Washington State Drought Contingency Plan

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Washington State Drought Contingency Plan

by:

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Department of Agriculture

Department of Commerce

Department of Ecology

Department of Fish and Wildlife

Department of Health

Office of Washington State Climatologist

Washington Military Department, Emergency Management Division

Washington State Conservation Commission

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And HDR, Inc.

Water Resources Program
Washington State Department of Ecology
Olympia, Washington

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Acronyms

Acronym	Definition
DNR	Washington Department of Natural Resources
EMD	Washington State Military Department, Emergency Management Division
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency
EWEC	Executive Water Emergency Committee
FERC	Federal Energy Regulatory Commission
FSA	Farm Service Agency
HPA	Hydraulic Project Approval
MOA	Memorandum of Agreement
NDMC	National Drought Mitigation Center
NIDIS	National Integrated Drought Information System
NMME	National Multi-Model Ensemble
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OFM	Office of Financial Management
PDSI	Palmer Drought Severity Index
PUD	Public Utility District
RCP	Representative Concentration Pathway
RCW	Revised Code of Washington
SPI	Standardized Precipitation Index
USDA	U.S. Department of Agriculture
USGS	United States Geological Survey
UW	University of Washington
WAC	Washington Administrative Code (WAC)
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Areas
WSAC	Water Supply Advisory Committee
WSDA	Washington Department of Agriculture
YRBWEP	Yakima River Basin, Water Enhancement Program

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Executive Summary

This plan was completed with the support of a federal WaterSMART grant from the Bureau of Reclamation. This grant award enabled the Department of Ecology to convene a Drought Contingency Planning Task Force, and to contract with HDR, Inc. for facilitation and strategic services.

The Year 2015 was the most extreme drought Washington had experienced in recent decades. Record warm winter temperatures caused a record low snowpack, or snow drought. Reduced snow-water storage, and very dry spring and early summer, resulted in extremely low stream flows in many watersheds across the state.

The drought proved to be a learning experience for water managers and water users statewide. Much of that new understanding is reflected in this revised Washington State Drought Contingency Plan (DCP). This plan replaces Washington State's existing Drought Contingency Plan, published in 1992.

Background
The Background section provides an introduction to the current drought framework and the development of this plan by the DCP Task Force. This section recommends various actions where the state response framework can be improved.

In Washington State, drought is defined in statute (RCW 43.83B) as conditions where water supply is anticipated to be less than 75 percent of normal and there is anticipated hardship to water users and uses.

Washington's current drought response framework emphasizes emergency response and provides a discrete set of tools for addressing water supply shortage emergencies. Those tools include emergency water right permitting, emergency water right transfers, and – if funding is made available – grants and loans to public entities for emergency infrastructure needs.

A key recommendation is to provide more certainty regarding the availability of drought funding to improve the timeliness of drought response and the state's ability to communicate with and provide relief to water users experiencing hardship.

The plan also makes recommendations for streamlining the disbursement of money to state agencies responsible for drought response. These options include the pre-staging of spending agreements and contracts, and working with the Legislature to enable direct appropriations to agencies, rather than routing the money through Ecology.

Anticipating drought conditions depends on the availability of skillful forecasts of precipitation and temperature conditions in the coming weeks and months. While there are continuing advances in hydro-meteorological forecasting systems, there is likely to remain considerable uncertainty in long range forecasts in the years ahead. Thus, more value is likely to be gained from putting more emphasis on drought preparation and the streamlining of drought response.

Operations and Administration

The Operations and Administration section discusses the challenge of making resources available for drought relief in time for water managers to benefit. Irrigators have largely committed to planting and growing by the time water supply forecasts are clarified for the coming spring and summer. If the state intends to make alternatives available for growers, those options must be quick to implement. The plan recommends that the Legislature provide year to year drought contingency funding for drought actions.

The DCP Task Force proposes that Washington State move to a 2-stage drought system, Advisory and Emergency. The current drought framework stipulates that the state may issue a drought emergency declaration. The task force believes that also using "Drought Advisories" would provide a valuable tool for communicating to the public when conditions are below normal but not yet at a level where the risk of hardship is high.

Advisory and Emergency stages are summarized as follows:

Stage 1 – Advisory Conditions: Long-term forecast indicates drought of any level of severity may occur, or short-term forecast indicates minor drought conditions may occur in at least some area of the state.

Stage 2 – Emergency (issue Declaration) Conditions: Short-term forecast indicates high probability that drought conditions meeting the statutory definition will occur in some portion of the state; or drought conditions have actually materialized in some area of the state (at any level of severity – minor to severe).

The plan recommends that the state periodically update the drought plan in conjunction with the state's natural hazard mitigation planning process.

Actions

This section describes resiliency and response actions which can reduce the impacts of drought on water users and the environment. Resiliency actions include projects and ongoing programs which mitigate the impacts of future droughts (e.g., irrigation efficiency, water system planning). Response actions are those that occur during drought emergencies (e.g., emergency water right permits, emergency grants and loans, fish rescue).

Drought Monitoring and Forecasting

Washington State's formal definition of drought is based on water supply. Yet, consideration of multiple drought indicators (tools using precipitation, temperature, streamflow, and/or snowpack, and so on) can provide complementary information and a more comprehensive perspective on the state of the system. This chapter provides an overview of some of the most relevant drought indicators in the region. It also identifies what stage of drought (i.e., onset, existing, and the end) each indicator is most suitable.

Most of the drought indicators described use multiple variables in their definition, but there are several stand-alone variables that are quite useful for assessing drought conditions. The state's Water Supply Availability Committee (WSAC) already uses many of these to monitor drought on a monthly basis. For example, the average temperature departure from normal, percent of normal precipitation, and streamflow percentiles are commonly assessed and can be determined for multiple time scales.

Current mountain snowpack conditions in the form of snow water equivalent are also extremely useful during the winter months. Derived quantities such as the percentage of normal for that particular time of year, or the percentage of peak snowpack can be very useful in assessing the statewide conditions. Another example would be stream temperatures in the spring and summer months when high temperatures can indicate unfavorable conditions for certain species of fish. These indicators have strengths in common that they are relatively easy to understand and communicate to others, and are accessible. On the other hand, more sophisticated indicators may have the potential to identify a developing drought sooner, which would put the state in a better position to respond quickly and proactively.

Vulnerability

This chapter summarizes previous research on Washington State's vulnerability to drought and supplements it with information gained during the 2015 drought. Additionally, it discusses how vulnerability of key sectors is the result of the interaction of several key factors: exposure, sensitivity, and adaptive capacity. These concepts are defined.

Sectors which rank highest for vulnerability to drought are irrigators with junior water rights and fisheries. Most municipal drinking water systems are highly resilient to drought impacts. Smaller water systems, which are more likely to depend on single sources, shallow wells, or both are more vulnerable, but data regarding how small water systems managed during recent droughts is not formally tracked. Energy is highly resilient due to regional coordination and trading of power. In the recreation sector, ski resorts reported massive drops in ski visitors in the winter of 2014-2015. Whitewater boaters also reported a large drop in the number of days that rivers were runnable.

Following the 2015 drought, WSDA provided an estimate of the cost of drought impacts to agriculture. WSDA concludes that the estimated economic loss due to the 2015 drought reached between $633 million and $773 million.

This chapter also summarizes the number and location of emergency drought permits issued in 2001, 2005, and 2015. There is a declining trend in the number of temporary emergency drought authorizations issued during drought years. Most permits have been issued in the Yakima Basin and in other agriculture basins east of the Cascades, where there is significant irrigation using surface water supplies. In 2015 there were a few drought permits issued west of the Cascades, more than during previous droughts.

In 2015 the Department of Ecology reviewed the impacts of the drought on groundwater conditions. Major findings included:

- The data indicate little impact of the drought on groundwater levels.

- The time lag between a drought's occurrence and corresponding water level responses (particularly in deep basaltic wells) makes it difficult to discern cause and effect relationships.
- It is often difficult to detect short-term, drought-related trends due to widespread regional groundwater declines.

Purpose of Plan

This Washington State Drought Contingency Plan has been prepared for the purpose of guiding those state agencies responsible for planning and responding to drought conditions in the state of Washington. The Department of Ecology (Ecology), as the state lead agency for drought response, holds emergency powers during a declared drought to take expedited actions to address drought-related water supply shortages. These actions include emergency water right permitting and disbursing funding to other agencies and governments to mitigate the impacts of drought conditions on water uses in agriculture, public health, environment, and energy sectors. Our goal with this plan is to improve the state's ability to effectively respond to drought in a timely manner, but also to reduce the vulnerability of water users to drought in the long run.

Intended Plan Audience

This plan's intended audience is primarily staff at Washington State agencies who are responsible for forecasting and monitoring drought conditions, and planning and implementing drought response actions. Other water managers, water users, researchers, and members of the public who seek to understand the state drought framework and drought processes should also find this document informative.

Background

When droughts occur in Washington State, they can disrupt economic activities, compromise public health, and harm natural resources. Washington State government has an interest in reducing these effects to protect the public welfare. Based on relevant statutes and its responsibilities for managing water resources, Ecology takes a lead role in drought response. A number of other state agencies collaborate closely with Ecology to carry out their missions under the stresses imposed by droughts.

This Washington State Drought Contingency Plan (drought plan) provides a framework for coordinating state agency activities to prepare for and respond to droughts. It replaces the previous Drought Contingency Plan adopted in 1992 and a draft update that was prepared in 2005. It is aimed specifically at the activities of state government. Many local agencies and organizations have their own drought contingency plans or emergency response plans. This drought plan does not override or replace those local plans.

Washington State's framework for emergency drought response provides a discrete set of tools for addressing water shortages and alleviating hardships. These tools include emergency water right permitting, potential supplemental funds for state agencies to carry out drought response actions, and potential funding for grants and loans to public entities experiencing drought-caused hardship. These tools have been effective in instances where water supply shortages can be addressed through emergency water right permitting actions, or financial aid can support emergency infrastructure with immediate benefits.

The existing framework does have a few significant challenges, however:

- Imbalances between water supply and demand are usually more complex than can be resolved within an emergency framework. Washington State seeks to resolve water supply challenges using an integrated water management strategy. An integrated strategy entails working collaboratively with diverse groups of water users to find solutions which serve multiple objectives. The time required for these processes to yield results exceeds emergency response timeframes.

- The lack of dependable drought response funding makes it difficult to plan and publicize the scale and scope of the state's drought response.

- How funding is routed to Ecology and other agencies can cause delays in drought response. Money routed to Ecology to disburse to other agencies is delayed by contracting and other administrative requirements.

- Awarding emergency grants only to those projects which provide benefit in the current drought emergency limits the number of projects which can be approved. Design work, bidding of contracts, scheduling work, and permitting make it difficult to complete projects before drought conditions improve as the water year concludes.

- Establishing emergency water right leasing in the context of a drought year has had mixed success. It has worked well with split-season leases, where farmers forgo a late season cutting of hay. This provides more time to plan and finalize agreements. But where the expectation is for a participating farmer to forgo an entire season's crop, unveiling a leasing program in early spring is too late.

- Waiting until a drought year to lease water means paying a premium for water. In 2015, the going rate for water in the Yakima Basin was roughly twice what it was in 2005, the previous drought year.

- In the Yakima Basin, official water supply forecasts are not available until early March. This challenges the ability to roll out drought response measures in the Yakima Basin in time for irrigators to incorporate them into their own planning. Obtaining probabilistic water supply forecasts earlier in the season would provide more lead time for response measures such as water right leasing and emergency wells.

- The existing drought response framework requires that drought conditions be "anticipated." While there is high skill in forecasting near-term weather patterns, there is much less confidence in longer term forecasts. This is especially true in rain-dominant watersheds, which do not benefit from the predictive power of snowpack conditions.

Within the scope of this plan, the following measures to improve drought mitigation should be prioritized. These measures also emphasize the improvement of the emergency drought response framework:

- Maintain and expand the capacity to pursue integrated water management strategies to resolve major water supply imbalances, such as occur in heavily agricultural areas like the Yakima and Walla Walla basins. This should be a priority for the state as, in the long run, continued investment in this strategy is likely to yield more enduring solutions for these and other areas of the state.

- Obtain support for year-to-year drought contingency funding. Build certainty into funding structure.

- Obtain authorization and funding support for long term, dry year option water right leases.

- Simplify and streamline the distribution of drought funding to state agencies, to enable more timely support of their respective sectors.

- Eliminate the need for emergency rulemaking during drought years. This process delays the release of funding, and emergency rules expire after 120 days. This will require a more stable definition of drought funding priorities in statute, which would allow Ecology to draft a permanent funding rule.

- Provide grants and loans to support longer term projects which minimize drought vulnerability, including the preparation of local drought contingency plans. The state should have a goal of creating a WaterSMART program at the state level, just as the federal government has done at the federal level.

- Improve the drought declaration system to include Advisory and Emergency phases. This would provide a more formal communication structure for conditions where the potential for hardship is low or not known and allow us to initiate the mobilization of resources.

- Washington State statute defines drought as a water supply deficit (below 75 percent of normal). Climate change is expected to re-define what is "normal" and, thus, re-evaluating other metrics would be appropriate in the future.

- Washington's drought metric largely hinges on water supply forecasts and does not lend itself well to watersheds where water supply forecasts are not available.

- Continuing advances in the science and operations of hydro-meteorological forecasting would support earlier identification of potential drought conditions. Formal recognition and financial support of an Office of Washington State Climatologist in state statute would ensure that there is a credible and expert source of climate and weather information for state and local decision makers and for agencies working on drought and related issues.

Statutory Basis for State Drought Response

For purposes of guiding the state's actions, the state Legislature defined drought conditions in RCW 43.83B.400 as follows:

> *"…'drought condition' means that the water supply for a geographical area or for a significant portion of a geographical area is below seventy-five percent*

of normal and the water shortage is likely to create undue hardships for various water uses and users."

Ecology further define how this definition is applied in rule at WAC 173-166-050. On an ongoing basis Ecology convenes a Water Supply Advisory Committee (WSAC) to coordinate data and make judgments as to whether a drought is likely to occur or has begun. Recommendations from WSAC are communicated to the Emergency Water Executive Committee (EWEC) comprised of agency directors. EWEC may recommend the Governor instruct Ecology to issue a formal drought declaration. Once a drought declaration has been issued, Ecology and other agencies have the authority to disburse any drought funding made available by the Legislature, and to activate certain emergency procedures designed to alleviate the effects of drought on water users and natural resources.

This drought plan update uses the legal foundations in RCW and WAC and the established process of drought declaration as the basis for drought response actions. In addition this drought plan update outlines methods to better prepare for droughts in advance.

Federal Grant for Drought Plan Update

The federal government provided a grant to support this drought plan update. The grant is administered by the Department of the Interior, Bureau of Reclamation (the Bureau), through its WaterSMART program, Agreement No. R15AC00082.

Reclamation has issued a guidance document titled Drought Response Program Framework, WaterSMART Program (Reclamation 2015). The guidance document recommends that drought contingency plans address these topics:

- Drought Monitoring
- Vulnerability
- Mitigation Measures
- Response Actions
- Operational and Administrative Framework
- Plan Update Process

This drought plan update addresses each of these topics. In addition, based on prior experience with droughts in Washington State, this drought plan update includes a section on communications leading up to and during a declared drought emergency.

Process for Preparing the Drought Plan Update

To prepare this drought plan update, Ecology convened a task force comprised of these Washington State agencies that engage in drought response:

- Department of Ecology (Ecology)

- Department of Health (Health)
- Department of Fish and Wildlife (WDFW)
- Department of Agriculture (WSDA)
- Department of Commerce (Commerce)
- Military Department, Emergency Management Division (EMD)
- Washington Conservation Commission (WCC)
- University of Washington, Office of State Climatologist (UW-OSC)

Ecology led monthly meetings of the Task Force for a 16-month period, assisted by a contracted facilitator. The Task Force reviewed the state's statutes and code requirements, prior drought contingency plans, drought plans prepared by other states, reports to the Washington State Legislature describing drought effects and response activities in 2001, 2005 and 2015, and a range of scientific information pertaining to drought occurrence in the Pacific Northwest. The UW-OSC provided technical input and convened a separate group of experts to review drought forecasting capabilities and methods.

The Task Force also met with representatives of three interest groups that tend to be highly impacted by droughts: municipal drinking water purveyors, agriculture, and tribal governments. In addition, Ecology organized an Advisory Committee with representatives of these same interest groups. Advisory Committee members participated in many of the Task Force meetings over the course of the project, and commented on a draft of the updated drought plan.

Using the information and recommendations gathered from this process, Ecology led preparation of this drought plan update. Where appropriate, individual subsections were authored by staff of the agencies whose responsibilities are described.

Geographic and Climatological Setting of Planning Area

The state is divided topographically and climatologically by the Cascade Mountain Range, which prevents moist ocean air from reaching the eastern two thirds of the state (Western Region Climate Center). West of the Cascades, Washington State's climate is dominated by marine influences and is mild year-round. East of the Cascades, the climate is affected by both marine and continental influences, and subject to significantly greater annual swings in temperature. The east side is drier year round, warmer in the summer, and cooler in the winter.

Differences in precipitation can be dramatic. Forks, on the west side of the Olympic Peninsula, averages 119 inches of rain annually while Prosser, in Benton County, receives an average of less than 9 inches.

Temperature regimes vary from the west to the east side as well. West of the Cascades, the average January maximum temperature ranges from 40° F in the lower elevations to 30° F at the 5,500-foot elevation. Minimum temperatures range from 30° F in the lower elevations to 20° F in the higher elevations. On the east slope of the Cascades, the average January maximum temperature varies from 25° to 35° F and the minimum temperature from 15° to 25°.

The crest of the Cascades divides the state hydrologically as well. The warmer, wetter conditions on the west side mean that winter snows are more transient and confined to higher elevations. To the west, multiple watersheds discharge directly to Puget Sound, the Strait of Juan de Fuca, the Pacific Ocean, and to the Columbia River. West of the Cascades at lower elevations, the geology consists largely of unconsolidated glacial deposits containing extensive groundwater aquifers. These aquifers recharge fairly quickly in response to fall-winter precipitation.

East of the Cascades, every river within Washington drains to the Columbia River. The Columbia Plateau is largely characterized by extensive layers of Columbia River basalts. Beyond alluvial areas adjacent to rivers, groundwater is often scarce, and found at greater depths. These aquifers receive less annual recharge from precipitation, and thus are more vulnerable to years of heavy pumping, during which the volume of withdrawal exceeds the volume of recharge. Much of the Columbia Basin is already experiencing significant declines in groundwater levels.

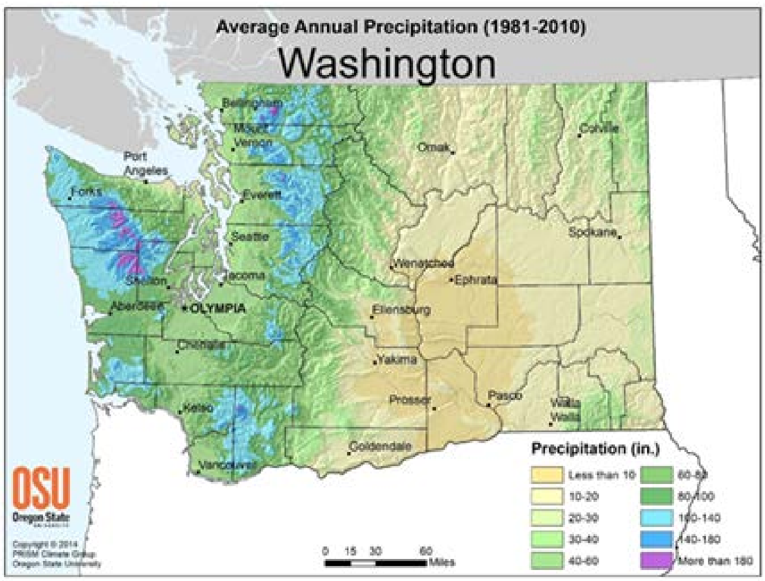

Figure 1. Average annual precipitation for Washington (1981-2010) (PRISM Climate Group, Oregon State University, copyright 2014).

Snow versus rain dominant watersheds

Washington's watersheds can be classified according to their ratio of precipitation in the form of snow versus rain. This information informs their exposure and sensitivity to drought conditions, as driven by above-normal temperatures, below-normal precipitation, or some combination of both. Watersheds that normally receive substantial snowpack are likely to be more sensitive to warm winters than other watersheds.

Snow dominant watersheds are areas where the ratio of April 1 snowpack (snow water equivalent, SWE) to Oct-March total precipitation is high (above 40 percent). In other words, at least 40 percent of the precipitation that falls during those six months remains stored in snowpack on April 1. For rain dominant watersheds, less than 10 percent of their October-

March precipitation is stored as snow, while the range is 10-40 percent for mixed rain and snow basins. In warmer than normal years, precipitation falls more as rain than snow as the freezing level rises. Because precipitation is not retained at higher elevations in the form of snow, more runoff is prone to occur during the winter months, rather than during the spring and early summer snowmelt.

Runoff volumes and timing are affected by a complex interplay of meteorological and hydrologic factors, including precipitation, soil moisture, snowpack, and groundwater influences. Appendix C displays sequences of monthly average runoff patterns during prior years of statewide drought. These patterns demonstrate that in drought years the changes in normal runoff patterns can vary seasonally and geographically across the state. These differences can be attributed the interaction of specific watershed characteristics (e.g., snow and soil moisture conditions) and the distribution and location of precipitation which occurs prior to and during the runoff period.

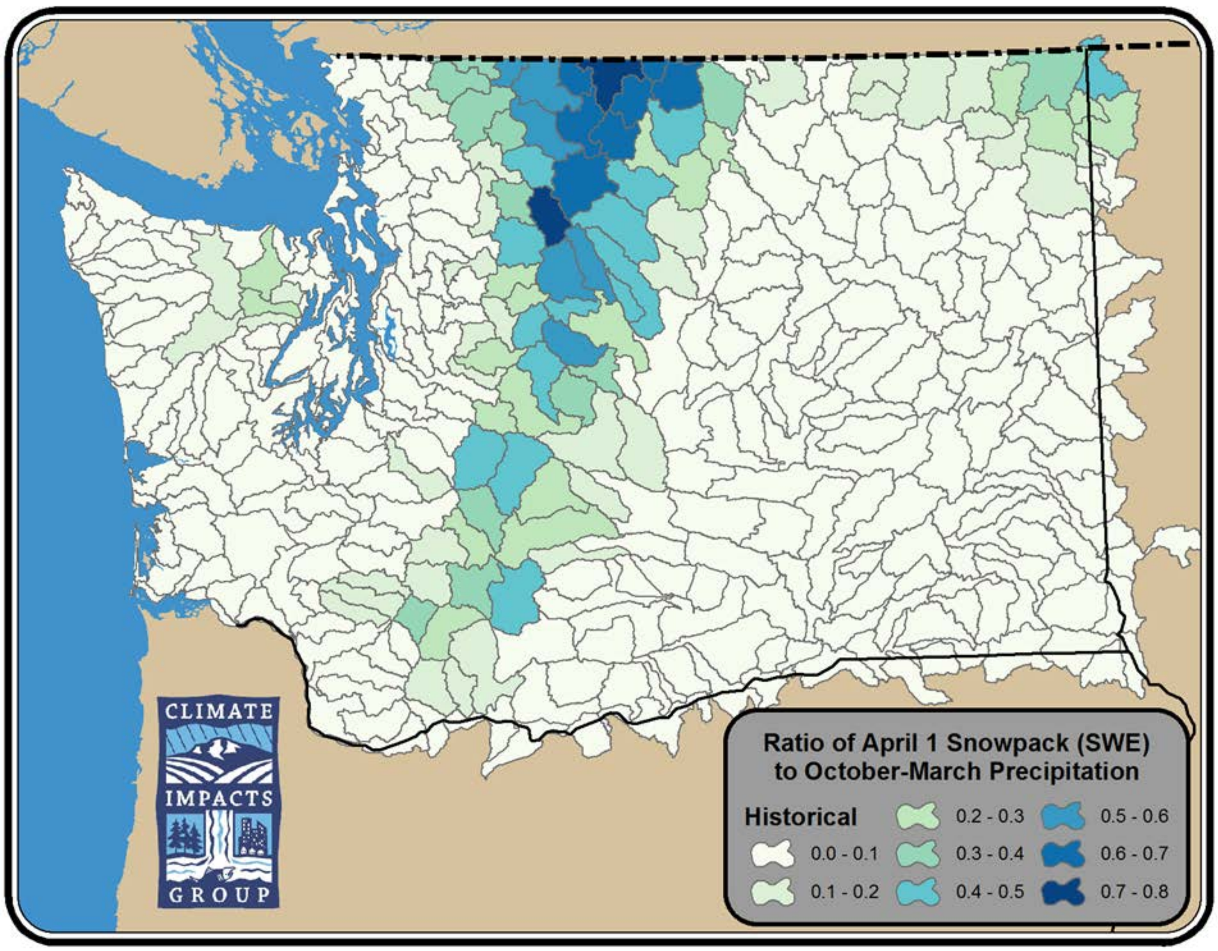

Figure 2. Ratio of April 1 snowpack to October - March precipitation.

History of Drought in Washington State

The hydrologic trigger used in Washington State's definition of drought (less than 75 percent of normal water supply) is itself a statistical measure which may be used to describe the frequency of drought.

"Normal water supply" is defined in WAC 173-166-030 (6) as:

> "For the purpose of determining drought conditions, the median amount of water available to a geographical area relative to the most recent thirty-year base period used to define climate normal. The determination of drought conditions will consider seasonal water supply forecasts, other relevant hydro-meteorological factors (e,g, precipitation, snowpack, soil moisture, streamflow, and aquifer levels) and also may consider extreme departures from normal conditions over subseasonal time frames."

For the purpose of forecasting water supply conditions, both the National Weather Service and Natural Resources Conservation Service use the average or median values for a 30-year base period (1981-2010).[1] Seventy-five percent of median is equal to the 37.5 percentile (0.75 * 0.50). This suggests that the hydrologic threshold of Washington's state drought criteria would be expected to be met roughly 37 percent of the time, or every 3 to 4 years at any given river forecast point. But because normal is calculated for a specific 30-year period rather than the entire period of record, this expectation is not met. A review of the entire 1949-2016 record shows streamflows observed during April through September fell below 75 percent of normal about 13 percent of the time at the Northwest River Forecast Center's 118 streamflow stations.

Another way to gain perspective on the frequency of drought (as defined in statute) is to identify the number of years during which the state has declared drought up to 2016. To be sure, the sample size is small and only includes very recent history. Washington's drought declaration framework was established by the Legislature in 1989. Since 1990, Washington State has declared statewide drought in three years – 2001, 2005, and 2015 – and watershed specific droughts in 1992, 1994, and 2006. Thus, drought has been declared for at least some portion of the state about 1 out of every 4 years. Drought declarations covering the entire state have been characterized by forecasts of a large percentage (~48 - 87 percent) of river stations to have less than 75 percent of normal water supply.

[1] The 30-year base period used to establish climate normal is updated every decade, in accordance with agreements between the World Meteorological Organization and nations of the world.

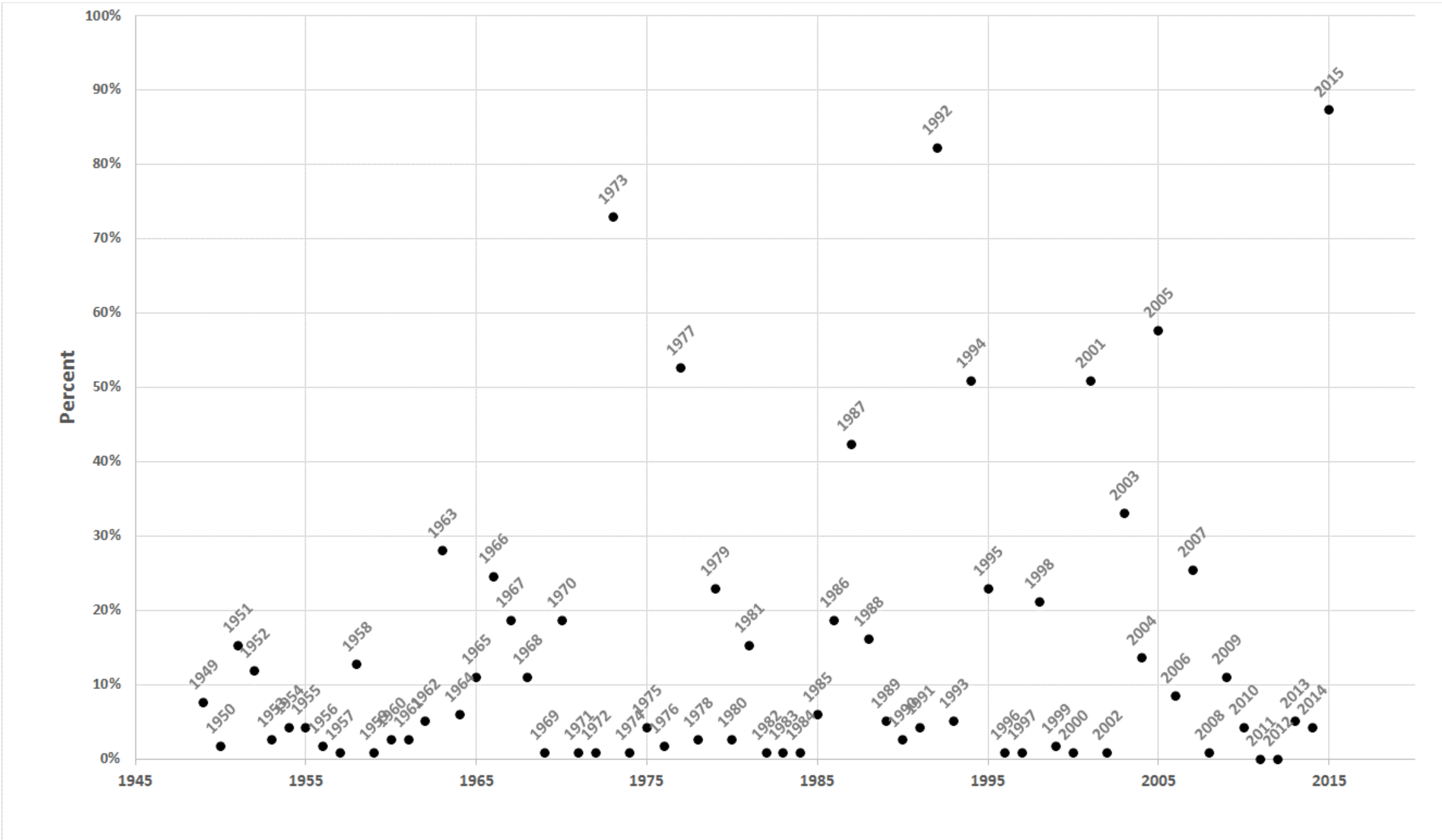

Figure 3. Percent of river stations below 75 percent of normal (1942 - 2015) (Based on data provided by the Northwest River Forecast Center).

Three "flavors" of drought

Bumbaco and Mote (2010) used the water years (Oct through Sept) of 2001, 2003, and 2005 to illustrate three distinct types or "flavors" of recent drought in Washington State:

1) Low winter precipitation
2) Dry summer
3) Warm winter temperatures

The first, in 2001, had low winter snowpack caused by low winter precipitation, and had most of its impacts in the spring and summer. In addition to the generally low streamflow in the winter (Dec-Feb), the snowmelt-dominated streams in the state (mostly in Eastern Washington) had streamflows during summer (June-September) that ranked among the 5 lowest in 55 years.

The second flavor of drought – the dry summer drought – occurred in Washington in the summer of 2003 as a result of the second warmest and second driest (at the time of journal publication) July-August period for Washington and Oregon combined. Even though summers are typically dry in the region, there were record or near-record low flows during the June-September period for streams that are not snowmelt dominated. The fire season was also particularly bad in Oregon and British Columbia, but Washington was mostly spared.

The last flavor of drought – and the one that is particularly relevant to 2015, was the drought of 2005. Warm winter temperatures decreased the snowpack, leading to both winter and summer drought. Precipitation in the Washington Cascades was between 70 and 80 percent of normal during the winter, but due to the higher-than-normal temperatures, snowpack was only 20 percent of normal for much of the winter. Late winter storms were accompanied by such warm temperatures that snow water content declined even at the highest elevations monitored.

A graphic depicting the statewide monthly temperature and precipitation anomalies for the years 1977, 2001, 2005, and 2015 is included below. Note the extremely warm temperatures that played a key role in the 2015 drought, causing the near-normal precipitation to fall as rain rather than snow in the mountains. This occurred to some extent in 2005, when a few intervals of warm, wet weather associated with atmospheric rivers actually depleted snowpack (Bumbaco and Mote 2010) while the rest of the season had periods of lesser precipitation and near-normal temperatures. Other droughts in Figure 3 (1977 and 2001) were largely driven by lack of winter precipitation rather than extreme temperatures.

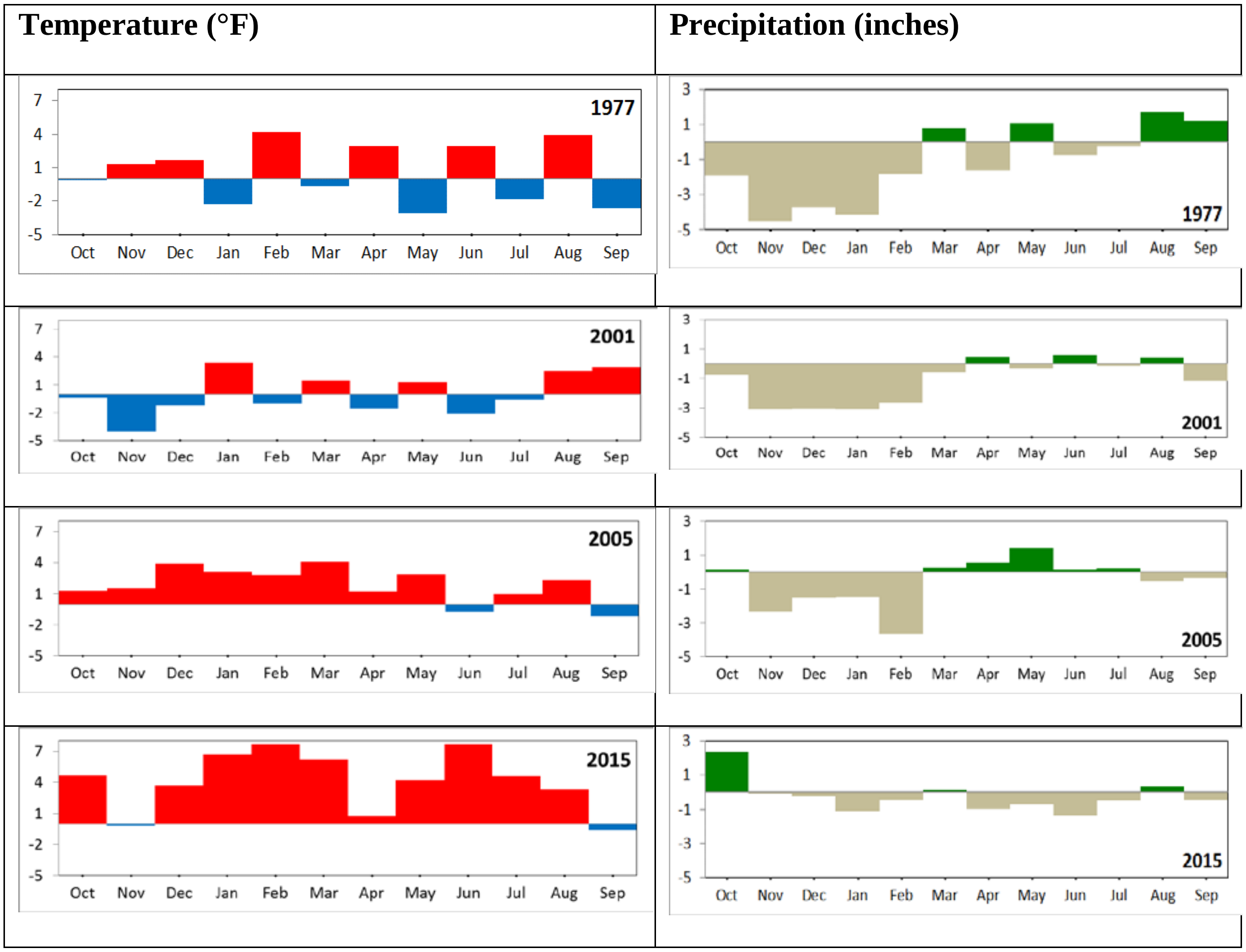

Figure 4. Washington State temperature and precipitation anomalies for water years 1977, 2001, 2005, and 2015 (Graphic courtesy of Karin Bumbaco, Office of Washington State Climatologist).

Prehistorical evidence for drought (tree rings, other)

The Pacific Northwest, like much of the western United States, experiences periodic droughts. Drought is often difficult to define, as no single definition fully represents the different types of drought that can impact different sectors. Drought is typically separated into categories such as meteorological, hydrologic, agricultural, and socioeconomic depending on the drought impacts experienced (Wilhite and Glantz 1985). Impacts have long been recognized as an important defining factor in drought. The historical record of drought is examined here based on a few different drought definitions.

Long records of drought can be reconstructed using tree rings of tree species that are sensitive to different climate parameters. Gedalof et al (2004) created a historical record (1750-1987) of hydrologic drought for the entire Columbia River Basin (including parts of Washington, Oregon, Idaho, Montana, and British Columbia) using tree rings throughout the Pacific Northwest. This information was used to reconstruct mean water year flows for the Columbia River at The Dalles, Oregon. Notable findings emerged from this reconstruction of a historical record for drought (Figure 3). Specifically, several multi-year hydrologic droughts were identified on the Columbia River, including the worst in the record (1840s-1855) and the second-worst (1930s).

The most recent period in the reconstruction (1950-1987) was anomalous compared to the rest of the record in that no multi-year droughts were observed, suggesting that more severe droughts than what have occurred in the second half of the 20th century are possible in the region. Other prolonged drought periods occurred in the 1890s and 1770s with shorter intervals of low flows on the Columbia River in 1775, 1805, and 1925.

An updated reconstruction of Columbia River streamflow at The Dalles has been produced by Littell et al. (2016). This recent effort features updated tree-ring chronologies and a more complete account of seasonal effects on the hydrological variability of the Columbia River. Its key finding is that the droughts that occurred from the 1500s through the early 1900s were of comparable duration and magnitude as droughts during the observational record. In particular, Littell et al. (2016) suggest that low flows in the 1840s were not as severe as indicated by previous reconstructions. They also discuss how climate model projections of streamflows indicate the potential for increased hydrological variability in future decades.

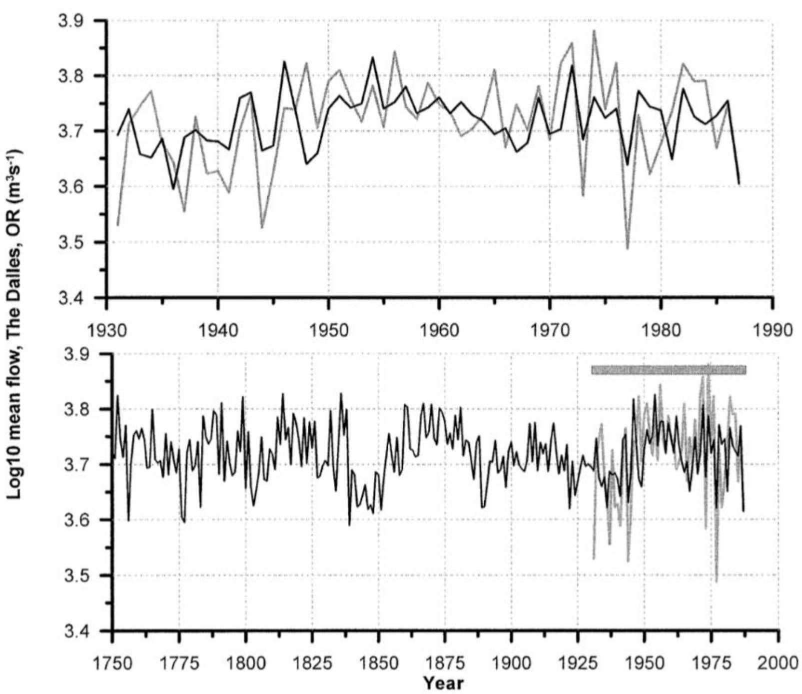

Figure 5. Reconstructed mean water year flow of the Columbia River at The Dalles, Oregon, from Pacific Northwest tree rings.[2]

[2] The gray bar represents the period in which observations (gray trace) were compared to the reconstruction (black trace). A closer look at the comparison period is shown in the top plot (from Gedalof et al. 2004). Note that the reconstructed flow underestimates the magnitude of the low flow events.

