tribes that incorporate cultural burnings as a drought mitigation practice; solutions for the water crisis impacting the Confederated Tribes of Warm Springs; and engagement with non-federally recognized tribes, such as Chinook Indian Nation, in drought prevention, mitigation, and relief efforts.

(1a) Tribal Water Task Force

The OWF Water Justice Framework names the need to support a Tribal Water Justice Task Force whose input shapes decision making regarding water resources in the state (Brown et al. 2022, p 9). The members of the Task Force must be remunerated, and their recommendations engaged in concrete action items by state agencies, utilities, counties, and municipal authorities (Brown et al. 2022, p 9). The Secretary of State Advisory Report on Water Security echoes some of the recommendations found in OWF's Water Justice Framework by engaging questions of food sovereignty and Indigenous water justice leadership. It prioritizes the protection of habitat for culturally significant fish and other aquatic species and the need to engage Indigenous traditional ecological knowledge in state-led water stewardship ("Advisory Report" 2023, p 68).

(1b) Food Sovereignty

Food sovereignty is one of the major issues raised by Indigenous water justice leaders throughout the state; and one that is directly impacted by droughts. Food sovereignty is dependent on clean and cool waters (OWF Conversation with Confederated Tribes of Grand Ronde Natural Resources Department 2021). Water temperatures and quality impact the ability of plants, fish, and animals to survive and reproduce ("Advisory Report" 2023, p 20). While water temperatures rise and water quality is imperiled during droughts, a large variety of species and the humans who rely on them are at risk ("Advisory Report" 2023, p 8). Fish species that are critical to Oregon tribal communities are threatened by warmer water temperatures, including salmon, lamprey eel, and sturgeon, among others (Mucken and Bateman 2017, p 80; 119). Higher water temperatures can also result in toxic algal blooms that are health hazards to the water ecosystem, mammals, fish, shellfish, and humans ("Advisory Report" 2023, p 8). We have already seen the devastating effects of algal blooms on drinking water supplies, shellfish, and recreational water use in Coos Bay, Salem, and Ontario (Reyes-Santos et al. 2021, p 36; McKibben et al. 2015; Oregon Health Authority: Cyanobacteria Blooms).

Furthermore, as drought becomes more common in Oregon, there is a higher chance that springs, streams, and rivers will dry up (Mucken and Bateman 2017, p 74). When this occurs, species, such as fish, beavers, deer, and elk, that rely on those water systems no longer have the means to survive. When these species are at risk, food sovereignty as well as other cultural resources essential for Native communities' physical and cultural survival are at risk too ("Advisory Report" 2023, p 20).

Native plants and fish are already struggling to compete for resources with invasive species (Reyes-Santos et al. 2021, p 31). As drought conditions become more common, native species will feel the strain even more (Reyes-Santos et al. 2021, p 31). However, by engaging Indigenous leadership and traditional ecological knowledge, the state and tribal governments will be able to strengthen water security and ensure healthy water systems for all. It has been proven, for instance, that cultural burnings lower water temperatures and protect springs, while preventing the spread of wildfires and sustaining the health of soils and traditional foods such as acorns ("Advisory Report" 2023; Norgaard 2019).

(1c) Cultural Burnings

Cultural burnings, unlike prescribed fires, are an ethical responsibility embedded in Indigenous understandings of the interdependent relationship between humans and the rest of the natural world. Indigenous communities around the world rely on their traditional law and practices to determine when it is best for the landscapes' overall health to conduct a fire. In Indigenous worldviews humans have the responsibility to support the biodiversity and safety of habitats through cultural burnings (Clark et al. 2022). Cultural burnings foster biodiversity which protects underground water sources, springs, and river tributaries. Cultural burnings reduce the area of canopy that is vulnerable to lightning. Cultural burnings enable the growth of smaller plants, brush and trees (Clark et al. 2022). Reducing the canopy and dense populations of tall trees reduces pressure on underground water resources which can then be accessed by smaller plants with short root systems, can be stored in aquifers, and feed streams and rivers.

The ash produced by cultural burnings sustains the overall chemical composition of the soil, eliminates pests that threaten plant life, enables oaks to produce healthier acorns for consumption, and supports the proper growth of branches in hazel trees to be used in basket weaving; ash also protects water from quick evaporation during the hot hours of the day (Traditional Ecological Knowledge Inquiry Program: Cultural Burn Training 2021; 2022). A healthier, biodiverse, forest less prone to wildfires protects surface water and aquatic life by providing shade to nearby streams and rivers ("Advisory Report" 2023, p 68; Clark et al. 2022; Conversation between Oregon Water Futures Collaborative members and Joe Scott, Takelma/Siletz elder and cultural fire practitioner 2022; Shelenz 2022). Currently Takelma, Siletz, Modoc, Chinook, Yakama, and Warm Springs tribal members, among others, as well as the Klamath Tribes and the Confederated Tribes of Grand Ronde, and Indigenous and Afro-Indigenous Latin American community members, are revitalizing cultural fires in the state to support the health of multiple ecosystems and reduce the spread of wildfires during the summer. These revitalization projects can be understood as drought mitigation initiatives as well, since they reduce the dangerous potential of large-scale wildfires during droughts.

Two other water justice considerations relevant to Indigenous communities facing droughts and documented in various venues - including OWF's reports, Oregon Environmental Council's 2022 State of Water in Oregon (Dalgaard 2022), and the 2023 Secretary of State Advisory Report - are:

(1d) Confederated Tribes of Warm Springs

The need to solve the water crisis in the Confederated Tribes of Warm Springs where the combined impact of drought, climate change, and outdated water infrastructures leaves the community without drinking water every summer. Persistent drought in Wasco County - where the tribe is partially located - also poses a threat to well water sources ("Governor Tina Kotek Declares Drought Emergency in Wasco and Harney Counties" 2023; "Drought Conditions for Wasco County" 2023);

(1e) Non-federally Recognized Tribes

The need to engage non-federally recognized tribes, such as Chinook Indian Nation (CIN), in water stewardship, drought prevention, mitigation, and any drought relief efforts in the future emerged as an important water justice issue during OWF's community engagement. Like the more than 200 hundred non-recognized tribes in the nation, CIN is rarely consulted on water management, policy, and infrastructure in their ancestral territories (O'Neill 2021; "Recognition" 2023). CIN faces similar challenges to other tribes during droughts but has limited access to state resources to address environmental and public health challenges. For example, CIN is not eligible to apply for grants through the Indian Environmental General Assistance Program. Considering that multi-year droughts are impacting the quantity and quality of groundwater and surface water essential for drinking, and culturally significant foods and activities such as canoe journeys, it will be necessary to reimagine state investments to tribes by expanding their reach to non-federally recognized ones ("Advisory Report" 2023, pp 67-68).