Twentieth century indicators

There are sufficient precipitation and temperature observations to assess the character of past Washington State droughts since about the beginning of the 20th century. Here the focus is on the seasonality, spatial variability, and duration of drought.

We first consider the Palmer Drought Severity Index (PDSI), for which monthly records are available back to the end of the 19th century for each of the state's 10 climate divisions, and for the state as a whole. The PDSI includes the effects of temperature as well as precipitation, but not snowpack. This limits its applicability for characterizing drought in Washington, but represents a reasonable index for the present purposes. A more complete description of the PDSI is included on page 77.

Time series of the PDSI for Washington State as a whole are plotted in Figure 4 for the years of 1900 through 2016, separately considering the wetter first half of the water year of October through March and the drier second half of April through September. These time series reveal an extended period from the early 1920s to the 1940s when the PDSI was generally negative during both the wet and dry portions of year, interrupted by a period of wetter conditions in the late 1930s.

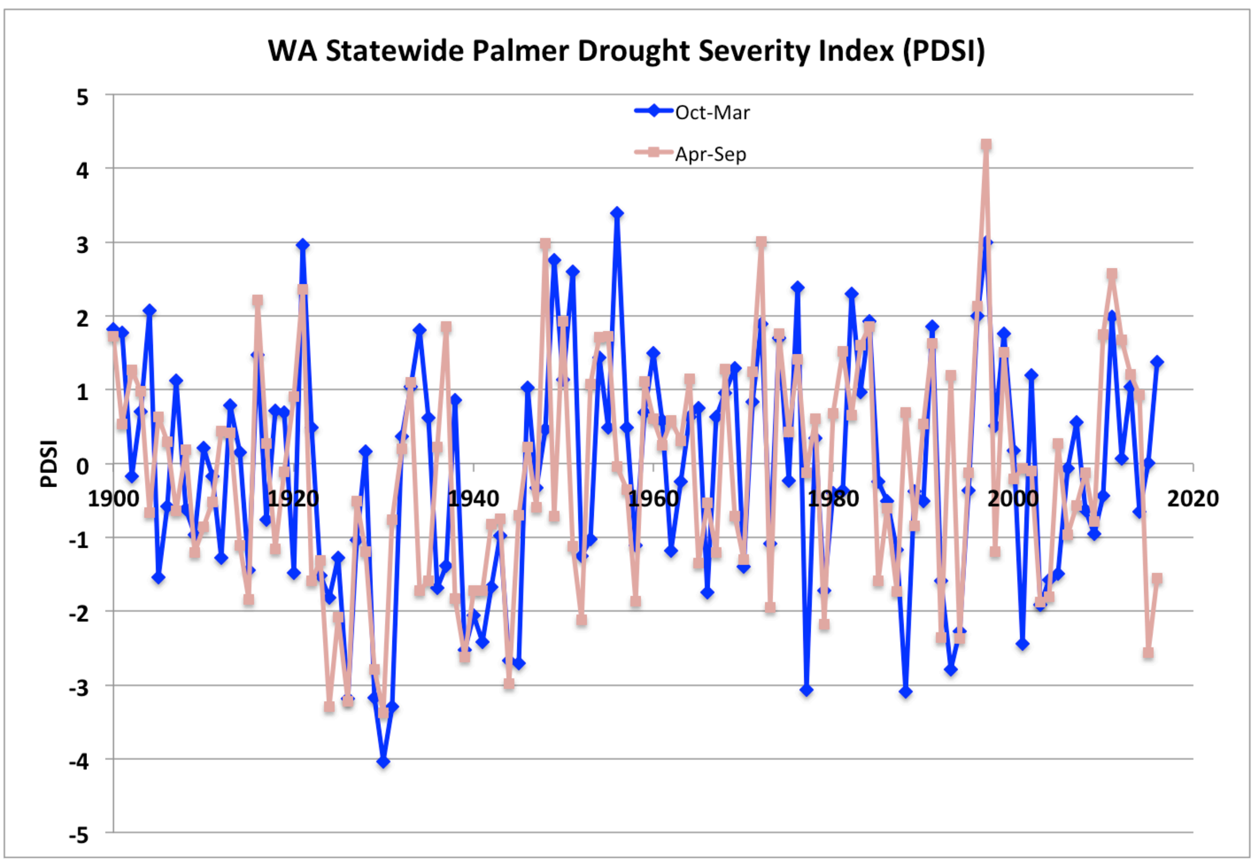

Figure 6. Time series of Palmer Drought Severity Index (PDSI) for Washington State 1900 - 2016 for October through March (blue line) and April through September (pink line).

As mentioned above, the period from the middle 1940s to the present (2016) has been characterized by mostly year-to-year fluctuations. For example, the years of 2003 through 2005 were the only 3-year period with three consecutive values of wet season PDSI of about -1.5 or less. The two time series also indicate that low PDSI wet seasons tend to be followed by low PDSI dry seasons, and vice versa, with some exceptions. The linear correlation coefficient between the two series is ~0.52. The implication is that poor conditions at the end of the first half of the water year are unlikely to be alleviated until the following wet season.

The PDSI record has also been used to explore spatial variations in drought across Washington State. An example is shown in Figure 7, in the form of water year (October through September) averages of the PDSI for the West Olympic and Palouse/Blue Mountains climate divisions located in the northwest and southeast corners of the state, respectively. These series positively correspond with one another with a linear correlation coefficient of ~0.51. The PDSI for the Palouse/Blue Mountains climate division is more variable and hence more prone to extreme droughts by this particular measure; relatively large variability in the PDSI was found for other climate divisions east of the Cascade Mountains crest (not shown). As suggested by Figure 7, typically the spatial footprints of droughts in Washington State are large enough to encompass most if not all of the state.

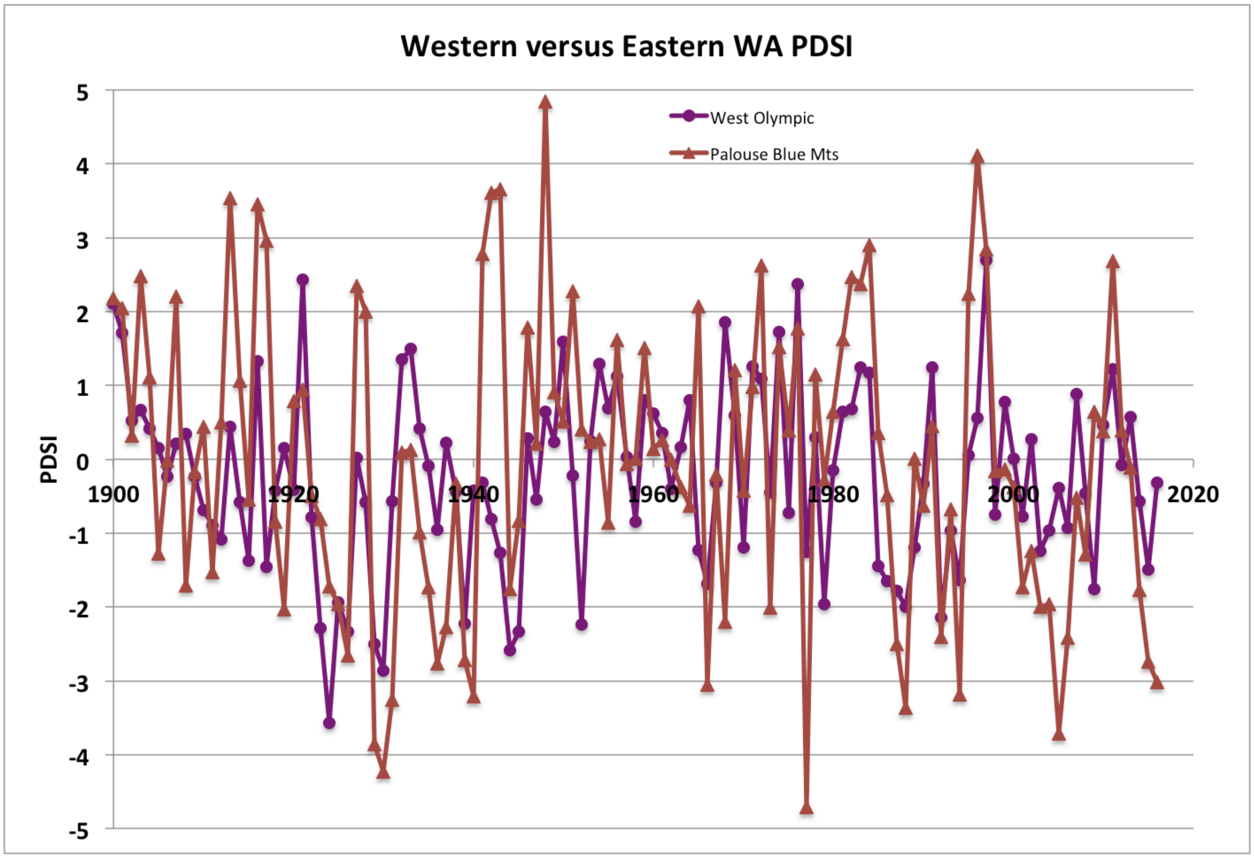

Figure 7. Time series of PDSI for the water years 1900 - 2016 for the West Olympic climate division (purple line) and the Palouse/Blue Mountains climate division (burgundy line) of Washington State.

A relatively long record (1930-2007) of snowpack for the western slope of the Cascade Mountains was produced by Stoelinga et al. (2009). Their series is based on a water balance using measurements of streamflows, precipitation, and temperature. The method for the last two-thirds of the record was checked against direct snowpack observations. The time series of estimated 1 April snow water equivalent (SWE) from their analysis is reproduced in Figure 6. This time series indicates particularly low SWE for the winters of 1940-41, 1976-77, and 2004-05. The latter two events resulted in water supply issues for Washington, and appear more anomalous in terms of the 1 April SWE of Figure 8, than in the PDSI of Figure 6. On the other hand, the temporal character of the snowpack record estimated by Stoelinga et al. (2009) is consistent with that of the PDSI, in that each record indicates that a substantial drought of multi-year duration has not occurred in Washington for many decades.

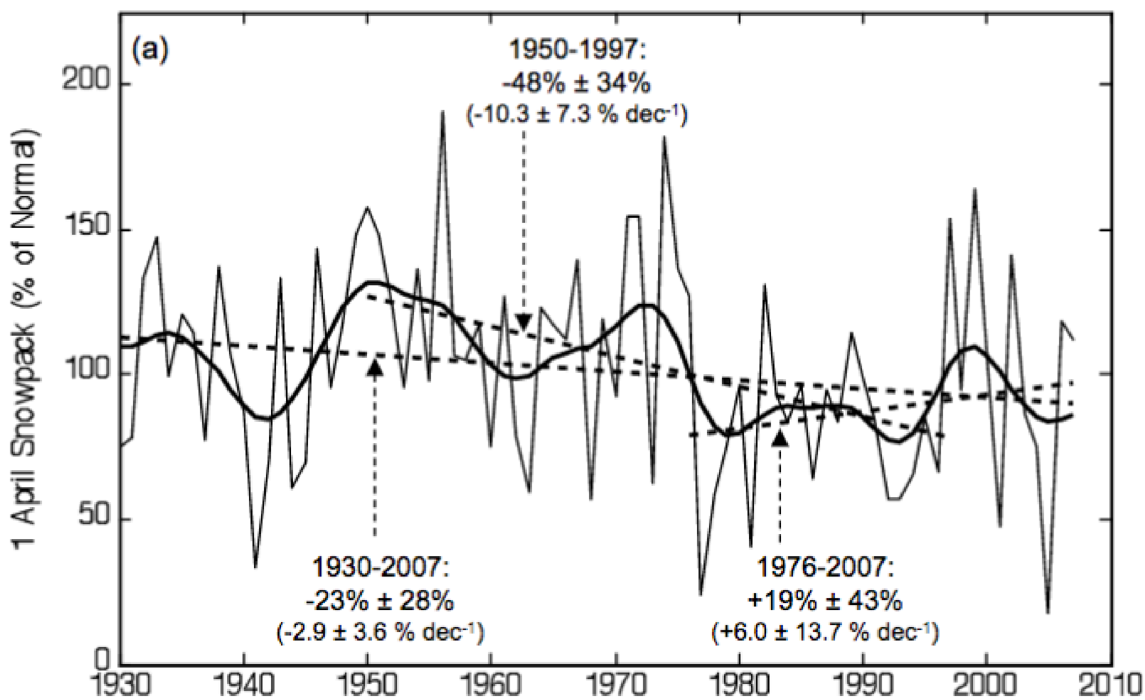

Figure 8. The April 1 water-balance snowpack (percent of 1961 - 1990, thin solid line); smoothed version (heavy solid line); trend lines over the periods indicated (heavy dashed lines), with trend values (total percent change and percent per decade) and 95 percent confidence intervals listed.[3]

We conclude this section with a brief review of historical streamflows during the growing season. Specifically, the mean flows during the months of May through August for the years of 1930 through 2016 are shown in Figure 9 for three unregulated rivers: the Dungeness River near Sequim (USGS #1204800), the Klickitat River near Pitt (USGS #14113000), and the Stehekin River near Stehekin (USGS #12451000). These time series are generally consistent with the results presented above.

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[3] Reproduced from Stoelinga et al. 2009.

While past dry (and wet) periods have had different manifestations, in broad terms there tends to be a correspondence between the streamflow variations in the various portions of Washington State. A similar result was suggested by the PDSI example illustrated in Figure 7.

The period of the late 1940s through middle 1970s included mostly higher streamflows, as would be expected given the mostly positive values of PDSI and above normal snow pack those years. There appears to be somewhat less year to year variability in the streamflows than the other two measures, as exemplified by the mostly lower flows that prevailed from the late 1970s until the mid-1990s. It is possible that the groundwater contribution serves to smooth out shorter-term fluctuations in streamflows, but a thorough analysis of this factor is beyond the scope of the present piece.

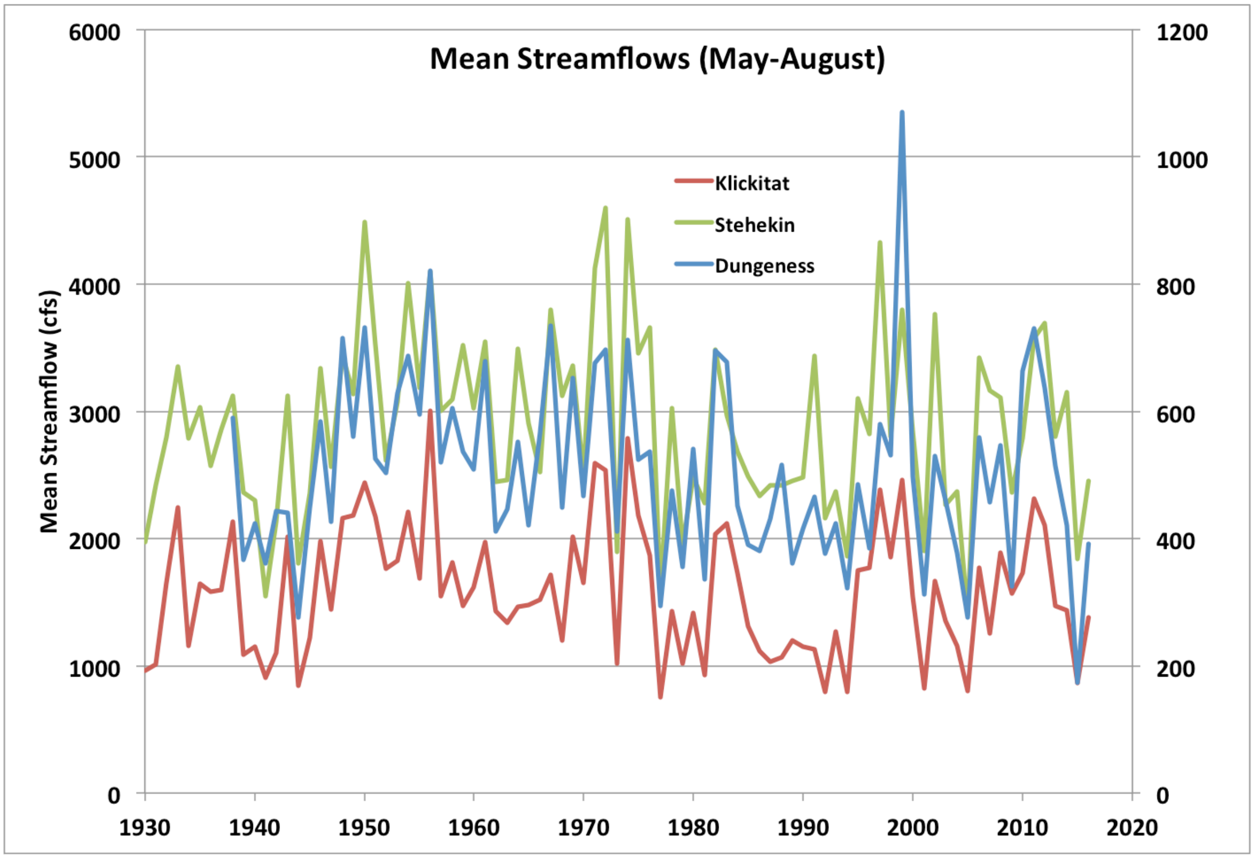


Figure 9. Mean streamflows May through August for the Klickitat (red line, left axis), Stehekin (green line, left axis), and Dungeness (blue line, right axis) in cubic feet per second for the years 1930 - 2016.

Operations and Administration

The State of Washington serves a dual role in assisting its citizens to cope with future droughts. State agencies, as resource managers, are responsible for monitoring and forecasting anticipated drought conditions. When conditions reach the statutory threshold and a drought is declared, Ecology is authorized to expedite emergency water right permitting actions.

Additionally, to the extent that funding and staff resources allow, the state will also assist local communities through emergency and non-emergency programs, when local capabilities and resources are inadequate to deal with the drought event.

Challenge of Timely Response

Drought is often described as a slow-moving disaster but, in fact, conditions can develop rapidly, challenging government's ability to respond in a timely manner. Figure 10 illustrates the challenge associated with planning and responding to drought conditions.

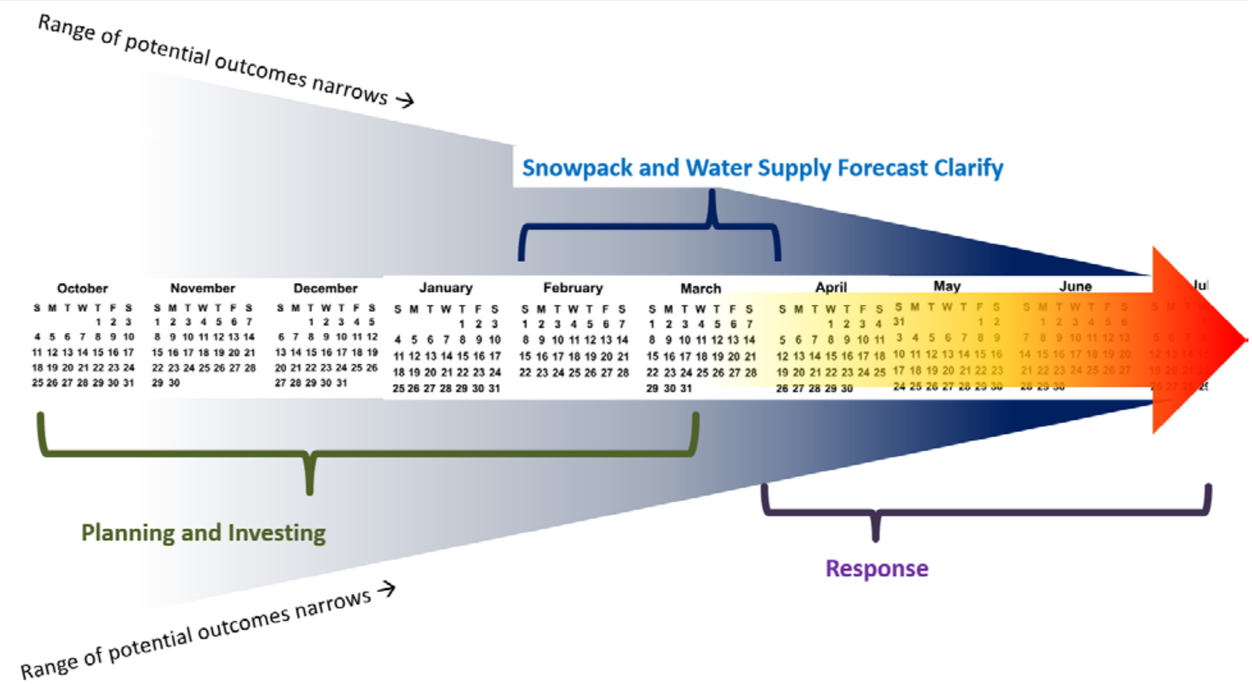


Figure 10. Forecasting certainty in relation to water supply planning and drought response.

Droughts can develop at any time of year, but given the strong (wet/dry) seasonality of Washington's climate and the importance of snowpack and winter precipitation in shaping water supply conditions, it is logical to frame this challenge in the context of a water year.

At the beginning of a new water year (October), there are a large number of potential water supply outcomes for next year's critical water supply season, ranging from much-above to much-below normal. Large, hemispheric climatic influences such as El Niño or La Niña may shape, but do not necessarily determine, the outcomes. During the fall months, water supply forecasts for the next spring and summer largely depend on climatology (i.e., what has happened historically) to generate a range of potential outcomes. As the calendar year draws to a close, the spread of potential hydrologic outcomes for the following summer is still quite broad. The snowpack may start out slow, but then accumulate more consistently. Or it may start out strong but then stall and fall below normal. As winter moves toward spring, the probabilities of various water supply outcomes begin to narrow, as actual (measured) snowpack and precipitation conditions begin to constrain the outcomes of water supply models.

By March, it is possible to predict summer (APR-SEP) seasonal water supply conditions with significant skill. But this timing also creates challenges for responding in a timely manner, if conditions point toward drought. By early March, many agriculture growers have already committed to a particular plan for the summer. Fields may already be planted, which means that certain actions like leasing water rights may be difficult. For other sectors, there may be more time to react, but obtaining funding and mobilizing resources can easily take weeks or months.

There are two major ways to improve the timeliness of state response. One is to gain lead time through enhancements in forecasting and the prediction of drought conditions. The other is to improve the state's ability to react to drought.

An earlier warning provides more lead time to prepare for anticipated conditions. As is discussed in the Drought Monitoring and Forecasting chapter, forecasting skill is continually improving, though enormous technical challenges remain. For at least the next decade, it is unlikely that forecasting improvements will significantly expand the lead time for decision-making.

Thus, the more promising strategy is for the state to become more agile in how it responds to drought conditions. There are multiple aspects to this strategy:

- Adopting a 2-Stage Drought Framework, including an option for a Drought Advisory to provide an early-warning to water users of potential drought conditions.
- Mitigating drought impacts so that the probability of emergency hardship is reduced.
- Assuring that there is a stable, dependable source of drought contingency funding.
- Adopting practices which reduce the time and effort required to mobilize and deploy state resources.

A Two-Stage Drought Framework

With the plan revision, the state is committing to use a 2-Stage Drought Framework: Advisory and Emergency. As depicted in the below graphic, these two stages are triggered by different criteria within a recurring process of monitoring and forecasting to determine whether water supply conditions meet hydrologic or hardship triggers. When the hydrologic criteria are met for a geographic area (e.g., a specific watershed, region, or the entire state) a drought advisory may be issued. When <u>both</u> the hydrologic criteria *and* the hardship criteria are met, a formal drought declaration emergency may be issued.

Stages and Triggers

The Advisory Stage provides a framework for communicating about water supply conditions which do not clearly exceed Washington's statutory threshold for drought, but which nonetheless indicate cause for caution, the need for preparation and the mobilization of resources. The Emergency Stage is only reached when the statutory threshold for drought conditions is met.

This staged approach emulates some other forms of progressive messaging, e.g., the advisory/watch/warning system used by the National Weather Service and the 4-stage water shortage response framework used by municipalities to manage water demand via increasing levels of water use reduction (advisory thru rationing). A few other states also use multiple drought stages. Some of them include as many as five distinct stages, which are triggered by various drought indices and precipitation percentiles. We have kept our Advisory trigger purposely broad and general, in terms of environmental metrics we will consider. This is to provide more flexibility in shaping our messaging to the public. A summary of the drought stages and triggers is provided below, followed by a detailed description of advisory stage goals and actions.

Summary of Drought Stages and Triggers

Stage 1 – Advisory

Conditions: Long-term forecast indicates drought of any level of severity may occur, or short-term forecast indicates minor drought conditions may occur in at least some area of the state.

Triggers:

- *Water supply trigger*: Consideration of the following factors suggest a strong likelihood of reduced water supply, that careful management of water supply and demand is advisable, and that concerns should be conveyed to natural resource managers, water users, and the public:
    - Below normal snowpack;
    - Below normal river forecasts;
    - Below average reservoir refill or carry-over from the previous year;
    - Depleted soil moisture or groundwater;

- Extended precipitation deficit (e.g., the Standardized Precipitation Index is -1 or below); and/or
- Forecasts of high temperature or low precipitation for an extended period.

- *Hardship trigger*: There is a potential for hardships to water users and uses in the affected area due to drought conditions.

Response: Heightened awareness, increased preparation. Communicate existing monitored conditions and forecasted short term climate outlooks (1-3 months). Coordinate communication with local water managers and affected governments (state, local, tribal). Water users who anticipate hardships would be informed they can petition Ecology for assistance with drought preparedness/response actions. State agencies may begin mobilizing resources, communicating with the Legislature and Office of Financial Management (OFM) on potential funding needs, and preparing for drought response actions.

Stage 2 – Emergency (issue Declaration)

Conditions: Short-term forecast indicates high probability that drought conditions meeting the statutory definition will occur at least in some areas of the state; or drought conditions have actually materialized in at least some area of the state (at any level of severity – minor to severe).

Triggers:

- *Water supply trigger:* Forecasted seasonal runoff is likely to be less than 75 percent of normal; and/or other water supply indicators, as summarized above, have deteriorated to more extreme levels.
- *Hardship trigger:* There is high confidence of existing or imminent hardships to water users in the affected area due to the drought conditions.

Response: Issue Drought Declaration for affected areas. Communicate existing monitored conditions and forecasted short term climate outlooks (1-3 months). Coordinate communication with local water managers and affected governments (state, local, tribal). Activate state systems for response actions defined in the state's Drought Contingency Plan. (Note: Water users would need to provide evidence of imminent or demonstrated hardship when requesting permits or funding for specific actions under the emergency drought provisions of state law.) Seek emergency funding as needed from the Legislature and coordinate with OFM.

Drought Advisories

Under the 2-stage approach, a formal Drought Advisory triggers actions in three major areas.

1. Communicating Advisory status to both external and internal audiences.
2. Mobilizing resources internally in preparation for a formal declaration of drought emergency.
3. More intensive monitoring of water supply conditions and forecasts, including reports of existing or pending impacts.

Communication

Under an advisory phase, the state response emphasizes communication to water users in affected areas. Key audiences are both internal and external to state agency organizations. Ecology has the lead responsibility for media outreach and broad messaging while individual agencies are responsible for communicating with their specific sectors at a more detailed level and establishing an effective two-way flow of information between the state and stakeholders.

Execution of the communication strategy would follow the guidance of the drought communication plan, which is included at Appendix G. The table below summarizes key actions.

Note that communication actions also are included for times when there is neither an Advisory nor Emergency in effect. Communication during this time is geared to keeping the public informed on water supply conditions and summarizing the discussion of the Water Supply Advisory Committee. These are described as Water Supply Updates.

Table 1. Drought Communication Actions

	Actions	Communications
Water supply updates (year round)	• Ecology regularly convenes the Water Supply Advisory Committee (WSAC) to review conditions and anticipate potential problems • Ecology continues its drought mitigation efforts	• Ecology updates its website, blog, and social media based on WSAC findings • Other state agencies are involved in communications, as necessary • Highlight successful projects or plans that increase drought resilience (e.g., Office of Columbia River work)

<table>
<tr><th></th><th>Actions</th><th>Communications</th></tr>
<tr><td>Stage 1 – Advisory (regional or statewide)</td><td>Ecology issues an advisory for the affected area(s)
Involved state agencies have heightened awareness and increased preparation
Involved agencies may begin mobilizing resources and preparing for drought response actions
Ecology invites water users who anticipate hardships to petition for assistance with drought preparedness/ response actions</td><td>Ecology convenes the drought communication coordination team
Ecology leads the effort to communicate about existing conditions and forecasted climate outlooks
Coordinate communication with major water managers and affected governments (county, city, and tribal)
Drought Advisories may also be used at the back-end to communicate when drought conditions are improving from emergency conditions, but have not yet reached full recovery
Tone: Concerned but not panicked; clear and conversational</td></tr>
<tr><td>Stage 2 – Emergency declaration (regional or statewide)</td><td>Ecology issues a drought declaration for the affected area(s)
Ecology activates systems for response as defined in the state’s drought contingency plan
Involved agencies mobilize resources</td><td>The drought communication coordination team (Ecology convenes this group, if advisory step is skipped) highlights information about relief efforts and how affected people can access resources
Ecology continues communicating about existing conditions and forecasted climate outlooks; state agencies support
Team coordinates communication with major water managers and affected governments (county, city and tribal)
Tone: Calm, direct and empathetic</td></tr>
</table>

Mobilization of Resources

Applications for emergency water right permits

At the Drought Advisory stage, Ecology will prepare to accept applications for emergency drought permits. Historically, holders of proratable irrigation rights in the Yakima Basin have filed the majority of these applications. Fewer application have been filed in other areas of the state.

In a drought advisory phase, Ecology should begin refreshing application templates and drafting decision documents (e.g., formal declaration language). Some basins may require special preparatory work and public outreach. In the Yakima Basin, for example, the regional staff should begin to assess the number of water right holders whom may be interested in using emergency drought wells. In the past, the region has scheduled workshops to explain the requirements for operating an emergency drought well. In 2015, applicants for emergency wells were issued their permits at workshop completion. Irrigators benefit from having certainty over the use of their well as soon as possible.

In other locations, emergency water right applications are processed as they are received. Because drought permit applications have a short, 15-day decision timeline, it is prudent for Ecology staff to encourage water users to consult with Ecology before submitting their application. Ecology staff can offer recommendations over how best to proceed and identify any information needs to better ensure they will be able to process the application promptly.

Assessment of funding adequacy

Depending on future drought funding structures, State agencies may or may not have contingency funding available at the time an advisory is declared. Agency staff will need to assess whether to make an additional funding request to the Legislature and Governor's Office. Options for funding emergency drought work by drawing on accounts for other purposes will need to be evaluated. Reviewing the expenditures of past drought emergencies, including reviewing previous inter-agency agreements and work plans, will be useful in gauging needs in the current year.

Review and refresh existing agreements

Existing MOAs/MOUs between Ecology and other agencies or organizations should be reviewed and refreshed. Contacts for implementing the agreements should be identified and consultation amongst the involved agencies or other parties should be initiated. Any additional costs required to implement the agreement should be identified, if not already described in the agreement itself.

Planning for temporary reassignment of staff duties

If the state transitions to an Emergency stage drought declaration, then agencies' staff will need to be assigned to carry out state response actions. The Advisory Stage provides a short time period for agency managers to assess potential staffing needs, identify appropriate personnel to carry them out, and make arrangements for backfilling their normal duties. Since this may affect each agency's ability to provide normal services to the public, the effects of reallocating staff need to be communicated to existing applicants and affected staff.

Identifying most vulnerable public water systems

The Department of Health (Health) is responsible for querying its data base to identify those systems which are likely to be most vulnerable to drought conditions. Once these systems have been identified, Health would be responsible to contact them to provide a status report on state drought response, potential future developments, and to determine if any systems require technical or other assistance.

Monitoring Drought Conditions

In an Advisory Stage, water managers are faced with the question: Are conditions getting worse? A sharpened focus on whether hydrologic conditions are likely to slip below 75 percent of normal is appropriate:

- River forecasts are updated daily and should be reviewed daily.
- Recent precipitation and temperature trends (e.g., weekly to monthly) should be reviewed to see if anomalies are worsening or abating.
- Near-term (8-14 day, 3-4 week) and seasonal forecasts should be reviewed to assess whether conditions are likely to change for the better or worse.

During drought advisories, the tempo of Water Supply Availability Committee meetings should increase as well. Bi-weekly or even weekly discussions may be more suitable.

Drought Declaration Process and Considerations

Forecasting and monitoring the water supply: the Water Supply Availability Committee (WSAC)

Assessing whether water supply is likely to be below 75 percent of normal for any area of the state is the responsibility of the WSAC. WSAC is chaired by Ecology, and consists primarily of State and federal agencies with expertise in water supply forecasting, drought monitoring, and climate.

- Department of Ecology (chair)
- Office of Washington State Climatologist
- U.S. Geological Survey

- National Weather Service
- Natural Resources Conservation Service
- U.S. Bureau of Reclamation
- U.S. Army Corps of Engineers (optional)
- Bonneville Power Administration (optional)

Representatives of major water utilities (e.g., Seattle, Tacoma, Everett, and Puget Sound Energy) are invited to provide updates of their respective water system status as well.

Ecology convenes WSAC over the course of the year as needed, based on Ecology's monitoring of conditions and forecasts. Generally speaking, meetings are scheduled more frequently (e.g., every 4 to 6 weeks) in winter months than during the summer and fall. This reflects the state emphasis on forecasting of water supply conditions as the current water year's snowpack takes shape. These meetings are open to the public. The discussion is summarized in meeting minutes provided on Ecology's website.

Meetings are held less frequently during the summer. By late spring, after snowpack has peaked and snowmelt is underway, there is good confidence regarding the probability of water supply conditions over the next several months, though precipitation and temperature still need to be monitored. The window for mounting a timely response to drought narrows as the end of each water year approaches in the fall, when water demand drops due to the moderating influences of shorter, cooler days and the end of irrigation season.

Relevant drought and water supply indicators are described in the Drought Monitoring and Forecasting chapter on page 74. Generally, WSAC meetings should address the following topics:

- Recent trends and anomalies in regional temperature and precipitation
- Ocean conditions; probabilities for the development El Niño or La Niña conditions, either of which can affect northwest weather in the coming months
- Seasonal water supply forecasts (National Oceanic and Atmospheric Administration (NOAA) and National Resources Conservation Service (NRCS))
- Long term temperature and precipitation forecasts or other models (e.g., National Multi-Model Ensemble (NMME))
- Mountain snowpack and precipitation status
- Status of major water supply projects (e.g., storage status, special forecasts)
- Current streamflow and groundwater conditions (e.g., percent of rivers above or below normal)
- Water supply impacts
- Other indicators of drought conditions

Water supply forecasts are the most critical indicator. When a forecast is less than 75 percent of normal, WSAC needs to evaluate whether that forecast is likely to hold, or whether it is premature to act. If the forecast is likely to hold, then WSAC must evaluate whether to recommend that Executive Water Emergency Committee (EWEC) convene to evaluate the potential for hardship as a result of that water supply shortage.

Requirements for consensus

WSAC recommendations are reached via facilitated group discussions of water supply forecasts and other relevant information. Where there is a lack of consensus, Ecology will determine whether or not to forward the recommendation to EWEC or to continue monitoring and reconvene at a later date.

Evaluating hardship and impacts: the Executive Water Emergency Committee

Assessing whether water supply deficits are likely to cause undue hardships to water uses or users is the responsibility of EWEC. EWEC is chaired by the Governor's Office and assesses information provided by the Water Supply Availability Committee, and determines whether water users within water-short areas will likely incur undue hardships.

EWEC is an executive-level committee, which is convened on an ad-hoc basis, at the recommendation of the Water Supply Availability Committee. Past participation on the committee has included representatives from the following agencies:

- Governor's Office (chair)
- Washington State Conservation Commission (WCC)
- Washington Department of Agriculture (WSDA)
- Washington Department of Commerce (Commerce)
- Washington Department of Ecology (Ecology)
- Washington Department of Fish and Wildlife (WDFW)
- Washington Department of Health (Health)
- Washington Department of Natural Resources (DNR)
- Washington State Military Department, Emergency Management Division (EMD)

Evaluating the potential for hardship requires that EWEC have some understanding of past drought related impacts. Sources of this information include:

- Information regarding drought impacts from previous droughts (e.g., vulnerability assessments, economic studies).
- Staff assessments of risk
- Petitions or requests from water users

EWEC meeting protocol

As executive sessions, EWEC meetings are not open to the general public. Each agency is expected to speak to impacts which affect their respective sector of responsibility. Staff level employees are expected to have briefed their respective directors prior to the meeting. Discussion is facilitated by either the Governor’s Office or Ecology.

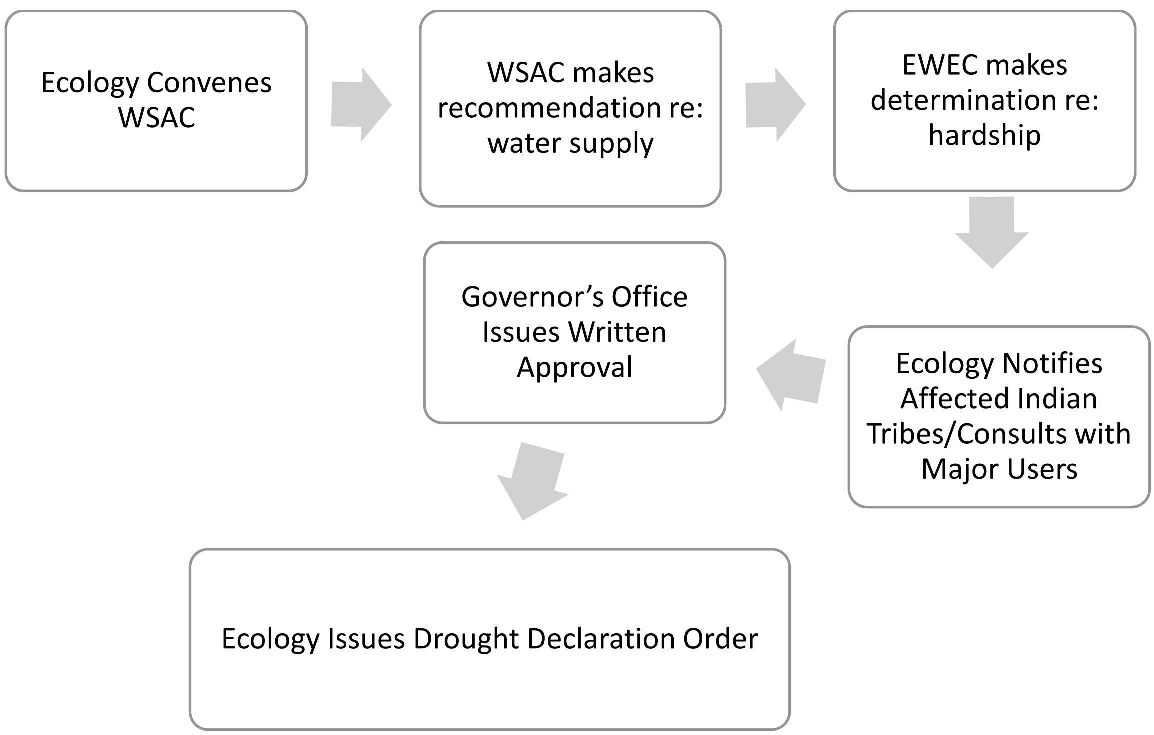
If EWEC recommends that any part of the state be declared as drought and the Governor's Office concurs, the Governor's Office must formally request Ecology to issue an "Order and Determination of Drought" (See example memo in Appendix H).

As noted above, WSAC recommendations regarding water supply shortages are communicated to EWEC, which is charged with making a final recommendation whether to declare a drought Advisory or Emergency Declaration.

Before issuing an Emergency Declaration, the state must also notify affected tribes in affected drought areas. This notification is important for providing a point of contact to tribes and informing them of the type of drought response actions which are likely to occur in areas where they have interests.

Pursuant to this plan, the state will also communicate with major water users who may be affected by a drought Advisory or Emergency Declaration. In particular, large municipalities have expressed a desire for Ecology to coordinate drought communication with them so that they can manage their own communications with their own users.

This process is illustrated in the graphic below:



Drafting and Publication of Drought Order

Drought Orders must comply with the requirements specified at WAC 173-166-060(2):

> *"The order declaring drought conditions for a geographical area or part of a geographical area must contain the following elements:*
> *(a) A description of the geographical area or part of a geographical area which is being so designated.*
> *(b) The facts leading to the issuance of the order.*
> *(c) The statutory authority upon which the order is being issued.*
> *(d) The commencement date and termination date of the order. The termination date may be no later than one calendar year from the date the order is issued.*
> *(e) Brief descriptions of the actions which are possible under the order.*
> *(f) Provisions for the termination of withdrawals if essential minimum flows are jeopardized."*

An example is provided at Appendix H.

Defining Normal Water Supply

Because Washington State defines drought as a percentage of normal water supply, it is necessary to define normal water supply. The definition of normal water supply is found at WAC 173-166-030 (6):

> *Normal water supply is:* "…the median amount of water available to a geographical area relative to the most recent thirty-year base period used to define climate normals. The determination of drought conditions will consider seasonal water supply forecasts, other relevant hydro-meteorological factors (e.g., precipitation, snowpack, soil moisture, streamflow, and aquifer levels) and also may consider extreme departures from normal over sub-seasonal timeframes."

Seasonal water supply forecasts are provided from the National Weather Service's Northwest River Forecast Center (NWRFC) and the Natural Resource Conservation Service (NRCS) and are described in more detail in the Drought Monitoring and Forecasting chapter. The lists below describe the available seasonal forecasting periods provided each as of 2017.

National Weather Service

- APR-SEP
- APR-JUL
- JAN-SEP
- JAN-JUL
- OCT-SEP
- Month by Month

- 10- & 120-Day
- Minimum Flow
- Columbia River Low Stage

Natural Resources Conservation Service

- APR-SEP (available Jan – May
- APR – JUL (available Jan – May)

APR – SEP water supply forecasts are generally most critical for drought forecasting as this is when higher water demand associated with irrigation coincides with low precipitation and high temperatures. Outside of the APR-SEP forecast period, the fall period is important to water managers who need fall rains to replenish depleted reservoirs. In such circumstances, shorter term forecasts (Month by Month, 10- and 120-Day) are relevant. As noted in the Drought Monitoring and Forecasting chapter, however, there has been less skill demonstrated for sub-seasonal and seasonal forecasts during the fall months. This means attempts to predict water supply conditions more than several weeks in advance are likely to be characterized by high levels of uncertainty.

The NWRFC and NRCS each use the World Meteorological Organization base period for determining the 30-year average water supply conditions, currently 1981-2010. Due to climate change, we expect that runoff will shift from spring-summer seasons to the fall-winter seasons. Consequently, "normal" runoff for the APR-SEP runoff period is likely to decline and "normal" runoff for the OCT-SEP runoff period is likely to increase. In turn, the 75 percent of normal drought threshold will be met at a lower forecasted volume than currently for the APR-SEP period.

Consideration of other water supply indicators

Ecology's administrative rule expressly provides that a determination of drought conditions may include precipitation, streamflow, snowpack, and other hydrological and meteorological factors. The use of a broader suite of criteria, in addition to water supply forecasts, has been incorporated into the advisory stage triggers for this Drought Plan update, and can also be considered at the emergency phase. See the chapter on Drought Monitoring and Forecasting.

Given Washington's water supply-focused definition of drought conditions, these broader criteria are most pertinent to watersheds lacking official streamflow forecasts. In the past, WSAC has considered available water supply forecasts as a proxy indicator for nearby watersheds lacking official forecast values. Information regarding major sources of water supply (e.g., groundwater, surface water, the status of surface water storage) can help decision makers assess whether water users are at risk of hardship. Over time, the number of watersheds lacking predictive water supply information will decline as new tools like the National Water Model, which provides comprehensive coverage, become suitable for operational purposes. (See the chapter on Drought Monitoring and Forecasting.)

Precipitation deficits may also contribute to water supply shortage, but forecasting precipitation with consistent skill is difficult. Generally speaking, a precipitation deficit which develops late in the water year is probably less troubling than one which develops earlier. The sooner the deficit develops, the more time that impacts could accumulate at a time when the imbalance between water supply and demand are at their highest.

Groundwater as water supply indicator

Groundwater level information can indicate whether aquifers are experiencing long term declines or failing to rebound from years of heavy well pumping. Ecology has a well monitoring network consisting of approximately 420 water level measuring wells, but very few of them have been measured as long or consistently enough to provide a good understanding of baseline "normal" conditions. This limitation will be solved over time, provided the state continues to devote resources to measuring these wells.

There are wells in key areas where year to year changes in groundwater levels have been documented as a result of higher pumping levels in drought years (the Yakima Basin and within the Columbia Basin Irrigation Project). In the past several years Ecology consolidated its groundwater data to a central database (the Environmental Information Management System) to support easier queries and visualization of trends.

The United States Geological Survey (USGS) also conducts groundwater monitoring in Washington, and makes the data available through the National Water Information System (http://waterdata.usgs.gov/nwis/gw). Most of these data have been collected as a result of groundwater studies. Ecology has taken over operation of those monitoring circuits (e.g. Island County; Yakima County; the Dungeness watershed; and the original Odessa subarea).

A small subset of groundwater-level monitoring conducted by the USGS in Washington is associated with the national USGS Climate Response Network which is used to monitor the effects of droughts and other climate variability exclusive of human influences. Nationwide, this network includes about 130 wells, which includes three transducer-equipped, real-time and four monthly-measured wells in Washington (see Figure 11 below).

In addition to the above initiatives, the USGS has established a National Ground-Water Monitoring Network (NGWMN), aimed at providing access to data from major and principal aquifers nationwide over a network interface called the Data Portal. The NGWMN Data Portal provides access to groundwater data from multiple, dispersed, primarily state-maintained databases in a web-based mapping application.

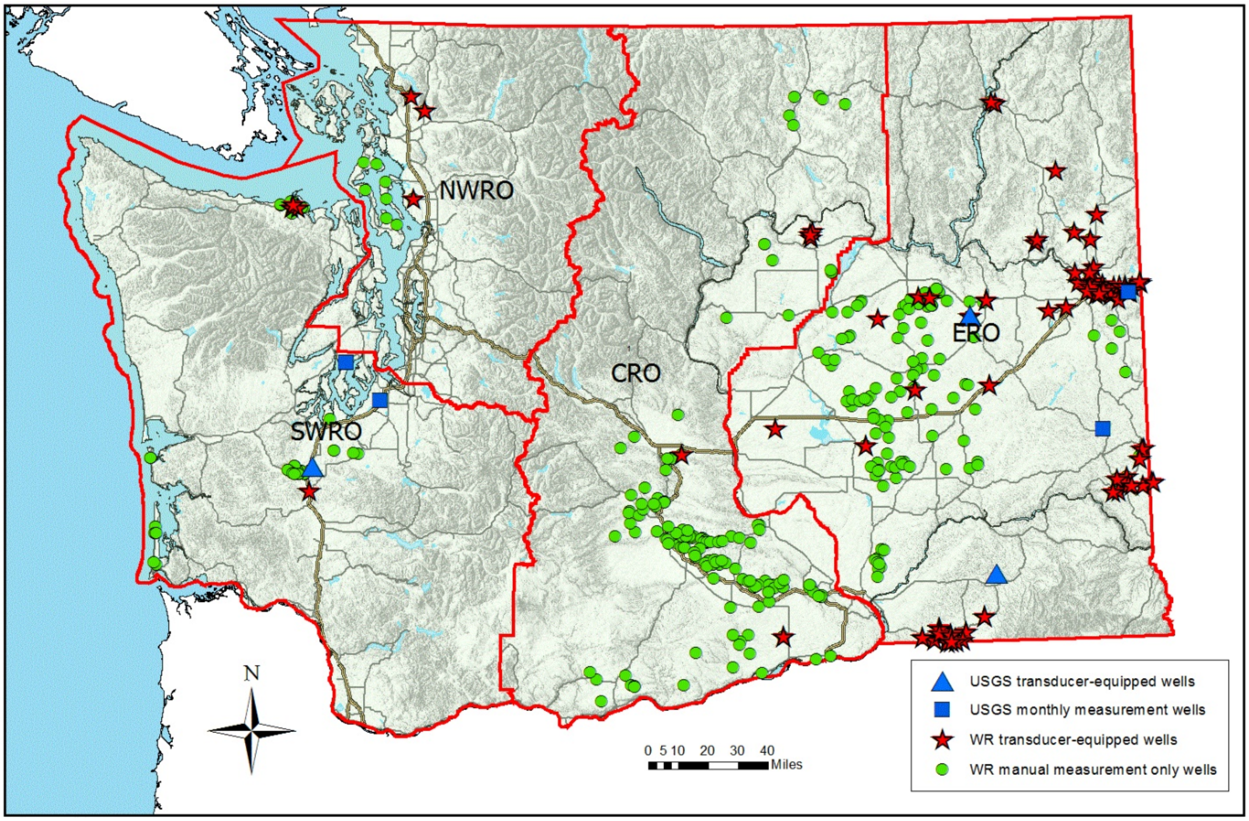


Figure 11. Well monitoring locations.

Consideration of artificial storage where natural water supply conditions are below 75 percent of normal

River forecasts model the seasonal volume of natural flow to be measured at a particular point in a watershed. They may not factor in the existence of artificial storage in a watershed that is available to satisfy water demands for drinking water, irrigation, etc. Reservoirs compensate for the lack of natural runoff during the spring and summer and may mitigate the risk of hardship to water users and uses. These water uses include not only the direct water users of stored waters but potentially other uses downstream of the reservoir through managed releases of water to benefit fishery populations.

In drought years, reservoir managers may be required to maintain river flows at levels specified by agreements, permits, or licenses. Spilling water is only likely to benefit the mainstem reaches directly downstream of the project. Therefore the evaluation of hardship must also consider water uses on tributaries and elsewhere in the watershed.

Determination of Hardship

When considering a drought declaration, hardships and vulnerabilities evidenced during previous drought years suggests where impacts are likely to occur in the future. This provides a sufficient basis to affirm the potential for hardship.

Where there is no evidence of past hardship, EWEC must consider whether anticipated conditions merit the declaration of an emergency, or whether a drought advisory would be more appropriate. Ecology can use a drought advisory to solicit more information from water users and invite them to petition for a full drought declaration if they are at risk of hardship.

When Ecology has declared a drought emergency within a geographic area, water users may be eligible for emergency drought permits and financial assistance. Any user with a previously authorized water use may apply for an emergency drought permit. Financial assistance in the form of grants and loans is limited to public entities. At this stage, the burden for documenting hardship falls upon the applicant. Neither the Legislature nor Ecology has formally defined "hardship." However, the entity seeking a permit or assistance should be able to demonstrate that the ongoing or anticipated water shortage is likely to cause a severe economic injury, a public health emergency, or severe environmental harm.

Avoided hardship can be economic, environmental and social:

- Authorizing the use of emergency wells where otherwise a grower would suffer severe economic losses resulting from a loss of orchard trees.
- Funding new wells for a small community dependent on springs which were drying up during drought.
- Funding work crews responsible for removing stream blockages to salmon migration.
- Authorizing emergency water transfers between water right holders to enable junior water right holders to replace lost water supplies.

Determining Geographic Areas

A drought emergency or advisory may be issued for a specific geographic area. "Geographical area" is an area within the state of Washington which can be described either by natural or political boundaries and which can be specifically identified in an order declaring a drought emergency. The state has broad discretion to define drought areas.

Examples of specific geographical areas include, but are not limited to:

- The state of Washington
- Counties
- Water resource inventory areas (WRIAs) as defined in chapter 173-500 WAC
- Individual sub-basins which constitute only a portion of a WRIA but whose boundaries can be topographically described
- Groundwater management areas and subareas as defined in WAC 173-100

- Designated sole source aquifers
- Combinations of the above areas

In practice, the state has used Water Resources Inventory Area (WRIA) boundaries, which define watershed areas for the purpose of administering water rights and water resources related rules (e.g., the priority water rights system and instream flow regulations).

Defining the geographic areas by watershed works well for water managers, but it can create communication challenges with the media and public who may be unfamiliar with the names and locations of watersheds. Including the names of affected counties and cities in drought orders and advisories helps the public better understand who may be affected, as does creating maps with clearly delineated boundaries.

Another factor in determining the geographic area is deciding how broadly or narrowly the area should be construed. This question requires not only addressing water supply forecasts and conditions, which may be better understood in some areas than others, but also evaluating the potential for hardship, which may be better understood in some watersheds than others. Broadly defining the drought areas risks including water users in "emergency status" who aren't actually affected by drought conditions. On the other hand, drawing the areas too narrowly risks omitting genuinely affected users. However, as discussed below, advisory or declaration areas can be expanded in response to petition, new information, or evolving conditions by WSAC and EWEC.

When defining an area for either Advisory or Emergency status, the state will also describe the types of uses most likely to be affected by drought conditions, such as illustrated in the two examples on the following pages.

Petitions for Declaration

WAC 173-166 provides that petitions to declare areas for drought may be submitted to the Ecology. Petitions must be submitted by letter and contain information describing the nature of relief, the area which is being requested for designation, and the facts underlying the petition.

EXAMPLE 1: Hydrologic conditions indicate drought in central Washington

A Stage X drought is declared for parts of Chelan, Douglas, Grant, Kittitas, Yakima, and Benton counties. This stage means: ____________.

River basins affected within those counties are the Wenatchee, Entiat, Chelan, Lower Yakima, Upper Yakima, Naches, and Alkali-Squilchuck. (WRIAs 27, 38, 39, 40, 45, 46, 47).

Affected areas:

The affected water users and natural resources may include farms that rely on surface water sources; communities drawing from surface water sources; communities and homeowners drawing from shallow wells in unconfined aquifers; and fish in each of the affected basins including tributary streams.

Farms in the Yakima River Basin that receive water from the Bureau of Reclamation should consult with their irrigation district managers. As of the current date, Reclamation has indicated Total Water Supply Available of ___ percent. The TWSA forecast will be confirmed or updated by Reclamation, at least monthly.

Customers of public water systems in the affected area should look for communications from their local water utility to determine whether shortages are expected.

Unaffected Areas:

Farms and communities receiving water from the Columbia River and Lake Roosevelt are not expected to experience shortages this year if current weather trends continue.

Because information regarding anticipated drought impacts is imperfect, the state should actively publicize the opportunity for petitions in communications regarding drought advisories or declarations. Petitions can bring new information to the attention of state officials.

Petitions for drought status are a prerequisite for the declaration of drought in some other states (e.g., Oregon and Idaho). An advantage of petitions is that they are likely to provide greater clarity to state officials as petitions will presumably arise from local, specific circumstances. A disadvantage of petitions is that they may delay state action until such time as impacts have already been felt. Washington State's drought statute requires the state to anticipate drought conditions, and this forward-looking approach can be valuable in enabling a more rapid response.

Upon receiving a petition for a drought declaration, Ecology has 15 days to provide a decision to the applicant as to whether the petition will be acted upon. Prior to making a decision, Ecology must consult with WSAC and staff members of EWEC agencies. A decision to issue or expand an emergency drought declaration may only be made after a formal recommendation of EWEC to the Governor's Office.

EXAMPLE 2: Hydrologic conditions indicate drought in northwest corner of state

A Stage X drought is declared for parts of Whatcom, Skagit, and Snohomish counties. This stage means: ____________.

River basins affected within those counties are the Nooksack, Lower Skagit/Samish, Upper Skagit, and Stillaguamish basins (WRIAs 1, 3, 4, and 5).

Affected Areas:

The affected water users and natural resources may include farms relying on natural rainfall for a large portion of their water needs; communities drawing from surface water sources; communities and homeowners drawing from shallow wells in unconfined aquifers; and fish in each of the affected basins, especially in smaller creeks.

Customers of other public water systems in the affected area should look for communications from their local water utility to determine whether shortages are expected.

Unaffected Areas:

The City of Bellingham lies in the affected area but is not expected to experience shortages this year if current weather trends continue.

The City of Everett and communities receiving water from Everett's regional water supply system lie outside the affected area of Snohomish County, and are not currently expected to experience shortages this year. This unaffected area includes Arlington, Lynnwood, Marysville, the Alderwood Water and Wastewater District, and other communities in the southern half of Snohomish County.

Importance of Pre-Agreements

Front-line responders to natural disasters such as fires, floods, and earthquakes understand the importance of pre-staging critical tools and supplies where they can be deployed quickly. This same principle can be applied to executing administrative requirements necessary to support drought resiliency and response activities identified in the Actions chapter. Reducing response time can help compensate for the inherent uncertainty in the forecasting of drought conditions.

- A key area where pre-agreements can expedite response is in having interagency agreements, work plans, budgets, and scopes of work available prior to the onset of drought. This will speed the disbursement of money from Ecology to other agencies and organizations needing drought response funding.

- The Washington Water/Wastewater Agency Response Network allows water and wastewater systems to receive rapid mutual aid and assistance from other systems in an emergency. Utilities sign the network's standard agreement which then allows them to share resources with any other system in Washington that has also signed the agreement. Mutual aid agreements between water users can specify that participating systems will make equipment and other resources available in the event of a water supply emergency. See Appendix E.

- Some water right transfers may be recurrent in drought years. To the extent the participants require state authorization to proceed with the transfer, parties should work with Ecology to obtain prior approval for measures which can proceed on the basis of simple notification to Ecology.

Funding Issues

Contingency funding

A predictable and timely source of funding is necessary to support drought resiliency and response actions. While droughts do not occur every year, they are likely to occur in some part of the state every decade, and are expected to become more frequent as climate changes. When droughts do occur, a stable source of contingency funds is needed to initiate extraordinary actions (e.g., emergency water leases, hiring temporary staff, supporting emergency infrastructure).

If contingency funding is not available, the scope of state agency response will be limited to core actions such as issuing emergency drought permits and regulating water users where necessary to enforce the water right priority scheme. The emphasis will be on regulation, not relief.

The state should work to secure a continuing source of funding for drought resiliency actions which can be available prior to an actual drought emergency. This would allow a more systematic, transparent review of proposed remedies to drought vulnerabilities, with a goal of providing a permanent solution to a water supply imbalance. Efforts underway in the Columbia Basin, including the Yakima Basin, are examples of this approach.

The manner in which funding is provided to state agencies in drought emergencies can also be structured in a way to facilitate more expedient response. Historically, the Legislature has appropriated drought funds to Ecology, which has been responsible for subsequently disbursing the funds to other state agencies via interagency agreements and contracts. Contracting and finalizing agreements can consume significant blocks of time (multiple weeks), resulting in delayed response.

Direct agency appropriations

An alternative, streamlined approach may be for the Legislature to provide direct appropriations to each agency for the purpose of supporting extraordinary drought related costs. Direct appropriations could eliminate the need for interagency agreements and contracts, thereby shortening response time. Direct appropriations of contingency funds would additionally improve deployment of money and resources to address hardship.

In Washington State's budget process, state agencies develop budget requests in consultation with the Office of Financial Management, for inclusion in the Governor's Budget Request to the Legislature. The timing for the process occurs in the fall, long before the water supply picture of the new water year is clear. There is always some probability that drought conditions may develop. This probability supports building in requests for contingency funding as a matter of practice.

Ad hoc supplementary funding requests

If contingency funding is not available, then state agencies must be prepared in the event of a formal Drought Advisory to advocate for an ad hoc supplementary funding request. The success of this strategy will of course depend on progress and dynamics of ongoing budget discussions in the Legislature. If the Legislature is not in session, then agencies must consider whether to reallocate money dedicated for other purposes to emergency drought response. However, if emergency drought relief differs significantly from the authorized purpose, shifting money from one account to another may not be supportable.

Estimating funding needs

Expenditures during previous drought emergencies can be used to approximate funding needs, although changes in conditions, inflation, and the geographic scope of the drought need to be taken into consideration. A further caution in relying upon past expenditures is that past expenditures may be a reflection of how much money was allocated, rather than how much may have been needed.

Costs for non-grant and grant expenditures should be estimated separately. Non-grant expenditures represent agency costs (salaries, office space, and equipment) and spending on specific projects (e.g., emergency water right leasing). These costs should be described and approximated in agency agreements such that they can be refreshed relatively easily in times of pending drought (See Importance of pre-agreements).

Grant expenditures represent money allocated via a formal grant application process. That amount can be capped but the number and costs represented by individual applications will vary from drought to drought.

Emergency grants and loans

Ecology has been responsible for allocating grants and loans for emergency drought relief in past droughts. In each instance, Ecology has drafted an emergency rule to define the application process and specific eligibility criteria for grant awards. Emergency rules are limited in duration to 120 days. Because they are limited, an emergency drought grant program may only cover a limited extent of a drought emergency.

Ecology is responsible for all aspects of the emergency rule process including:

- Drafting rule
- Publishing the rule
- Developing application forms
- Processing applications
- Managing grant and loan contracts

State Agency Coordination during Drought Emergencies

State agencies will coordinate during drought emergencies to ensure that drought relief can be provided in an efficient, expeditious manner. EWEC should identify staff employees from each agency to staff an inter-agency coordination committee, which can agree upon a meeting schedule and protocol appropriate to the scale and severity of the drought. The key objective of the committee is to ensure a continuous and timely information flow amongst state agencies and to ensure each agency is aware of actions that other agencies are taking. The committee will be responsible for coordinating on issues relating to:

- Funding
- Communication
- Permitting
- Monitoring of impacts
- Implementation of interagency agreements

EWEC's role in state wildfire planning and response

EWEC membership includes DNR and the EMD, which play central roles in state wildfire response. EWEC itself does not have a role in planning and responding to state wildfire. It is important for DNR and EMD to take part in EWEC for three important reasons:

1. To ensure that the state has an effective communication strategy, given that "fire" and "water supply" are both drought issues in the public's mind. During the 2015 drought, DNR officials were present during media events to announce drought declarations. Even though the basis of the declaration is water supply, many reporters asked questions regarding the wildfire risk for the coming summer.

2. To ensure that connections are being made between managers and staff from both agencies regarding communication of drought conditions.

3. To determine whether wildfire and water response agencies need to coordinate more closely given current circumstances.

Role of state, contrasted with water managers at the local levels

State agency responsibilities with respect to drought planning and response can be distinguished from the role of other levels of government. A key distinction is that the state is not a water supply provider or purveyor, as is the case in some other states (e.g., California). Washington State owns and operates no water supply projects. Other than regulation of junior water rights, the state does not have the authority to restrict water demand in times of drought in order to extend supplies. Rather, the state's role includes a range of regulatory, coordination, and support roles.

The state may restrict the water use of other governments only insofar as it is necessary to protect the seniority of other water rights or to stop the waste of water. Thus, Washington can be distinguished from California and other states, where state water resources regulators have required cities to reduce their water demand by certain percentages. Washington State does have municipal water efficiency standards, but these standards apply uniformly to municipal water supplies, irrespective of drought periods.

Timing of Drought Declarations

A drought declaration can be issued at any time of year, but historically all forecasts have been issued in the spring months. Early in the water year (Oct - Dec), water supply forecasts for the coming Apr – Sep season still have a wide range of possible outcomes. Because snowpack is a major component of water supply conditions over much of the state, the spring brings much more clarity on water supply.

The uncertainty inherent in seasonal forecasts may create some tension between the desire to wait for more certainty, to not overreact, and the desire to stay ahead of conditions. There is no easy or fast rule here. The challenge is appreciating the probabilities of different outcome and their consequences. Judgement needs to be exercised regarding the risk of acting versus not-acting, and choosing between an advisory or an emergency. Delaying action will foreclose some options for response as the water year continues. Where risks to vulnerable users in the absence of state action are high, it may be prudent to move forward with a drought advisory or declaration.

Expiration of Drought Declarations, Timing Considerations

Drought declarations are not open-ended. They may only be issued for up to a one-year time period (RCW43.83B.405 (2)). The duration may be extended up to one additional year with written consent of the Governor. Consequently the drafter of the drought order is faced with a decision whether to schedule the termination of the order in accordance with a convenient administrative date or to attempt to estimate how long conditions are likely to last, just so long as that time period does not extend past one year.

Past practice has been to set the expiration date to a time which corresponds to the end of the calendar year (December 31). This timeline allow water managers to wait until the new water year is well underway before issuing an “all clear.” However, a wet fall is no predictor of a wet spring, and water managers will need to evaluate whether allowing an order to lapse could be premature. Issuing a decision to extend a drought declaration in December may prove challenging to communicate to the public, as even an anomalously dry and warm December may not feel very drought-like to a non-climatologist. Moreover, there still is ample time after December for weather to flip to a different pattern before spring.

A more preferable option may be to target an expiration date which better positions water managers to make a clear decision. A declaration issued in mid-March, for example, could be set to expire in mid-March the following year. The advantage of this strategy is that there will be more certainty in the following March whether the state has genuinely recovered from drought conditions, or whether an extension is merited. Nevertheless, this approach does not totally do away with the communication challenge of explaining why a drought emergency should be sustained through the winter.

With any alternative, water managers should strive to avoid the “twitchiness” of an on-again/off-again approach to issuing drought orders or communicating drought conditions.

Training and Exercises

Widespread moderate to severe drought conditions that would necessitate implementation of the Drought Contingency Plan generally do not occur on an annual basis. Consequently, in-depth familiarity of the plan and its components may naturally diminish over time in between drought incidents and through routine transition of state agency staff and other plan stakeholders.

In order to maximize awareness and familiarity of the Drought Contingency Plan, a training and exercise regimen is necessary to ensure that inter-agency staff and the organizations they represent are able to develop and retain an understanding of the plan and its actions in advance of drought incidents. This will help ensure that the state is able to effectively implement the plan during a drought emergency.

Training

Ecology’s Water Resources Program, in collaboration with key stakeholders, will offer a Drought Contingency Plan overview and refresher training for organizations identified within the plan on an annual basis. This training will occur during late winter/early spring months in advance of drier summer and fall months in which drought plan implementation is most likely to occur.

External stakeholders may be invited to take part in the training to ensure the whole community understands current mitigation measures used in advance of a declared drought emergency, as well as strategies and tactics that may be applied during a drought response.

Exercises

Exercises play a vital role in any emergency planning process by enabling plan stakeholders to test and validate planning assumptions, identified actions, and detect additional capabilities in order to ascertain both capability gaps and areas for improvement.

Periodic exercises of the Drought Contingency Plan will ensure the capabilities and actions outlined in the plan are able to be effectively accomplished. Support for plan exercises will be provided by the Washington Emergency Management Division's (EMD) Exercise and Training Section, which specializes in exercise development.

Drought Contingency Plan exercises will occur on a bi-annual basis. Six months in advance of a scheduled exercise, Ecology will work with EMD training staff to begin the exercise planning process. Biennial discussion-based exercises may include, but are not limited to: seminars, workshops, and/or tabletop exercises. Exercise outcomes will be captured through a corrective action program and used to address capability gaps as well as update the current Drought Contingency Plan.

Monitoring of Impacts

Monitoring of impacts during drought is important for assessing whether resources may need to be directed, and whether mitigation and response measures are effective. Over time, the continuous documentation of impacts can create a record which can be correlated to physical and hydrologic conditions. This record can help us understand if impacts are changing as climate changes evolve (See the discussion on the "Time of Emergence" concept in the "Planning for Climate Change" section below.) This should improve our ability to predict the likelihood of drought-caused hardship. These data can also inform water managers whether impacts are getting worse, particularly as climate change alters seasonal water availability, or whether vulnerabilities are being reduced as water users adopt resiliency measures.

Capturing these impacts can be a challenge. As BeCraft (2017), in her study of the Oregon 2015 drought experience, has written:

> "… [I]t is challenging to identify the impacts of and responses to drought for multiple reasons. For example, there is not a sole entity at the state or federal level responsible for tracking or compiling information about the impacts of a drought. Instead, numerous agencies … are involved in monitoring and responding to drought such that data and knowledge are decentralized. Another reason it is challenging to determine the effects of drought is that many impacts and responses are difficult to measure, be it due to complexity (e.g., economic impacts) or sparse data (e.g., change in groundwater usage). In addition, it is often impossible to fully attribute conditions and management decisions, such as soil erosion and a farmer switching to a new crop, to drought."

Washington State shares these challenges, but has also supported work to formally assess impacts and vulnerabilities in past droughts. Documenting drought experiences in post-drought reports to the Legislature has proven valuable as it supports information retention and encourages agencies to formally evaluate the economic impacts to their respective sectors.

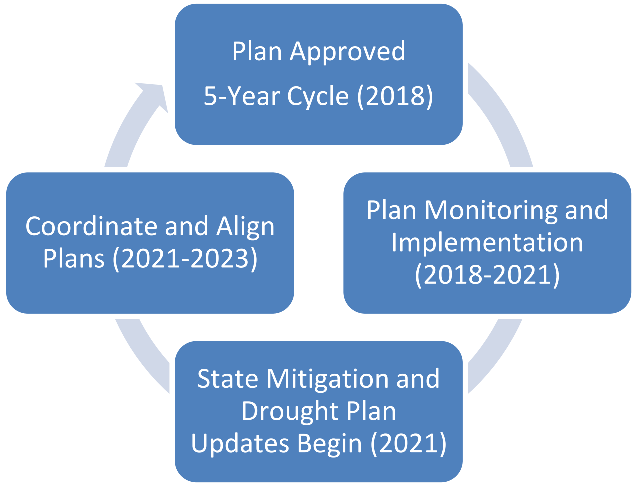
In future droughts, Washington State should consider, as a matter of practice, encouraging the public and agency staff to report impacts to the Drought Impact Reporter, which is maintained by the National Drought Mitigation Center (NDMC). Information captured by the impact reporter resides in a database with the ability to run queries by location and time. As of this writing, the NDMC is developing enhancements to improve the easy of data collection and visualizations of drought impact data.

Plan Update and Maintenance

In addition to the Drought Contingency Plan, which is developed and maintained by Ecology, Washington maintains a State Enhanced Hazard Mitigation Plan (SEHMP) through its Emergency Management Division. Both plans contain a drought hazard overview and state-level mitigation actions that can be implemented to reduce risk and minimize impacts of drought. The Drought Contingency Plan contributes to the SEHMP through the drought mitigation strategies and drought hazard vulnerability and risk assessment. The SEHMP in turn guides local jurisdiction mitigation planning best practices, encouraging the use of data and methods from the Drought Contingency Plan.

The SEHMP is updated every five years with the current update scheduled to complete in summer 2018. In order to ensure consistency between plans and leverage the best available science, the Drought Contingency Plan will be updated every five years, in the two years preceding the SEHMP update. Thus, the next update will be completed by 2023.

Washington Emergency Management will begin the mitigation plan update process two years prior (approximately in 2021) to the SEHMP's expiration and will use the state's mitigation plan review and monitoring steering committee (currently the Hazard Mitigation Workgroup). At this time Ecology will also initiate updating of the Drought Contingency Plan. Appropriate Ecology staff will participate as members of the Hazard Mitigation Workgroup and other relevant committees in order to facilitate ongoing dialogue and enhance identification of proactive mitigation measures that can be implemented at a state-level.



Additionally, at Ecology's request, EMD will provide copies of local jurisdiction mitigation plans that also capture locally identified mitigation strategies to reduce the impacts of drought for possible action or incorporation into the Drought Contingency Plan.

Actions

This chapter discusses resources and methods to improve the state's resiliency before a drought, which can also be described as mitigation, and actions to reduce adverse effects during drought. Sectors identified as potentially vulnerable to drought are targeted individually. Multi-sector actions benefit more than one high risk sector. These sectors include:

- Agriculture
- Energy
- Fish and wildlife
- Groundwater
- Public water supplies
- Recreation

Scope of drought impacts covered by this plan

This plan focuses state mitigation and response on those impacts which are directly related to water supply, consistent with Washington's legislative definition of drought. It does not address non-water supply related impacts.

Multi-Sector Resiliency Actions

Water management

The essential framework of first in time, first in right, which has been in place since the late 1800s in Washington State, is still what determines who gets water in drought years. Junior water users – both instream and out of stream – are most at risk in drought years of not receiving their full water supply. The consequences of losing access to a water supply in water short years can be severe to users, communities, and the environment. Over the decades, the Washington State Legislature has supported various initiatives to improve water supply reliability for all users.

Columbia River Water Supply

Ecology's Office of the Columbia River is charged with aggressively seeking out new water supplies for both instream and out-of-stream purposes. Created following the 2006 passage of the Columbia River Water Management Act (Chapter 90.90 RCW), the Office of the Columbia River is tasked with six directives:

- Find sources of water supply for pending water right applications. (RCW 90.90.020(3)(b)).
- Develop water sources for new municipal, domestic, industrial, and irrigation water needs within the Columbia River Basin (RCW 90.90.020(3)(d))
- Issue supply and demand reports. (RCW 90.90.040(3)).

- Secure alternatives to groundwater for agricultural users in the Odessa subarea aquifer. (RCW 90.90.020(3)(a)).
- Find a new uninterruptible supply of water for the holders of interruptible water rights on the Columbia River mainstem. (RCW 90.90.020(3)(c)).
- Develop water supplies for instream as well as out-of-stream uses." (RCW 90.90.020(1)(a)(ii)).

The same legislation set up the Columbia River Basin Development Account, and provided $200 million in funding. As of January 1, 2016, the Office of the Columbia River has added almost 376,000 acre-feet of water to Eastern Washington's water supply at a cost of $506 per acre-foot. Another 320,000 acre-feet of water will be made available in the near term. More water is under long-term development tied to future demand projections.

Lake Roosevelt Incremental Storage Releases

The Lake Roosevelt Incremental Storage Releases Project is based upon an agreement between the state and federal government, and affected Indian Tribes. It enables the Bureau of Reclamation (Bureau) to release more water to provide for drought relief, municipal and industrial supply, replacement of groundwater use in the Odessa Subarea, and enhanced stream flows for fish, using the Bureau's Grand Coulee Dam storage right (6.4 million acre-feet). In drought years, 132,500 acre-feet would be released to serve the above uses, provide another 50,000 acre-feet for stream flows, and supply interruptible water rights on the Columbia River Mainstem.

Yakima Integrated Plan

The Yakima Integrated Plan is a nationally significant watershed enhancement proposal for the Yakima Basin which, when completed, would significantly reduce drought vulnerability in the Yakima Basin. Details and supporting documentation for the plan are available from Bureau and Ecology websites. The plan includes seven elements:

- Fish passage at existing dams
- Structural and operational changes
- Surface water storage
- Groundwater storage
- Habitat protection and enhancement
- Enhanced water conservation
- Market-based reallocation

The total cost of all actions in the plan is estimated to be approximately $4 billion. Funding is subject to further review and authorizations at the federal, state, and local levels. If funded, the actions would be carried out over a period of approximately 15 to 20 years in distinct phases. Additional storage and efficiency measures would ensure that junior irrigation districts receive at least 70 percent of their normal water supply even in drought years.

Support of local drought contingency plans

Local governments may prepare their own drought contingency plans. Support for local drought planning is made available by both state (via State Conservation Commission) and federal funding (WaterSMART Grants). Local entities that plan for drought are better positioned to cope with drought impacts, and better able to prioritize and seek state support of drought mitigation and response investments.

Water storage

To address long-term water demands and the impacts of climate change, the state should evaluate opportunities for new water storage. Additional storage may take the form of:

- Large new reservoirs
- Smaller off-channel storage reservoirs
- Enhancing storage at existing reservoirs
- Aquifer storage
- Adopting development standards which preserve and enhance the infiltration of surface runoff into groundwater supplies

This analysis is already underway in the Columbia Basin, under the leadership of the Office of the Columbia River, in cooperation with federal, state, and local governments and major water users. Whether it is appropriate or necessary to replicate this approach on the west side of the Cascades is a large public policy question that is beyond the scope of this plan, but it is reasonable to assume that doing so would provide more financial and analytical support for water supply resiliency projects in west side watersheds.

Technical assistance

Washington State Conservation Commission and conservation districts

Washington State Conservation Commission and many of the state's conservation districts[4] offer direct technical assistance to landowners and land-operators. Washington conservation districts help people take care of everything they can see outside their windows – from farms, to forests, to urban yards, to rivers, lakes, and coastline. For more than 75 years, they have served as trusted, non-regulatory local partners helping people care for natural resources. Each of Washington's 39 counties is represented by at least one conservation district.

Districts offer a range of voluntary services including assistance with: irrigation water management, irrigation efficiency, fish barrier removals, erosion control, habitat restoration, manure management, wildfire prevention/mitigation, stormwater management, forest plans, noxious weed control, livestock stream crossings, and more.

[4] See map: http://scc.wa.gov/conservation-district-map/

Technical Resources for Engineering Efficiency

Ecology’s Technical Resources for Engineering Efficiency team consists of Ecology scientists and engineers with expertise in industrial processes and pollution prevention. The team provides a free service to Washington businesses and organizations. Through research, process modeling, benchmarking best practices, and engineering analysis, the team determines the potential cost savings of reducing resource use and waste – including water waste. The team documents the opportunities and potential benefits in a report, which they present to the client.

Funding Programs

Irrigation Efficiencies Grant Program

Ecology works in collaboration with the State Conservation Commission to enable irrigators to meet water demand while using less water, leaving more water instream for the benefit of fish. The Irrigation Efficiencies Grant Program targets over-appropriated tributaries in the 16 Salmon Critical Basins and other basins where conflicts between instream and out-of-stream needs can be mitigated with a reduction in the demand for irrigation water diversion. As of December 2016, the program has enhanced stream flow in targeted tributaries by a cumulative total of 65 cubic feet per second with 16,130 acre feet of saved water.

WaterSMART grants

WaterSMART is the Department of the Interior's sustainable water initiative that uses the best available science to improve water conservation and help water resource managers identify strategies to narrow the gap between supply and demand.

Categories of WaterSMART grants include:

- The Cooperative Watershed Management Program provides funding for watershed groups to encourage diverse stakeholders to form local groups to address their water management needs.
- WaterSMART Water and Energy Efficiency Grants provide funding for projects that conserve water and address the connection between water use and energy use.
- WaterSMART System Optimization Review Grants prioritize proposals that evaluate potential renewable energy and energy efficiency improvements in the delivery of water, in addition to identifying options to improve water efficiency.
- WaterSMART Advanced Water Treatment Grants prioritize projects that consider reduced energy requirements and renewable energy components as new sustainable water supplies are brought online.

Multi-Sector Response Actions

Financial Assistance - Grants and Loans

The State Legislature historically has appropriated money for the distribution of grants and loans during drought emergencies. These appropriations may be provisioned to ensure that money is distributed equitably across various sectors, prioritizes certain sectors, or establishes eligibility criteria.

Water Management

The State Legislature has defined the primary goal of emergency drought response as: "To provide emergency powers to the department of ecology to enable it to take actions, in a timely and expeditious manner, that are designed to alleviate hardships and reduce burdens on various water users and uses arising from drought conditions." To accomplish this goal, Ecology is empowered to authorize emergency withdrawals and water right transfers and, when funded, to provide emergency grants and loans.

Water right curtailment and enforcement actions

Enforcement of the water right priority system is a major workload during low water and drought years. Ecology's regional offices proceed to curtail after first giving affected water users notification that curtailment is likely. This notification is followed up by more formal requests to cease withdrawals and diversions and, if necessary, formal orders to do so. In some basins, where curtailment is tied to enforcement of an instream flow rule, Ecology provides a toll-free hotline for users to call in each day to determine whether they may divert water that particular day, or whether regulation is still in effect.