(2) Renter's Rights

Renters are very vulnerable during times of drought. Throughout the coast, South, Central and Eastern Oregon, and even in the Willamette Valley renters will experience higher degrees of vulnerability as droughts impact water levels in wells. Already, wells in parts of those regions are going dry during the summer or cannot provide sufficient and/or potable water all year long. Rural renters are more likely to rely on domestic wells, and on labor markets that can be easily impacted by droughts, such as farms, cattle ranches, and food processing plants (Dalgaard 2022, p 26). Renters in urban areas face the challenge of municipal water systems that also see their water sources depleted and compromised as multi-year droughts do not allow groundwater and surface water sources to replenish properly to keep up with demand. Both in rural and urban areas renters tend to have little to no information about water quality at home, including when the amount and potability of water is compromised by drought conditions. Community engagement suggests that renter's rights can be best supported during droughts by acknowledging and addressing renters' specific vulnerability; the challenges renters face when well water quality is compromised; the high costs of well testing and remediation that both landlords and renters fear; and limited access to information about water quality.

(2a) Renters' Vulnerability

Though landlords are required to maintain habitable premises for renters, including access to clean drinking water, renters may feel too vulnerable to advocate for themselves if they have concerns regarding well water or municipal water quality, and landlords may lack resources or information about existing funding streams to address water challenges. Renters relying on domestic wells in rural and urban areas are particularly vulnerable during times of drought. There are no legal requirements for landlords - or anyone - to routinely test wells, except when a property is being sold and purchased (Dalgaard 2022, p 26). If renters have water quality challenges, such as bad odors or unusual appearance, they are vulnerable (Dalgaard 2022, p 27). If they raise a concern, many fear that landlords will not renew their leases (Dalgaard 2022, p 24; OWF Conversations with renters in Ontario 2020; OWF Conversations with renters in Hermiston 2023). For low-income tenants in real estate markets with low supplies of affordable housing, these fears keep them from raising issues with landlords (Dalgaard 2022, p 24). If tenants are immigrants or people of color, these fears include serious concerns that they will not find another place to live because other landlords will not wish to rent to them due to racial and ethnocentric biases, or cultural and linguistic differences (Dalgaard 2022, p 24; OWF conversations with renters 2020-2023).

(2b) Renters and Well Water Quality

Experiencing multi-year droughts means that domestic wells are drying up at a higher rate in the past few years requiring renters, as well as homeowners and landlords, to spend money purchasing water to drink, cook, wash dishes, do laundry, etc. This is an unexpected burden ("Advisory Report" 2023, p 17; Reyes-Santos et al. 2021, p 67). Lower water levels in wells may turn potable drinking water into a health hazard by mobilizing or exacerbating contamination issues (Dalgaard 2022, p 41). For instance, a well may provide water that is safe to drink during wetter seasons, but then may provide water with a dangerous level of contaminants once water levels are reduced (Dalgaard 2022, p 41).

(2c) Renters' and Landlords' Fears: Cost of Well Testing and Remediation

Therefore, as the frequency and severity of droughts increase, and water levels in wells decrease or are depleted, being able to afford and have access to water testing, as well repair, remediation or replacement, becomes an essential water justice consideration (Dalgaard 2022, p 34). In some areas, state agencies may pay costs associated with well testing, such as a recent Oregon Health Authority program in Hermiston, Oregon, which provided vouchers for free water testing. If similar programs require renters and homeowners to pay out of pocket to be reimbursed, they may be inaccessible to many low-, moderate-, and fixed-income communities. A well water test kit can cost between $40.00 to $400.00. For example, a well water testing company in Corvallis, charges $298.00 for their "Peace of Mind" package that tests for the most common health hazards found in well water; but does not include tests for volatile organics. For low-, moderate- and fixed-income households, covering these out-of-pocket costs can be prohibitive or intimidating; it requires having a way to cover costs up-front, knowing how to do the proper paperwork to apply for reimbursement, and trusting that they will be reimbursed. Moreover, renters usually do not have access to information about programs ("Advisory Report" 2023, p 51; OWF Conversations with renters in Hermiston 2023).

While funding has been allocated by the Oregon Legislature in 2021 and 2023 to support well abandonment, repair or replacements, some environmental justice communities may find barriers to access them. In 2021, the legislature authorized funding and prioritized low- to moderate-income homeowners whose wells had been impacted by wildfires and drought. Those funds can only be used by homeowners who meet that eligibility criteria. The language of the bill does not restrict use of funds for rental properties by owners or renters; however, it has been the Department's policy to direct funds to primary residences only. It is unclear if all environmental justice communities who could benefit from these sources know or will easily know about them or feel comfortable applying for them. In a recent visit to Hermiston to conduct well water testing, OWF Collaborative affiliates learned that none of the households visited knew about these funding allocations. If landlords pay out of pocket to repair, remediate or replace a well - they may pass the cost to renters in higher rental fees (Dalgaard 2022, p 34). This is a concern expressed by renters from Ontario, Oregon that requires further exploration (Oregon Water Futures Conversation with Euvalcree members 2020).

(2d) Renters: Limited Access to Information about Water Quality

These challenges are compounded by the limited access to information about water quality we know renters, and at times homeowners too, on public or small water systems experience (Reyes-Santos et al 2021; OWF Conversations with Community Members in Hermiston 2023). During the algal bloom incident in Salem in 2019, many low-income immigrant renters learned too late that their drinking water was not potable and that boiling it would increase its damaging impacts to human health (Reyes-Santos et al. 2021, p 40). All over the state, even when communities are informed about water quality, they may not be provided with information in accessible English language - meaning that it is jargon free - and/or languages spoken by the renter or homeowner (Reyes-Santos et al. 2021, p 38). During droughts, the possibility of algal blooms increases; meaning that there must be mechanisms to inform renters when such incidents and other drought-related hazards impact their drinking water sources, whether on well water or municipal water systems.

(3) Water Access and Affordability

Access to water and affordability are two major concerns for environmental justice communities facing droughts. During droughts, rural and urban communities may lose their access to potable drinking water unexpectedly; groundwater and surface water sources may dry up during the summer or be compromised by low water levels (Dalgaard 2022, p 41). A few potential areas of intervention regarding water access and affordability impacted by drought relevant to environmental justice communities may include: recognizing the human right to water; increasing environmental justice communities' access to funds for well repair, remediation and replacement; developing solutions to drinking water quality challenges; supporting innovative approaches to water uses in agricultural businesses; and finding creative ways to sustain home and community gardens serving food insecure communities during droughts.