Expedited water right permitting

Under an emergency drought declaration, the Ecology is authorized to issue emergency drought permits to water right holders if their water supply is likely to be below 75 percent of normal and they are at risk of experiencing hardship. Emergency drought permits may only be issued for a previously established use within a geographic area declared to be in drought. Not all water users and uses will suffer hardship in a drought-declared watershed. Thus, a determination that the applicant's water supply is below 75 percent of normal and that he or she anticipates or already experiences hardship must be made before an application is approved. Emergency drought permits must also be issued in conformance with the criteria specified in WAC 173-166.

Applications might request an alternate point of groundwater withdrawal or surface water diversion to compensate for loss of surface water supply, or temporary transfers of a water right to another user.

Yakima Basin Water Transfer Working Group

Speed, certainty, and convenience are important factors for drought year water right transfers. In the Yakima Basin, the Water Transfer Working Group is a voluntary team of agencies and water users that meet to provide technical review of proposed water right transfers in the Yakima

Basin. The Water Transfer Working Group uses a predetermined set of rules tailored to the Yakima River basin that are intended to protect other water rights to the Yakima River and tributary streams. Prospective water users submit water right transfer proposals to the group for their review, and the process guides applicants to those types of water right changes and transfers that more expeditiously gain approval from the state.

Leasing of Water Rights

To reduce the impact of low instream flows on fishery populations, Ecology may temporarily lease water from irrigators if funding is available. Leasing activity is focused on streams where there is a high fishery value and where senior water rights are available which would not be subject to curtailment.

Past experience indicates that leasing is more effective if invitations for leasing are made well before the leasing period. For example, in 2015 late-summer leases in the Dungeness Basin – which allowed irrigators time to consider their options – were more successful than earlier season leasing attempts in the Yakima Basin.

Competition for water is greater during drought years. High water prices limits the volume of water that can be successfully purchased using state funds.

Executing a single season leasing program requires a number of actions:

1) Determination of the state's willingness and ability to pay
2) Identifying basins for leasing activity
3) Determining which entity should take the lead in reaching out to individual irrigators
4) Public workshops to educate users about leasing opportunities
5) Publication and notice of invitation to bid
6) Review of bid offers to determine if the water rights meets the state's suitability criteria
7) Additional rounds of invitation to bid if necessary
8) Negotiation and drafting of lease contracts
9) Ensuring that lessees remain in compliance with the terms of the lease (e.g., by forgoing irrigation)

Past experience also indicates that leasing may be more effective where water users have had time to become familiar with how leasing works, as well as develop trust with the non-governmental organizations who typically facilitate such transactions.

Education

When drought is declared, state agencies may schedule community workshops to inform and educate community members about expected drought impacts and opportunities to obtain state financial or permitting assistance. (See communications plan in Appendix G.)

Prioritization of Resiliency and Response Actions

In the table which follows, drought resiliency and response actions are categorized according to whether they are mandatory (i.e., required by statute or rule) or contingent upon additional funding (currently there are no permanent drought contingency funds). The table also indicates whether the action occurs in the Advisory or Emergency Phase (or both), and whether the action is ongoing (not limited to drought events). A "P" indicates that the action is considered to provide high value in reducing the drought vulnerability of the sector. We also note that actions which are effective in reducing drought vulnerability are also likely to be effective in reducing vulnerability to the effects of climate change. In a drought event where sufficient drought response funds are not available, legislatively prescribed mandatory actions will be prioritized, even to the exclusion of other actions which may also provide high value in reducing drought vulnerability.

Prioritization Codes

M = Mandated in times of Drought Emergency

C = Contingent on supplemental drought Funding

P = Considered High Value for Reducing Vulnerability to Drought Conditions

Table 2. Multi-Sector Drought Actions

	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)	Notes
Financial Assistance (Grants and Loans)	CP		X		
Water Right Curtailment and Enforcement Actions	MP	X	X	X	Washington is a prior appropriation state.
Expedited Water Right Permitting	MP		X		
Yakima Basin Water Transfer Working Group	P	X	X	X	
Leasing of Water Rights	PC		X		
Education	C				

Table 3. High-Risk Sector: Agriculture

Vulnerabilities				
• A large portion of the state's agricultural production is located in the Yakima Valley where irrigation is necessary for nearly all crops and post-1905 water rights are pro-ratable in low water years. • Areas where farmers rely on rain to water crops or support foraging have little or no recourse when the rain doesn't come. If forced to purchase feed to support livestock, they must also pay premium prices as demand is high. • Fruit trees—particularly apples—need reliable water supplies or the tree itself is lost as well as the year's crop. This results in costs from the removal of dead trees, purchase and planting of new trees, and years of lost revenue waiting for new trees to mature and bear fruit. • Potatoes are a high water demand crop and a top producer of agricultural profits in four counties. • Berries with inadequate water produce fewer and smaller fruit with reduced quality. This is a pattern amongst many farmers during the 2015 drought: reduced production, of lesser quality, with higher expense. • Nursery stock growers may be challenged to keep plants healthy, while the market for the plants falls dramatically. • Growers also report higher costs for pest and weed control.				
Resiliency Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)
The Washington State Conservation Commission is the leading entity for supporting the adoption of farm-related irrigation efficiency tools.				X
Environmental Quality Incentives Program (EQIP) – (Landowner): The Natural Resources Conservation Service (NRCS) provides conservation assistance to participating farm operations on an annual basis. A number of different programs may be able to assist farm operations to install water efficient irrigation methods for crops, or Firewise-friendly irrigated hedgerows.				X
Irrigation Water Management Plans: As an approved Technical Service Provider for NRCS, a conservation district could assist irrigators develop Irrigation Water Management Plans as a component of EQIP Contracts.				X

High Risk Sector: Agriculture (continued)					
Response Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)	Notes
Livestock Forage Program: Producers who own or lease grazing land in a county rated by the U.S. Drought Monitor as having severe drought (D2) conditions for eight consecutive weeks during the normal grazing period are eligible to receive assistance equal to one monthly payment. Increasing drought intensity on the drought monitor triggers eligibility for additional payments. An eligibility tool for qualifying is available through http://droughtmonitor.unl.edu/fsa/Home.aspx.					Federal Program
Emergency Loan Program: This program provides emergency loans to assist producers in recovering from production losses due to drought. These funds can be used to repair or restore property, payment of some production losses, and refinance debts. Producers become eligible for emergency loans when they operate in a county declared a disaster area or a contiguous county and have suffered at least a 30 percent loss in production.					Federal Program
Tree Assistance Program: This program provides assistance to orchardists and nursery tree growers to replant or rehabilitate trees, bushes, or vines lost from drought. Commercially produced crops are eligible for this program with the exception of trees used for pulp or timber. Trees must have suffered at least 15 percent mortality to become eligible. Losses must be visually observed by an FSA agent and cannot be preventable by reasonable and available means. Producers must replace the trees, bushes, or vines within one year from application approval.					Federal Program

Table 4. High risk Sector: Energy

Vulnerabilities				
• Reduced volume of streamflow and reservoir storage due to drought reduces hydropower generation. • Ordered spill rates for fish flows can have a large impact on the water available for power generation.				
Resiliency Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)
The Pacific Northwest power system mitigates drought risk by assuming for resource planning purposes that every year is a drought year. RCW 19.280 requires all state electric utilities to maintain plans that forecast future load, identify resource options, and detail power costs and resource management.	P			X
The Pacific Northwest Coordination Agreement provides the framework for managing the region's hydropower resources.	P			X
The Northwest Power Pool Reserve Sharing Program establishes requirements for maintaining operating reserves and providing reserves to other participants in the power pool (Northwest Power Planning Council Reserve Sharing Program, 2017).	P			X
Standards for determining adequate capacity for long-term planning are a matter of common practice (Pacific Northwest Utilities Coordinating Committee, 2010).	P			X
The regional power council has a resource adequacy standard. Although it is not binding on individual utilities most utilities consider it to be a useful guideline that provides a floor for their own reliability standards (Northwest Planning and Conservation Council, 2011).	P			X
Response Actions				
Governor may declare an Energy Supply Alert or an Energy Emergency, which convenes the Joint Committee on Energy Supply and Energy Conservation	P		X	

Table 5. High Risk Sector: Fish in Nature

Vulnerabilities
• Low flows expose physical blockages to migration, and can strand migrants in dewatered stream segments. • Low flows or reservoir levels shrink habitat, causing crowding, low dissolved oxygen, disease, less food available, and higher mortality of juvenile and adult fish. • High stream temperatures, due to low flow and/or higher air temperatures, can kill fish and create thermal blockage which upstream migrants will not pass. • Low flows reduce riffle depth or dry up stream reaches, preventing upstream migrants from entering streams or reaching normal spawning grounds. • Low flows shrink spawning habitats, leading to low egg survival. • Reservoir outflows can be curtailed by drought conditions, causing low-flow problems downstream.

Resiliency Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)
Work with water managers on controlled streams to assure adequate consideration is given to fish needs. Forge written agreements that will minimize water-use conflicts and become incorporated into provisions determining project operations. For example, most FERC licenses include provisions for maintaining instream flows and enabling resource managers to advise project operators during drought years.	P	X	X	X
Use the Hydraulic Project Approval (HPA) permitting authority to ensure that projects in or near the water are designed to protect fish.	P			X
Purchase water rights to restore flows in critical areas with flow-limited fish habitat. Operate the state's hatchery system to support harvestable fisheries and preserve wild stocks. Remove long-standing fish-passage barriers to prime spawning and rearing habitat to improve resiliency.	P			X

Set instream flow levels into administrative rule. Although instream flows do not put water back into the stream, they do protect existing flows from future appropriation for new uses, and from impairment from changes to existing water rights.	P			
High Risk Sector: Fish in Nature (continued)				
Response Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)
Determine which remediation methods to employ and implement in priority basins; channel modifications (such as trenching, sandbagging, or berming), temporary fishways, trapping and hauling fish, removing rock dams, or other alternatives.	P		X	
Work with water managers in highly diverted systems to develop coordinated pulse flow programs that provide temporarily adequate flows for upstream migration.	P	X	X	
Monitor for temperatures, blockages, and passage issues, including recreational rock dams, which can impede fish passage.	P	X	X	
Augment stream flows (or pulse flows) through acquisitions, temporary source exchanges, or leases and/or transfers of surface and groundwater rights.	P	X	X	
Implement signage and outreach at recreation sites to prevent construction of rock dams for recreation and to alert recreational users to the needs of stressed fish.	P	X	X	
Implement rescue operations to relocate fish from lakes and reservoirs suffering poor water quality or barrier issues.	P			
Prioritize drought-related HPA applications.	PM			
Implement emergency closures or restrictions on HPAs already issued (through permit modifications) as needed to protect fish	P			
Implement emergency rules closing or restricting pamphlet HPA activities as needed to protect fish.	P			

Assess and implement temporary changes to the Hydraulic Project Approval (HPA) permit program consistent with the provisions of RCW 43.83B.410 in order to adequately protect fish life under drought-related emergency conditions	P			

Table 6. High Risk Sector: Hatchery Fish

Resiliency Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)
Prioritize improvements for hatcheries most vulnerable to drought, such as modifying intake systems, installing chillers, or putting in back-up wells.	P			X
Modify fishways to efficiently pass fish during low flow conditions	P			X
Response Actions				
Monitor for and respond to disease problems as they occur. Agency fish pathology experts should frequently consult with individual hatchery personnel to address such problems.	P		X	
Manage dissolved oxygen levels in holding and rearing ponds with the use of bottled gas, oxygen generator systems, or mechanical aeration.	P		X	
Hatchery water supplies may need to be modified, or alternative water supplies employed, to provide adequate water supply and/or maintain adequate water quality.	P		X	
Fish may need to be released earlier or relocated to safe havens.	P		X	
Modify stream channels or make use of temporary fish collection weirs as needed to ensure fish passage to hatcheries and adequate broodstock collection.	P		X	

Table 7. High Risk Sector: Terrestrial Wildlife

Resiliency Actions	Prioritization Code	Advisory	Emergency	Ongoing Action
Protect riparian ecosystems through Forest Practice Approvals.	P			X
Prioritize habitat for protection and restoration, and encouraging development away from ecologically sensitive or vulnerable areas through watershed characterization and the Priority Habitats and Species Program.	P			X
Negotiate mitigation and settlement agreements for energy projects to benefit natural resources.	P			X
Prioritize and implement programs to sustain wildlife and protect public and private property.	P			X
Set instream flow levels into administrative rule.	P			X
Response Actions				
Increase capability to capture and relocate dangerous wildlife that may come in close proximity to the public in search of food or water, or to flee wildfires.	P			
Manage Wildlife Areas to provide additional forage for wildlife as necessary, such as reducing grazing leases, especially on winter range.	P			
Implement an emergency winter feeding program when necessary to ensure survival of wildlife.	P			
Close facilities as needed to protect wildlife or reduce fire danger.	P			
Work with landowners and local governments to prioritize and implement actions to protect water sources for fish and wildlife, including: • Construct fences and other exclusion structures to restrict wildlife access in selected areas where property damage is likely. • Where needed, temporarily impound or divert water to critical habitats or to upland watering devices. • Protect natural water sources by fencing and other infrastructure, such as piping and stock tanks, to provide water while preventing damage to riparian habitats.	P			

Table 8. High risk Sector: Public Water Supplies

Vulnerabilities					
Public water systems are generally designed and operated to avoid water shortages. However, water systems with certain characteristics may be more vulnerable. These characteristics include: • Water Systems dependent on single source (i.e., no backup) • Water systems dependent on shallow wells and unable to draw from deeper levels of declining aquifers. • Water systems dependent on aged well construction and appurtenant equipment • Water systems with excessive system leakage • Water system with low operational capacity (that ability to pump at rates which match higher demand) • Water systems which lack system redundancy • Water systems with water quality treatment concerns					
Resiliency Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)	Notes
Assist utilities in their planning prior to realizing drought impacts (WAC 246-290-100 and -105).					
Ensure the consumer metering requirement is met and leakage is evaluated and addressed per rule (WAC 246-290 Part 8).					
Response Actions					
Consult with Ecology and the Governor's Office on anticipated impacts to public water systems.	P	X	X	X	
Map "at-risk" areas for identify where at risk water systems are located to enable targeted communications based on level of risk of drought.	M	X			
Survey large and medium water systems (>20,000) in anticipation of a drought declaration to assess existing conditions, drought preparedness, and response capability.	P				
Establish regional operations contacts for addressing drought questions from water purveyors.	P	X			
Create and distribute drought related technical assistance and publications targeted to water system size and level of risk.	P	X	X		

High Risk Sector: Public Water Supplies (continued)					
Response Actions (continued)	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)	Notes
Coordinate with local health jurisdictions on Group B and private water system issues and concerns.	P	X			
Develop and maintain a list of suppliers for trucked water.	C				
Respond to phone calls, emails, and requests for information from the public.	M				
Develop an action plan for Health's Office of Drinking Water response to water systems during the drought.	P	X			
Proactively communicate with utilities in drought-sensitive water sources or locations when a drought is declared, including filling raw water reservoirs, and monitoring groundwater withdrawal and drawdown.	P				
Provide technical assistance to Ecology by evaluating requests for relief by public water systems – including emergency grant applications, temporary water rights transfers, and action on new water rights.	P		X	X	
Provide direct technical assistance to water systems that are dealing with immediate impacts from drought conditions (i.e., emergency water supplies, broken water mains, trucked water, and emergency interties).	M	X	X		
Assist water system with access to emergency funding and grant applications. Offer technical and financial assistance through our emergency Salmon Recovery Fund loans to fund infrastructure improvements, such as deepening an existing well, rehabilitating an inactive source, constructing an intertie with an adjacent utility.	PM	X	X	X	
Request Ecology prioritize review and decision making on drought response water right applications (emergency, temporary, or permanent) (i.e., write a "Hillis letter" - see WAC 173-152-050).	P	X	X	X	

High Risk Sector: Public Water Supplies (continued)					
Response Actions (continued)	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)	Notes
The USDA can support municipal water system in emergency or disaster recovery scenarios if needed. http://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/index		X	X		Federal program, but state can assist applicants.
Consult with Ecology and the Governor's Office on anticipated impacts to public water systems.	P		X	X	
Map "at-risk" areas for identify where at risk water systems are located to enable targeted communications based on level of risk of drought.	M	X			
Survey large and medium water systems (>20,000) in anticipation of a drought declaration to assess existing conditions, drought preparedness, and response capability.	P	X			
Establish regional operations contacts for addressing drought questions from water purveyors.	P	X	X		
Create and distribute drought related technical assistance and publications targeted to water system size and level of risk.		X			
Coordinate with local health jurisdictions on Group B and private water system issues and concerns.		X		X	
Develop and maintain a list of suppliers for trucked water.	C				
Respond to phone calls, emails, and requests for information from the public.	MP				
Develop an action plan for Health's Office of Drinking Water response to water systems during the drought.					
Proactively communicate with utilities in drought-sensitive locations or with drought-sensitive sources when Ecology and the Governor declare drought, including filling raw water reservoirs, and monitoring groundwater withdrawal and drawdown					

Table 9. High Risk Sector: Recreation

Vulnerabilities					
• Low snowpack can render areas unsuitable for skiing, snowboarding, snow-showing, snowmobiling and other forms of winter recreation. • Low flows can render rivers and streams unsuitable for whitewater kayaking, rafting and canoeing. • Low reservoir levels can strand boat ramps, making the reservoir inaccessible for flatwater boating.					
Resiliency Actions	Prioritization Code	Advisory	Emergency	Ongoing Action (outside drought)	Notes
Some ski resorts are taking action to diversify their operations to include revenue generating activities in the summer (e.g. mountain biking, summer concerts, water slides, etc.)				X	
Response Actions					
Boat launch modifications: Extreme low water conditions can trigger the need to extend boat launches to keep them open. In some cases, gravel and rock berms that are created by repeated boat retrievals must be removed to keep a ramp open.			X		
Downhill ski resorts and river guide services are private enterprises and generally not eligible for state funding. They may be eligible for Non-Agricultural Economic Injury Loans issued by the federal Small Business Administration. Snowmaking machines can compensate for the lack of snow, but their effectiveness is diminished in warm winters. Another strategy is to use machinery to concentrate snow where ski runs need it.					Federal Program
WDFW has used drought monies in the past to maintain access to fishing opportunities, such as extending boat ramps in drawn down reservoirs, and issuing closures to fishing activity to preserve fishing opportunities in the long run.			X		
Access to state lands for recreational purposes when drought condition raise wildfire risk is overseen by the Department of Natural Resources.	P	X	X		

Effectiveness of Existing Framework

Goals and priorities for state agency drought response and planning are established by the Washington State Legislature, which has emphasized an emergency response framework. The Legislature expressed its intent that the state be able to take actions "…in a timely and expeditious manner, that are designed to alleviate hardships and reduce burdens on various water users and uses arising from drought conditions."

Washington State's framework provides a discrete set of tools for addressing water shortages and alleviating hardships. These tools include expedited emergency water right permitting and supplemental funds to support agency drought response and grants and loans to public entities at risk of drought-caused hardship.

How well does the existing framework achieve the goals set out by the Legislature? To the extent water supply emergencies can be solved via temporary changes to existing water rights, the current process provides an expedited pathway. This process is particularly valuable for junior users who otherwise would be curtailed in order to protect senior water rights.

Alleviating hardship may also require the installation or construction of emergency infrastructure (e.g., pumps and wells). To support these needs, the state has provided funding in times of drought to provide both grant and direct assistance to water users who are at risk of hardship. This funding has been instrumental in averting costs and losses of a much greater magnitude. This is true particularly in the Yakima Basin, where financial support for emergency wells and water right transfers is provided to irrigation districts with junior water rights who are growing high value, permanent crops.

The existing drought response framework does have weaknesses which challenge the state's ability to alleviate hardship and reduce burdens on water users in drought years. Most concerning is that most water supply imbalances cannot be solved in the context of a limited, emergency declaration. Water supply imbalances generally require longer term, more strategic solutions that arise out of multi-party discussions at the watershed level, analysis of alternatives, and significant public and private investment. An emergency framework, where the goal is timely and expeditious decision-making, does not support this type of approach.

Other weaknesses in the current framework include the following points:

- The lack of a dependable funding source causes uncertainty in drought response. It makes it difficult to plan the scale and scope of drought response and communicate intentions to external parties.

- How funding is routed to Ecology and other agencies can cause delays in drought response. Money routed to Ecology before disbursal to other agencies is delayed by contracting and other administrative requirements.

- Conditioning the award of emergency grants to only projects which will have benefit in the current drought emergency limits the number of projects which can be approved. Design work, bidding of contracts, scheduling of work and permitting, etc., make it difficult to complete projects before drought conditions improve as the water year concludes. In 2015, most applications for emergency drought relief funds were rejected, some of them because it not clear that the project could be completed before expiration of the current drought emergency declaration.

- Implementation of an emergency grant and loan program, when funded in an ad hoc manner, requires Ecology to complete an emergency rule-making process. This process diverts time and resources away from actual drought response. It would be preferable if the emergency rule-making was not necessary. A predictable funding structure embodied in statute, with stable funding criteria, would make it easier for Ecology, via a permanent rule, to stay in sync with legislative priorities.

- Emergency rules also are limiting in that they may only be in effect for 120 days, or about four months. An emergency rule may only be extended if the intent is to draft a permanent rule. Drought conditions may extend beyond four months. This is another reason a more stable funding structure would be preferable to ad hoc drought funding.

- Establishing emergency water right leasing in the context of a drought year has had mixed success. It was worked well where the objective is to enable farmers to forgo a late season cutting of hay. This provides more time to plan and finalize agreements. But where the expectation is for participating farmers to forgo an entire season's crop, rolling out a leasing program in early spring is too late.

- Waiting until a drought year to lease water means paying a premium for water. Negotiating long-term dry year lease options can provide better pricing and surety.

- The emphasis on emergency response and the anticipation of drought conditions places great weight on the skill of seasonal water supply forecasting. In the Yakima Basin, official water supply forecasts are not made available until early March. This challenges the ability to roll out drought response measures in the Yakima Basin in time for irrigators to incorporate them into their own planning. Obtaining probabilistic water supply forecasts earlier in the season would provide more lead time for mobilizing outreach for a leasing program (though long-term dry year lease options would be preferred).

Sector-Specific Assessment of Existing Framework

Agriculture

The 2015 drought had significant impacts on the agricultural industry even with the state response actions. WSDA completed an analysis of the impacts of the 2015 drought on the agricultural economy. The report analyzed the combined effect of both extreme heat and reduced water availability and determined that the effects of the 2015 drought were significant and widespread. Some notable impacts from the report are an estimated loss of nearly $200 million to the wheat industry and losses totaling over $75 million in the Roza Irrigation District (a proratable irrigation district in central Washington). The report conservatively estimates statewide impacts to agriculture between $633 million and $773 million. These losses would likely have been much higher without state response actions such as permits for use of emergency drought wells and expedited water leasing arrangements.

At this time, there are no tools in place to assist the dryland farmers during times of drought. The impacts to the wheat industry made up over 25 percent of the estimated agriculture losses in the state. Developing methods to mitigate impacts to dryland farmers could greatly reduce drought impacts on the agricultural economy. The findings of the report also highlight the need for additional storage to provide pro-ratable districts with water during times of curtailment.

The impact of drought on agriculture could be reduced if appropriate resources were available to meet some or all of the following goals. These goals are targeted to reduce the vulnerabilities discussed in the Vulnerability chapter of this report.

- Development of an ongoing data collection network to monitor impacts to agricultural production. This background data would be useful in comparing impacts between different climatic events (including different types of drought) and could be used to target relief efforts based on climatic conditions.

- Additional research into modifying irrigation water rights to increase drought resiliency. Because of the potential for warmer winter and spring temperatures and the resulting change in both the timing of spring runoff and evapotranspiration rates in agricultural crops, it may become necessary to begin irrigation earlier than historically necessary or currently legal relative to irrigation water right turn-on dates. Also, evapotranspiration rates may increase with warmer temperatures requiring earlier planting dates than we are accustomed to. Additionally, a regulatory allowance for earlier diversion of water would allow for shallow aquifer recharge utilizing existing irrigation conveyance systems.

- Additional support and funding to the Washington Conservation Commission and regional conservation districts for irrigation efficiency education, training, and equipment specifically targeted in regions vulnerable to the impacts of drought.

- Increasing the efficiency of irrigation application systems can reduce water demand. Much wider adoption of technologies such as LEPA (low energy precision application) and LESA (low elevation sprinkler application) could conserve large amounts of water, and this conservation is greatest during the times of greatest shortages. Half of irrigated acreage in Washington is under center pivots, and LESA gets 18 percent more water to the ground per gallon pumped, so these savings could be substantial. https://www.bpa.gov/EE/Sectors/agriculture/Pages/LEPA%20and%20LESA.aspx

- Funding of additional research in dryland farming resiliency, for example, studies focused on using cover crops and No-Till to build soil structure, improve soil health, and increase water holding capacity. Soil scientists report that for every 1 percent of organic matter content, the soil can hold 16,500 gallons of plant-available water per acre-foot. That is roughly 1.5 quarts of water per cubic foot of soil for each percent of organic matter. (Sullivan, 2002)

- To assist in mitigating for low flows, the state, through technical assistance, could assist agriculture to increase soil health. Soil tilth improvement through the use of cover crops in dryland agriculture is being studied by the Okanogan Conservation District.

- Funding additional research into evapotranspiration and crop coefficient estimation. Often, crop coefficient data that is currently published for use by Washington growers was developed in other regions of the United States. Localized data could lead to increased water savings when combined with relative evapotranspiration rates available to growers through the AgWeatherNet system at Washington State University.

- Ongoing monitoring of groundwater levels to determine trends statewide. This could be prioritized to basins most sensitive to drought conditions.

- State funding for localized water storage projects and research to increase available water supply. Storage is a compensator for the loss of snowpack water storage and retiming of river flows. One alternative is for small storage projects in the lowlands near the end users, although due to land-use conflicts, this may prove difficult in some areas. Working to keep water longer in the uplands may be preferable. Higher elevations and increased canopy cover associated with the uplands could keep water temperatures lower and hence better for aquatic species. Much research is being done regarding this idea, including the use of beaver-derived and manmade biogenic dams, which are examples of strategies to improve water retention in shallow riparian aquifers.

- Increase state investment in conservation education through conservation districts and the Washington State University Extension. This would include direct technical assistance to landowners and irrigators to develop farm plans and irrigation water management plans using both drought-potential and climate change-potential conditions as planning considerations.

- Increase state investment in the AgWeatherNet. The addition of more weather stations would allow broader access to evapotranspiration and soil moisture data. The information provided by the AgWeatherNet system allows irrigators to make data-informed decisions about irrigation scheduling. This recommendation would not only include additional weather stations, but the addition of soil moisture equipment at existing stations lacking them.

Drinking Water

Washington State's existing framework is highly effective for reducing drought vulnerabilities in the drinking water sector because it entails the continuous evaluation and reduction of risks to water system reliability by system managers. This is less the case for smaller water systems, however, which may lack professional operation and management, and the financial resources to invest in infrastructure improvements. The Department of Health supports efforts by larger systems to acquire and consolidate smaller systems.

Another exception is that, although state drought response emphasizes providing assistance to public entities, private well owners are not eligible for emergency funding. However, the state can provide funding to local governments such as county public works or environmental health departments which, in turn, may be able to offer support to private homeowners. The state should encourage and support local governments in the creation of their own drought contingency plans as a means of bridging the gap between state assistance and small, private water users.

A further concern is that the state does not track whether water systems of any size experience drought-caused problems of any kind. This limits the ability of the state to confidently estimate the likelihood that water systems are likely to experience hardship conditions during anticipated drought conditions. Improving its data collection should be a goal and priority for the Department of Health.

Power Supply

Washington State's power supply framework is highly resilient to drought impacts due to existing, long standing coordination agreements between power producers allowing the exchange of power from a common pool. Generation in the Northwest is diversified and, over time, has become increasingly less dependent on hydroelectric energy. Hydroelectric energy still makes up the majority of Washington's energy supply.

The Department of Commerce is the state agency response for state energy planning. It should continue to keep the State Water Supply Availability Committee and Executive Water Emergency Committee informed regarding developments in the energy section which may increase the vulnerability of energy supplies in the Northwest. Commerce should also take the lead in communicating with the energy sector during low water years and in developing communication messages to the public in conjunction with major power utilities.

Fisheries

Drought is an additional, high intensity stressor to the long list of factors already limiting fish populations. Drought occurs at a landscape scale and thus poses a significant challenge for resource managers. In areas where there is existing infrastructure – for example, a large storage reservoir – it may be possible to augment water supplies, but for most of the state, ensuring the protection of quality habitat may be the best assurance of resiliency. With good habitat, fish populations can recover from short term drought conditions.

Washington State's existing drought framework does not match the regional scale of fisheries impacts arising from drought conditions. In 2015, waterbodies throughout the Columbia Bain reached lethal temperatures. Emergency fish response actions in isolated instances to save relatively small numbers of fish are important, especially if they represent unique stocks of high ecological and culture significance. Still, these actions are unlikely to be adequate at landscape scales

Ensuring that habitat can provide refuge in times of drought is a long-term effort which requires the cooperation of multiple jurisdictions using both regulatory and non-regulatory approaches. WDFW is charged with advocating for fish, but has limited regulatory authority over land use decisions and other actions which directly, indirectly, and cumulatively degrade watersheds. WDFW's mission is further made difficult by the fact that salmonid species are dependent on favorable marine conditions to complete their life cycle. One can say that most of the habitat needed for Washington salmon to thrive is outside of WDFW jurisdiction. In 2015, warm ocean temperatures and the absence of upwelling nutrients compounded the severity of drought impacts and sharply reduced the numbers of returning salmon.

WDFW has more direct control over its own facilities, such as fish hatcheries. These facilities play an essential role in fish production and restoring depleted runs, especially in areas of degraded habitat.

WDFW goals for improving mitigation include the following:

- Assess hatcheries for relative vulnerability to drought, and identify investments needed for mitigation. These investments could include redesigning water intake systems, installing chillers, or developing back up wells. Any investments would be subject to funding availability.

- Assess the relative vulnerability of watershed basins statewide, and develop enhanced monitoring protocols for those determined to be highly vulnerable. Developing a common understanding of vulnerable systems will also allow for the possibility of more targeted investments into habitat restoration projects and restoring aquatic connectivity.

Planning for Climate Change

While Washington State's drought response framework emphasizes emergency response, planning for long term climate change is an important part of preparedness. Changing climate conditions are expected to push the Pacific Northwest into a more frequent state of "snowpack drought." Following recent droughts, many have raised the question, "is this the new normal?" Given the relatively large year-to-year variability in the Northwest's climate, this can be a challenging question to answer.

The Climate Impacts Group at the University of Washington has explored this question using a "time of emergence" concept illustrated in Figure 12. The time of emergence is defined as the year when the climate change signal – represented by the slope of the linear trend from a climate projection – no longer falls within the range of historical variability[5]. In other words, it represents when the climate change signal "emerges" from the noise of past climate variability.

[5] Users can specify the size of the range (e.g., 60% or 90% of the range of historical variability). It should be noted that the estimates for the time of emergence are sensitive to the assumptions about the point at which impacts occur, i.e., "how low does snowpack need to be to cause a problem?"

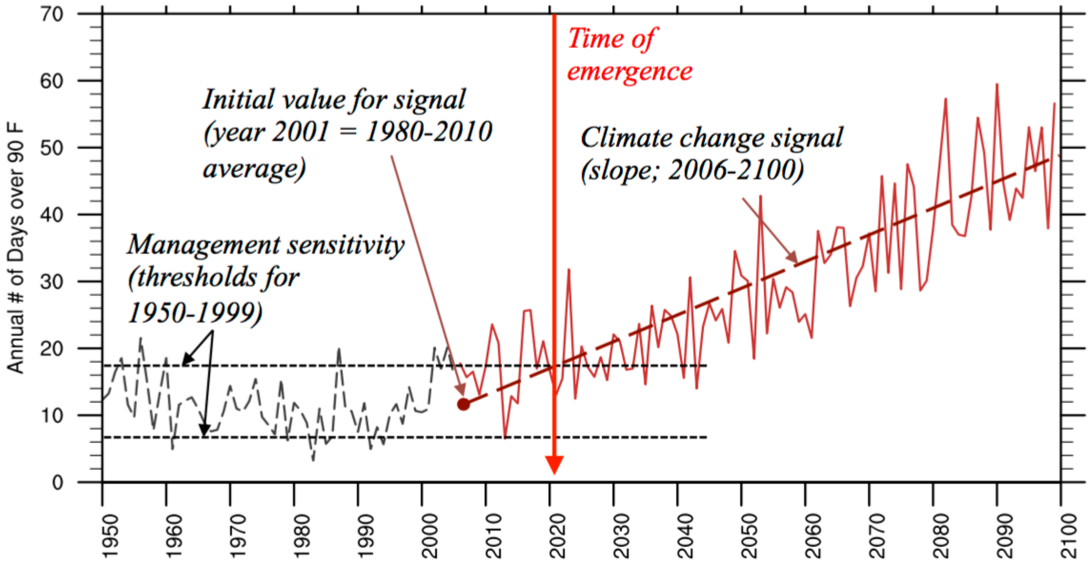


Figure 12 Illustration of how to identify the "time of emergence", or when the climate change signal becomes separate from normal year-to-year variability for a particular variable. From the Climate Impacts Group: http://toe.cig.uw.edu/sites/default/files/content

Some general conclusions[6] regarding estimates of the time of emergence for hydrologically important variables include:

- Changes in average temperature typically emerge across the region sooner (next few decades) than other results. This means that future water demands in the spring and summer are likely to be greater than in past decades, and that past patterns in demand are not predictive of future conditions.
- Most variables related to seasonal and annual precipitation do not emerge until the second half of the 21st century. These changes are also not as spatially broad as those for temperature and snow.
- The trend toward lower spring snowpack will emerge at different times in the Cascade Mountains depending on how "management sensitivity" is defined. For resource managers with greater sensitivity to low snowpack, the "new normal" for low snowpack would emerge in the coming decades; for those managers with the ability to tolerate a greater range of snowpack conditions, the low snowpack conditions would not emerge until later in the 21st century (Figure Y).

[6] The time of emergence results can be explored at several different interactive websites: https://public.tableau.com/profile/robert.norheim#!/vizhome/TimeofEmergenceTemperatureMap/TimeofEmergence; https://public.tableau.com/profile/robert.norheim#!/vizhome/StreamFlowVizDraft_0/AnnualStreamflowMetrics; and http://toe.cig.uw.edu/

- For watersheds where snowmelt contributes to spring and summer streamflow, lower streamflow emerges in many locations in the 21st century. Emergence tends to occur earlier (prior to 2050) for streamflow in June and July, and slightly later (after 2050) for August and September.

Climate change projections for Washington State, and their implications for drought, are discussed further in Appendix A.

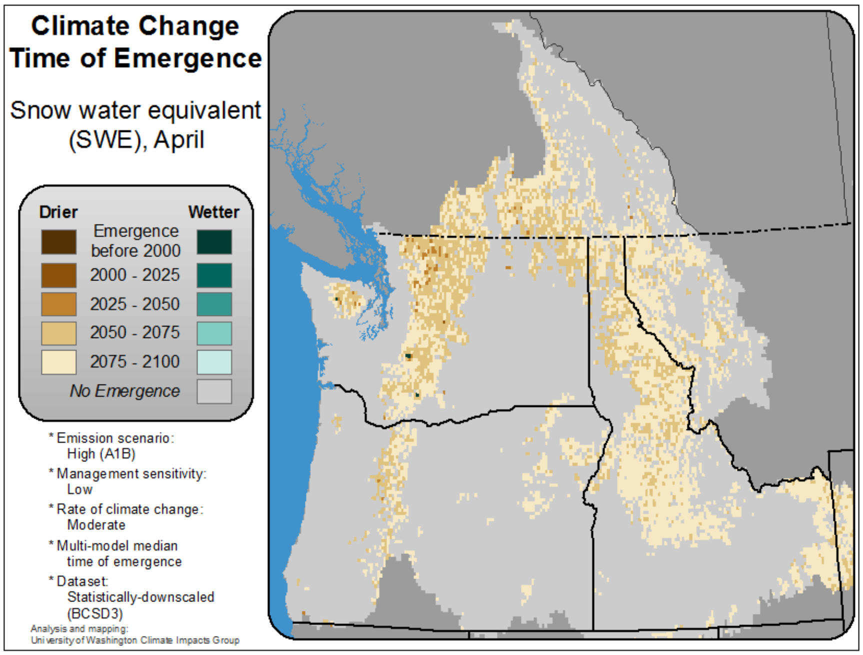


Figure 13. Climate Change Time of Emergence: Snow Water Equivalence – Low Sensitivity

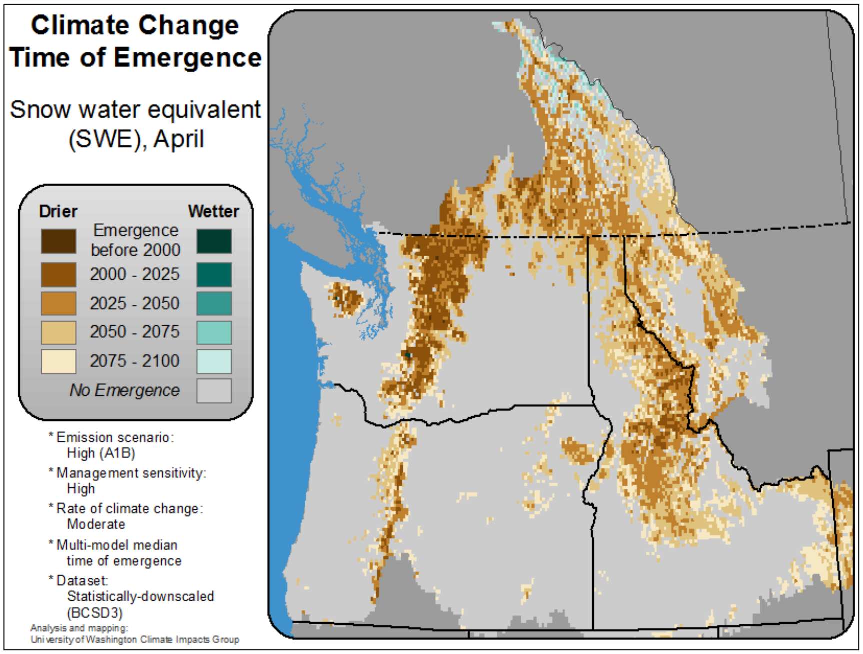


Figure 14. Climate Change Time of Emergence: Snow Water Equivalence – High Sensitivity

Time of emergence for reductions in April 1 snow water equivalent (SWE) for a high emissions scenario for low sensitivity (Figure 13) and high sensitivity (Figure 14). Regardless of the assumptions about the point at which impacts occur ("the management sensitivity"), the trend toward lower snowpack emerges throughout the Cascades in the 21st century (Climate Impacts Group).

With the time of emergence concept in mind, it is critical to continue to track drought impacts as we also monitor our changing climate so that the bounds of management sensitives can be better understood. Post-drought impact assessments are useful for this. It also is important to build a continuing record of impacts as they occur in less anomalous years as well. This will help indicate when the amount of normal "wear and tear" is becoming significantly different than that experienced historically.

Two examples underway of efforts to build this period of record include:

- As part of their annual water system inventory surveys, the state Department of Health's has committed to begin tracking public water systems which encounter water shortages due to drought conditions.
- The Department of Agriculture is collaborating with NASA to begin tracking the amount of fallowed land from one year to the next.

At a statewide level, Washington State's Integrated Climate Response Strategy, lays out a framework that decision-makers can use to help protect Washington's communities, natural resources, and the economy from the impacts of climate change. Actions pertaining to water availability in particular include the following:

- Manage water resources in a changing climate by implementing Integrated Water Resources Management approaches in highly vulnerable basins.

- Improve water supply and water quality in basins most likely to be affected by changing climate.

- Implement water conservation and efficiency programs to reduce the amount of water needed for irrigation, municipal, and industrial users and to improve basin-wide water supply.

- Build the capacity of state, tribal, and local governments; watershed and regional groups; water managers; and communities to identify and assess risks and vulnerabilities to climate change impacts on water supplies and water quality.[i]

As Washington State's climate warms and snowpack declines, it will become increasingly critical for the state to find solutions which compensate for the loss of natural water storage in the form of snow and ice. Water markets, water reuse and reclamation, new technology, and conservation and efficiency measures will be key, but may not be enough to totally offset the loss of snowpack.

The state will need to evaluate opportunities for new water storage. Additional storage may take the form of 1) large new reservoirs; 2) smaller off-channel storage reservoirs; 3) enhancing storage at existing reservoirs; 4) aquifer storage; or 5) adopting development standards which preserve and enhance the infiltration of surface runoff into groundwater supplies. This analysis is already underway in the Columbia Basin, under the leadership of the Office of Columbia River, in cooperation with federal, state, and local governments and major water users. Whether it is appropriate or necessary to replicate this approach on the west side of the Cascades is a large public policy question that is beyond the scope of this plan. Still, it is reasonable to assume that doing so would provide more financial and analytical support for water supply resiliency projects in west side watersheds.

Drought Monitoring and Forecasting

Drought monitoring indicators

The simplest definition of drought is “insufficient water to meet needs” (Redmond 2002), but ultimately drought can be defined in different ways depending on the impacts experienced. For example, drought can influence water supply and quality, stream habitats, forest health, and hydropower generation. A large number of indices of varying complexity have been developed, some which rely solely on meteorological conditions while others include hydrological information such as soil moisture. Different indices reflect different meteorological and hydrologic properties and it is therefore recommended that multiple drought indices be used to characterize droughts and their potential impacts (Heim 2002).

While Washington State’s formal definition of drought is based on water supply, consideration of multiple drought indicators can provide complementary information and a more comprehensive perspective on the state of the system. Here we summarize some of the most relevant drought indicators in the region. We also highlight during what stage of drought (i.e., onset, existing, and the end) each indicator is most suitable. A more comprehensive list of drought indicators can be found in the Handbook of Drought Indicators and Indices by the World Metrological Organization and Global Water Partnership (2016) although their utility for the Pacific Northwest is not explored.

Most of the drought indicators described below use multiple variables in their definition, but there are several stand-alone variables that are quite useful for assessing drought conditions. The state’s Water Supply Availability Committee (WSAC) already uses many of these to monitor drought on a monthly basis. For example, the average temperature departure from normal, percent of normal precipitation, and streamflow percentiles are commonly assessed and can be determined for multiple time scales. Ideally, the “normal” period is at least 30 years long. At the time of this writing, the official National Oceanic and Atmospheric Administration (NOAA) climatological period is from 1981 to 2010.

Current mountain snowpack conditions in the form of snow water equivalent are also extremely useful during the winter months. Derived quantities such as the percentage of normal for that particular time of year, or the percentage of peak snowpack can be very useful in assessing the statewide conditions. Another example would be stream temperatures in the spring and summer months when high temperatures can indicate unfavorable conditions for certain species of fish. All of these indicators have the strengths that they are relatively easy to understand and communicate to others, and are accessible. On the other hand, more sophisticated indicators, as described below, may have the potential to identify a developing drought sooner, which puts the state in a better position to respond quickly and proactively.

The improvement of subseasonal and seasonal weather forecasts has become more of a priority for the weather/climate community. Present research is focusing on the potential sources of predictability, and the methods for combining various sources of information to produce the best calibrated predictions including attendant uncertainties.

On sub-seasonal time scales, a cycle on the 30-60 day time scale known as the Madden-Julian Oscillation (MJO) shows considerable promise. The MJO is a tropical phenomenon with remote effects on the higher-latitude circulation that are akin to those associated with El Niño-Southern Oscillation. Experimental forecasts on the time scale of 3-4 weeks into the future are now being produced by the National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center; these forecasts are based on the MJO and extended predictions from operational weather models. Continued development of capabilities on these time scales is indicated in HR 353, "The Weather Forecasting and Innovation Act of 2017," an authorization bill passed by Congress and signed into law in April 2017. In particular, Section 201 of this bill is titled "Improving subseasonal and seasonal forecasts." Progress in forecast skill is not expected to be rapid. Still, given the interest and importance of weather predictions on intermediate time scales, it may be possible to anticipate the onset and cessation of droughts with somewhat more lead time in the foreseeable future.

The timing and magnitude of the early fall rains heralding the end of the dry season are matters of substantial concern to many utilities, water managers, and other interests in Washington State. There is considerable variability in the onset of the wet season. For example, the September of 2012 was the second driest on record with only 0.16" of precipitation in terms of the statewide average; the following September of 2013 was the wettest on record with 5.60". Wetter weather tends to arrive at least by October but even here there are notable exceptions such as October 1987, during which only 0.25" (about 7 percent of normal) precipitation occurred statewide. Unfortunately, there is tentative evidence that seasonal forecasts of precipitation in Washington during fall are especially problematic. The recent track record of forecasts from NOAA's Climate Prediction Center indicates a relative lack of predictability for that time of year.

It is quite possible that there exist real barriers to forecast skill on seasonal time scales as the atmospheric circulation transitions from its summer to winter regime. It is possible that improvements in sub-seasonal forecasts may help during this time of year. Still, it should be recognized a small number of storms make the difference between dry and wet conditions, effectively limiting our ability to anticipate changes in water supplies with much confidence.

The following indicators are grouped by whether they focus on meteorology or hydrology. Within each category, they are listed from simple to more complex. There are also several indicators that are composites or blends that are grouped into a third "Composite" category.

Meteorological indicators

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) was first developed in Colorado in the early 1990s as an alternative drought index to the Palmer Drought Severity Index, described below (McKee et al 1993). The Standardized Precipitation Index is now considered to be the global standard index to identify meteorological drought by the World Meteorological Organization (Hayes et al 2011; WMO and GWP 2016).

The index uses only precipitation and requires at least 30 years of complete data, although missing data are allowed (McKee et al 1993). Precipitation is standardized using the mean and standard deviation over the period of record (McKee et al 1993), and the probability of occurrence is determined by fitting the data to a Pearson Type III distribution (Guttman 1999).

The index spans values from -4 to 4 to indicate dry and wet periods. A value of -1 usually signifies the beginning of drought and as the index becomes more negative, it indicates increasingly severe and infrequent conditions (McKee et al 1993).

Strengths of the Standardized Precipitation Index include the ability to identify dry and wet periods on multiple time scales (weekly to monthly to yearly), ease of use and availability (maps are available at the Western Regional Climate Center[7]), and consistent interpretation throughout the country (Guttman 1998, WMO and GWP 2016). The weaknesses are that the Standardized Precipitation Index is only a precipitation index, and does not consider temperature, nor does it differentiate precipitation that falls as rain or snow (WMO and GWP 2016).

Crop Moisture Index

Palmer (1968) developed the Crop Moisture Index (CMI) as a response to criticism received about the Palmer Drought Severity Index (discussed below). It is a simple index meant to assess moisture on the short time scales for agricultural interests. It uses temperature and precipitation as an input and a simple temperature-based estimation of potential evapotranspiration. The index is calculated on a weekly time scale and is the difference between the potential evapotranspiration and the moisture received (WMO and GWP 2016). Weekly maps are available at the Climate Prediction Center.[8]

Since the Crop Moisture Index is a short-term index, it may depict recovery from a long-term drought when in actuality long-term deficits persist. In addition, it resets to zero at the beginning of the growing season, and thus ignores multi-year drought (Keyantash and Dracup 2002). It is most effective during the warm season (Heim 2002), and is likely only relevant for non-irrigated agricultural areas of Washington State (e.g., dryland wheat and pastures).

Standardized Precipitation Evapotranspiration Index

The Standardized Precipitation Evapotranspiration Index (SPEI) is a relatively new index that is similar to the Standardized Precipitation Index, but also includes temperature through estimating potential evapotranspiration (Vicente-Serrano et al 2010). Like the Standardized Precipitation Index, the Standardized Precipitation Evapotranspiration Index is available on monthly time scales, but can be calculated for varying time periods (e.g., weekly and daily). It identifies both wet and dry periods and can be compared between different locations.

Since the Standardized Precipitation Evapotranspiration Index includes a temperature component, it is one of the few indices that can be used to identify trends due to a warming

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[7] SPI: http://www.wrcc.dri.edu/spi-products/

[8] CMI: http://www.cpc.noaa.gov/products/analysis_monitoring/regional_monitoring/cmi.gif

climate. In other words, it is one of the few indices that can identify an increase in drought severity in a warmer climate due to higher water demand (Vicente-Serrano et al. 2010).

Monthly maps of SPEI can be found on the WestWide Drought Tracker website.[9] Monthly maps can be considered a weakness as the SPEI may miss a rapidly developing drought on a shorter time scale. Additionally, maps on the WestWide Drought Tracker site use estimated potential evapotranspiration using only temperature and the Thornthwaite equation (1948), which fails to represent evapotranspiration as well as more physically explicit calculations (Hobbins et al. 2016). More sophisticated methods of calculating potential evapotranspiration can be used, however, if more input data are available. Finally, the SPEI cannot be calculated if there are missing data, making it less ideal in data poor regions.

Reconnaissance Drought Index

The Reconnaissance Drought Index is based on precipitation, similar to the Standardized Precipitation Index, but it also includes potential evapotranspiration, making the index more representative of the full water balance (Tsakiris and Vangelis 2005). Ideally, the actual evapotranspiration would be used since that represents the real system output, but since actual evapotranspiration is rarely measured and sensitive to local effects, the index relies on pET estimated using temperature and the Thornthwaite equation (1948). Of course these simple estimates based on temperature can be prone to error. Tsakiris and Vangelis (2005) found that the Standardized Precipitation Index often underestimated drought severity in their case study locations in Europe. However, adding in pET does give a more realistic representation of drought severity.

Like the Standardized Precipitation Index, the Reconnaissance Drought Index can be calculated on multiple time scales, and the standardized version can be directly compared to the Standardized Precipitation Index. It is similar to the Standardized Precipitation Evapotranspiration Index in that it uses similar inputs; however, it is calculated differently. While software to calculate the Reconnaissance Drought Index is available,[10] real-time maps do not appear to be publically available, making it problematic for monitoring conditions in Washington.

Palmer Drought Severity Index

The Palmer Drought Severity Index was developed in the mid-1960s (Palmer 1965) and became the first widely used drought index. The index uses monthly precipitation and temperature as inputs, and then makes assumptions about the water content of the soil and evapotranspiration to compute a water balance. The Palmer Drought Severity Index is often referred to as a "meteorological drought" index, but it does reference hydrology and agriculture within its definition (Alley 1984), and has been highlighted for its usefulness in agricultural drought (Guttman 1998).

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[9] SPEI: http://www.wrcc.dri.edu/wwdt/index.php

[10] RDI: http://drinc.ewra.net

The main strengths of the Palmer Drought Severity Index are that it has been in use for a long time, has an easily accessible historical record, and is generally well known. There have been many studies that have highlighted its weaknesses, however. The most important shortcoming for application in the Pacific Northwest is that the index does not account for water stored as snow and assumes that precipitation is immediately available. It is therefore unsuitable during periods when snow water storage is important (Zargar et al 2011). Other criticisms include that it was originally developed for Iowa and Kansas, and thus the assumptions may not be as applicable to the Northwest; that the thresholds for the severity of drought are somewhat arbitrary; and that soil type, soil moisture, and evapotranspiration do not change seasonally or with vegetation (Alley 1984).

It has also been recognized that since the Palmer Drought Severity Index is based on water balance, it is a long-term index that can lag behind the start of a drought (Guttman 1998). It is therefore not well-suited for identifying the onset or end of a drought. Weekly Palmer Drought Severity Index maps are available from a number of sources including NOAA's Climate Prediction Center.[11]

Evaporative Demand Drought Index

The Evaporative Demand Drought Index (EDDI)[12] is a new index that has the potential to identify developing drought conditions sooner than other indicators (Hobbins et al 2016; McEvoy et al 2016). The index computes potential evapotranspiration based on the North American Land Data Assimilation System (described below) model input (e.g., air temperature, specific humidity, pressure, solar radiation, wind) data, and is implemented on a 0.125° grid across the United States. The potential evapotranspiration computation uses the Penman-Monteith formula, which is a more physically based estimation than using temperature alone (Hobbins et al 2016). The evaporative demand, or potential evapotranspiration, is then compared to the climatology over the period of interest.

Like many of the other indicators, the Evaporative Demand Drought Index can be computed on weekly to monthly time scales. In addition, the classification scheme is the same as the one used for the U.S. Drought Monitor (described below) – with the dry categories ranging from D0 to D4 (Hobbins et al 2016).

McEvoy et al (2016) showed that the Evaporative Demand Drought Index identifies drought periods consistent with other indicators, such as the Standardized Precipitation Index, and has the potential to identify the onset of drought up to two months before the U.S. Drought Monitor shows drought conditions. Hobbins et al (2016) illustrates the characteristics of the index using four example basins (none in Washington State). They showed that the longer-term Evaporative Demand Drought Index calculations (10-12 months) were the best at identifying drought in the Upper Colorado and identified drought before it was depicted in the U.S. Drought Monitor.

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[11] PDSI: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif

[12] EDDI description: http://wwa.colorado.edu/publications/reports/EDDI_2-pager.pdf

Hobbins et al (2016) hypothesized that shorter-term, the Evaporative Demand Drought Index did not match the drought conditions as closely because of the snowmelt-dominated hydroclimatology of the basin. In other words, the Evaporative Demand Drought Index would show dry climate anomalies during the snowpack season while the Drought Monitor may not depict drought until the impacts are seen in the irrigation season up to five months later. Though not tested, this may be the case for Washington as well: the long-term Evaporative Demand Drought Index may be better suited for the snowmelt basins in Washington and the short-term version may be better suited for those that are more precipitation-dominated.

Exactly what defines "long-term" and "short-term" for Washington State remains to be seen since our recent droughts have not been multi-year events. It is worth monitoring this product in the coming years to assess its applicability to Washington State, and whether it can be used as an early drought indicator. Since it is a very new product, it has undergone less scrutiny than some of the other indicators, so caution is warranted. While this is still an experimental product, online maps are produced for Washington State on a weekly basis.[13]

Hydrological indicators

United States Geological Survey streamflow percentiles

The United States Geological Survey (USGS) monitors streamflow throughout the US, with just over 300 real-time stream gauges in Washington State. Percentiles of real-time, daily, 7-day average, 14-day average, 28 day-average, and monthly streamflow are available at these stations at USGS.[14] Record length varies at these sites, with many sites having at least a 65-year record. These sites are useful during ongoing drought, particularly during the low flow summer season, and could potentially be used in determining the end of drought.

Palmer Hydrological Drought Index

The Palmer Hydrological Drought Index (PHDI) is very similar to the Palmer Drought Severity Index (PDSI), and was created as a part of Palmer's drought suite (Palmer 1965). Similar to the Palmer Drought Severity Index, it uses monthly temperature, precipitation, and default values for the water-holding capacity of the soil as inputs. The difference is that the Palmer Hydrological Drought Index is meant to reflect hydrological conditions on longer time scales. In other words, it is slower to end a drought than the Palmer Drought Severity Index. According to Keyantash and Dracup (2002), "the PDSI considers a drought finished when moisture conditions begin an uninterrupted rise that ultimately erases the water deficit, whereas the PHDI considers a drought ended when the moisture deficit actually vanishes." For this reason, the Palmer Hydrological Drought Index may be particularly useful for indicating the end of a drought through its monitoring of the water supply.

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[13] EDDI: ftp://ftp.cdc.noaa.gov/Public/mhobbins/EDDI/WADOE/

[14] Streamflow Percentiles: https://waterwatch.usgs.gov/index.php?m=real&r=wa&w=map

Similar to the Palmer Drought Severity Index, the Palmer Hydrological Drought Index lacks a snow component and is therefore unsuitable for locations and times for which the snowpack represents a significant portion of the water supply. Additionally, irrigation and management decisions are not taken into account in terms of demands (WMO and GWP 2016). Monthly maps of the Palmer Hydrological Drought Index are available at the National Centers for Environmental Information.[15]

Surface Water Supply Index

The Surface Water Supply Index (SWSI) resembles the Palmer Drought Severity Index with the inclusion of additional data on water supply (snowpack, streamflow, and reservoir data) as well as precipitation. It is calculated for basins on an individual basis with the weighting of the different contributions to the water supply specific to the basin (Shafer and Dezman 1982; Doesken et al 1991).

The Surface Water Supply Index works best in basins that have reservoir storage, which is not the case for every snowpack-dominated basin in Washington. Because the calculations and components vary by basin, it is not advised to make comparisons between regions (WMO and GWP 2016). On the other hand, this index has the important attribute that it directly accounts for snowpack and was developed with western drought in mind. For that reason, it has predictive capabilities since hydrologic responses are often lagged in snowmelt-dominated basins (Doesken et al. 1991).

It is used by other western states in their drought plans (e.g., Colorado), but is not calculated or available for Washington. It requires long-term and consistent data sets for calibration, but is an index that could be considered for use throughout Washington with additional research.

UW Drought Monitoring System for the Pacific Northwest

The UW Drought Monitoring System for the Pacific Northwest[16] is a near real-time (1 day lag) model-based system that represents hydrologic conditions throughout the Pacific Northwest, including the Canadian part of the Columbia River Basin. The system ingests meteorological station observations, which are processed and gridded to create a 1/16° data set that is used as input to a macroscale hydrological model (the Variable Infiltration Capacity (VIC) hydrologic model; Liang et al 1994). The hydrological model then creates daily gridded fields of soil moisture and snow water equivalent, which are combined as total moisture. The drought monitor displays these fields as percentiles relative to the same day for the historical period of 1920-2010. For example, a percentile value of 80 percent on May 1 means that the current May 1 is wetter than 80 percent of the May 1 days during 1920-2010.

The system includes an archive that allows the user to view the percentile maps for other drought years on a monthly time scale. In addition to gridded maps of current soil moisture, total moisture, and snow water equivalent, the option exists to view the current calendar year time

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[15] PHDI: https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/

[16] UW Drought Monitoring System: http://www.hydro.washington.edu/forecast/monitor_west/index.shtml

series for watersheds throughout the state. A major strength of this tool is that it uses the VIC hydrologic model to fill in gaps where observations are not available, such as soil moisture and snow water equivalent, which are not widely observed. On the other hand, it is important to keep in mind that it shows modeled values, and not directly observed data.

The University of Washington, in collaboration with the University of California - Los Angeles, also operates similar systems for the entire West[17] (at 1/16°). Both of these systems derive from the UW Surface Water Monitor (described in Wood 2008), which since 2004 has produced daily analyses for the entire continental United States,[18] at a coarser resolution of 1/2°.

The ability of the system to capture surface water dynamics has been discussed in a number of studies that have compared historic droughts with their representation in the UW Drought Monitoring Systems. For example, Xiao et al (2016) used output from the system to examine historical droughts in the Pacific Northwest. Shukla et al (2011) compared different drought indices (including soil moisture percentiles) and their ability to identify the onset and termination of four major droughts in Washington State relative to recorded drought declarations. In all four droughts (water years 1977, 1989, 2001, and 2005), the products available from the drought monitoring system would have identified drought sooner than drought was declared by the state (Shukla et al 2011).

Composite indicators

Objective Blends of Drought Indicators

The U.S. Drought Monitor's Objective Blends of Drought Indicators (OBDI)[19] are weekly products that combine several drought indices into a short-term and a long-term blend:

- The short-term blend includes the Palmer Drought Severity Index (7 percent), the Palmer Z index (35 percent; essentially a short-term version of the PDSI), observed precipitation for the past month (20 percent) and past three months (25 percent), and a soil moisture index from the Climate Prediction Center (13 percent).

- The long-term blend includes the Palmer Hydrologic Drought Index (25 percent); observed precipitation for the past 6 months (15 percent), 12 months (20 percent), 24 months (20 percent), and 60 months (10 percent); and the Climate Prediction Center's soil moisture index (10 percent).

The blended products are helpful for quickly looking at conditions on the two time scales, with some caveats. The Climate Prediction Center's Soil Moisture Model, for example, is a simple, one-layer hydrologic model that does not include snow, which compromises soil moisture

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[17] West-Wide System: http://www.hydro.washington.edu/forecast/monitor_cali/index.shtml

[18] Continental US: http://hydro.washington.edu/forecast/monitor/

[19] OBDI: http://www.cpc.ncep.noaa.gov/products/predictions/tools/edb/droughtblends.php

estimates in mountainous regions of the western United States. The rest of the products are precipitation-focused, but do not differentiate between rain and snow, and do not account for soil or snow processes, so caution is warranted for use during the winter months. Finally, the climate division scale of the products is rather coarse for many drought applications.

North American Land Data Assimilation System Soil Moisture

In the late 1990s, the North American Land Data Assimilation System (NLDAS) began its first phase with four different land surface models (Noah, Mosaic, Variable Infiltration Capacity (VIC), and Sacramento). These land surface models provide information on hydrologic variables that are often sparsely observed (e.g., soil moisture, evaporation, etc.). The models all run on a common 0.125° grid and use 4-dimensional data assimilation.

The first phase of NLDAS consisted of a 3-year period (1997-1999) when model comparisons and model validation was performed (Mitchell et al 2004). Phase 1 resulted in substantial improvements to both the forcing data and the models.

Phase 2 extended the period to a 29-year retrospective (1979-2007; Xia et al. 2012b). As of 2014, the second-generation NLDAS models (NLDAS-2) are operational.

While there are multiple output variables derived from these models, we focus on soil moisture here due to its applicability to drought. Model output for soil moisture anomalies and percentiles for each model and the average of the four (known as the "ensemble") can be found on the NLDAS website.[20] The anomalies are based on a 28-year climatology (1980-2007) and maps for the top meter as well as the total soil column are available. The upgrades for NLDAS-2 have increased the agreement between the models for all variables, and the seasonal cycle in soil moisture averaged over the Northwest is consistent among each model (Xia et al 2012a).

There are higher absolute soil moisture values for the Noah and Sacramento models compared to VIC and Mosaic. Examining the differences spatially shows that the biggest disparity between models are in the Cascade and Olympic mountains (Xia et al 2012a). Therefore it is important to exercise caution when viewing the mountain values for the state since there is less agreement and more uncertainty among models. In addition, winter soil moisture anomalies in the mountains (or anywhere else where snow provides significant storage) are unrealistic since snow is not accounted for in soil moisture anomalies.

Soil moisture anomalies, percentiles, and recent changes can help monitor drought, particularly later in the water year, and can also be useful for determining where drought is more likely to develop, or when it has eased. For example, an area with below normal soil moisture can cause a feedback loop that exacerbates dry conditions. Dry soils lead to reduced evaporation, resulting in higher ground temperatures and warmer and drier days (Trenberth and Guillemot 1996). A benefit of the NLDAS-2 tool is that the different models are in one location, which can help emphasize that these are indeed model simulations (with each having their own biases) and not

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[20] NLDAS: http://www.emc.ncep.noaa.gov/mmb/nldas/drought/

observed data. Expect model improvements to continue, such as implementation of an improved soil moisture scheme developed by Nearing et al (2016).

U.S. Drought Monitor

The U.S. Drought Monitor[21] (USDM) is an operational composite approach to quantifying drought (Svoboda et al 2002; WMO and GWP 2016). Numerous indicators are considered in producing the weekly product; some examples (e.g., Palmer Drought Severity Index, weekly streamflow percentiles, and Standardized Precipitation Index) are shown on their classification webpage,[22] but these are just part of the information considered. One of the strengths of the U.S. Drought Monitor is that it is easily adaptable with new indicators added as they are shown to be meaningful and become reliable. The process used involves a "convergence of evidence" approach that reflects a consensus of indicators (and impacts) in determining drought intensity.

The primary partners of the U.S. Drought Monitor include the National Drought Mitigation Center (NDMC), U.S. Department of Agriculture (USDA), and the National Oceanic and Atmospheric Administration (NOAA). The National Drought Mitigation Center is currently updating the types of impacts that occur at each drought category for each state (personal communication, Mark Svoboda) with the most valuable indicators being highlighted.

There are four drought categories and one drought "watch" category, which are tied to percentiles of drought likelihood based on the period of record available. The lowest category – "D0" or "abnormally dry" – is used to show an area where drought may develop or where lingering impacts remain from a drought that is waning. The four drought categories increase in drought intensity from D1 to D4 representing "moderate drought," "severe drought," "extreme drought," and "exceptional drought," respectively. For guidance, the percentile chance of each category occurring in any given year in a particular location is shown in Table 17.

Table 10. Chance of each drought category occurring in any given year at any given location.

Drought Category	Likelihood of occurring per year
D0	21-30%
D1	11-20%
D2	6-10%
D3	3-5%
D4	$\leq$ 2%

[21] USDM: http://droughtmonitor.unl.edu

[22] http://droughtmonitor.unl.edu/AboutUs/ClassificationScheme.aspx

The final piece of the U.S. Drought Monitor composite is guidance from local, state, and federal experts that help "ground truth" the product by providing input (e.g., data, impacts) each week (Svoboda et al 2002). For Washington State, the Office of the Washington State Climatologist leads a weekly call when dry conditions exist to give suggestions based on local conditions. National Weather Service hydrologists from all four offices that cover Washington take part in the call, and occasionally other local experts such as agricultural specialists. In addition, there are short-term (S) and long-term (L) designations used on the maps to indicate the time scale of the drought conditions.

The U.S. Drought Monitor is a highly visible product that is often quoted by the media to describe the extent of drought conditions for a particular region. This could be perceived as both a benefit and a weakness. Since the U.S. Drought Monitor depicts different types of drought – such as agricultural, hydrologic, meteorological – and the state's definition is focused on water supply, there can often be a mismatch between the conditions depicted and whether the state has declared drought. This can lead to confusion, especially when the detailed nuances are not communicated.

While the U.S. Drought Monitor does not trigger state action, it can activate federal financial assistance during grazing periods according to the 2014 Farm Bill (U.S. Department of Agriculture). Assistance is activated when a county is designated at a "D2" level or worse for eight consecutive weeks.

Another benefit that can also be interpreted as a weakness is the multiple indicators that go into the map. While the convergence of indicators strengthens the drought depiction, some may find that the variety of indicators contributes to a lack of transparency about the relative weighting of the indicators used. There is a weekly narrative that accompanies the U.S. Drought Monitor map, however, which often explains the indicators that were relied upon for adjustments.

Lastly, it is important to keep in mind that the U.S. Drought Monitor is a monitoring tool, not a forecast tool, so it cannot be used to identify the onset of drought ahead of time. On the other hand, it may be possible to use it to help determine when to end a state drought declaration.

Strengths and weaknesses of drought indicators

The following three tables summarize the topics brought up in the previous section and lists the strengths and weaknesses of each indicator as well as which stage of drought (i.e., onset, existing, end) the indicator is most useful for.

Table 11. Strengths and weaknesses of Meteorological drought indicators.

Indicator	Stage of Drought	Strengths	Weaknesses
Standardized Precipitation Index	Existing	Easily accessible; comparable across locations; calculated for multiple time scales	Based only on precipitation; does not differentiate between rain or snow
Crop Moisture Index	Existing	Weekly maps easily accessible; agriculture focused (non-irrigated)	Only measures short-term drought; simple potential evapotranspiration (pET) estimate; snow not included
Standardized Precipitation Evapotranspiration Index	Existing	Easily accessible; comparable across locations; detects trends in temperature; can use more complex pET estimate if data available	Temperature included but not used to differentiate between rain and snow; only monthly readily available; simple pET estimate common
Reconnaissance Drought Index	Existing	Multiple time scales available; includes water balance component	Lack of accessibility; simple pET estimate
Palmer Drought Severity Index	Existing	Well-recognized and accessible	No snow included; not particularly suited for Washington
Evaporative Demand Drought Index	Onset/ Existing	Weekly to monthly scales; more physical pET calculation; identifies early onset of drought	Experimental; short-term index may not be as useful to snowmelt dominated basins

Table 12. Strengths and weaknesses of Hydrological drought indicators.

Indicator	Stage of Drought	Strengths	Weaknesses
USGS Streamflow Percentiles	Existing/ End	Easily accessible; long historical record for context	Only available for gauge locations; flows are affected by water resources operations (such as reservoir releases)
Palmer Hydrological Drought Index	Existing/ End	Does not show drought ending until moisture deficits are gone	Lacks a snow component; only monthly
Surface Water Supply Index	Onset/ Existing	Empirical index, not a model; includes snow, reservoirs, and streamflow with western drought in mind	Not available for Washington; intensive calculations and data required; varies by basin
UW Drought Monitoring System	Onset/ Existing	Fills in gaps where observations aren't available; identified past Washington droughts before state declarations; easily accessible; near real-time	Subject to model biases; can be difficult to understand data behind the maps

Table 13. Strengths and weaknesses of Composite drought indicators.

Indicator	Stage of Drought	Strengths	Weaknesses
Objective Blends of Drought Indicators	Existing	Composite of multiple indicators; easily accessible	No snow included in the soil moisture model; does not differentiate between rain or snow; coarse scale
NLDAS Soil Moisture	Existing	Multiple models used to give idea of uncertainty; maps provided online	Higher uncertainty in mountain soil moisture values
US Drought Monitor	Existing/ End	Uses multiple indicators; produced weekly; summarize in sound byte	Represents multiple types of drought which do not all align with Washington State definition

It is worth reiterating that there is no single drought indicator that is suitable to define drought in Washington State. Washington State statute defines the technical trigger of drought as water supply at, or projected to be, below 75 percent of normal for a particular region. Thus, hydrological indicators are generally more relevant in defining drought in Washington State. Nevertheless, the meteorological indicators described above are extremely useful for providing warning when drought conditions are developing. We recommend a combination of these indicators be continually monitored, with the strengths and weaknesses of each kept in mind.

We have outlined these characteristics in this section, but a more detailed analysis would be useful. It is beyond the scope of this summary, but systematically evaluating each of these indicators on the basis of a set of specific criteria would be beneficial for potentially including them in the state's drought plan. These criteria could include assessing the performance of each of these indicators during past droughts, and objectively classifying them in terms of which stage of drought, season, and sector each is most useful.

Our "stage of drought" classification presented here (onset vs. existing vs. end) is based on the literature and is somewhat subjective since it has not been assessed for Washington State explicitly. In addition to comprehensive analyses on the drought indicators and their applicability to Washington State, it is recommended that the drought indicators be reviewed on a semi-regular basis. This would help address not only new research on drought monitoring indicators, but would ensure that climate change does not strongly impact the temporal stability of the indicators and their applicability for depicting drought in Washington State.

Forecast Tools

Droughts are declared due to a lack of sufficient water given present or anticipated conditions. This raises the question of whether long-term seasonal forecasts provide useful information in setting drought status levels. Forecasts, similar to drought indicators, are made in a variety of different ways that focus primarily on climate parameters (temperature and precipitation) or hydrology (streamflow). Several of those methods are reviewed here. It is also worth noting that there are also two drought forecast products produced by the NOAA's Climate Prediction Center (monthly[23] and seasonal[24]) that predict either improvement or development of drought in the areas with U.S. Drought Monitor designations.

Climate forecast tools

The skill for two different seasonal climate forecast products are reviewed in this section. First, we discuss the temperature and precipitation seasonal forecasts from the Climate Prediction

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[23] Monthly: http://www.cpc.ncep.noaa.gov/products/expert_assessment/mdo_summary.php

[24] Seasonal: http://www.cpc.ncep.noaa.gov/products/expert_assessment/sdo_summary.php

Center and then the National Multi-Model Ensemble (NMME) temperature and precipitation seasonal forecasts.

Climate Prediction Center forecast skill

The Water Supply Availability Committee (WSAC) has been using NOAA's Climate Prediction Center produced monthly seasonal climate forecasts, but we determined we should assess how useful they are. An archive of past CPC seasonal forecasts of temperature and precipitation,[25] and corresponding observations, has been analyzed for the years of 1995-2015, focusing on Washington State. This archive includes seasonal forecasts for a series of lead times, with the lead-time referring to the interval (in months) between the time that the forecast is produced and the start of the period being predicted. We focused on forecasts with lead times of 0.5 and 3.5 months. For example, we have examined the 3-month seasonal forecasts for October through December that would have been made in mid-June (3.5 lead time) and mid-September (0.5 lead time) of the same year. Results for the seasons of Jan-Mar, Apr-Jun, and Jul-Sep are also analyzed separately.

The forecasts are categorical, indicating the probability of mean temperature and precipitation anomalies reaching thresholds of below or above normal conditions versus near-normal. The procedure used was to compare the forecasts with the observations for the five national forecast divisions (#72-76) encompassing Washington State;[26] division #73 extends into northeast Oregon and northern Idaho while division #74 extends into northeast Oregon. For these divisions, we average the Heidke Skill Score (HSS) over all five regions (Table 19). The HSS is a measure of forecast accuracy, and relates to the frequency of correct forecasts relative to that which would occur by chance. We estimate the HSS using the following equation:

$$HSS=(c-e)/(t-e)*100$$

Where e is the number of grid points expected to be correct by chance, c is the number of correct grid points, and t is the total number of grid points.

The HSS has a range from -50 (the "worst possible" forecast) to 100 (a "perfect forecast") for a three-category forecast system. A value of 0 represents a forecast that is no better than flipping a coin (O'lenic et al 2008; Peng et al 2012) and a score of 50 implies that two-thirds of the individual forecasts verified as correct. An HSS value of around 30 represents the threshold of "useful" forecasts in many applications.

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[25] CPC Verification: http://www.vwt.ncep.noaa.gov/

[26] Map of divisions: http://www.cpc.noaa.gov/products/predictions/long_range/poe_index.php?lead=1&var=thttp://www.cpc.noaa.gov/products/predictions/long_range/poe_index.php?lead=1&var=t

A second analysis was done using a different Climate Prediction Center website[27] with seasonal forecast verifications for lead-time of 0.5 months over a historical period beginning in 1995. We used the same four non-overlapping seasons from 1995 through 2016 for Washington State as a whole.

We determined the number of correct forecasts of below or above-normal conditions versus the number of category 2 errors, that is, with a validation of opposite sign to the forecast. For example, a category 2 error would occur if below normal temperatures were forecast for a majority of Washington State, but in actuality, the temperatures verified as above normal for that same period. We disregarded periods with a near-neutral forecast or validation. The counts of correct/incorrect forecasts are shown in Table 6.

Table 14. Heidke Skill Scores for 0.5 and 3.5 month lead times for Washington State (1995 - 2015)

Season	0.5-Month Lead temperature	3.5-Month Lead temperature	0.5-Month Lead precipitation	3.5-Month Lead Precipitation
Oct - Dec	-1.5	1.0	-7.5	6.5
Jan - Mar	38.1	24.0	7.6	22.5
Apr - Jun	22.5	21.5	-1.5	3.5
Jul - Sep	30.0	31.0	25.0	17.5

Table 15. The number of correct and incorrect (by two categories) forecasts for temperature and precipitation in Washington State (1995 - 2016)

Season	Correct temperature	2 Category Errors temperature	Correct precipitation	2 Category Errors Precipitation	Total forecasts
Oct – Dec	4	3	5	6	21
Jan - Mar	12	1	5	2	22
Apr - Jun	9	5	6	3	22
Jul - Sep	8	1	8	2	22

[27] CPC Verification: http://www.cpc.ncep.noaa.gov/products/predictions/long_range/tools/briefing/seas_veri.grid.php

The results of our analysis are used to draw some general conclusions. First, seasonal temperature predictions tend to be more skillful than seasonal precipitation predictions, as found in previous studies (e.g., Peng et al 2012). The overall difference in skill between the 0.5 and 3.5-month lead times was small, with the shorter time horizon yielding substantially better predictions only for temperature in winter and for precipitation in summer. For precipitation in winter, the longer lead forecasts were actually superior.

The lack of skill is striking in the seasonal forecasts for both temperature and precipitation for the first three months of the water year (October through December). October through December 0.5-month lead precipitation forecasts had the highest number of Category 2 errors in the 1995-2016 time period (Table 6), though the temperature and precipitation 0.5-month lead forecasts for Jan-Mar had relatively few (1 and 2, respectively).

It is of special interest to ascertain the extent to which below-normal precipitation can be reliably predicted. Towards that end, the results for all of the 0.5-month lead seasonal precipitation forecasts in all four 3-month periods from a statewide areal average basis have been combined into a contingency table (Table 21).

Table 16. The 0.5 month lead precipitation forecasts versus observed conditions for each forecast category and all seasons.

	Observed Below	Observed Normal	Observed Above	Total Forecasts
Forecast Below	13	4	8	25
Forecast Normal	23	10	16	39
Forecast Above	5	7	11	23
Total Observed	31	21	35	87

Key results are summarized in the second column and second row of Table 7 relating to the seasons with below-normal precipitation observed and forecast, respectively. Forecasts of below normal preceded 13 of the 31 seasons with observed precipitation in the below-normal category as compared with 5 forecasts of above-normal precipitation. There were 25 seasons for which forecasts of below-normal precipitation were made, and hence slightly more than one-half the time, the observed precipitation was also below normal. It bears noting that almost one-third (8 out of 25) of the below-normal forecasts were associated with above-normal observed precipitation.

We also note that there were almost twice as many forecasts of normal precipitation (39) as observed (21). This result is understandable because clear signals regarding seasonal precipitation are often lacking; in these cases the Climate Prediction Center forecasts generally indicate equal chances of each category.

For all of the Climate Prediction Center seasonal forecast verification results presented here, it is important to note that the small sample size of the seasonal forecasts that were available for validation may have resulted in unrealistic and misleading Heidke Skill Scores. A longer period of historical seasonal forecasts would provide more statistical certainty, but might obscure long-term improvements in forecast skill.

National Multi-Model Ensemble forecast skill

The numerical forecasts from coupled global climate models constitute a primary source of information for the seasonal weather forecasts produced by NOAA's Climate Prediction Center and by other climate centers. Motivated by research showing that combining outputs from multiple models could enhance forecast skill (e.g., Krishnamurti et al 2000), the weather and climate prediction enterprise has launched multi-model prediction experiments.

In climate forecasting, NOAA leads the National Multi-Model Ensemble (NMME) experiment, which involves six centers running different climate models to predict climate for up to seven months. Multi-model ensemble mean distributions of monthly and seasonal temperature and precipitation anomaly distributions give a range of outcomes, and are generally used to account for the uncertainty associated with individual model errors and biases. The National Multi-Model Ensemble (and those of the related International Multi-Model Ensemble; IMME) are statistically merged, forming products that are available online in near real-time.[28]

This has been a recent effort, and online archives[29] of operational past National Multi-Model Ensemble forecasts extend back to only 2011. The real-time National Multi-Model Ensemble forecasts have been examined from a Washington statewide perspective for the 20 non-overlapping seasons from Oct-Dec of 2011 through Jul-Sep of 2016, considering only 0.5-month leads, and again from a categorical perspective.

Results show that 16 of the 20 temperature projections from the National Multi-Model Ensemble were in the same category as the Climate Prediction Center forecasts. Of the four that were different, the Climate Prediction Center forecast was superior 3 times and inferior once, as compared with the National Multi-Model Ensemble forecast. With regards to precipitation, there were 6 deviations between the two sets of 20 forecasts, with Climate Prediction Center and National Multi-Model Ensemble each better one-half the time (3 each). In other words, the Climate Prediction Center and National Multi-Model Ensemble forecasts were of comparable skill.

Our interpretation of these results, which are highly tentative due to the small sample size, is that the Climate Prediction Center forecasts rely, to a substantial extent, on the results from numerical climate models. The other information used in making Climate Prediction Center's official seasonal forecasts (e.g., recent trends, empirical relationships based on El Niño-Southern Oscillation, and several statistical climate forecast tools) may be of secondary importance in

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[28] Current NMME Forecasts: http://www.cpc.ncep.noaa.gov/products/NMME/

[29] Archived NMME Forecasts: http://www.cpc.ncep.noaa.gov/products/NMME/verif/seasindex.html

forming the forecasts. It would be interesting and informative to evaluate the individual models whose forecasts comprise the National Multi-Model Ensemble, especially if the full hindcast archive (1982-2010) can be leveraged to provide a larger sample size.