(3a) Human Right to Water

The Oregon Water Justice Framework recommends that the Oregon Legislature recognize access to potable water as a human right. The United Nations General Assembly has established the human right to water and sanitation. Deploying a human right to water during droughts means centering the poor and the historically marginalized in any prevention, mitigation and relief programs. California has followed the UN's lead recognizing water as a human right, and establishing the Safe and Affordable Drinking Water Fund which will provide $1.4 billion over 11 years for water infrastructure projects, strengthening the state's commitment to the human right to water. This fund prioritizes disadvantaged communities, and funds can be used for operations and maintenance (Brown et al 2022, 17). The implementation of a human right to water approach to policy and law in Oregon may entail: guaranteeing water affordability for low income communities through bill assistance programs; ensuring that sanitation and water stewardship systems are in place to sustain the health of all waters; creating clear and accessible avenues for all peoples, in particular those historically marginalized, to participate in advocacy and decision making; provide resources for people who are not on municipal systems to properly maintain their wells or other water sources; understand the state as a duty-bearer that must guarantee access to clean water for all; and prioritizing the most vulnerable communities in any action that impacts access to water, water quantity and quality, especially during droughts (Murray and Kominers 2021).

(3b) Access to Well Repair, Remediation and Replacement Resources

Affordability of well repair, remediation and replacement continues to be a water justice consideration as droughts impact the capacity of wells to provide potable water, even though Oregon has, as recently as 2021, invested significant resources to support low- to moderate-income and other community members. These three programs are offered statewide and can serve Oregon's households affected by drought: (1) The Water Well Abandonment, Repair and

Replacement Fund (WARRF), which provides financial assistance to permanently abandon, repair or replace a water well used for household purposes. Priority is given to low- to moderate-income household wells that have been recently affected by drought or wildfire ("Well Abandonment, Repair and Replacement Fund (WAARF) 2023); (2) The U.S. Department of Agriculture Rural Development Single Family Housing Repair Loans & Grants, which offers loans to low-income homeowners of up to $40,000 to repair or improve homes, including private water wells. It also offers grants up to $10,000 to low-income seniors (age 62 or older) to remove health and safety hazards ("Single Family Housing Programs" 2023); (3) The Rural Community Assistance Corporation's Household Water Well System Loans program, which offers low interest Household Water Well System Loans for up to $18,000 to construct, refurbish, or replace individual water well systems (RCAC, 2023).

In addition to regional programs funded by the state, these programs have been a significant step forward to support water access and affordability for those relying on wells during droughts, and to address the potential impacts of faulty septic systems on water quality and public health. It is too early to know if all environmental justice communities have found these programs accessible and are benefitting from them as intended in their inception. People are often unaware of existing resources to remediate wells, when those are available (Dalgaard 2022, p 36). A few barriers remain in their design to ensure accessibility: (1) resources for loan and grant providers to collaborate with tribes, CBOs, utilities and/or other entities to conduct outreach activities mindful of cultural, literacy, and income diversity; (2) limited resources to share information with and support applications from those community members who have not heard about these programs, who may not have access to online tools, who may have difficulty understanding their criteria, application process, or implementation, or who may feel intimidated by government bureaucratic processes; (3) these funds are mostly for homeowners and for their primary residence; (4) grants from the Water Well Abandonment, Repair and Replacement Fund require homeowners to pay contractors and then get reimbursed, which can be difficult - or present material and psychological obstacles - for most low, moderate, and fixed income homeowners making ends meet daily; (5) loan-based programs or programs requiring cost-match can pose similar challenges for low, moderate, and fixed income homeowners who cannot assume another debt, even if at a low interest rate; (6) it can be difficult for communities to find information about resources to support small water systems that tend to provide drinking water to communities constituted by 10-25 households throughout Oregon, and that are often managed by a community member without expertise on state or federal grants.

(3c) Additional Private Drinking Water Challenges and Solutions

Some community members take the risk of investing in drilling deeper wells to find more water to mitigate the impacts of multi-year droughts, which may or not solve the problem of water insecurity in their homes ("Advisory Report" 2023, p 59). In Burns, Oregon homeowners drilling deeper wells must now use filtration systems to eliminate arsenic from their drinking water and/or buy bottled water. Others cannot remediate or replace their wells and must buy water tanks that are delivered to their homes or purchase bottled water to meet their basic household needs (Reyes-Santos et al. 2021, p 37).

Drought may also increase the dangers of contaminants in bodies of water as the concentration of hazardous compounds in water may increase when water levels are lower than usual. Contaminants in water require that people buy bottled water to protect their families, especially their children, adding another household expense to their monthly budget (Reyes-Santos et al. 2021, p.37; p. 60).

To ensure water access and affordability, counties and the state are already developing creative solutions. In 2021, Klamath County, in partnership with the State of Oregon and others, provided free water filling stations, free water storage tanks, and free water delivery to households whose wells had gone dry or were producing less water than needed due to drought (Frequently Asked Questions: Free Water Storage Tanks, Water Filling Station and Water Delivery in Response to Dry Wells in Klamath County, Oregon 2021 Drought, 2021). This water could be used within the household or for cattle, not for gardens; the County does not recommend using it for drinking or cooking. County guidelines state that it must be disinfected before using it for human consumption because there are no guarantees that the water remains potable as it is transported and stored.

(3d) Innovative Approaches to Agriculture

During droughts, agricultural businesses, a core economic activity in rural communities, may be heavily impacted ("Drought Annex" 2016, p 6; Mucken and Bateman 2017). Drought response has focused on shifting water supplies, and has traditionally relied on groundwater resources, to address shortages in surface water that impact agricultural businesses ("Drought Annex" 2016, pp 16-17). This approach is already proving to be insufficient at a time when drought has jeopardized groundwater and surface water quantity and quality across Eastern Oregon ("Advisory Report" 2023, p 8). There is less water available to distribute among farming communities ("Advisory Report" 2023, p 8). And, if water sources have been compromised by hazardous compounds, pollutants, and biosolids, the water used to irrigate food staples is a public health concern ("Advisory Report" 2023, p 8)

If farmers do not have access to water, they may need to make operational changes (Mucken and Bateman 2017, p 81). During droughts, access to potable drinking water for farmworkers at work sites may also become compromised; already many farmworkers report questionable water quality at workspaces relying on well water (Reyes-Santos, et al 2021). Droughts may make it difficult for employers to provide drinking water to farmworkers as required by OSHA. Policies or investments to support farmers during droughts can better enable them to conserve water such as to (Mucken and Bateman 2017, pp 125-126): shift their water supply and irrigation patterns; replace crops that rely on significant amounts of water to drought-resistant ones; and develop sustainable agricultural and water conservation practices, such as rain gardens, and permaculture, hydroponic and rainwater harvesting systems. Currently, USDA's Disaster Assistance Emergency Conservation Program can provide resources for drought mitigation to farmers, including well replacement, remediation or repair. Outreach with small farmers, Native farmers, women and queer farmers, and farmers of color could enable these environmental justice communities to more efficiently access such resources (Disaster Assistance: Emergency Conservation Program (ECP), 2023).

(3e) Food Insecure Communities: Home and Community Gardens

Another water affordability issue during droughts is that individual and community food gardens that support access to food among low- and middle-income peoples - particularly relevant among Black and immigrant communities in the state - may struggle to pay their water bill. Higher temperatures or less rainfall may require more water consumption to grow food staples; water use increases and, therefore, water bills increase. Higher water bills as droughts become a regular feature of Oregon's weather patterns may limit the capacity of individuals and community gardens to provide food for families and communities. Already community gardens such as Huerto de la Familia in Eugene consider the water bill before deciding if they can expand their services into a new neighborhood even though there is such high demand for their services that people may wait on average three years to get a garden plot. NAACP Eugene-Springfield's community garden must also cover the water bill as an organizational expense (Reyes-Santos et al 2021).

The 2017 report on Executive Order 15-09 recommends that government agencies continue watering urban trees despite drought ("2017 Report to Governor Kate Brown: Implementation of Executive Order 15-09" 2018, p 10). This sets a precedent to support individual and community gardens' food crops. The state could invest in subsidies to reduce individual and community gardens' water bills, in particular among food insecure environmental justice communities. Moreover, during droughts, to reduce water use, drinking water providers may institute curtailment measures for outdoor water use. These measures could consider how these regulations may impact food insecure communities and modify them as needed to allow for community or personal food gardens to be watered.

(4) Natural and Built Infrastructure for Clean Water

Economically vulnerable communities, and, specially, rural, Native, BIPOC, and immigrant communities, experience an inequitable consequence of drought, as natural and built infrastructures lose the resiliency that otherwise provides them with invaluable natural and cultural resources. To enjoy resilient ecosystems, government can invest in stewardship practices that support the overall health of natural infrastructures: watersheds, streams, rivers, lakes, and seas. Stewardship must be shaped by Indigenous traditional ecological knowledge, the expertise and leadership of environmental justice communities, and respect for the cultural and spiritual values those communities bring to water stewardship ("Advisory Report" 2023, p 70; Reyes-Santos et al. 2021, p 18). Investing in outdated built infrastructures - whether in public utilities, private wells, or small water systems - can also reduce drought impacts on environmental justice communities by addressing water quantity and quality challenges and reducing the associated costs of infrastructure improvements for low-, moderate- and fixed-income communities. To address drought impacts to natural and built infrastructure, the following may be productive avenues for action: engaging indigenous land stewardship practices, facilitating water conservation and re-use at home, ensuring food security through water re-use systems and fishing regulations, and continue investing in improving outdated utilities and well systems impacted by drought and wildfires.

(4a) Natural Infrastructure: Indigenous Land Stewardship and Drought Mitigation

Stewarding natural infrastructures requires prioritizing the conservation of water, its redirection to the soil and aquifers, and its overall health and filtration as rain falls on roofs, sidewalks, and streets. It can mitigate drought conditions by sustaining healthier water levels underground, in root systems, in the soil, and surface waters, and reducing consumption, while supporting environmental justice communities' access to food and clean waters.

As described in the sections above, lower levels of water or higher temperatures may increase the concentration of toxic compounds, pollutants, and biosolids in bodies of water and drinking water, such as algal blooms, nitrates, and arsenic. Low income, Native, Indigenous Latin American, Latinx, Black, Asian American, Pacific Islander, Middle Eastern, and African communities all access bodies of water as affordable sites for recreation, fishing, and harvesting, and/or significant spiritual and ceremonial spaces (Reyes-Santos et al. 2021, pp 12-13). Lower stream levels can then expose their children, elderly, adults, and immunocompromised community members to toxins that pose a threat to human health (Oregon Health Authority, 2023; Lehman et.al, 2017).

Planting native trees and shrubs - including oaks, alders, and willows - near bodies of water supports natural infrastructures. It may in some cases direct water to the soil and aquifers, and provide shade to keep waters cool, which can reduce the impact of drought on public health. Propagating these plants can sustain the plant, fish, insect, birds, and animal life that rely on surface water; enable culturally–important activities such as Indigenous canoe journeys; ensure the overall health of species that are culturally significant for tribal communities' food, basket weaving, and medicinal practices; and improve food security among environmental justice communities who fish, gather, harvest, and hunt to feed their families and communities as we face more frequent drought conditions. Education about and access to drought-resistant and native plants, including edible ones, can also support cultural resiliency, food sovereignty and food access during droughts (Clinton et al, 2019).

Collaborating with Indigenous leadership to implement cultural burnings is another significant step towards healthier natural infrastructures and centering the expertise of environmental justice communities in drought mitigation. Cultural burnings may protect shallow or seasonal springs from evaporation, as well as cool the temperature of streams and rivers; cold waters are necessary for species such as wapato, salmon, lamprey eel, and sturgeon to survive ("Advisory Report" 2023, p 69-70 (OWF Conversation with Joe Scott, 2021; Letter: Oregon's Nine Tribes Ask for Voice in Water Planning, 2021).

(4b) Natural Infrastructure: Water Conservation and Re-Use

Rainwater harvesting, rain gardens and graywater systems are three approaches to water conservation and re-use that support the health of natural infrastructures during droughts ("Water-Efficient Technology Opportunity: Rainwater Harvesting Systems", 2023; "Rain Gardens: Low Impact Development Fact Sheet", 2018). Environmental justice communities engaged by OWF are eager to learn how to implement these water conservation practices (Reyes-Santos et al. 2021, p 18). Regulations and investments to support, design, and implement rain gardens in apartments, single residence homes, and mobile home parks can have the multiple effects of: (1) supporting the health of both groundwater and surface water; (2) conserving water sources both in municipal and rural water systems; (3) reducing the strain on existing water treatment facilities; and (4) sustaining food sovereignty and access to affordable foods (Reyes-Santos et al. 2021, p 15).