Presuming that the output from global climate models is increasingly relied upon for seasonal climate forecasts, coupled with continued improvement of these models with time, one might assume that seasonal forecasts are getting better. At least for Washington State, that does not appear to be the case. Time series of Climate Prediction Center official forecast skill (not shown) lack any sort of systematic trends in skill for temperature and precipitation. Moreover, the record readily available online for assessing regional prediction skill is too short to be able to establish meaningful trends of this sort.

It is known that the skill of climate models, and of seasonal climate predictions, is enhanced for the Pacific Northwest during El Niño-Southern Oscillation (ENSO) events (e.g., Higgins et al 2004), which could lead to improved seasonal streamflow forecasts during such conditions (e.g., Hamlet et al 1999; Wood et al 2005). Ongoing research is being devoted toward identifying and exploiting additional sources of predictability for the weather on seasonal time scales, but progress here is slow. The mid-latitude atmospheric circulation is chaotic on time scales longer than a few weeks, and hence there are inherent limits to the predictability of future weather beyond those time scales.

Streamflow forecast tools

Current seasonal streamflow forecasting efforts are described in this section. The Water Supply Availability Committee (WSAC) already uses the seasonal water supply forecasts produced by the National Weather Service's Northwest River Forecast Center and the Natural Resources Conservation Service when monitoring conditions around the state. The National Water Model is a relatively new product that has yet to be used on the state level.

Northwest River Forecast Center seasonal water supply forecast

A portion of the state's drought declaration process is triggered when water supply (i.e. seasonal runoff volumes) is either anticipated to or falls below a flow threshold of 75 percent of normal. The state currently relies heavily on the seasonal streamflow forecasts and runoff estimates provided by NOAA/National Weather Service's Northwest River Forecast Center (NWRFC) in order to determine a river's observed or forecast condition with respect to this 75 percent threshold. The NW River Forecast Center produces seasonal water supply forecasts for a variety of predefined periods including the April through September snowmelt runoff period.

Currently, the NW River Forecast Center offers forecasts in two related and adjusted configurations that differ in how they account for human activities upstream of a given location.

- The Water Supply configuration provides runoff adjustments for upstream storage at select stations according to published rules. These rules are generally comparable to adjustment techniques used by other federal agencies that produce water supply forecasts for the state.

- The Natural forecast configuration attempts to recreate natural flow at specific locations. This method removes the effects of major diversions, upstream storage, consumptive use for irrigated areas, and routing effects.

The NW River Forecast Center currently publishes Water Supply forecasts at 30 locations in Washington State and Natural forecasts at 69 locations in the state. The forecasts are updated daily beginning in July of the preceding water year and use the National Weather Service's Community Hydrologic Prediction System (CHPS) model.

The forecast technique uses Ensemble Streamflow Prediction (ESP) to produce a range of possible future streamflows. Each ensemble member is the result of a model run that combines current conditions (weather leading up to the present day) with temperature and precipitation in each year in the historical record (e.g., weather in 1948 is one ensemble member, weather in 1949 is another, and so on). The resultant ensemble provides a range of uncertainty based on past weather sequences. If each ensemble outcome is assumed equally likely to occur, which is the assumption used by the NWRFC, then by definition, the median of the ESP forecasts is the most expected outcome.

The historical data of the Ensemble Streamflow Prediction is typically augmented by embedding the latest 5- or 10-day weather forecast instead of the historical weather record for the initial part of the streamflow forecast. The NW River Forecast Center refers to the 10-day version as ESP10 and considers it to be the official National Weather Service forecast. All flavors of the forecast are available on their website:[30] the ESP5 forecast uses a 5-day weather forecast, while the ESP0 forecast uses only historical weather data, or climatology.

It is important to note that these forecasts do not take into account the seasonal climate forecasts produced by NOAA's Climate Prediction Center. Instead, each historical weather year is considered to be equally likely, regardless of the current climate state or prediction (e.g., El Nino-Southern Oscillation phase). Forecast skill generally increases as the water year progresses as the determinants of runoff (precipitation, temperature, snowpack) become better known through observation.

NRCS statistical water supply forecasts

Seasonal streamflow forecasts are also provided by the USDA’s Natural Resources Conservation Service (NRCS). In years past, Natural Resources Conservation Service and the NW River Forecast Center would coordinate forecasts and produce only one for the Western States, but as of 2011, each agency now issues their own “official” forecast (Pagano et al 2014). This is a benefit to water planners as they may now consider two independent forecasts that use different methods when making decisions.

The Natural Resources Conservation Service streamflow forecast is a statistical forecast, which means that a statistical regression is used to forecast streamflow based on historical data. It uses snow, precipitation, antecedent streamflow, and El Nino-Southern Oscillation indices to produce

[30] NWRFC Forecasts: https://www.nwrfc.noaa.gov/ws/index.html

a forecast for spring and summer streamflow. The forecasts are for "natural flow" and do not take any upstream influences into account; they are produced monthly from January through May.

Maps[31] showing the April through September streamflow percent of normal at the 50 percent exceedance level (the median forecast) are available online. The reports[32] have more information, and also list the 10 percent, 30 percent, 70 percent, and 90 percent exceedance probabilities for the April-September and the April-July periods for each forecast point. To interpret the probabilities, the 90 percent exceedance value means that there is a 90 percent chance that the actual streamflow volume will exceed the forecast value, and a 10 percent chance the actual streamflow volume will be less than the forecast value. The 90 percent exceedance forecast would be a more conservative value to base water supply decisions on compared to the median forecast.

Like the NW River Forecast Center seasonal streamflow forecasts, the Natural Resources Conservation Service forecast uncertainty decreases through the water year. One of the large drivers of uncertainty in these forecasts is the winter weather, so as the season progresses, the future conditions become known and uncertainties in the streamflow decrease. Since winter snowpack is a good predictor of spring/summer water supply, forecasting the water supply for rain-dominated basins is more challenging. For Washington State, that means that many of the forecast points in the rain-dominated regions of Western Washington have higher uncertainty. This characteristic also applies to the NW River Forecast Center Ensemble Streamflow Prediction (ESP) forecasts, since their skill arises in specification of snow water equivalent and soil moisture conditions at the start of the forecast.

NOAA National Water Model

In August 2016, the NOAA/National Weather Service's Office of Water Prediction announced the operational release of the National Water Model (NWM),[33] when it began running continuously on a National Centers for Environmental Prediction supercomputer. The initial version (v.1.0) forecasts streamflow and other aspects of the water cycle (e.g., precipitation, snow water equivalent, and soil moisture) on multiple time scales for 2.7 million river forecast points nationwide. The input data includes current streamflow observations from USGS gauges and estimates of observed precipitation. The core of the National Weather Model is based on the Weather Research and Forecasting Hydrologic model from the National Center for Atmospheric Research. The modular framework uses a suite of model options and weather inputs in order to produce hydrologic guidance across four time horizons – analysis (current), short-range, medium-range, or long-range (NOAA August 2016 Newsletter).

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[31] NRCS Maps: https://www.wcc.nrcs.usda.gov/cgibin/colu_strmflow.pl?state=columbia_river

[32] NRCS Reports: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/wa/snow/waterproducts/?cid=stelprdb1265591

[33] National Water Model: http://water.noaa.gov/about/nwm

Of particular interest to Washington State's drought work is the long-range streamflow forecast, which spans 0 to 30 days and is produced daily using a 16-member ensemble on a 1 km grid. The forecast uses meteorological output from NOAA's Climate Forecast System (CFSv2). While 30 days is too short to be considered a seasonal climate forecast, the CFSv2 is a global model that initiates each meteorological forecast with the current state of the atmosphere-ocean system. In other words, the initialization takes into account current climate system conditions, such as the Ensemble Streamflow Prediction (ENSO) state and the Madden-Julian Oscillation (MJO), and could improve streamflow forecast during the relevant sub-seasonal window (out to 30 days). The CFSv2 produces a high number of simulations, which helps bound and describe the uncertainty ranges of the initial climate system conditions used.

While the National Water Model is operational in a technical sense, its output is experimental and currently undergoing extensive verification. Progress should be monitored to determine whether the forecasts of interest, such as the 30-day predictions, offer any skill. Although planned yearly enhancements may yield quality long-range forecasts that extend out 90 days or more, the National Water Model output will not replace the NW River Forecast Center seasonal forecasts in the foreseeable future. Still, the sub-seasonal horizon of its long-range forecast[34] could be useful as (experimental) supplementary guidance for the state's WSAC, particularly as the National Water Model matures. The long-range forecast provides information on an intermediary time scale, bridging the gap between short-term and seasonal forecasts. An added benefit of the National Water Model is that forecasts are provided at locations currently not available from the NW River Forecast Center.

The National Water Model has been, and will continue to be, a collaborative venture. The newly created National Weather Service's National Water Center works closely with the National Center for Atmospheric Research, National Weather Service headquarters and field offices, and other NOAA and external agencies to operate, assess, improve, and enhance the National Water Model. Subsequent versions are planned, including v.1.1 in April 2017 and v.1.2 in October 2017, and likely a new version each year beyond 2017. The National Water Model version 1.1 has already shown improvements in the long-range streamflow forecast (Brian Cosgrove, personal communication).

Related research and development

The previous sections review current drought indicators and forecasting tools, and while not an exhaustive list, it does provide a fairly comprehensive review of what is available as of the 2016 writing of this report. Climate and hydrologic research is always moving forward, however, and particularly with the recent drought in the Pacific Northwest, there are interesting and exciting projects on the horizon. Here we highlight just a few examples of work and resources that could help advance the state's process of determining and declaring drought in Washington should these projects move from the research stage to operational.

[34] NWM Forecasts: http://water.noaa.gov/map

Northwest Climate Toolbox

The Northwest Climate Toolbox is a website[35] that provides interactive climate and water resources decision support. It is being developed by leads John Abatzoglou (University of Idaho), Katherine Hegewisch (University of Idaho), and Bart Nijssen (University of Washington), and funded by the Climate Impacts Research Consortium (CIRC) and NIDIS.

While still in development with expansion planned, the website is usable now to monitor potential drought conditions on the state level. For example, the website (under "Site Tools" and "Seasonal Forecast" tool) shows the National Multi-Model Ensemble (NMME; described above) temperature and precipitation forecasts. These forecasts are downscaled to a chosen point, and offer more information than shown in the traditional National Multi-Model Ensemble forecast maps. For example, the mean temperature difference average can be shown for a given point and forecasts can be viewed as a time series on the same graphic. Figure 13 shows this for the National Multi-Model Ensemble 1-month average temperature forecast near Seattle from February 2017 through August 2017. In addition, the downscaled temperature or precipitation forecasts are available for different time periods (1-month to 7-month averages).

[35] Climate Toolbox: www.climatetoolbox.org

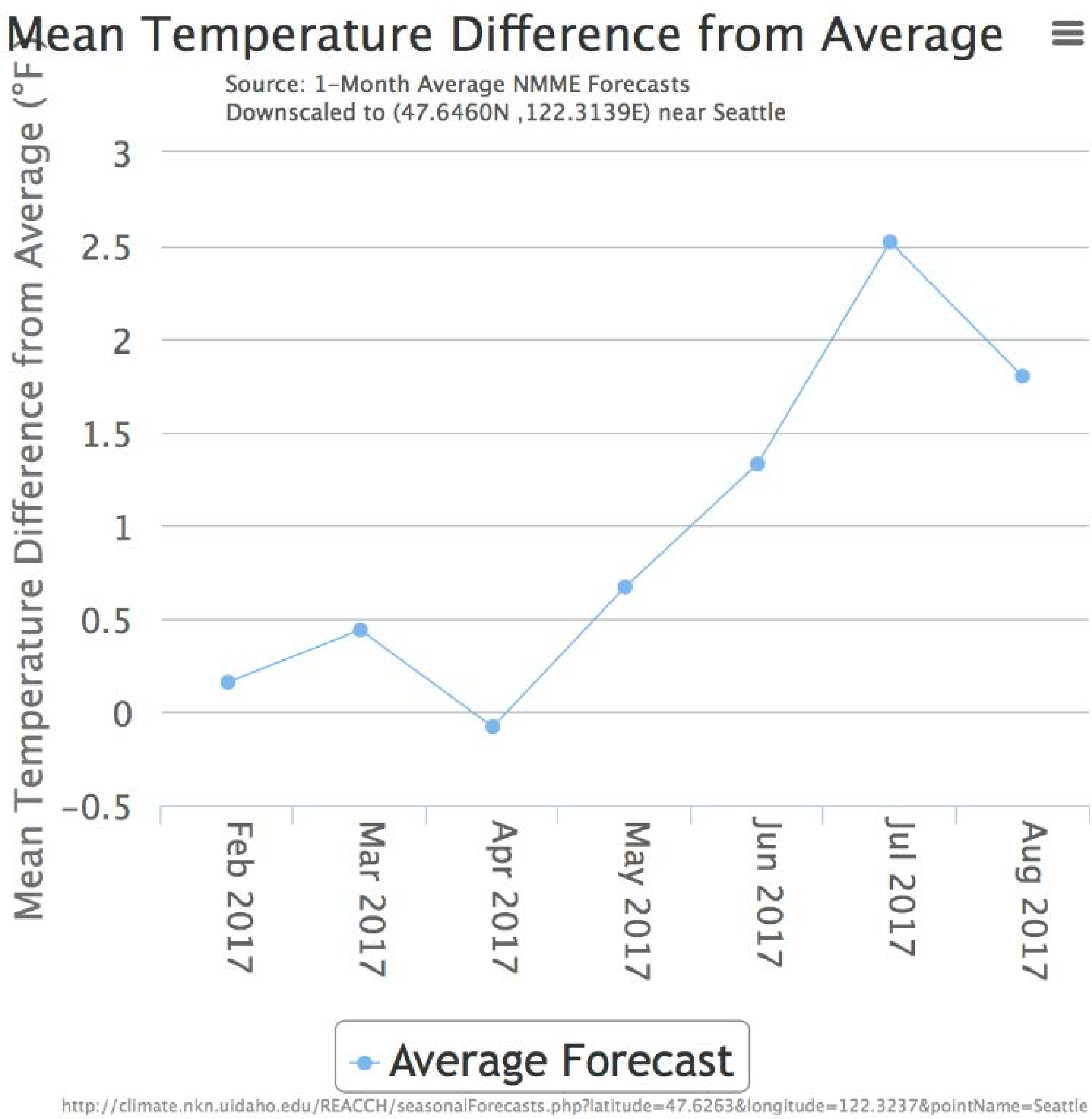

Figure 15. One month temperature forecasts for the Seattle area (difference from 1981 - 2010 normal) from the NMME models.

The Northwest Climate Toolbox also displays historical average climate data in graphical format using the University of Idaho gridded dataset.[36] Another large section of the site is dedicated to future climate change projections for temperature, precipitation, wind, and potential evapotranspiration, among other variables. The output is from Coupled Model Inter-comparison (CMIP5) models, which are described in the climate change portion of this drought plan. As mentioned previously, more developments are in store for the Northwest Climate Toolbox, including migrating the UW Drought Monitoring System (described in the Hydrological

[36] Univ. of Idaho Surface Meteorological Dataset: http://climate.nkn.uidaho.edu/METDATA/

indicators section above) over to the toolbox in the next few years. (The snow percentiles and soil moisture percentiles from the UW Drought Monitoring System are already available on both websites.) The UW Drought Monitoring System process will remain the same, but the meteorological input dataset will be different. The output and maps will be consistent with the products available on the Northwest Climate Toolbox.

Climate Prediction Center Experimental 3-week forecast

A new product released in 2015 from NOAA's Climate Prediction Center attempts to fill the gap between short-term weather forecasts and longer-term seasonal predictions. The climate Prediction Center is producing experimental forecasts of temperature and precipitation for the U.S. on a time horizon of 3-4 weeks. These forecasts are updated once a week and available online.[37] The information consists of the expected distributions of the anomalous temperature and precipitation for the 3- to 4-week period as a whole in the same three-tier format used for the seasonal forecasts (below normal; equal chances of below, near-normal, or above; and above normal).

The site includes a forecast discussion indicating the basis for the forecasts includes output from ensembles of extended numerical weather prediction model simulations from NOAA's CFSv2 model and from model simulations of two other international centers. (Additional model simulations may be included in the future.) Consideration is also given to the present state of slowly varying components of the atmosphere-ocean-land system, such as ENSO. In addition, these forecasts exploit the Madden-Julian Oscillation (MJO), which represents a major source of variability in the tropics on 40-60 day time scales. The Madden-Julian Oscillation often has some predictability out a few weeks; the phase of the oscillation correlates moderately with the atmospheric circulation and weather at higher latitudes, including precipitation in the Pacific Northwest during October through March (Bond and Vecchi 2003).

It remains to be seen how much skill these 3-4 week forecasts will have in a real-time setting. The weather and climate community has substantial interest in exploiting the potential predictability on this time scale.

Water Resources Monitor and Outlook

The Water Resources Monitor and Outlook (WRMO)[38] is a new online tool currently under development that integrates, synthesizes, and expands existing NOAA forecast products. NOAA leads the effort, with involvement from the National Integrated Drought Information System (NIDIS), the Western River Forecast Centers (RFCs), the Physical Sciences Division (PSD), and the Climate Prediction Center.

The Water Resources Monitor and Outlook will provide access to the NOAA River Forecast Center's ensemble streamflow prediction (ESP) water supply forecasts from all western river basins along with other visualization tools. The initial focus of this product is on the western

[37] CPC 3-4 Week Outlooks: http://www.cpc.ncep.noaa.gov/products/predictions/WK34/

[38] WRMO Information: http://www.cbrfc.noaa.gov/WRMO

United States (including the Pacific Northwest region) and will be released in Beta form in spring 2017 and refined based on stakeholder feedback through 2018.

The product is being designed based on the needs of water management users, and includes streamflow forecast information, verification of the forecasts, and visualization tools to help communicate forecast evolution. Ultimately the product suite will contain three web-based elements:

- Water resources monitoring information.
- Water resources outlook products that are an enhancement of the current operational NOAA River Forecast Center products (both elements 1 and 2 will be updated daily).
- Sub-seasonal to seasonal climate outlook for water resources, leveraging the existing analysis and operational forecasts from CPC.

NOAA/NWS Hydrologic Ensemble Forecast Service

NOAA/National Weather Service's River Forecast Centers (RFCs) are currently experimenting with a probabilistic streamflow forecasting system known as the Hydrologic Ensemble Forecast Service (HEFS). HEFS is a nationwide effort that is run locally at individual River Forecast Centers. At the NW River Forecast Center, Hydrologic Ensemble Forecast Service output is undergoing validation and not currently available, but it is another product that may be useful to the state in the near future.

For the Northwest region, 63 headwater basins are currently being run through the ensemble forecast system at the time of this writing. Hydrologic Ensemble Forecast Service produces a daily probabilistic streamflow forecast from 0 to 365 days, thereby offering short term and seasonal water supply forecasts. Figure Y shows an example of the short-range forecast (0-10 days lead time) for potential flooding on the Snoqualmie River near Snoqualmie, Washington. Rather than having one deterministic forecast (blue line in Figure 22; existing NW River Forecast Center river forecast capability), the Hydrologic Ensemble Forecast Service forecast shows a range of possibilities (red envelopes) based on an ensemble of different model runs. Hydrologic Ensemble Forecast Service forecast envelopes help to describe the potential for a range of outcomes and can be a planning asset over deterministic "single answer" forecasts in which uncertainty is generally not specified.

As for the model input, temperature and precipitation from the National Weather Service's Global Forecast System (GFS) forces the first 15 days of the Hydrologic Ensemble Forecast Service forecast. For days 16-270, the temperature is taken from the NOAA Climate Forecast System version 2 (CFSv2) seasonal forecast model and the precipitation is from the historical precipitation record. The precipitation portion of the model input for days 16-270 is similar to the current official Water Supply forecast from NWRFC. For days 271-365, the historical records for both temperature and precipitation records are used.

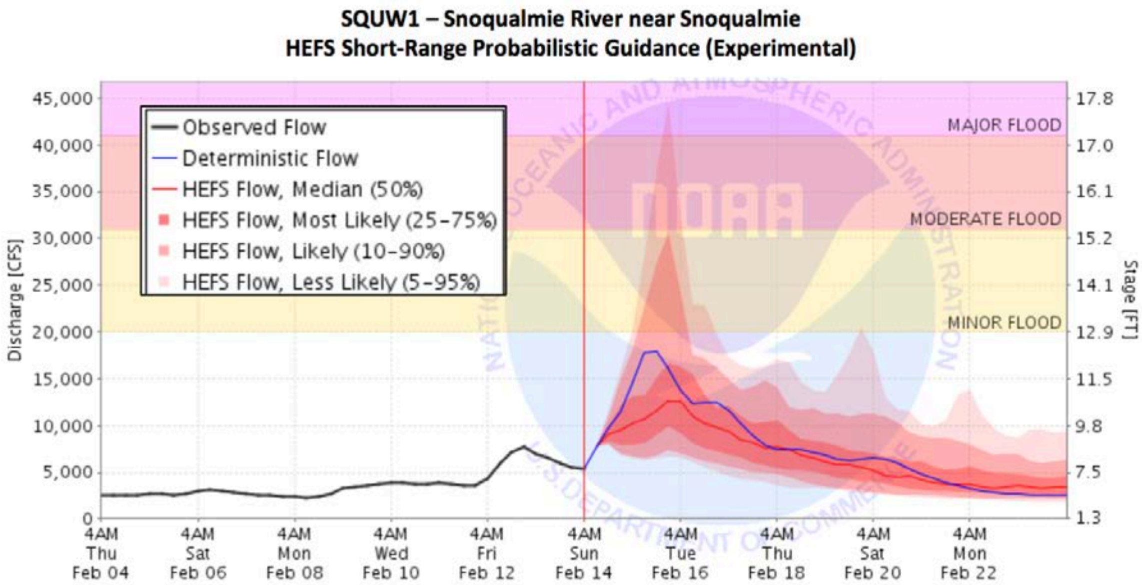

Figure 16. Example of a prototype short-term forecast product for the Snoqualmie River near Snoqualmie based on HEFS (NOAA)

The entire Hydrologic Ensemble Forecast Service forecast method is in contrast to NW River Forecast Center's current Ensemble Streamflow Prediction system that combines a short-term deterministic weather forecast (e.g., 10 days) with longer-term variables based on the climatological record of temperature and precipitation. The Hydrologic Ensemble Forecast Service use of the CFSv2 for the temperature input is an exciting development since seasonal temperature predictions are known to have skill and have been shown to improve streamflow forecast accuracy (Shukla and Lettenmaier 2011). Whether the streamflow forecasts for the Northwest are improved via the Hydrologic Ensemble Forecast Service methodology is currently being verified. We envision this type of forecast product, particularly in the 16 to 270 day range, to be valuable for WSAC once it becomes operational.

The 'Over-the-Loop' Seasonal Streamflow Forecast Demonstration Project

The National Center for Atmospheric Research (NCAR) is leading an effort in collaboration with the University of Washington to investigate potential advances in short to medium range (1 to 15 days) and seasonal streamflow prediction methods. The Bureau of Reclamation, U.S. Army Corps of Engineers, and NOAA support the multi-year project. The overarching goal[39] is to assess forecasting strategies that incorporate scientific advances from the last several decades in areas of modeling, weather and climate prediction, ensemble frameworks, and statistical techniques such as data assimilation. These strategies promote an 'over-the-loop' paradigm in contrast to the current 'in-the-loop' paradigm in which expert forecasters modify forecast system states and outputs. This design follows the rationale that the automation and reproducibility of

[39] Project description: https://ncar.github.io/hydrology/projects/streamflow_forecasting

the predictions allows for systematic benchmarking and adoption of new alternatives, as well as an accurate documentation of forecast performance.

Several water supply forecasting methods are being tested, including ensemble forecasting, statistical forecasting, and hybrid methods; the hybrid dynamical-statistical approaches have already been shown to boost water supply forecast skill by incorporating additional climate information. This initial testing is being done in the western U.S.

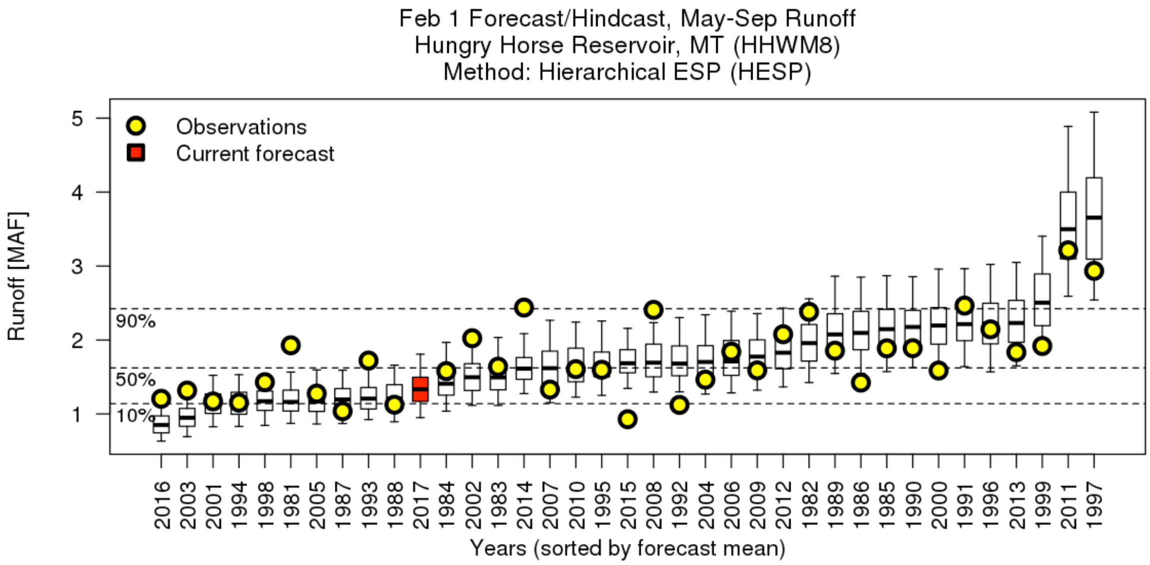

Figure 17. A water supply forecast product initialized February 1, 2017 for April - July Hungry Horse Reservoir inflow.

The current forecast (red symbol, showing the 10, 30, 50, 70, and 90th percentiles) is presented along with the forecasts (open boxes) and observations (yellow dots) from a 35-year hindcast datatset made in a consistent workflow but for past years. The dotted Lines are the 90th, 50th, and 10th percentiles from historic quantities.

An example of a new water supply forecast product that is enabled by the over-the-loop approach is a water supply forecast for the Hungry Horse Reservoir in Montana (Figure 15). The forecast shown is based on a Hierarchical Ensemble Streamflow Prediction (ESP) that blends ESP and teleconnection-based climate information.

As the real-time forecast is entirely consistent with a retrospective hindcast dataset (i.e., avoiding the real-time adjustments of the 'in-the-loop' paradigm), it can be presented in the context of several decades of past forecasts from the same day of year, along with their verifying observations. Aside from the benefits of climate information, this type of verification is a powerful tool for interpreting the quality of the predictions before connecting them to decisions (for more details see Mendoza et al 2017). As the project is currently running semioperationally, these real-time forecasts for several Western basins, including one in Washington, are available online.[40]

As this is currently a demonstration project, we are not recommending its immediate use by the state for drought decisions. Instead, the water agencies have supported this work to highlight promising opportunities and strategies for improving streamflow predictions. We would encourage its use in the future should increased streamflow forecast skill be shown for Washington streams by including climate information (as shown in previous studies, e.g., Shukla and Lettenmaier 2011), as this information is critical to the state's drought monitoring goal. Earlier, more reliable and accurate water supply forecasts can help the state respond to developing drought faster.

Conclusions

This review of the prospects towards better forecasting the onset, continuation, and end of droughts is based on the information available at the time of writing. It can be anticipated that new resources and tools will be forthcoming. In particular, projections are becoming increasingly probabilistic in character, and as part of this trend, will include uncertainty estimates that are better calibrated. Nevertheless, it bears emphasizing that there are real limits in the predictability of the weather on time scales greater than a few weeks and hence our ultimate ability to forecast changes in drought conditions. This critical point underscores the need for the state to place equal, if not greater, emphasis on preparedness.

[40] Seasonal Streamflow Predictability: http://hydro.rap.ucar.edu/hydrofcst/forecasts

Vulnerability

Overview

This chapter assesses the vulnerability of five sectors to drought – agriculture, drinking water, fish and wildlife, energy, and recreation. To date, the most comprehensive assessment of drought vulnerability in Washington State was conducted by researchers at the University of Washington in 2007, with support from Washington State agencies and others, following the statewide drought in 2005. This chapter summarizes their work and supplements it with information gained during the 2015 drought, which exhibited more severe hydrologic conditions across most of the geographic area of the state.

Additional perspective is provided by summarizing data on emergency drought permit authorizations issued in statewide droughts during 2001, 2005, and 2015.

Each statewide drought is characterized, in varying degrees, by anomalies in either precipitation, temperature, or both, which occur over different areas of the state. The character of these droughts is discussed and resulting runoff patterns are provided in Appendix C – Runoff Patterns in Drought Years.

Climate change projections for temperature and precipitation for the mid-21st century are also presented, including how this may impact future droughts in Washington State. In addition, information regarding drought impacts on groundwater conditions, and how climate change may affect groundwater recharge longer term, also is discussed. The Puget Sound Water Supply Forum's assessment of groundwater vulnerability is highlighted.

University of Washington Drought Project

Fontaine and Steinemann (2007) prepared a report on the impacts of the 2001 and 2005 droughts in Washington State. This is the most comprehensive assessment to date on impacts of drought to a wide range of water uses in Washington State. Previous work addressing vulnerability of natural hazards and climate change had been published by the Intergovernmental Panel on Climate Change (IPCC 2001), Schröter and Metzger (2004), and others. Drawing upon the broader literature and their own findings in Washington State, Steinemann and Fontaine proposed a vulnerability assessment method to quantify vulnerability to drought. The conceptual model of the vulnerability assessment is based on the three variables of exposure, sensitivity, and adaptive capacity (Fontaine and Steinemann, 2009).

1. *Exposure* incorporates frequency and severity of drought; severity includes magnitude, duration, and spatial extent.

2. *Sensitivity* is the susceptibility of a water user (or users) to the effects of the drought.

3. *Adaptive capacity* is the ability of a water user to manage or reduce adverse effects of a drought, through actions taken before, during, or after the drought. Exposure and sensitivity determine the potential impact. Adaptive capacity determines the portion of the potential impact that becomes an actual impact.

The combination of the three components results in a net impact or vulnerability to the drought.

These concepts can be illustrated by the following examples of several types of water users. A large metropolitan city which also owns a large storage reservoir is able to compensate for the lack of natural precipitation or low snowpack. A city may also have resources and technical staff available to forecast, model, and monitor water conditions. A city will likely have developed plans to manage low water year conditions. Additionally, it is not uncommon for large purveyors to have developed redundant sources of water, e.g., groundwater sources which can supplement surface water supplies and which are buffered from the impacts of short-term precipitation deficits. Finally, a city can use various tools (rates, public education, etc.) to influence water demand, which gives additional control over its ability to withstand drought impacts.

In contrast, a farmer who depends on naturally available streamflow to irrigate his or her fields is likely to have fewer resources to forecast water supplies and climate conditions. Without compensating storage, the farmer is at the mercy of year-to-year runoff. His or her ability to withstand low water years will also depend on the priority of his or her water right. A farmer with a junior water right may lose the ability to divert in order to protect more senior water rights. The ability to withstand drought conditions also will be affected by crop types. Loss of long-lived crops like tree fruit can result in economic losses extending years into the future.

Finally, fishery populations have a high exposure to drought conditions as it directly affects their habitat requirements - abundant, cool water and the ability to move volitionally between upper and lower watershed areas. Their ability to adapt depends on their mobility, their ability to locate areas of temperature refuge, e.g., where groundwater discharges into streams, and such factors as whether instream flows can be maintained via releases from water storage facilities.

Fontaine and Steinemann examined 34 subsector-region combinations to evaluate their vulnerabilities. They interviewed water users, using questions related to exposure, sensitivity, and adaptive capacity, and calculated a vulnerability score. They used Likert-type questions on these components using a five part scale, ranging from 1-Very Low to 5-Extreme. They interviewed 67 water users from regions of the state affected by previous droughts and likely to be affected in future drought, and representing key sectors: agriculture, environment, municipal and industrial, recreation, and power. The vulnerability scores were grouped according to region of the state, as shown in the figure and in Table 9 below.

Exposure

All areas and water uses carry some risk of exposure to drought conditions. Exposure was ranked the highest for dryland famers (those who do not use irrigation), junior water-right holders, hydropower generators, ski areas, and fish populations in watersheds with large surface water withdrawals. All these subsectors have a large presence in Washington State.

Sensitivity

Sensitivity was reported high for dryland famers, junior water right holders farming exclusively tree fruit, and fish populations already stressed by surface water withdrawals and other habitat impacts. Salmon which spend a long time rearing in freshwater streams were considered especially sensitive to drought conditions. Dryland farmers depend solely on naturally available precipitation and generally do not supplement their fields using irrigation. Tree fruit cannot survive prolonged interruptions of water.

Adaptive Capacity

Adaptive capacity was reported high for large municipalities and hydropower generators. Municipalities that have storage of surface water are better positioned to optimize their supply in conjunction with other measures using a combination of demand-side management, controlled releases, and other strategies.

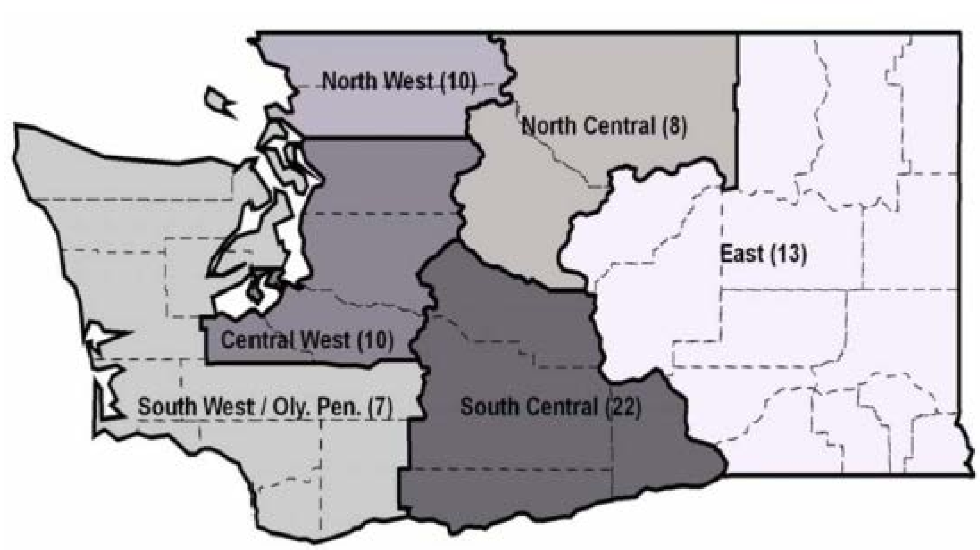

Figure 18. Map showing regions and number of interviewees per region[41]

[41] Adapted from Fontaine and Steinemann 2009

Table 17. Counties and interviewees in each region.

Region	Counties	Interviewees
North West	Skagit, Whatcom	10
Central West	King, Pierce, Snohomish, Thurston	10
South West /Olympic Peninsula	Clallam, Clark, Cowlitz, Grays Harbor, Island, Jefferson, Kitsap, Lewis, Mason, Pacific, San Juan, Skamania, Wahkiakum	7
North Central	Chelan, Okanogan	8
South Central	Benton, Kittitas, Klickitat, Yakima	22
East	Adams, Asotin, Columbia, Douglas, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	13

Table 18. Sectors analyzed within each region and average subsector vulnerability score.[42]

Region and sector	Interviews	Subsector	Score
Northwest region	10		
Agriculture		Irrigated berries	1.88
Agriculture		Irrigated row crops	2.17
Agriculture		Landscape industry*	3.50
Agriculture		Dairy	2.00
M&I		Purveyor	2.50
Environment		Fisheries	3.25
Central west region	10		
Agriculture		Landscape industry*	3.67
M&I		Large municipality supplier	1.63
Environment		Fisheries	2.33
Southwest/Olympic Peninsula region	7		
Agriculture		Landscape industry*[43]	3.50
Agriculture		Irrigated diverse agriculture	2.33
Agriculture		Dairy	2.00
Agriculture		Irrigated berries	3.50
M&I		Municipal	2.50
Environment		Fisheries	1.75

[42] Adapted from Fontaine and Steinemann 2009

[43] Landscape industry is referred to as green industry in the original UW Drought Report. It includes growers, nurseries, landscapers, and other services / supplies for outdoor landscaping.

Region and sector	Interviews	Subsector	Score
North central region	8		
Agriculture		Irrigated fruit trees	2.50
Agriculture		Cattle ranchers	2.33
Environment		Fisheries	3.46
M&I		Municipal	3.00
South central region	22		
Agriculture		Irrigated junior rights	3.28
Agriculture		Wine grapes	1.67
Agriculture		Irrigated senior right	2.00
Agriculture		Dryland	4.50
Agriculture		Cattle	2.33
M&I		Municipal	3.00
Environment		Fisheries	4.08
East region	13		
Agriculture		Irrigated surface water	2.50
Agriculture		Irrigated ground water	2.33
Agriculture		Dryland	4.36
M&I		Municipal	2.78
Environment		Fisheries	3.06
No specific region			
Recreation		Golf courses	1.50
Recreation	3	Ski areas	4.00
Energy	6	Hydropower	1.67

Primary Findings of Impacts

The University of Washington drought report identifies impacts of the 2001 and 2005 droughts in all regions of the state. The UW report's Analysis of Drought Vulnerability and Adaptive Capacity is excerpted as Appendix D. The drought impacts summarized in Steinemann and Fontaine (2009) are highlighted:

- In the agricultural sector, impacts were greatest in cases where lack of supply reduced the quantity and quality of product. Irrigators throughout the state reported increased cost associated with water management during drought.

- Tree fruit growers with pro-ratable water rights[44] commonly reported reduced fruit quality; however, impacts to quantity were not as widely reported.

- Many proratable water users left row crop fields fallow to ensure adequate supply for perennial crops or to supply other fields that were planted.

- Reduced cuttings of hay and alfalfa were also widespread. The decrease in production of feed crops increased costs of feed for livestock. Dryland farmers reported crop reductions of up to 70 percent during drought.

- The landscape industry (the industry that grows, installs, and maintains landscaping, including landscape professionals, landscape nurseries, garden centers, horticulturists, and turf grass growers) in Western Washington reported severe reductions in sales due to early advisories and perceptions of drought in Western Washington.

- Interviewees also reported many secondary drought impacts such as reduced sales of field equipment, increased unemployment, and reductions in assessed land value per capita.

- Fish management officials throughout the state reported that, in most years, fish are negatively affected by water withdrawals from streams and alteration of the natural hydrograph. Drought can magnify these harmful conditions, resulting in additional stress and increased mortality of adult fish migrating upstream, juvenile fish migrating downstream, and resident fish populations.

- The raw value of lost hydropower generation in the state was estimated to be approximately $3.5 billion during the 2001 drought. Average annual value of hydroelectric energy for the Northwest was estimated as $17.2 billion.

- In 2005, ski areas in Washington received less than a third of the business of an average year. (More information on impacts to ski area visits is provided below, updated to 2016.)

Ranking of Resources Requiring Protection

Washington State's drought framework applies to all types of water users and does not explicitly prioritize resources according to importance. But state law (including statutes and administrative rules) restricts emergency relief in the form of grants and loans to public entity recipients (irrigation districts, public utility districts, cities, tribes, etc.). The Washington State Constitution prohibits lending to private parties.