Rain gardens can reduce the amount of water withdrawn from water sources, and can redirect water to the ground, instead of sending it to water treatment facilities ("Rain Gardens", 2018). Treated water can warm bodies of water at a higher rate during droughts, a process that can be damaging to fish and aquatic plants ("Methods to Reduce or Avoid Thermal Impacts to Surface Water: A Manual for Small Municipal Wastewater Treatment Plants", 2007). Plants, soil, and stones in these gardens also filter potential pollutants gathered by stormwater as it passes through roofs and plumbing; and enable water to more easily feed aquifers. Rain gardens also can sustain plants, pollinators, and other species without requiring more irrigation.

(4c) Natural Infrastructure: Food Security

Installing rainwater catchment and graywater systems can also be of great service to environmental justice communities wishing to sustain their surrounding natural infrastructures during droughts and secure food (Brown et al 2022; Reyes-Santos, et al 2021, 5; "Water", 2023; "Soak up the Rain: Rain Gardens", 2023). Re-used water can be used for personal and community food gardens, and to irrigate and protect households' surrounding areas when dry weather conditions pose higher risks of wildfires. Through OWF's community engagement, it became evident that environmental justice communities wish to afford and implement rain and graywater systems as water conservation and affordability measures that can have direct impact in their access to water and food during droughts (Reyes-Santos et al. 2021, p 5).

For renters who are forbidden from keeping gardens to avoid increasing landlords' water bills, rainwater harvesting, and rain gardens can be very desirable; not to mention that many interviewees from immigrant communities spoke of harvesting rain and using graywater in their countries of origin - from Mexico to Somalia - as water conservation techniques passed down for generations (Reyes-Santos et al. 2021, pp 50-52). Limited access to information about how to implement such practices here, about what regulations apply across counties, and affordability continue to be obstacles. For this reason, investing in these technologies, and increasing access to them, to steward water infrastructures, should be done in coordination with environmental justice communities to ensure that the process itself is accessible to them (Reyes-Santos et al. 2021, p 14).

(4d) Natural Infrastructure: Fishing Restrictions and Food Security

Stringent fishing restrictions during drought are at times deployed to manage strained fisheries. However, for environmental justice communities, this practice can be harmful, reducing access to culturally specific foods, and increasing food insecurity ("Advisory Report" 2023, p 8). Fishing is an important food source for low-, moderate-, and fixed-income Oregonians of all racial and ethnic backgrounds. As droughts become a regular aspect of our climate patterns, telling those who rely on fishing to feed their families that they cannot fish is not a sustainable, long-term, practice for those communities. Ensuring Oregon tribal communities' food sovereignty requires access to culturally significant fishing sites across public and private lands, as well as healthy watersheds that sustain fish and plants essential to their diets since time immemorial ("Advisory Report" 2023, p 18; Reyes-Santos et al. 2021, p 18). Indigenous Latin American, non-Indigenous Latinx, and Pacific Islander immigrants in the Willamette Valley and Eastern Oregon often rely on fishing for food and to recreate healthy fish-based diets from their countries of origin (Reyes-Santos et al. 2021).

(4e) Built Infrastructure: Municipal Utilities, Wells, Wildfires, and Potable Drinking Water

Stewarding natural infrastructures is a recommendation from OWF's Water Justice Framework that lays out productive paths of action for drought mitigation. Investing in the improvement of built infrastructures (e.g., sewage and stormwater systems, water pipes, etc.), is also another water justice and public health concern in the Framework pertinent to drought response. These investments are meant to ensure proper water quantity and quality in rural and urban areas, and affordable water access for people in municipal and private water systems.

For those relying on rural and urban utilities that have not undergone necessary upgrades, droughts may further endanger the quantity and potability of the water they consume at home and at work. Without state investments, water consumers on municipal, private and small well water systems carry the burden of purchasing water and indirectly paying the cost for those upgrades in their water bill. For those relying on well water, if their drinking water at home is compromised by drought, they may still consume it to avoid another expense, tap into already strained household budgets to purchase bottled water, or ration water consumption (Reyes-Santos et al. 2016, p 15). People in urban areas face similar economic challenges. When municipal waters are compromised, purchasing bottled water becomes the solution. For renters who are not kept informed about the quality of the water they have access to, and low- and fixed-income communities who cannot afford purchasing water, these are public health hazards that can be remediated by investments in built infrastructure.

Most farmworkers and food processing workers interviewed by the OWF Collaborative only have access to well water at work; some were provided bottled water or water in storage tanks. If wells are compromised by drought, this workforce faces the choice of either taking the risk of drinking non-potable water or only drinking what they can carry from home to work: often only one bottle (Reyes-Santos et al 2021). During droughts and related heat waves, reduced water consumption at such worksites can lead to deadly consequences for workers.

Droughts also increase the chances of wildfires and how quickly they expand (Mucken and Bateman 2017, p 74). State investments can productively address wildfires' impact on water systems and water quality, including damage to wells, public utilities, and treatment plants, and toxic pollutants being released into bodies of water as structures burn. The Water Well Abandonment, Repair and Replacement Fund funded in the legislative session in 2021, intends to provide resources to communities where wildfire or drought compromised household well infrastructures. Investing in the built infrastructures of utilities and treatment facilities may be another important drought relief measure to ameliorate environmental justice communities' experiences of public health emergencies due to drought.

(5) Emergency Preparedness

Droughts can lead to or worsen existing emergencies, such as wildfires and water insecurity. Oregon Water Justice Collaborative's interviewees shared a number of recommendations for emergency preparedness. In environmental justice communities, especially rural and low-income communities and those for whom English is a second language, emergency preparedness must be culturally competent (able to provide information in multiple cultural and linguistic registers) and accessible (free of jargon). Economic resources must also be readily available to provide water, food and medical care to those most impacted or to evacuate them as needed (Reyes-Santos et al. 2021, p 17).

People with disabilities, people of color, immigrants, and low income and unhoused communities, have distinct vulnerabilities during emergencies, potentially including life threatening loss of electricity and potable water, limited mobility, and access to water, jobs and economic aid, as well as linguistic barriers to benefit from state resources ("Clinton et al, 2019; "Mapping Socially Vulnerable Communities", 2023; Alai Reyes Santos et al, 2021). Trauma-informed approaches to emergency response are recommended when working with environmental justice communities who are often experiencing chronic levels of stress and distrust of state institutions usually deployed during emergencies, such as the police, fire departments, and the National Guard. Doctors, clinics, and hospitals must also be prepared to address the impacts of drought on public health in rural and urban areas, while being trained on how to best serve and conduct outreach with environmental justice communities (Clinton et al, 2019).

(6) Community Empowerment

Communities care deeply about water security and water stewardship and carry with them important knowledge about the issues impacting water resources and solutions to the challenges we all face during droughts. State agencies then have a prime opportunity to seriously engage community-led water stewardship to prevent, mitigate and organize relief efforts in response to droughts. Community members interviewed by OWF expressed across the board the desire to learn more about water stewardship, resources, utilities, services, advocacy, and emergency preparedness. Consulting the general public and creating opportunities for the state to provide accessible information about droughts, their impact, and mitigation strategies, enables people to feel more empowered to act. Information must be distributed in multiple formats through radio, mail, television, and social media, in a variety of languages, free of jargon, and with attractive formats and mediums, such as short educational videos and educational materials that children can share with their parents (Reyes-Santos et al 2021). Technical jargon and faulty translations continue to be an obstacle in government efforts that seek to serve environmental justice communities facing water insecurity (Reyes-Santos et al. 2021, p 38).

(6a) Closing Information Gaps

Investing in collaborating directly with tribes and community-based organizations (CBOs) is a proven methodology to close existing information gaps between communities and state agencies (Reyes-Santos et al. 2021, p 14; Dalgaard 2022). During the algal bloom in Salem in 2019, the farmworker organization PCUN (Pineros y Campesinos Unidos del Noroeste) ensured that people living in the apartment buildings it administers received notifications about water quality in a timely and accessible manner (Reyes-Santos et al. 2021, p 37). During and after the pandemic and wildfires numerous CBOs - Unite Oregon, NAACP in Eugene and Springfield, PCUN in Woodburn, Euvalcree in Eastern Oregon, and Coalición Fortaleza in Southern Oregon, among others - served as hubs that assisted community members' access to health care, food pantries, government economic assistance, and housing (Reyes-Santos et al. 2021, p 57; OWF Conversation with Euvalcree 2023; Coalición Fortaleza 2022).

These organizations are trusted by community members and have the cultural competencies necessary to reach them. With very limited staff capacity, they are also already conducting the work of building relationships between individuals and state agencies. They can be more effective in intentional partnership with state agencies that fund staff and other necessary resources for the organizations to conduct accessible outreach activities. Euvalcree, for instance, is effectively supporting home energy conservation audits by utilities among environmental justice communities in Hermiston. They receive funding to cover staff's time to go to people's homes, assess their energy use and consumption, identify areas of improvement and economic resources people can access to reduce energy spent in their homes, and help them apply for those resources. Recently Euvalcree also recruited participants in Hermiston for a free well water testing program funded by Oregon Health Authority and conducted by Willamette Partnership with support from University of Oregon. During home visits this program offered information about well water quality issues and resources - as well as nitrates in Morrow and Umatilla County wells - and reduced fears regarding the impact of iron bacteria in water odor. These visits were conducted in English and Spanish, and included an Euvalcree staff member who speaks Indigenous Mam as well. Similar projects could be created and funded with tribal entities and community-based organizations as partners to create accessible outreach relevant to drought prevention, mitigation, and relief.

(6b) Co-leading and Co-designing with EJ Communities

Working with tribes and CBOs requires remunerating them for staff time and participation costs, and co-leading and co-designing outreach strategies, educational content, and relief efforts with them to be effective. Such collaborations would prove fruitful when drought hits our communities. These steps would enable the most vulnerable to drought to have better access to information about how to mitigate its impacts on water resources, including drinking water, groundwater and surface water, and can help communities tap into resources and information to access relief efforts, and improve food and water security.

(6c) Governmental Outreach Practices

Various governmental reports, executive orders, and state agencies name the need to conduct outreach with the public regarding water stewardship and drought. The 2015 annual report on the implementation of Executive Order 15-09 discusses the need to consider disproportionate impacts on underserved communities before implementing water conservation measures in state agencies (“Executive Order No. 15-09" 2015). The Oregon Youth Authority encouraged inmates to take leadership roles on water conservation (“2016 Report to Governor Kate Brown: Implementation of Executive Order 15-09” 2017, p 11). The Department of Fish and Wildlife began a pilot project harvesting rainwater as a water conservation practice: a major desire among all communities interviewed by OWF (“2016 Report to Governor Kate Brown: Implementation of Executive Order 15-09” 2017, p 11). The Drought Annex tasks OWRD with conducting outreach related to provide information on drought conditions, including to Tribal governments to assess drought impacts in their communities (“Drought Annex” 2022, p 15).

Government community outreach plans regarding drought prevention, mitigation, and relief then must devote human and economic resources to accessibility, and invest the time required to build trust with communities. They must also frame initial conversations as open opportunities to learn about what Oregon’s rural, low income, coastal, Native, Indigenous Latin American, Latinx, Black, Middle Eastern, Asian American, and African communities can teach government and state agencies about their experiences of drought, how drought impacts their everyday lives, and how they see themselves supporting statewide goals of water conservation and stewardship.

Water Justice Considerations: 2021, 2022, and 2023 Legislative Sessions

The 2021, 2022 and 2023 Legislative Sessions approved bills that engage several needs and expertise of environmental justice communities relevant to drought prevention, mitigation, and relief systems in the state. To varying degrees, these bills address the six thematic areas named by the Water Justice Network and discussed in this assessment so far: (1) Indigenous Water Justice Leadership, (2) Renter’s Rights, (3) Water Access and Affordability, (4) Natural and Built Infrastructure for Clean Water, (5) Emergency Preparedness, and (6) Community Empowerment. A brief, non-exhaustive, discussion of bills is included here.

The groundbreaking 2021 Oregon water infrastructure legislative package made several significant steps towards engaging environmental justice communities and their concerns in rulemaking, policy and law pertaining to drought. Senate Concurrent Resolution 17 states that “access to clean water is a human right,” and that the State must prioritize and empower frontline communities, including “Native American, Indigenous and People of Color communities, essential workers, youth, low-income people and those who are most vulnerable in rural and urban communities,” in decision-making processes addressing climate change and promoting environmental justice (SCR0017 2021); it also resolves that state agencies consult with the Environmental Justice Task Force in future legislation and rulemaking (SCR0017 2021). House Bill 2167 formalized the role of the Racial Justice Council within the Office of the Governor and grants it authority to advise the governor on several issues including environmental equity; the Bill also requires racial impact statements in agency budget requests (HB 2167 2021). The legislature allocated $1.5 million for equitable water access and Indigenous energy resilience through OWRD. House Bill 2145 established a new funding program for a Water Well Abandonment, Repair and Replacement Fund and authorized prioritizing low- or moderate-income individuals (HB 2145 2021).