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[44] "Proratable" refers to water rights in the Yakima Project with a May 10, 1905 or later priority date, which may receive less than full supply entitlements during drought.

With respect to emergency water right permitting, emergency permits may only be issued for a previously authorized use of water. Landowners who depend exclusively on rainfall to meet their needs are not eligible for emergency wells or diversions.

In the UW Drought Report, wheat growers in Eastern Washington reported high vulnerability to drought. Wheat growing is a form of dryland agriculture which cannot benefit from emergency water right permitting. Individual wheat growers are not eligible for grants and loans from the state, but may be eligible for federal relief. Support of conservation district technical assistance and extension services outreach may help wheat growers improve their production by adopting new practices.

Winter recreation in the form of skiing and snowboarding is vulnerable to low snowpack conditions. No state programs exist to mitigate impacts to ski resorts, which are private businesses. At the federal level, the Small Business Administration offers economic injury assistance loans for non-agricultural businesses in drought-affected areas. However, these areas are determined by drought status designations in the U.S. Drought Monitor, not whether the state has declared drought conditions according to its own definition. Some ski resorts are taking action to diversify their operations by including revenue generating activities in the summer (e.g. mountain biking, summer concerts, water slides, etc.).

Number of Emergency Drought Authorizations

Expedited water right permitting has been a key element of state drought response in every recent drought. RCW 43.83B authorizes Ecology to issue emergency water right permits to individuals with previously authorized diversions. The number and location of emergency permits issued historically can be used as an indicator of drought-related hardships and vulnerabilities – at least in areas where an emergency water right permit can reduce hardship experienced by the water user. Most emergency water right permits allow the withdrawal of water from an alternate source, such as the use of groundwater from an emergency drought well, when a surface water source is not available.

As indicated by Table 10 and Table 11 below, most emergency drought authorizations have been issued in the Upper and Lower Yakima watersheds in Kittitas and Yakima counties. Fewer than 5 percent of the emergency drought authorizations issued since 1994 have been issued on the west side of the Cascades (16 out of 363 total). Of the 16 total emergency drought permits issued on the west side, 13 were issued in 2015.

The number of emergency water rights issued has dropped from a total of 169 in 2001, to 119 in 2005, to only 71 in 2015. This decline does not appear to correspond to the severity of drought conditions because runoff conditions were most severe in 2015 (Xiaodong and Wolock, et.al, 2016), the year of the lowest number of permits (though the level of proration for junior irrigation districts was more severe in 2005). Other factors affect the number of emergency permits:

- An emergency permit issued in a previous drought may have been in conjunction with infrastructure improvements which made a user more resilient to drought impacts.

- In the time between drought events, water users may have adopted more water efficient practices or otherwise improved their adaptive capacity.

- The terms under which emergency permits are approved have changed. In 2015, users of emergency wells in the Yakima basin were required to pay 50 percent of the cost of replacement mitigation water. No water charges were imposed by the state in prior droughts.

- The timing of drought declarations can differ. This affects the window of opportunity for accessing emergency permits. For example, in 2015 Ecology did not begin issuing emergency drought permits until May due to the evolving water supply forecast in the Yakima basin, which was revised downward as the spring progressed. Irrigation districts in the Yakima basin can begin delivering water as early as mid-March. The forecasted proration amount in early March was 73 percent. In April, the forecast was revised downward to 60 percent. By May the forecast had been revised downward to 47 percent.

Table 19. Number of emergency drought permits by country and year.

County	1994	2001	2005	2015	Total
Benton	1	21	39	12	73
Chelan		7	2	8	17
Clallam			3	1	4
Columbia			1	1	2
Douglas		14			14
Franklin		3			3
Grant				2	2
King			1	3	4
Kittitas		44	10	7	61
Klickitat		4	1		5
Lincoln			1		1
Okanogan		31	10	2	43
Skagit				4	4
Stevens			3	2	5
Walla Walla		5			5
Whatcom				4	4
Yakima	3	40	48	25	116
Grand Total	4	169	119	71	363

Table 20. Number of emergency drought permits by WRIA and drought year.

Watershed	1994	2001	2005	2015	Total
Alkali-Squilchuck		12	1	8	21
Colville			3	2	5
Duwamish-Green				1	1
Elwha-Dungeness			3	1	4
Esquatzel Coulee		2			2
Foster		4			4
Kitsap			1		1
Klickitat		1	2		3
Lower Crab				2	2
Lower Skagit-Samish				4	4
Lower Snake		2			2
Lower Yakima	3	56	81	35	175
Methow		11	7	2	20
Moses Coulee		12			12
Naches				2	2
Nooksack				4	4
Okanogan		17	3		20
Rock-Glade	1	4	6		11
Snohomish				2	2
Upper Crab-Wilson			1		1
Upper Yakima		39	9	7	55
Walla Walla		4	1	1	6
Wenatchee		2	1		3
Wind-White Salmon		3			3
Grand Total	4	169	119	71	363

Prior Appropriation and Regulation of Junior Water Rights

Curtailment is a double-edged sword which constitutes a vulnerability for junior water right holders while at the same time reducing drought-caused vulnerabilities for senior water right holders. Senior water rights may consist of privately held, adjudicated water rights or instream flow water rights held by the state, which have been established by rule. In adjudicated basins[45], senior water right holders may ask the state to curtail junior water rights whenever they are unable to access their full water right. Curtailment is not a rarity even in years without a state declared drought because the sum of appropriations may exceed the amount of water naturally available (e.g., Walla Walla, Yakima, Chamokane near Spokane, Harvey Creek in the Okanogan).

The numbers of water right holders curtailed in any year will vary depending on whether a senior water user makes a call for water or streamflows drop below an instream flow rule threshold. In 2015, close to 900 water rights were curtailed in areas depicted in Figure 14.

Although Ecology has not been tracking the year to year number of curtailed water rights, the number curtailed in 2015 probably exceeds that of other years. In 2015, Ecology reported that curtailments began earlier than normal, and were in effect for a longer period of time. The 900 water rights curtailed represents a small percentage of the approximately 225,000 water right records (permits, certificates, and claims) contained in Ecology's water right database. This is largely due to the fact that Ecology did not start adopting instream flows until the late 1970s/early 1980s. Instream flow regulations are therefore junior to most water rights. If more water rights are issued in basins with instream flow regulations, the number of water rights curtailed in low water years is likely to increase.

[45] Ecology maintains a registry of adjudicated watercourses at: http://www.ecy.wa.gov/programs/wr/rights/Images/pdf/adj_complete_inc_petioned.pdf. A map of adjudicated areas is available at: http://www.ecy.wa.gov/programs/wr/rights/Images/pdf/State-Adj-Map-03042016.pdf.

Table 21. Number of curtailed water rights by watershed, Drought 2015.

Northwest Region	
Nooksack River basin	9
Southwest Region	
Upper/Lower Chehalis River basin	93
Central Region	
Okanogan/Similkameen rivers	101
Wenatchee basin	91
Methow basin	70
Yakima basin	
Post 1905 rights	18
Teanaway	55
Teanaway 2nd notice (earlier priority date group)	32
Cowiche Creek	74
Reecer Creel	4
Little Klickitat River	1
Eastern Region	
Tucannon River/Asotin Creek	15
Harvey Creek	14
Colville River	58
Chamokane Creek	7
Cow Creek	20
Little Spokane basin	140
Touchet River basin	67
Yellow Hawk Creek	14
Walla Walla River basin	17

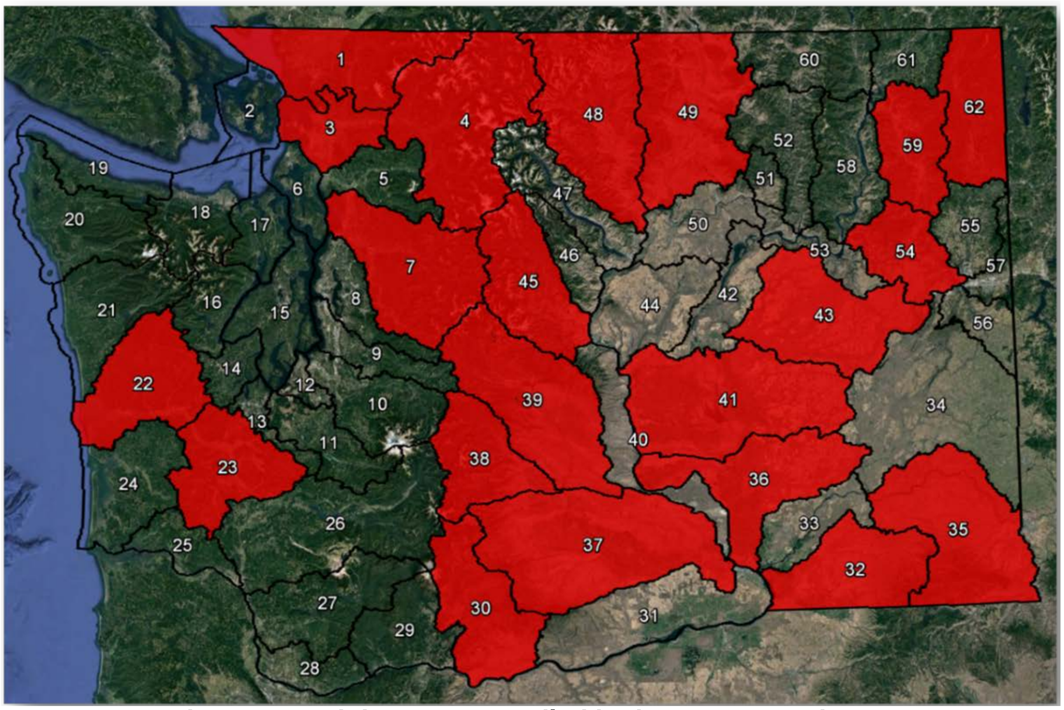


Figure 19. WRIAs where water rights were curtailed in the 2015 Drought.

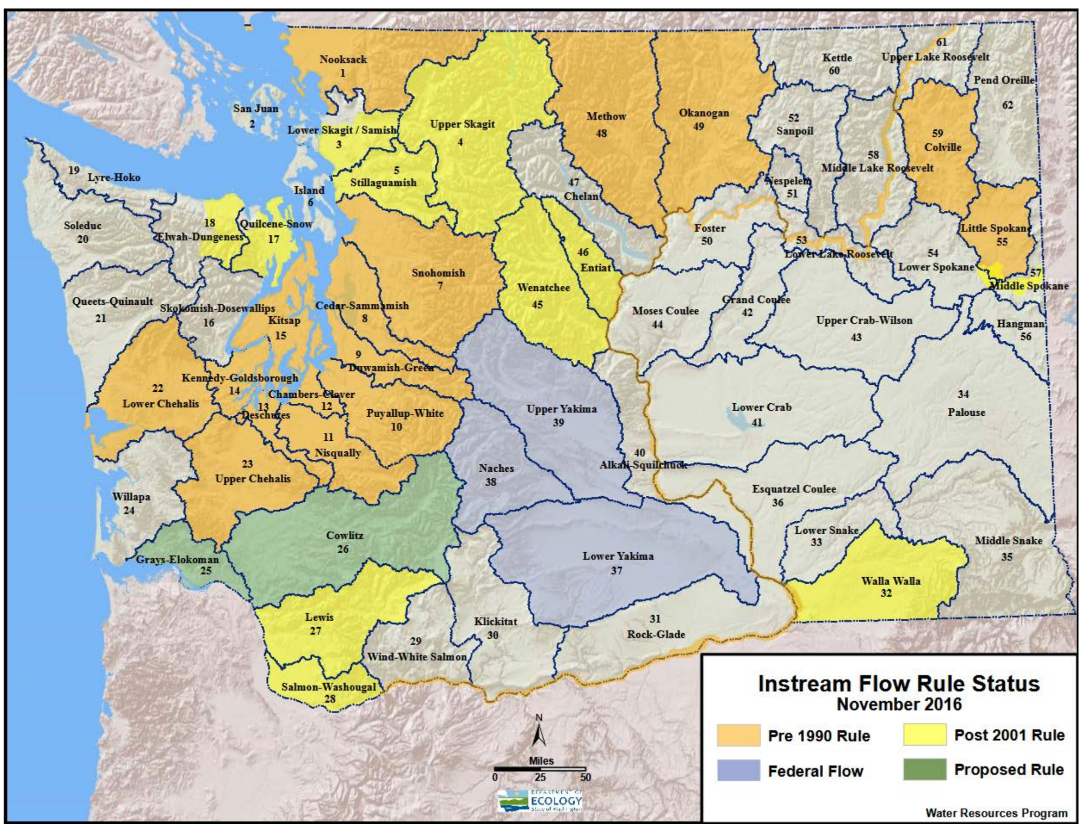


Figure 20. Statewide map of instream flows set in rule.

The Yakima Basin

Steinemann and Fontaine (2009) found that irrigated agriculture in South Central Washington with junior irrigation water rights had an above average vulnerability ranking. This geographic area includes the Yakima basin, which consist of substantial portions of Kittitas, Yakima, and Benton counties. The majority of emergency water right permitting actions in prior drought years has been to address water supply needs in the Yakima basin.

The Bureau of Reclamation (Bureau) operates the Yakima Project, consisting of five separate reservoirs in the Upper Yakima, Naches, and Tieton watersheds (Kachess, Keechelus, Cle Elum, Rimrock, and Bumping Lake reservoirs). At full capacity, these reservoirs store 1,065,400 acre-feet. They supply water to about 450,000 acres of irrigation land. Total out-of-stream water right entitlements in the Yakima basin equal 2,406,917 acre-feet (Bureau of Reclamation, June 2011).

Meeting these needs requires a combination of natural runoff from snowmelt and precipitation, releases from storage, and recapture of return flow from irrigated land. Natural unregulated runoff for the Yakima River near Parker during the Apr-Sept period averages about 2.2 million acre-feet (Vaccaro, 1986). The average annual unregulated flow of the Yakima River basin at Parker gage totals approximately 3.4 million acre-feet, ranging from a high of 5.6 million acre-feet (1972) to a low of 1.5 million acre-feet (1977). About 330,000 acre-feet of return flow, as measured at Parker is used to meet total water supply as well (the amount is more in wet years, less in dry years).

In years where storage and runoff are not sufficient to meet water demand, water is apportioned, in order of priority, between three classes of users:

- Non-proratable users possessing water rights senior to May 10, 1905 (date of Congressional authorization of the Yakima Project). So far water supply has been sufficient for these users to receive their full water supply in all years. Still, some users on tributaries upstream of the Yakima Project, with confirmed adjudicated rights, have been curtailed to protect other, more senior water rights.

- Proratable users with a priority date of May 10, 1905. These include most of the Roza Irrigation District and Kittitas Reclamation District, and portions of other districts. Together these districts account for 383,000 irrigated acres. These users receive reduced supply in drought years. (See Table 9. Yakima Project proration years and percentages.)

- Junior users with a priority date after May 10, 1905. These users receive no water in drought years.

Historic data regarding the effect of drought years on total water supply in the Yakima basin has been fully documented in support of the Yakima River Basin Integrated Water Resource Management Plan ("Yakima Basin Integrated Plan"). Through this process, a 70 percent proration level has been identified as an approximate threshold where proratable irrigation districts and farmers begin to experience major economic losses (Bureau of Reclamation, 2011, p. 25).

Table 22. Yakima Project proration years and percentages (Bureau of Reclamation Yakima Integrated Plan Final Programmatic EIS and August 2015 Water Supply Forecast)

Water Year	Proration Percentage
1992	58
1993	67
1994	37
2001	37
2005	42
2015	47

In no year to date have senior, nonproratable users received less than 100 percent of their water allocation from the Bureau (though this could change if droughts become more severe). Prorated users have historically been able to apply for emergency drought permits to make temporary use of groundwater withdrawals. In 2015, emergency withdrawals totaled about 2,000 acre-feet. The withdrawals are authorized for use only while the state-declared drought emergency is in effect.

The longer term continuation of this practice is contingent on funding and consent by Tribal, federal, and state water managers. Emergency groundwater pumping is an out-of-priority use of water in the Yakima basin and the hydrologic connection between groundwater and surface water has been well established scientifically (USGS Yakima River Study). Pumping of emergency drought wells risks impairment of other surface and groundwater water rights in the basin. As most of these wells are deep within basalt formations, the effect is presumed to be delayed for months or even years, but ultimately the extraction of groundwater will result in a flow depletion.

In more recent droughts, Ecology, the Bureau, and the Yakama Nation have agreed that pumping may proceed under condition the state offsets the long term impact of pumping on surface waters by permanently acquiring senior water rights in the basin. This agreement also requires users to record and report their withdrawals to Ecology. (See Appendix F). This agreement must be re-affirmed with every new drought emergency.

The vulnerability of proratable users may increase if funding to purchase mitigation water is not made available in future droughts. Without mitigation, other water users could oppose the use of emergency withdrawals, notwithstanding the remarkable level of current water-management cooperation in the Yakima basin. Due to these risks, the use of emergency wells is best viewed as a stop-gap measure until more permanent solutions are implemented. Long term, the Yakima Integrated Plan is designed to reduce the vulnerability of proratable users in drought years through a combination of irrigation system upgrades, enhanced surface water storage, structural and operational changes, groundwater storage, and water markets (Bureau of Reclamation 2011).

Agriculture

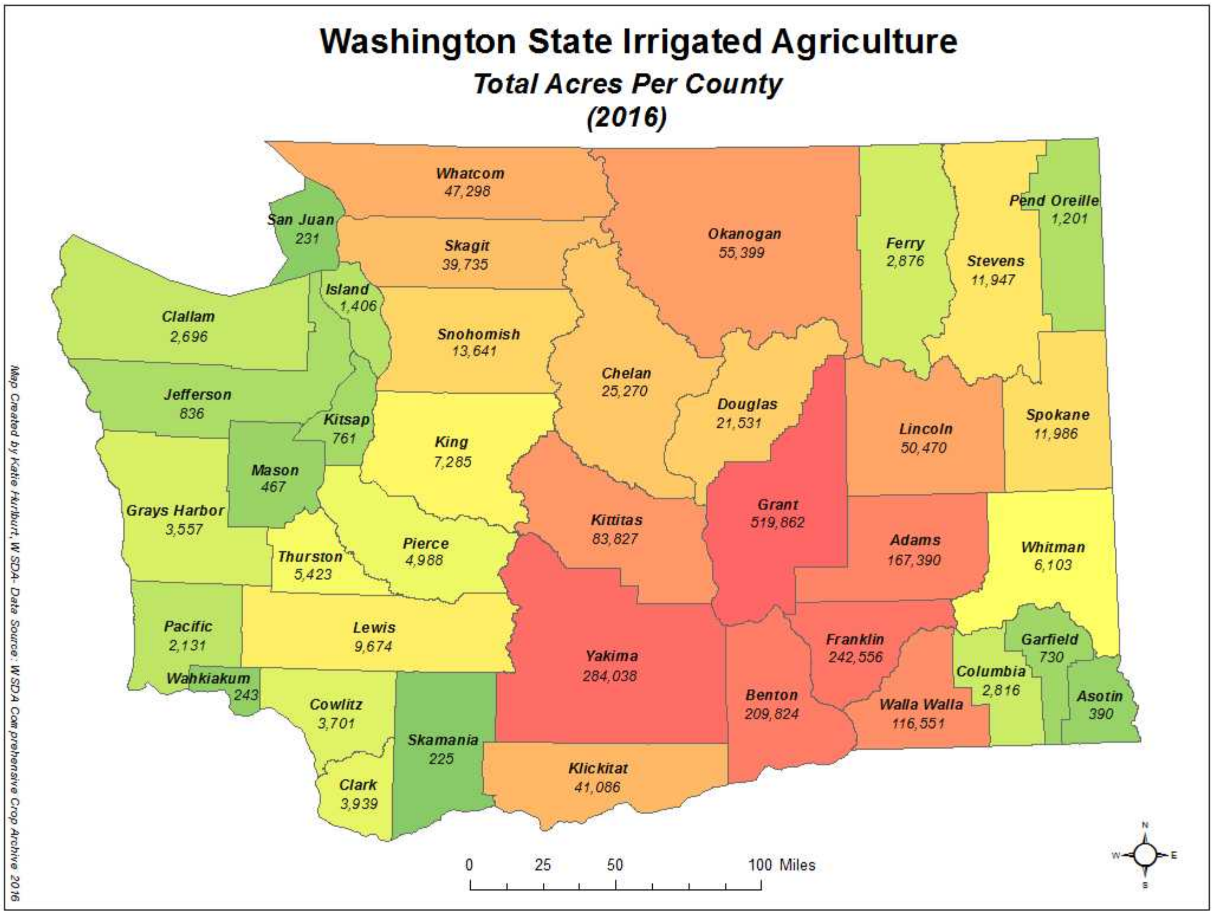
More than $10 billion worth of crops are grown annually each year in Washington State, which ranks first in the nation in the production of 11 different commodities. More than 300 commodity types are grown in total, at more than 37,000 farms. The overall value of the state food and agriculture industry is $51 billion, making agriculture 12 percent of the state economy. The top counties in market value are listed in Table 10.

Table 23. Top agricultural counties by market value.[46]

County	Crops
Grant	Apples, cattle, potatoes
Yakima	Apples, milk, hay
Benton	Potatoes, apples, grapes
Franklin	Potatoes, apples, hay
Walla Walla	Cattle, wheat, apples
Adams	Potatoes, wheat, apples
Whitman	Wheat, barley, peas, and lentils
Whatcom	Milk, raspberries, blueberries
Okanogan	Apples, cherries, pears
Skagit	Nursery/greenhouse, milk, potatoes

Estimates of irrigated acres in Washington State range from 1.6 million (2013 data, National Agriculture Statistics Service Census Survey Data) to 1.9 million acres (2015 data, Washington State Department of Agriculture (WSDA) crop mapping). Approximately one quarter of those acres (464,000) are located in the Yakima River basin in Yakima, Kittitas, and Benton counties. Another 671,000 acres are served by the Columbia Basin Project in portions of Grant, Lincoln, Adams, and Franklin counties. Most of the additional irrigated acres are located on the east side of the Cascades as well.

[46] A complete map of the agriculture value of all counties in Washington, based upon 2012 USDA Agriculture Census Data, is available at http://agr.wa.gov/AgInWa/docs/126-CropMap2015-ForCopier.pdf



Washington State Irrigated Agriculture
Total Acres Per County
(2016)
Whatcom 47,298
San Juan 231
Skagit 39,735
Okanogan 55,399
Ferry 2,876
Stevens 11,947
Pend Oreille 1,201
Island 1,406
Clallam 2,696
Snohomish 13,641
Chelan 25,270
Jefferson 836
Kitsap 761
Douglas 21,531
Lincoln 50,470
Spokane 11,986
King 7,285
Mason 467
Grays Harbor 3,557
Grant 519,862
Kittitas 83,827
Adams 167,390
Whitman 6,103
Thurston 5,423
Pierce 4,988
Pacific 2,131
Lewis 9,674
Franklin 242,556
Garfield 730
Yakima 284,038
Wahkiakum 243
Columbia 2,816
Benton 209,824
Walla Walla 116,551
Asotin 390
Cowlitz 3,701
Skamania 225
Klickitat 41,086
Clark 3,939
0 25 50 100 Miles
N S E W
Map Created by Katie Hurlburt, WSDA- Data Source: WSDA Comprehensive Crop Archive 2016

Table 24. Acres of irrigated agriculture by county.

County	NASS (2012)	WSDA (2016)
Adams	127,046	167,390
Asotin	482	390
Benton	197,305	209,824
Chelan	22,778	25,270
Clallam	4,164	2,696
Clark	3,721	3,939
Columbia	4,083	2,816
Cowlitz	7,556	3,701
Douglas	18,311	21,531
Ferry	2,823	2,876
Franklin	207,151	242,556
Garfield	795	730
Grant	428,200	519,862
Grays Harbor	8,635	3,557
Island	1,586	1,406
Jefferson	1,179	836
King	4,122	7,285
Kitsap	495	761
Kittitas	66,908	83,827
Klickitat	21,748	41,086
Lewis	8,235	9,674
Lincoln	34,655	50,470
Mason	777	467
Okanogan	51,723	55,399
Pacific	2,487	2,131
Pend Oreille	903	1,201
Pierce	2,834	4,988
San Juan	343	231
Skagit	19,239	39,735
Skamania	352	225
Snohomish	5,331	13,641
Spokane	10,286	11,986
Stevens	6,690	11,947
Thurston	5,309	5,423
Wahkiakum	48	243
Walla Walla	91,108	116,551
Whatcom	35,484	47,298
Whitman	4,293	6,103
Yakima	224,386	284,038
TOTAL	1,633,571	2,004,090

Impacts to agriculture from the 2015 Drought

The Washington State Department of Agriculture's (WSDA) Natural Resources Assessment Section (NRAS), at Ecology's request, conducted an analysis of the 2015 harvest and drought impacts (Washington State Department of Agriculture, 2017). It is summarized here:

Regional highlight areas were the Kittitas Reclamation District, the Roza Irrigation District, the Wapato Irrigation Project, and Skagit County. WSDA collected data in these regions through targeted mapping, anonymous interviews, and information collected by Washington State University's Skagit County Extension. In addition to the regional highlight areas, WSDA reviewed data from the U.S. Department of Agriculture's National Agricultural Statistics Service for a selection of 15 crops which account for 77.5 percent of the cultivated acreage in Washington. NRAS staff assessed the drought's impact on dairy and cattle operations in Washington as well through an online survey focusing on increased expenses for feed purchase, lease of additional land for grazing, and productivity losses.

Based on information from commodity-specific and regional grower's groups, WSDA estimates Washington State blueberries grown from 2015 were reduced in yield, size, and quality, with losses of $7.76 million. Red raspberries were reduced in both size and quality, with losses of $13.9 million. Across the Yakima Valley growers reported reductions in both yield and quality, increased fallowing, and changes in crop rotations. Some growers deferred planting permanent crops depending on access to emergency drought wells.

In the Kittitas Reclamation District, the analysis was based on targeted mapping work by WSDA, supported by district staff, and focusing on unharvestable or fallowed fields. The mapping survey included discussions with growers within the district to verify damage was drought related and gather qualitative information. Most of the damage was observed in timothy hay, alfalfa, and pasture, consisting of reduced cuttings on hays and dry pastures, and reduced grazing opportunities. Additionally, WSDA observed losses in apple, oat, pear, and other grass hays. The amount of acreage affected was paired with the 5-year average price per acre (2010-2014) to determine a total economic impact of $11,401,115.

In the Roza Irrigation District, WSDA also conducted mapping work to identify unharvestable or fallowed fields, as well as anonymous individual interviews with growers to identify additional expenses incurred due to drought. Mapping results identified dry, dead, unharvestable, or fallowed fields in apricot, nectarine/peach, pear, triticale, and wheat. WSDA interviews with growers documented reduced size, quality, and yield in apple, cherry, hops, blueberry, wine grape, juice grape, field corn, and alfalfa. Growers also reported increased costs for pest and weed control, emergency drought wells, and expected continued impacts during the 2016 growing season. Total losses for the Roza Irrigation District growers are estimated at $75,783,834.

WSDA conducted anonymous interviews with growers relying on water from the Wapato Irrigation Project. Growers reported losses in timothy, alfalfa, mint, carrot seed, wheat, apples, cherries, and potatoes, although losses were not consistent over the entire area. Based on consultation with the Wapato Irrigation Project board and growers, WSDA applied these losses to 90 percent of the acreage and estimated a total loss of $32,691,211.

Information on drought effects in Skagit County were compiled by Washington State University's Skagit County Extension, which estimated a 10 percent loss throughout the county on average, with a total loss of $27,200,000.

WSDA used data from the National Agriculture Statistics Service to identify additional losses across the state in a selection of crops that constitutes 77.5 percent of the total cultivated acreage in Washington. Data from 2015 was compared to historic results (2010-2014, 5-year average) for total crop acreage, price per acre, and yield per acre to assess losses due to reduced yield, reduced quality, or unplanted acreage. The 15 crops selected were wheat, barley, dry peas, lentils, apples, mint, dry beans, hops, sweet corn (processed), sweet corn (fresh), hay (excluding alfalfa), pears, cherries, alfalfa, and field corn. Based on these three methodologies losses of $501,002,853 were estimated statewide.

WSDA, with the assistance of the Washington State Dairy Federation, invited dairy and cattle producers to respond to a short online survey about their location, operation size, and potential additional costs incurred through the purchase of feed, rental of additional grazing land, milk or calving losses, and the potential for continued increased costs or losses in 2016. Respondents reported purchases of additional feed, both timothy and alfalfa, leasing additional land for grazing, and reductions in milk production. These results were extrapolated to all dairy producers based on advice from the Washington State Dairy Federation. Because there were relatively few responses from cattle producers, the analysis was not extended to the cattle industry in Washington. Total losses to the dairy industry are estimated at $33,279,564.

WSDA concludes that the estimated economic loss due to the 2015 drought reached between $633 million and $773 million. WSDA recommends that this report serve as a starting point rather than a final summary.

Among the agency's recommendations is that an assessment should be conducted of the statewide distribution of irrigation districts, identifying which growers rely on surface and groundwater, which have water rights that are susceptible to curtailment in low water years, and where access to emergency drought wells exists. In addition, now is the time to develop a robust plan for continued data collection. Identifying strategies for collecting needed data and ongoing analysis will give Washington State the ability to assist growers and plan for a future that includes increased incidence of severe weather events such as the 2015 drought.

Vulnerability of Fish and Wildlife to Drought Conditions

Fish populations are an important aspect of Washington State's economy, ecology, and quality of life. For Indian tribes, fish are culturally and economically significant. Most Tribes have Treaty rights which grant fishing rights and in some cases at least fifty percent of the harvestable fish. Many specific salmon stocks are considered threatened or endangered pursuant to the federal Endangered Species Act. Annual economic activity associated with commercial and sport fishing in Washington State totals $2.5 billion annually. More than 175 million salmon, steelhead smolt, trout, and warm water fish are reared at state hatcheries for release into Washington waters each year.

Steinemann and Fontaine's (2007) analysis indicated that fish are highly vulnerable to drought conditions in nearly all regions of the state. Vulnerability was classified as lower in southwest Washington and the Olympic Peninsula than in other regions of the state (this may reflect that low streamflows were most evident on the east side of the mountains in the 2001 and 2005 droughts; see Appendix C: Runoff Patterns). Fish managers throughout the state reported that, in most years, fish are negatively affected by water withdrawals from streams and alteration of the natural hydrograph. These deleterious conditions can be magnified by drought, resulting in additional stress and increased mortality of adult fish migrating upstream, juvenile fish migrating downstream, and resident fish populations. High air temperatures in conjunction with lower flow volume may cause water temperatures to increase, placing additional stress upon fish.

WDFW has identified a list of fish and wildlife vulnerabilities, which are described in the list below. The vulnerabilities are classified according to whether they affect fish in their natural habitat, fish in hatcheries, and terrestrial wildlife.

Vulnerabilities to fisheries and wildlife

Fish in nature

- Low flows expose physical blockages to downstream movement, and can strand migrants in dewatered stream segments.
- Dewatering and shallow stream reaches and irrigation ditches can lead to stranding of juvenile salmonids.
- Low flows shrink rearing habitats, reducing juvenile survival (crowding, low dissolved oxygen, disease, less food).
- High temperatures in certain stream reaches can cause thermal blockages which upstream migrants will not pass.
- High stream temperatures, either because flow is low (water is shallower) or because air temperature is higher (or both), can directly cause fish mortality.

- Low flows reduce riffle depth or dry up stream reaches, preventing upstream migrants from entering streams or reaching normal spawning grounds.

- Low flow congregates migrating fish, which are affected by crowding, low dissolved oxygen, and potential higher disease incidence, increasing pre-spawning mortality.

- Low flows shrink spawning habitats, causing fish to spawn in sub-optimal habitats (habitats that produce lower egg survivals), or to superimpose nests, which also leads to low egg survival.

- In streams with many agricultural diversions, the level of diversion reduces flows (and increases temperature) and therefore inhibits migration ability.

- Reservoir outflows can be curtailed by drought conditions, causing low-flow problems downstream.

- Low reservoir elevations (and rapid elevation changes) concentrate reservoir residents, causing crowding, low levels of dissolved oxygen, heightened disease, and mortalities.

Fish in hatcheries

- Hatchery fish will need more frequent medications due to virulence of disease organisms at lower flows and higher water temperatures.

- Hatchery water supplies may need to be modified, or alternative water supplies employed, to provide adequate water supply and/or maintain adequate water quality.

- Fish may need to be released earlier or relocated to safe havens, which results in higher trucking costs and increased handling stress and mortalities.

Terrestrial wildlife

- Terrestrial water shortages for birds, small game, and big game.

- Impacts to waterfowl, amphibians, and other species as wetlands recede.

- Loss of forage grasses and shrubs.

- Increased disturbance, road kill, predation, and incidents of problem and dangerous wildlife as animals are forced to seek water and food near more populated areas.

Effects of 2015 Drought on Columbia River fisheries

The 2015 drought demonstrated the importance of water temperature during drought conditions. In the mainstem Columbia and Snake rivers, unprecedented high temperatures led to catastrophic loss of sockeye fish in the Columbia River system (Columbia Basin Fish and Wildlife Bulletin, 2015). Temperatures in the Okanogan River reached 85°F - significantly above the lethal threshold of 68°F (Fish Passage Center Memorandum, 2015).

NOAA Fisheries concluded that, "…although June and July river temperatures in 2015 were unprecedented, it is reasonable to expect that similar events could occur in the future. If rare, events are unlikely to have a large or lasting impact to the viability of sockeye salmon populations because their complex life histories provide resiliency against catastrophic events. However, should similar events occur frequently, sockeye salmon populations in the Columbia River basin would be substantially impacted." (Northwest Power and Conservation Council, 2016).

Evidence of blockages and rock dams from 2015 Drought

During the 2015 Drought, observed April-September runoff at many USGS stations was the lowest observed in the prior 64 years (Northwest River Forecast Center). WDFW biologists and field staff recorded approximately 312 locations in 17 watersheds where migratory movement of fish in rivers and streams was impeded by the low flow constrictions or man-made recreational rock dams (e.g., locations where boulders have been rearranged to create wading pools). These rock dams, if left in place, can prevent fish from moving up and down a stream corridor, particularly if they span an entire channel. WDFW and tribal biologists, conservation corps workers, and volunteers removed boulders and restored connectivity to the stream reaches.

Reported locations do not represent a comprehensive survey of blockages, but only those locations observed by or reported to WDFW. It is reasonable to assume that the extent and number of blockages resulting from extreme low summer runoff was more extensive than reported and that, in rivers where flow-related constrictions form even in normal years, such barriers manifested themselves earlier in the season than average.

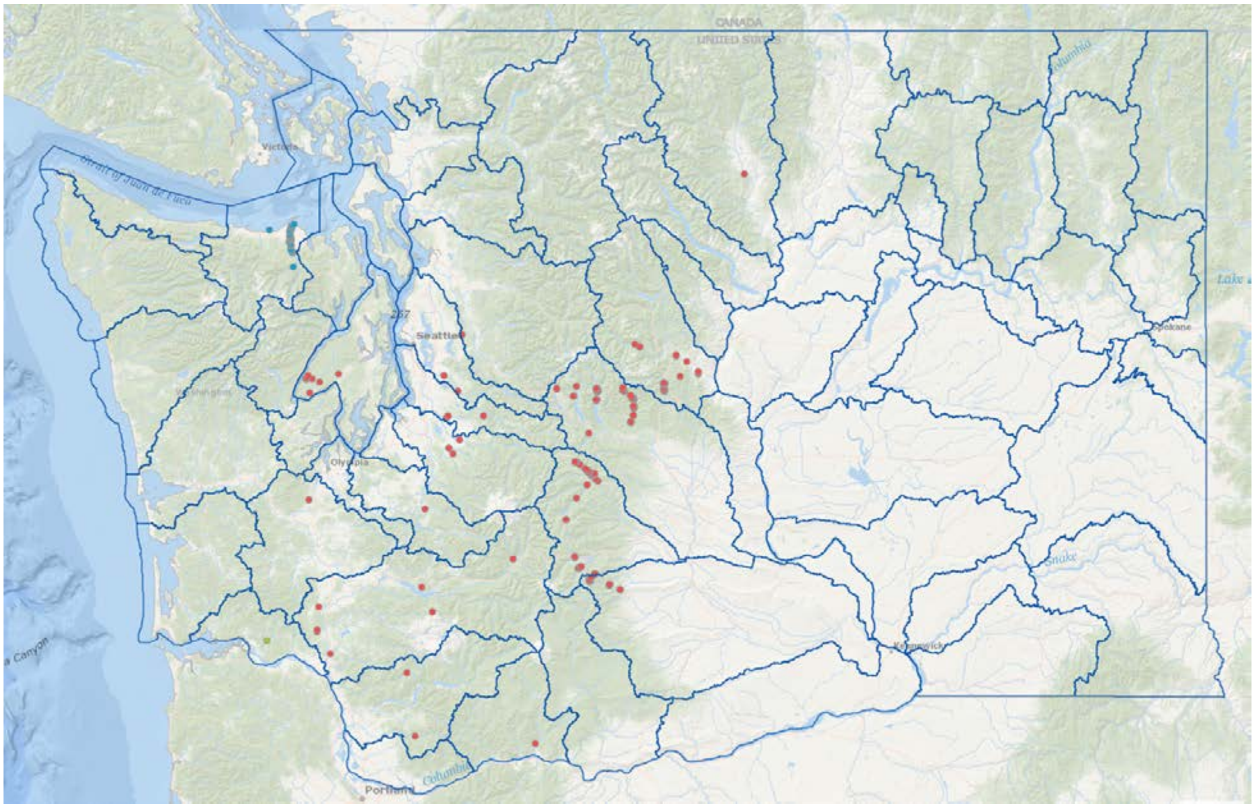


Figure 21. Locations of reported stream blockages in 2015 (WDFW)

Public Water Supplies

More than 5.5 million Washington State residents, 85 percent of the state's population, get their drinking water from public water systems. The remainder are dependent on individual private wells. Large water systems (those with more than 1,000 service connections) and new Group A community water systems in Washington State are required to prepare water system plans which are reviewed and approved by the State Department of Health (Health). Smaller water systems must develop and implement a Small Water System Management Program, but these plans are subject to less oversight and do not require Department of Health's approval.

Public water systems are required to demonstrate that existing and projected demand can be safely and reliably met. Therefore, the drinking water sector is generally well-prepared for drought conditions. All water systems with more than 1,000 connections are required to prepare water shortage response plans, which describe how a system manager will gradually escalate the level of response from advisory, to voluntary, mandatory, and emergency reductions in water use. Other public water systems are required to prepare water shortage response plans if they are experiencing or anticipate experiencing shortages. A water shortage can be any situation in which water supply is inadequate to meet demand. Causes may include drought but also other circumstances like water contamination, loss of power, and equipment failures.

Water systems are not required to notify Health if a formal water shortage response strategy is activated. The lack of systematic tracking of shortage incidents may lead to an under-awareness of the stresses faced by communities and small systems in times of drought. Currently, awareness largely depends on ad-hoc communication with utility managers, word of mouth, and media reports. Nevertheless, there have been few reports of water systems encountering serious water supply challenges (i.e., risk of significant or total loss of supply) in previous droughts. Those that are reported have included the drying up of spring sources, declining water levels in shallow wells, stressing of existing system vulnerabilities, reduced reservoir storage, and difficulty meeting demand while abiding by diversion constraints associated with instream flow protection measures.

Less than 5 percent of emergency drought permits issued in the 2001, 2005, and 2015 droughts were for municipal purposes. Still, some municipalities reported implementing other coping measures such as the activation of emergency backup sources, storing water above normal pool levels in reservoirs, and activating voluntary or mandatory reductions of water use by water utility customers.

Health has developed a preliminary drought vulnerability assessment which can be used as a filter to identify water systems which are most vulnerable to drought-caused water supply interruptions. This filter considers the following factors:

- Individual source susceptibility: (qualitative rating that evaluates each water source's depth, construction, aquifer characteristics (thickness, confined or unconfined), age, use, and capacity.