The 2022 Legislative session invested in protecting aquatic habitats and their impact on culturally significant foods for tribal communities. Senate Bill 1501 included $25.6 million for aquatic ecosystem protection (HB 5202, 2022). The Oregon Department of Fish and Wildlife received $2.6 million to identify cold water refugia, monitor streamflows and temperatures, and to address a backlog of new instream water right applications (HB 5202, 2022). The agency received an additional $8 million for fish barrier removal (HB 5202, 2022). The Oregon Watershed Enhancement Board received $10 million to issue grants for voluntary instream flow transfers. $5 million was added to the Oregon Conservation and Recreation Fund (HB 5202, 2022).

The 2023 Bipartisan Drought Relief and Water Security Package (BiDRAWS) targets key issues that are straining Oregon's water management and security during multi-year droughts. House Bill 2010 included a suite of drought related policies and investments including (1) establishing a new funding program to provide grants to communities to protect their water sources; (2) amending the statutory requirements for the Integrated Water Resources Strategy to require the consideration of natural hazards including drought; (3) expanding the agencies participating in developing the IWRS; (4) expressly requiring engagement with Environmental Justice communities and Tribes, and requiring agencies ensure balanced and equitable implementation for Place-based Planning and the IWRS; (5) establishing two new funding sources to support the use of Aquifer Recharge in areas identified as having groundwater concerns; (6) increasing the frequency of grant opportunities for the Water Projects Grants and Loans Program; (7) directing DEQ, in consultation with OWRD, to address barriers to water reuse and recycling practices and to provide technical assistance to support the use of these practices; (8) establishing a permanent place-based funding program; (9) authorizing OWRD to require water use reporting where it can require measuring, and (10) directing the Oregon State University to establish and administer a program to support agricultural producers in deploying new water management practices and accessing information that will support drought and climate resilience. In addition, two other bills added authorities to support OWRD's water rights administration including making permanent split-season leasing and authorizing OWRD to pursue injunctive relief for violations of state water law (HB 3164 A, 2929).

Investments in community outreach and engagement with environmental justice communities include: funding for the Tribal Water Task Force, a staff for engaging on the CTUIR settlement and funding for the place-based water planning fund. OWRD, DEQ, ODFW, and ODA received authority to provide planning and technical assistance for development and implementation of place-based plans.

The 2023 Legislative session includes other significant bills that can support Indigenous water justice leadership and natural and built infrastructures for clean water. House Bill 2971 would create a tax incentive for the voluntary leasing of water rights (HB 2971, 2023). House

Bill 3059 would establish a disaster response fund (HB 3059, 2023). These policies were paired with investments to support drought-related funding programs and agency capacity.

In 2023, unfortunately the $1.5 million allocated in 2021 for equitable water access and Indigenous energy resiliency among environmental justice communities was re-appropriated by the Legislature. However, $500,000 was appropriated and allocated to University of Oregon's Just Futures Institute to conduct research to understand and address water needs of environmental justice communities and to award grants to advance those goals during the next biennium (SB 5506).

Bibliography

Advisory Report: State Leadership Must Take Action to Protect Water Security for All Oregonians. 2023. Oregon Secretary of State and Oregon Audits Division.

Bateman, Brenda, Fridgen Scott, Pat Mucken, and Alyssa Middleburg. "State Water Plans: Monographs from 17 States" *American Water Resources Association Water Resources Impact* 21, no. 1 (2019).

Brown, L. et al. 2022. Oregon Water Justice Framework: Community Driven Principles and Priorities to Advance Water Justice. Oregon Water Futures. http://www.oregonwaterfutures.org/water-justice-framework.

Cahill, Maria, Derek Godwin, and Jenna Tilt. "Rain Gardens: Low Impact Development Fact Sheet." Oregon State University. June 2018. https://catalog.extension.oregonstate.edu/em9207/html.

Chinook Nation. 2023. Recognition. https://chinooknation.org/recognition/.

Clark, S.A., Miller, M., and D.L. Hankins. 2022. Good Fire: Current Barriers to the Expansion of Cultural Burning and Prescribed Fire in California and Recommended Solutions. .

Clinton, Chelsea, Mark Nystrom, and Alai Reyes-Santos. Climate Plan 2.0 Equity Panel: Case Study. 2019. City of Eugene.

Coalición Fortaleza. Presentation. University of Oregon. November, 2022.

"Community-Driven Well Water Testing." Oregon Water Futures. July 11, 2023. https://www.oregonwaterfutures.org/well-water-testing

Dalgaard, S. 2022. State of Water Justice in Oregon: A Primer on How Oregon Water Infrastructure Challenges Affect Frontline Communities Across the State. Oregon Environmental Council and Oregon Water Futures Project.

Department of Administrative Services and Oregon Water Resources Department. 2018. 2017 Report to Governor Kate Brown: Implementation of Executive Order No. 15-09 by Oregon's State Agencies.

"Disaster Assistance: Emergency Conservation Program." United States Department of Agriculture Farm Service Agency. July 11, 2023. https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/FactSheets/emergency-conservation-program-ecp-fact_sheet.pdf

Drought Annex: State of Oregon Emergency Operations Plan. 2016. Oregon Office of Emergency Management and Oregon Water Resources Department.

Evans, P. and D. Brown. 2018. Statewide Groundwater Monitoring Program: North Coast 2015-2016 Report. Oregon Department of Environmental Quality. https://www.oregon.gov/deq/FilterDocs/grw-northcoast2015-16.pdf.

H.B. 2010 – 82nd Oregon Legislative Assembly: Relating to water, creating new provisions, amending ORS 536.220, 537.767, 537.797, 537.798, and 541.669; and declaring an emergency. https://olis.oregonlegislature.gov/liz/2023R1/Downloads/MeasureDocument/HB2010/Enrolled.

H.B. 2142 – 82nd Oregon Legislative Assembly: Relating to state entities. 2023. https://olis.oregonlegislature.gov/liz/2023R1/Downloads/MeasureDocument/HB2142/Introduced.

H.B. 2145 – 81st Oregon Legislative Assembly: Relating to the performance of work on wells. 2021. §2. https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB2145/Enrolled.

H.B. 2167 – 81st Oregon Legislative Assembly: Relating to fees charged by the Water Resources Department; and declaring an emergency. 2021. https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB2167/Enrolled.

H.B. 5006 – 81st Oregon Legislative Assembly: Relating to state financial administration; and declaring an emergency. 2021. https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/HB5006/Enrolled.

"Mapping Socially Vulnerable Communities." College of Forestry Oregon State University Wildfire Risk Mapping. July 12, 2023.

McKibben, S. M., et al. 2015. Monitoring Oregon Coastal Harmful Algae: Observations and Implications of a Harmful Algal Bloom-Monitoring Project. *Harmful Algae*, *50*, 32-44.

Methods to Reduce or Avoid Thermal Impacts to Surface Water: A Manual for Small Municipal Wastewater Plants. June 2007. Washington Department of Ecology Water Quality Program.

Mucken, A., and B. Bateman. (Eds.). 2017. Oregon's 2017 Integrated Water Resources Strategy. Oregon Water Resources Department. Salem, OR.

Murray, K. and S. Kominers. 2021. The Human Right to Water in the United States: A Primer for Lawyers and Community Leaders. https://law.northeastern.edu/wp-content/uploads/2021/04/phrge-water-primer.pdf.

National Integrated Drought Information System. 2023. Drought Conditions for Wasco County. https://www.drought.gov/states/Oregon/county/Wasco.

Norgaard, KM. Author. 2019. Salmon and Acorns Feed our People: Colonialism, Nature, and Social Action. New Brunswick, NJ.

Lehman, P.W., T. Kurobe, S. Lesmeister, D. Baxa, A. Tung, S.J. Teh. "Impacts of the 2014 Severe Drought on the Microcystis Bloom in San Fransisco" *Harmful Algae* 63, (Mar. 2017): 95-108. doi: 10.1016/j.hal.2017.01.011.

"Letter: Oregon's Nine Tribes Ask for Voice in Water Planning." *The World*, September 24, 2021.

O'Neill, E.17 April 2021. Unrecognized Tribes Struggle Without Federal Aid During Pandemic. https://www.npr.org/2021/04/17/988123599/unrecognized-tribes-struggle-without-federal-aide-during-pandemic.

Oregon Health Authority. 2023. Cyanobacteria Advisory Archive. https://www.oregon.gov/oha/ph/healthyenvironments/recreation/harmfulalgaeblooms/pages/archive.aspx.

Oregon Health Authority. 2023. Public Health News and Advisories: Recreational Advisories. https://www.oregon.gov/oha/ph/newsadvisories/pages/recreationaladvisories.aspx

Oregon Water Futures Conversation with Confederated Tribes of Grand Ronde Natural Resources Department. Zoom. 2021.

Oregon Water Futures Conversation with Collaborative Members and Joe Scott (Takelma/Siletz elder and fire keeper). Zoom. March 2022.

Oregon Water Futures Conversation with Tribal Members. Zoom. November 2021.

Oregon Water Futures Conversation with Euvalcree members. Phone Calls/Zoom. November 2020.

Oregon Water Futures Conversation with Euvalcree staff. Hermiston. 2023.

Oregon Water Futures Conversation with Joe Scott (Takelma/Siletz elder and fire keeper). Zoom. March 2021.

Oregon Water Futures Conversations with Renters. Hermiston. 2023

Oregon Water Futures Conversations with Renters. Phone Calls/Zoom. Ontario. 2020.

Oregon Water Futures. "Early Actions for the State." Letter to Governor Brown, Senator Taylor, Representatives Reardon, Helm, and Owens. 2021.

Oregon Water Resources Department. 2015. Report to Governor Kate Brown: Implementation of Executive Order No. 15-09 Directing State Agencies to Plan for Resiliency to Drought.

Oregon Water Resources Department. 2017. 2016 Report to Governor Kate Brown: Implementation of Executive Order No. 15-09 Directing State Agencies to Plan for Resiliency to Drought, to Meet the Challenge That a Changing Climate Brings.

Oregon Water Resources Department. 2023. Well Abandonment, Repair and Replacement Fund (WARRF). https://www.oregon.gov/owrd/programs/GWWL/WARRF/Pages/default.aspx.

Reyes-Santos, A., Holliday, C., Dalgaard, S., Evans, T., and K.T. Witherill. 2021. Oregon Water Water Futures Project Report: 2020-2021 Community Engagement. Oregon Water Futures. https://www.oregonwaterfutures.org/report-20-21.

Rural Development. 2023. Single Family Housing Programs. https://www.rd.usda.gov/programs-services/single-family-housing-programs.

S.B. 5506, 82nd Oregon Legislative Assembly: Relating to State Financial Administration; Creating New Provisions; Amending Section 3, Chapter_, Oregon Laws 2023 (Enrolled Senate Bill 104), and Sections 7, 8, and 10, Chapter_, (Enrolled House Bill 33396); and Declaring an Emergency. https://olis.oregonlegislature.gov/liz/2023R1/Downloads/ProposedAmendment/25434.

S. Con. Res. 17, 81st Oregon Legislative Assembly. 2021. https://olis.oregonlegislature.gov/liz/2021R1/Downloads/MeasureDocument/SCR17/Enrolled.

Schelenz, R. 6 April 2022. How the Indigenous Practice of 'Good Fire' Can Help Our Forests thrive. https://universityofcalifornia.edu/news/how-indigenous-practice-good-fire-can-help-our-forests-thrive.

"Soak up the Rain: Rain Gardens." Environmental Protection Agency. July 12, 2023. https://www.epa.gov/soakuptherain/soak-rain-rain-gardens.

State of Oregon Newsroom. 19 April 2023. "Governor Tina Kotek Declares Drought Emergency in Wasco and Harney Counties." https://www.oregon.gov/newsroom/Pages/NewsDetail.aspx?newsid=157460.

Traditional Ecological Knowledge Inquiry Program. "Cultural Burn Training." Sprague River, 2021.

Traditional Ecological Knowledge Inquiry Program. "Cultural Burn Training." Vesper Meadows Ecological Preserve, 2022.

UN Water. 2023. Human Rights to Water and Sanitation. https://www.unwater.org/water-facts/human-rights-water-and-sanitation.

United States Environmental Protection Agency. 2023. Indian Environmental General Assistance Program (GAP). https://www.epa.gov/tribal/indian-environmental-general-assistance-program-gap.

"Water-Efficient Technology Opportunity: Rainwater Harvesting Systems." Federal Energy Management Program. July 12, 2023. https://www.energy.gov/femp/water-efficient-technology-opportunity-rainwater-harvesting-systems

"Water." Eugene. July 12, 2023. https://www.eugene-or.gov/877/Water-Reduction-and-Reuse.