- System aggregate sources' capacity (combined capacity for multiple sources), operational capacity (system size and population), and redundancy. (System size serves as a rough proxy of resources and management capacity.)

- Where information is unknown or unavailable — a moderate level or higher level of risk is assigned.

Table 25. Number of systems considered more susceptible to drought vulnerabilities (Health)

Description from DOH Sentry Database	# of Systems	Drought Risk
Group A systems with a single source and depth between 1 & 50 ft.	232	Tier 1 A
Group B systems with a single source and depth between 1 & 50 ft.	1046	Tier 1 B
Group A systems with combined source capacity less than 10 gallons per minute. This includes all Group A system types: community, NTNC, & TNC. This also includes systems with only a single source.	263	Tier 2 A
Group B systems with combined source capacity less than 10 gallons per minute. This includes systems with only a single source.	2029	Tier 2 B
Group A systems with a single source & depth between 51 & 100 ft.	533	Tier 3 A
Group B systems with a single source & depth between 51 & 100 ft.	2992	Tier 3 B
Group A systems with combined source capacity greater than 10 gallons per minute & less than 20 gallons per minute. This includes all Group A system types: community, NTNC, and TNC. This also includes systems with only a single source.	237	Tier 4 A
Group A systems with zero or missing source capacity. This includes all Group A system types: community, NTNC, and TNC. This also includes systems with only a single source.	118	Tier 5 A
Group B systems with combined source capacity greater than 10 gallons per minute and less than 20 gallons per minute. This includes systems with only a single source.	1940	Tier 4 B
Group B systems with zero or missing source capacity listed. This includes systems with only a single source.	966	Tier 5 B
Group A systems with a single source & no depth listed	193	Tier 5 A
Group B systems with a single source where the depth listed is blank or zero	1379	Tier 5 B

Tiers denote level of vulnerability (Lower Number = Higher Vulnerability.)

A or B refers to Water System Class (Group A or B). Group A systems are those systems which have 15 or more residential connections.

NTNC = Non-Transient, Non-Community: A public water system that regularly supplies water to at least 25 of the same people at least six months per year. Some examples are schools, factories, office buildings, and hospitals which have their own water systems.

TNC = Transient Non-Community Water System (TNCWS): A public water system that provides water in a place such as a gas station or campground where people do not remain for long periods of time.

Energy

Washington relies on hydroelectric power for about 66 percent of its electricity supply (2000-2015), and the availability of hydroelectric power varies significantly from year to year. This variation in hydroelectric output is due to year-to-year variations in precipitation, especially during the fall and spring. Some precipitation is stored in the form of snowpack. As the snow melts in the spring and summer, the operators of hydroelectric facilities manage the runoff to meet multiple objectives, including power generation, fish passage, flood control, and irrigation. In most years, the spring and summer runoff is greater than the capacity of the hydroelectric system to generate electricity or store the water behind dams, and some water is spilled over the dams without generating electricity.

Drought conditions in the summer affect power generation by reducing the amount of stored water that is available to generate electricity. The actual reduction in water entering the state's rivers as rainfall is a small factor in the drought effect. The more significant effect of drought is that fish passage requirements become a constraint on the amount of water available for generation. For example, in 2001, drought conditions prompted modifications to the operations of hydroelectric projects in order to ensure compliance with federal requirements to protect threatened and endangered species of salmon and steelhead.

Drought conditions would not be expected to endanger the adequacy of electric power supplies in the state. This is because the operators of the regional power system incorporate critical year, low-water conditions in planning for electric power resource adequacy. These conditions are based on the worst precipitation years in the historical record. Utilities maintain enough non-hydro power capacity – including natural gas, coal, nuclear, and wind – to meet projected consumer demand during adverse hydrologic conditions.

Relative to total supply, hydroelectric energy's share has been declining over the past 14 years, as a greater share has been taken up by other sources such as natural gas and wind. These trends are illustrated in the figure below, provided by the Northwest Power Planning Council.

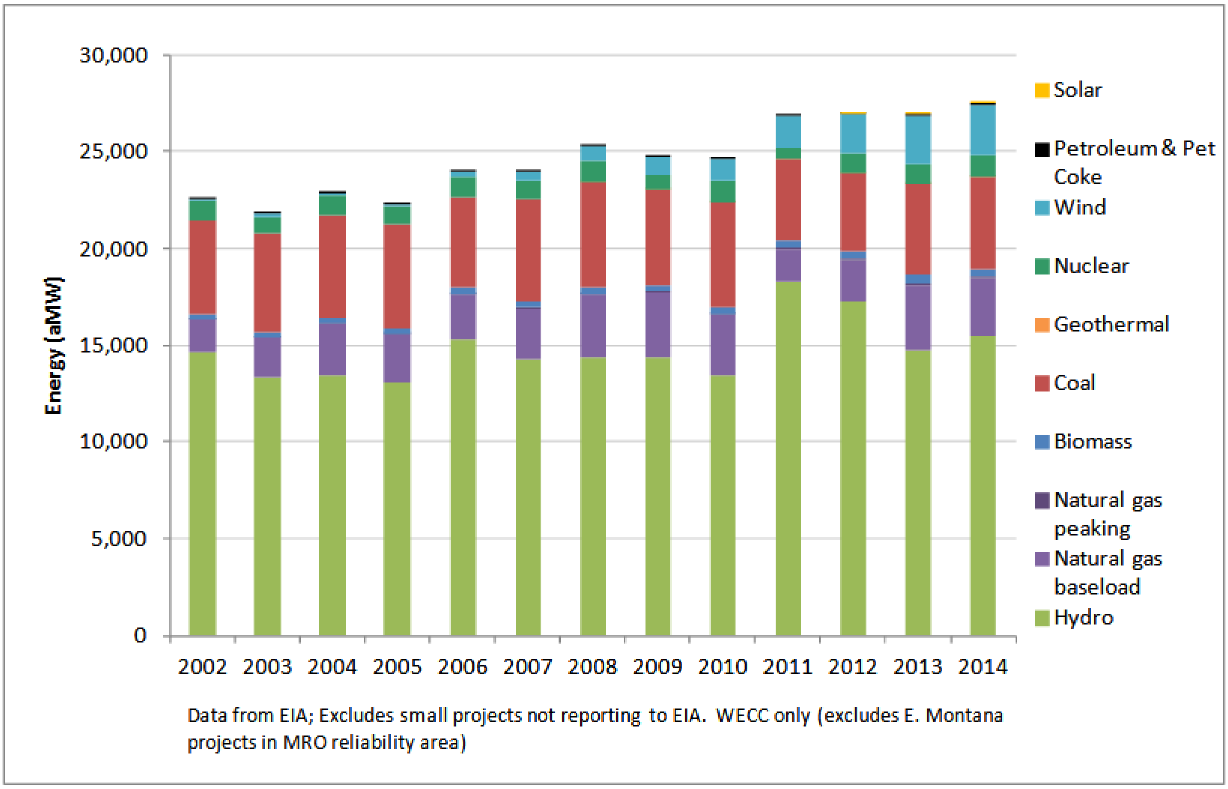


Figure 22. Historical energy production in the northwest since 2002.

Recreation

Skiing and snowboarding

Winter sports such as skiing, snowboarding, and snowmobiling have a high vulnerability because of their reliance on snowpack accumulation. Snowmaking machines can provide some compensation, but their effectiveness is diminished in warm winters. Other strategies include using machinery to concentrate snow where ski runs need it and diversifying into recreational activities suitable for summer months such as mountain biking, hiking, sightseeing, and slides. Information regarding visits to ski resorts was provided by the National Ski Areas Association and is depicted in Figure 20.

In years of major snow droughts, visitation dropped significantly. In the winter of 2004-2005, visitation to Washington State ski resorts dropped by 1.5 million visits from the prior year, a decrease of 77 percent.

During the 2014-2015 winter, visitation numbers dropped by more than 900,000 visits from the previous year, a decrease of 59 percent. For 6 of 12 measurement stations located at or near ski resorts, 2015 ranked as having the least snow depth ever measured on April 1. (Northwest Avalanche Center Snow Climatology Data, 2016).

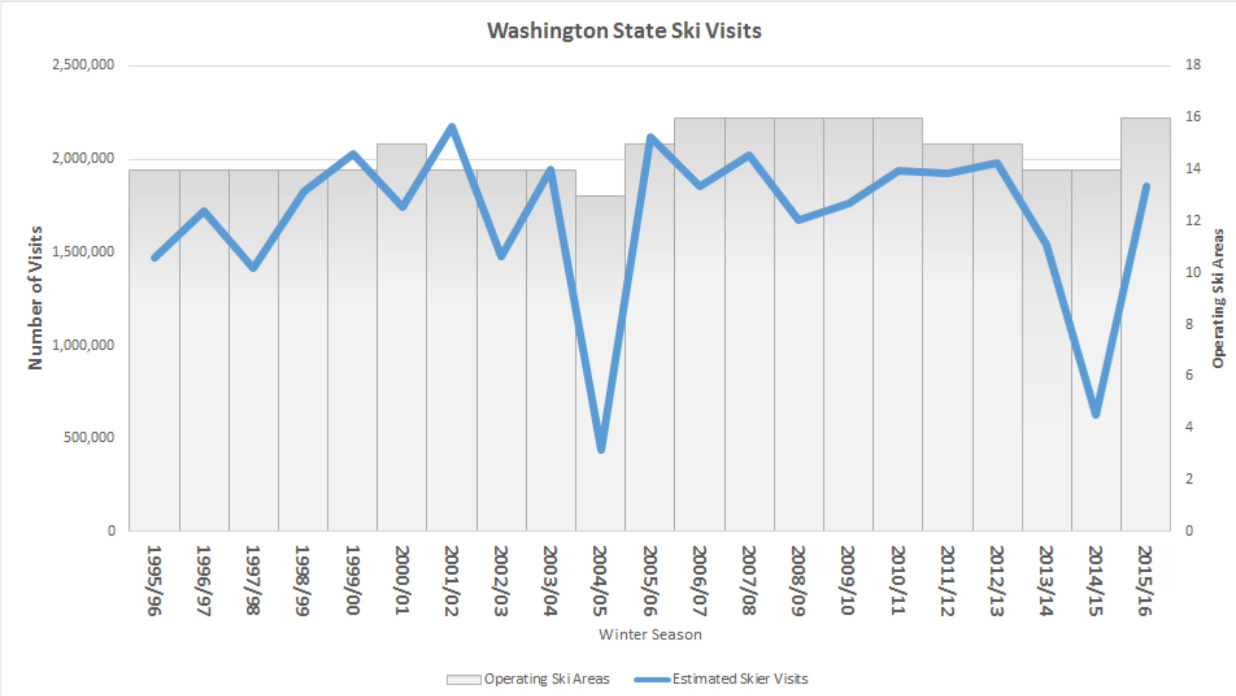


Figure 23. Washington State ski visits (national Ski Area Association).

Table 26. April 1 snow depths at select Washington and Oregon Ski resorts (inches)

Resort	Climate average depth	Maximum depth (thru 2016)/year		Minimum depth (thru 2016)/year	
Hurricane	105	252	1999	12	2015
Mt Baker	173	311	1999	17	2015
Stevens	100	192	1956	22	2015
Snoqualmie	85	170	1956	2	1992
Stampede	99	183	1956	17	1992
Mission	46	86	1983	0	2015
Crystal	71	144	1999	66	1941
Paradise	174	327	1956	66	1941
White Pass	55	110	1997	0	1992
Timberline (Oregon)	161	300	1999	57	2015
Meadows (Oregon)	127	199	2008	33	2015

Sno-Park permits

Washington State Sno-Park permits are required for the use of more than 120 designated parking areas which provide access to cross-country skiing, snow-shoeing, and snowmobile trails in Washington State. The Washington State Department of Parks provided permit and revenue data for Sno-Park areas in the state for four winter seasons. Purchases of Sno-Park permits during the 2014-2015 winter season were down considerably from the previous winter. That winter also had experienced below normal snowpack conditions until conditions dramatically reversed in February. Both years experienced lower permit sales and accompanying revenue compared to years with more normal snowpack conditions.

It is perhaps relevant that years accompanying low numbers of Sno-Park permits also were years in which Seattle's professional football team reached the Super Bowl, thereby creating an indoor recreational alternative on Sunday afternoons.

Table 27. Sno-Park permit sales 2012 through 2016.

Winter Season	Total Permit Sales	Total Revenue
2012-2013	33,089	$1,048,140
2013-2014	21,035	$679,460
2014-2015	13,033	$455,120
2015-2016	38,322	$1,176,540

The National Park Service did not open its snow-play, downhill sledding area at the Paradise Visitor Center on Mt. Rainer at all during the winter of 2014-2015, because snow never reached the minimum required depth of 60 inches.

River Recreation

We were not able to obtain visitation numbers for recreational river guiding services for the purpose of this plan. The state Department of Revenue collects reported business income for water-related scenic and sightseeing businesses (NAICS 4872)[47]. This sector includes whitewater rafting companies and also activities like dinner and sightseeing cruises. Whitewater recreation is dependent on sufficient flow for riverine navigation and challenge. Cruises occur on larger rivers and bodies of both fresh and saltwater, where the primary concerns are dock and moorage access and sufficient navigational depth.

It is not possible, using NAICS data, to determine specifically how whitewater businesses fared in 2015 compared with other years. Aggregate revenue for all water-related scenic and sightseeing businesses is depicted in Figure 8. Overall revenue in 2015 was down significantly, but it is unclear whether this can be attributed to drought conditions or other factors. A survey of individual businesses is beyond the scope of this analysis. One press report profiled a rafting company in Wenatchee which adapted to low water conditions by marketing rental opportunities

[47] The North American Industry Classification System (NAICS) is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.

for paddleboards and inner-tubing, even offering to shuttle clients back upriver so they could re-run stretches of the river.[48]

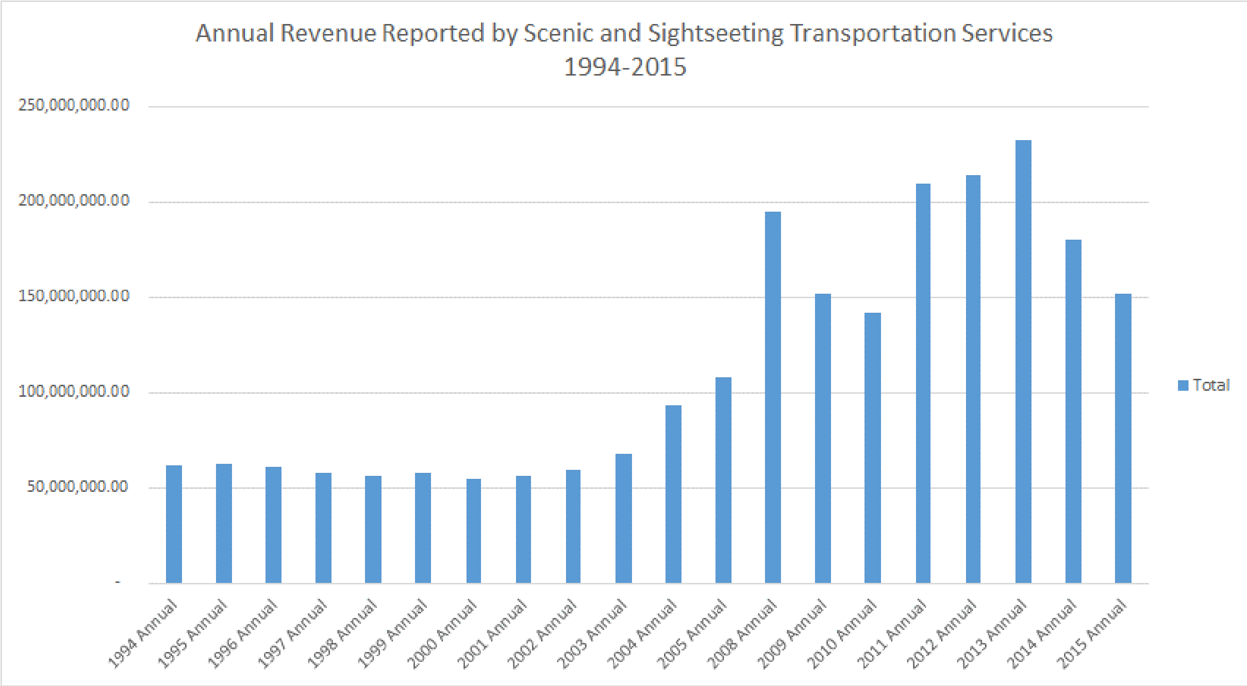


Figure 24. Annual revenue reported by scenic and sightseeing transportation services (Based on Department of Revenue data, 2016)

Reduced runoff during low snowpack years also affects the availability of flows suitable for individual whitewater enthusiasts. The American Whitewater Affiliation provided a summary of the 2015 Drought impacts to the 10 most popular whitewater rivers in the North Cascades. For these rivers, whitewater boater opportunities were "substantially impacted with summer opportunities effectively unavailable." (Department of Revenue, 2016). This analysis identified the date at which the descending limb of the snowmelt hydrograph dropped below optimal flow, compared to an average year. "In 2015 all these rivers had substantially shorter seasons with many of the rivers below optimal flow shortly after Memorial Day." As the table below summarizes, optimal flows became unavailable a few weeks to three months earlier than usual and, for some rivers, flows never reached a level suitable for boating.

Table 28. Whitewater flow availability -- average year versus 2015 Drought.

River name and segment	Average date of drop	Date in 2015 Drought
Wenatchee, Leavenworth to Monitor	July 31	June 14
Skykomish, Index (Sunset Falls) to Railroad Bridge	July 20	May 31
Skykomish, Railroad Bridge to Big Eddy	July 20	May 31
Snoqualmie, Middle Fork, Concrete bridge to Tanner (Middle-Middle)	July 16	April 5
Sauk, Whitechuck River to Darrington	August 20	June 13
Skykomish, N. Fork, Bear Creek (Drumbeater) to South Fork confluence	June 8	Never reached optimal flow
Wenatchee, Tumwater Campground to Leavenworth (Tumwater Canyon)	September 8	July 13
Nooksack, N. Fork, Douglas Fir Campground to Mt. Baker Highway milepost 27	September 9	July 12
Sultan, Powerhouse to Fishing Access	Meets flows all year	May 22
Methow, McFarland Creek access to Pateros (Black Canyon)	August 2	July 3

Groundwater

Ecology investigated the impacts of the 2015 drought on groundwater levels in Washington.

On the west side of the mountains, only two Ecology monitored wells (near Sequim in the Dungeness watershed) exhibited 2015 water levels that consistently fell below the wells' normal water level range. Both wells have experienced significant ongoing water level declines in recent years, however. This suggests their lower than normal water levels in 2015 may not be drought related, but rather reflective of changes in water management practices - in this case, converting from open-ditch systems to pressurized pipes, which reduced the amount of leakage to shallow aquifers, causing water levels to drop. The 2015 water levels for other west-side wells varied by month and ranged from slightly above to slightly below normal values. Collectively, these data suggest the drought had little overall impact on groundwater levels/storage in monitored wells west of the Cascades.

On the east side of the Cascades, particularly in the greater Yakima and Columbia basins, substantial on-going declines in groundwater levels/storage have occurred in recent decades. Consequently, the spring 2015 water levels for a significant number of wells in these basins were already either below normal or at the lowest levels ever measured - even before the full brunt of the drought was felt. Similar responses were observed in water level networks managed by other organizations including the: U.S. Geological Survey, Walla Walla Basin Watershed Council, and the Palouse Basin Aquifer Committee.

Over all, Ecology found:

- The data indicate little impact of the drought on groundwater levels.

- The time lag between a drought's occurrence and corresponding water level responses (particularly in deep basaltic wells) makes it difficult to discern cause and effect relationships.

- It is often difficult to detect short-term, drought-related trends due to widespread regional groundwater declines.

These findings must be caveated, however, as detection of short-term drought influences from longer-term ambient water level trends are hampered by the lack of wells with consistent long-term (>10 years) monthly water level measurement histories. Long term measurement records are essential for defining normal monthly water level ranges. Additionally, not all wells are consistently measured each year. Ecology is evaluating strategies and resource requirements to improving the scope and rigor of its current groundwater level monitoring network.

Puget Sound Water Supply Forum evaluation of groundwater impacts from drought

The Puget Sound Water Supply Forum is a planning process composed of utilities in King, Pierce, and Snohomish counties in the Puget Sound area. The cities of Seattle, Tacoma, and Everett, and the Cascade Water Alliance are the largest members. Collectively they serve a population of approximately 3,000,000 people - 40 percent of Washington State's population.

This process included a broad assessment of drought effects on groundwater supplies in King, Pierce, and Snohomish counties. Collectively, more than 900 wells are owned by water systems in the three counties. A Supply Forum survey of 45 different utilities indicated that only 8.33 percent of the respondents had ever had a groundwater supply not recover after seasonal recharge. Approximately 63 percent said that groundwater had never not recovered. However, the study also noted that dry years can stress groundwater resources:

- Groundwater sources are generally more resilient to drought than surface water sources. Many groundwater sources appear to be relatively unaffected by short-term events. Nonetheless, there are drought conditions that can stress aquifers in the Puget Sound Lowlands.

- An extended, multiyear drought with low precipitation (not just low snowpack) would have the largest potential impact on groundwater resources. This would be especially problematic if the extended drought included hot, dry summers that increase demand and prompt larger withdrawals from aquifers. Hot, dry summers are less problematic if they are accompanied by normal rainfall in the ensuing fall and winter months. In this type of event, high demands may temporarily stress aquifers, but winter rains typically recharge the aquifers so there is less of a cumulative impact.

- Finally, droughts consisting of low snowpack have the least impact on the region's aquifers because snowpack occurs at higher elevations that are outside the primary recharge areas. However, in a year with low snowpack, surface streams commonly experience low flows, and this can indirectly limit water users' ability to pump from their wells. In addition, years with low snowpack can drive water users to pump aquifers more heavily where stream flow does not limit groundwater use, and this can put stress on aquifers, at least temporarily.

- The forum identified three main physiographic regimes in the Puget Sound Lowlands: (1) major river valleys; (2) glaciated uplands; and (3) foothills/mountains.

- Aquifers in these different types of landforms vary somewhat in their response to drought, although broad patterns are similar and aquifers can be connected from one regime to another. The foothills/mountain aquifers are typically the most vulnerable, because they tend to be shallow or thin and store limited quantities of groundwater. However, these areas tend to have smaller population centers compared with the other two landforms. In the glaciated uplands, drought effects will be highly variable based on location and the particulars of the setting. By contrast most of the major river valleys in the Puget Sound Lowlands have deep, unconsolidated sediments that can support aquifers with significant storage. Deep aquifers in the major river valleys, especially those at low elevations (where the valleys are often widest and deepest), will be the least vulnerable to drought.(Puget Sound Water Supply Forum, 2016).

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Appendices

Appendix A. Drought Frequency and Severity under Climate Change

Occasional droughts are an important feature of the climate of Washington state and have a long history of occurring, as reviewed in an earlier section of this plan. Global climate change is projected to affect the frequency and severity of droughts in future decades. Though there are many different types of drought (e.g., low snowpack due to low precipitation, low snowpack due to increased temperatures, and spring/summer low precipitation), the focus on this section and many of the studies herein is on the precipitation-deficit type of drought. This section reviews the likely changes in the climate of Washington over future decades, relying primarily on the recent scientific literature.

a). Changes in Temperature

Washington state, and the Pacific Northwest as a whole, has warmed in recent decades relative to earlier in the 20th century, and there is high confidence that this trend will continue in the 21st century (e.g., Rupp et al., 2016). Average temperatures in the Pacific Northwest (Washington, Oregon, and Idaho) have warmed about 1.3°F (0.7°C) from 1895 through 2011 (Snover et al. 2013). Expanding the period to 2015 results in a similar temperature change with 1.5°F (0.8°C) of warming for Washington State alone (NCEI). Future warming is projected for the region. The magnitude of warming expected across Washington State – using an ensemble average of 37 CMIP5 models[49] – is illustrated in Figures 1a-b for the years of 2040-2069 relative to the historical period of 1979-2008. During the cool, wet season of November through January, there is a projected warming of roughly 4.5°F (2.5°C). For the warm, dry season of June through August, a warming of 5.4°F (3.0°C) is projected. For purposes of comparison, the average temperatures for Washington were 2.5°F (1.4°C) above the 1979-2008 average for November 2014 through January 2015 and 4.5°F (2.5°C) above average for June through August 2015. Therefore, the projected average temperatures for the 2040-2069 period are warmer than what the state experienced during the recent temperature-driven drought of 2015.

Geographically, there is greater warming indicated for east of the Cascade crest. The west side of the state is more strongly influenced by the ocean, which is projected to undergo approximately

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[49] The projections shown here are based on the latest Coupled Model Inter-Comparison (CMIP5) model results for the Representative Concentration Pathway 8.5 (RCP8.5). This is the highest greenhouse gas scenario of the 4 used in the Intergovernmental Panel on Climate Change (IPCC) report, and is used because it best resembles recent observed greenhouse gas emissions and concentrations. The projections shown are multi-model ensembles of 37 CMIP5 models and are displayed on a website maintained by NOAA's Earth System Research Laboratory: www.esrl.noaa.gov/psd/ipcc/. Projections for the middle portion of the 21st century are used; changes over this period are not highly sensitive to the RCP model experiments used but are generally large enough to be detectable above the natural variability in the climate.

3.2°F (1.8°C) of warming over the same interval (not shown). For the Pacific Northwest as a whole (WA, OR, and ID), all of the 37 models used to form ensemble averages indicate warming of greater than 2.7°F (1.5°C) by 2050; 80% of the members are within about 1.4°F (0.8°C) of the mean values shown in Figures 1a-b.

b). Changes in Seasonal Precipitation

Projections for the change in winter (November through January) and summer (June through August) precipitation, for the mid 21st century are shown in Figures 2a and 2b. The climate models indicate that the wet season is likely to become wetter and that the dry season will become drier. In other words, the model simulations suggest that the climate of Washington state will become more Mediterranean in nature. The absolute changes during the wet season are projected to be greater on the west side of Washington state, but on a percentage basis, both sides of the state have projected increases of roughly 7% for Nov-Jan. The projections for June through August include larger decreases from both an absolute and percentage perspective for western versus eastern WA. Projected changes in total annual precipitation for the state as a whole average about 5 cm, which represents an increase of roughly 4% over that of the 1979-2008 period.

It's important to note that the inter-model differences in projected precipitation are greater than those for temperature, and hence there is more uncertainty in future projections for precipitation compared to temperature. Figure 3 (reproduced from Rupp et al. 2016) illustrates the range of precipitation projections from the individual climate models for different times of year for the Columbia River watershed. Some of the model projections are actually indicating drier wet seasons (Oct-Jan and Feb-May) and wetter summers (Jun-Sep) through the 2080s. Nevertheless, by the 2050s and through the 2080s, there is a reasonably strong consensus that both the early and late portions of the wet season will include net increases in precipitation, and that the summer months will be drier, with somewhat less confidence.

c). Snowpack and Streamflow Timing

Increasing temperature will impact the timing of streamflow in many Washington river basins. This is important because the winter snowpack in the mountains represents an important supply of water in late spring and summer for many of Washington's streams. Due to the warming climate, the snowmelt in spring is anticipated to occur 3 to 4 weeks earlier by the middle of the 21st century for snowmelt-dominated basins in the Cascade Mountains (Snover et al. 2013).

A recent drought year – 2015 – represents an example of what is liable to become "average" in the 21st century. From a statewide perspective, the winter (November through March) of 2014-15 was about 3.5°F (2.0°C) warmer than the 1981-2010 normal, with near average precipitation. The result was more rain than snow than usual at higher elevations, resulting in relatively high streamflows during the winter. There were exceedingly low streamflows during late spring through summer on many rivers due to both a lack of snowpack and faster runoff because of warm temperatures, which lead to widespread shortages in water supplies and quality. This kind of scenario is expected to play out in future decades with increased frequency, as shown in various studies using hydrologic models forced by projected temperature and precipitation distributions. An example is shown in Figure 4 from Tohver et al. (2014)[50]. Their results indicate the shift of most presently snow-dominant watersheds to the "transition" category (also known as a mixed rain/snow basin), which typically includes both winter and spring peaks in streamflow. Many of the transition watersheds will shift to the rain-dominant type that have their peak flows in winter during periods of heavy precipitation. These shifts become quite evident by the 2040s. A complementary perspective is shown in Figure 5 (excerpted from Elsner et al. 2010). Projected average monthly streamflows for examples of the three types of watersheds indicate the greatest relative changes in seasonal streamflows on the Yakima River, which is now in the transient/mixed category but apt to shift to become increasingly rain-dominant with time. This is likely to have extremely important implications for summer water supplies for agriculture in the Yakima Valley, which presently relies on snowmelt for a considerable fraction of the water required during the growing season.

More evidence that spring snowmelt supply will become an issue in the future comes from another study by Lute et al. (2015) considering model projections of snow throughout the West. Low mountain snowfall years will become more frequent by mid-century (Fig. 6, reproduced from Lute et al 2015) due to the shift in precipitation type from snow to rain despite there being continued variability in wintertime precipitation totals. The Olympic and Cascade Mountains are relatively low in elevation compared to the Rocky Mountains, for example, with higher wintertime average temperatures, meaning that shifting precipitation type is expected to become a problem sooner than in higher elevation mountains (Mote et al 2005).

While we have addressed the impact of temperature on snowpack and streamflow timing, the amount of precipitation matters too. We expect continued variability in winter precipitation and some winters in future decades will of course be dry as well as warm. An especially early and meager snowmelt during dry years are liable to result in late spring and summer streamflows lower than experienced in the historical record. In more quantitative terms, the model results of Tohver et al. (2014) indicate that for streams draining the Cascade Mountains that the lowest 7-day mean flows in the 2040s during the low flow summer season will be on the order of 70 to 80% of their counterparts in the historical record (not shown). This reduction can be attributed to increases in evapotranspiration due to warming in combination with years of particularly low snowpack (Hamlet et al. 2013).

c). Soil Moisture

Future projections suggest decreases in summer (July 1) soil moisture across much of Washington State in the future (Figure 7; Elsner et al 2010[51]). There tend to be greater decreases in soil moisture on the west side of the Cascade Mountains, which Elsner et al. (2010) attribute to warming and earlier snowmelt. Some areas of the Columbia River Basin may experience

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[50] Note that this study used an older version of the climate models (CMIP3) and two different emission scenarios. The RCP8.5 scenario previously mentioned in this section assumes higher greenhouse gas emissions than either the A1B or B1 shown in Figure 3.

[51] The older CMIP3 models and the A1B and B1 scenarios are used for this study.

increases in summer soil moisture, likely due to increases in winter precipitation and greater infiltration into deep soil layers.

d). Multi-year Droughts

Droughts in Washington state since the middle of the 20th century have generally been relatively short-lived (~1 year), which raises the question whether multi-year precipitation deficit droughts might be more or less likely in future decades. We can begin to address this question by examining the average 1-year lag correlation in annual total precipitation statewide during 1979-2008, and comparing it to the same values for the 2040-2069 model projections[52]. During the period of 1979-2008, values of the correlation coefficient range from about 0.1 to 0.3 (not shown), with generally lower values of the correlation, i.e., persistence from one year to the next, in the wetter parts of the state. Considering output from RCP8.5 model simulations, the ensemble-average 1-year lag correlation in annual total precipitation during the years of 2040-2069 is slightly less than that during the years of 1979-2008 across Washington state (Fig. 8). These results suggest little reason to expect that back-to-back dry years (or wet years) will be any more or less likely in the future.

With respect to temperature, the climate models are indicating an increase in 1-year lag correlation across the entire western US but little change in standard deviations of annual mean temperature. In other words, there may be more incidences of back-to-back warm years (or relatively cool years) in our changing future climate. The enhanced persistence in temperatures might be a result of feedbacks related to soil moisture as represented in global climate models, but confirming that as an important mechanism is outside the scope of the present treatment. As noted above, increases in temperature will be accompanied by decreases in winter snowpack and summer flows in many streams. It is therefore reasonable to assume that Washington will experience a greater frequency of droughts of the temperature-related type such as what occurred in 2015 relative to the more precipitation-driven droughts of 1977 and 2001. While a precedent is lacking in the historical record, it is highly likely that there will be a winter in the next few decades that will be as warm as 2015 but also considerably drier than normal. The impacts of such an event are liable to be severe, and conceivably persist for an extended time into a period of more typical weather that follows.

With regards to extended (multi-year) events, Ault et al. (2014) used climate model simulations carried out for the IPCC to assess the future risk of decadal (11 year) and multi-decadal (35 year) droughts in the western US. Droughts here are defined as periods during which mean precipitation anomalies exceed 50% of the standard deviation in annual precipitation during the reference period of 1950-2000. For the Pacific Northwest and especially Washington state, the model simulations suggest a reduced risk of these long-term types of droughts during the period of 2050-2100 relative to that of 1950-2000 (not shown).

Overall, the research that has been carried out on the future climate of the Pacific Northwest has found minimal changes in the character of the short-term (seasonal to interannual) variability. These findings are based on climate model simulations, with attendant caveats associated with

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[52] The NOAA/ESRL web application used in section a and b was used to compute these values.

model limitations. That being said, the existing evidence strongly indicates that the mean conditions, namely warmer temperatures and reduced mountain snowpack, will be the primary factor related to drought. In other words, the change in baseline conditions implies that relatively modest temperature and precipitation anomalies, for the climate of the time, will result in streamflows and water supplies during the dry season characteristic of more extreme anomalies of the historical record.

e). Demand

Future droughts will depend on demands for water, of course, and while more effort has gone into assessing how climate change will influence the supply side, there have been estimates made of future demands. For Washington State, a particularly valuable resource is a draft report prepared by the Washington State Department of Ecology (Ecology). The agricultural sector is by far the biggest user of water; its overall demand is estimated to decline by about 5% due to an earlier growing season and a switch to crops with lower water needs. It is unclear to the extent that this decrease in overall demand will be accompanied by a decrease in water that will be drawn from streams. Groundwater represents a significant source in parts of Washington, notably portions of the Yakima Valley (Ely et al. 2011). Current rates of pumping may not be sustainable from a long-term perspective, which may mean that the proportion of water drawn from streams will increase. Changes in average supply and demand can mask the conflicts that occur during drought years when low-flow conditions arise. During years with low flows, maintenance of instream flows for ecological purposes and fulfillment of tribal water rights can constrain water supplies. Other users of water, for example, major municipalities and hydropower operators, have made projections of future demands relative to supplies as part of their long-term plans. Projected changes in cropping practices are likely to lead to modest changes in agricultural water demand relative to past conditions, but climate change is likely to lead to significant changes in the timing and amount of water supplied. Overall, climate change is more likely to influence the supply than the demand side of water use in Washington State.

f). Considerations for the Columbia River Basin

The mainstem Columbia River represents a special case from a Washington state drought perspective. First of all, climate change is expected to bring an increase in precipitation for its watershed, especially at its higher elevations in northwestern Montana and southern British Columbia. As with most streams in WA, the accompanying increase in runoff is apt to occur during the winter through early spring (Georgakakos et al. 2014; US Bureau of Reclamation 2016), with the consequence that flows during summer may drop more often below state and federal targets. The threat of low summer flows may be alleviated, however, since the Columbia River is highly regulated. While agricultural users can expect continued deliveries of adequate amounts of water from the Columbia Basin Project during the growing season, other uses (e.g., hydropower) and constraints (e.g., timing of flows for fish migrations) will continue to require balancing.

g). Considerations for Future Drought Definitions

An important and unresolved issue relates to whether the state's current definition of drought may need to be altered in light of climate change. "Normal" values of seasonal precipitation, snowpack, streamflow, etc. in the future will be different than their counterparts in the past. It may be necessary to establish thresholds based on actual values of current or short-term predicted water supplies rather than a fixed percentage of historical averages. The latter become less meaningful for gauging abnormalities in the state of the system during periods of systematic and substantial trends. Conceivably, an effort should be undertaken to better quantify the thresholds that constitute water scarcity hardships in the Water Resource Inventory Areas (WRIAs) of the state, and to use these thresholds (which may need to be adjusted due to evolving demands on a regional basis) to set absolute values of water supplies and streamflows that represent drought conditions.

h). Concluding Remarks

The objective of this section has been to summarize recent findings on how climate change is liable to impact droughts in Washington state. Despite our confidence in a number of future changes in the regional climate (e.g., warming, less spring snowpack, earlier timing of streamflow in transient or snowmelt-driven watersheds), significant year-to-year variability will continue to affect our hydrologic conditions and water supplies. Much of this variability is not directly tied to global climate change, and should be expected to continue in the future. For example, we will still periodically experience anomalously wet winters, as well as winters with snowpack that exceeds historical averages. Water managers will need to consider both the long-term changes in hydrologic conditions, as well as the shorter-term variability, when making policy, programmatic, and infrastructure decisions. Considerable research is devoted to improving our predictive capabilities of shorter-term variability (e.g., El Nino or a regional marine heat wave), and to understanding how these climate anomalies impact Washington's weather and ultimately its water supplies.

With that said, there is a wide body of resources available on what regional climate change impacts can be expected, and the uncertainties that are associated with the projections. Examples include reports from the Environmental Protection Agency (2016), Washington State Department of Ecology (2016), US Bureau of Reclamation (2016), the Climate Impacts Group of the University of Washington (2009 and 2013), and the Climate Impacts Research Consortium of Oregon State University (2013). These reports are available online; the URLs for them are included in the list of plan references.

Figures

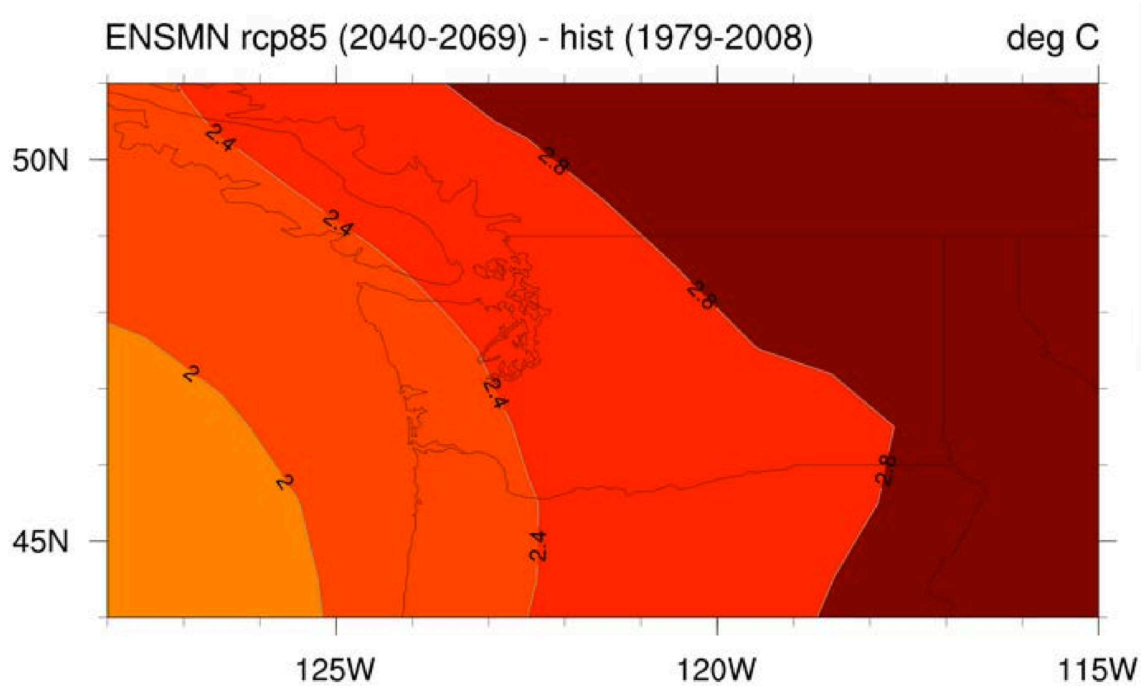


Figure 1a. Ensemble-mean change in modeled average November through January temperature (degrees C) from the period of 1979-2008 to the period of 2040-2069 under the RCP8.5 pathway.

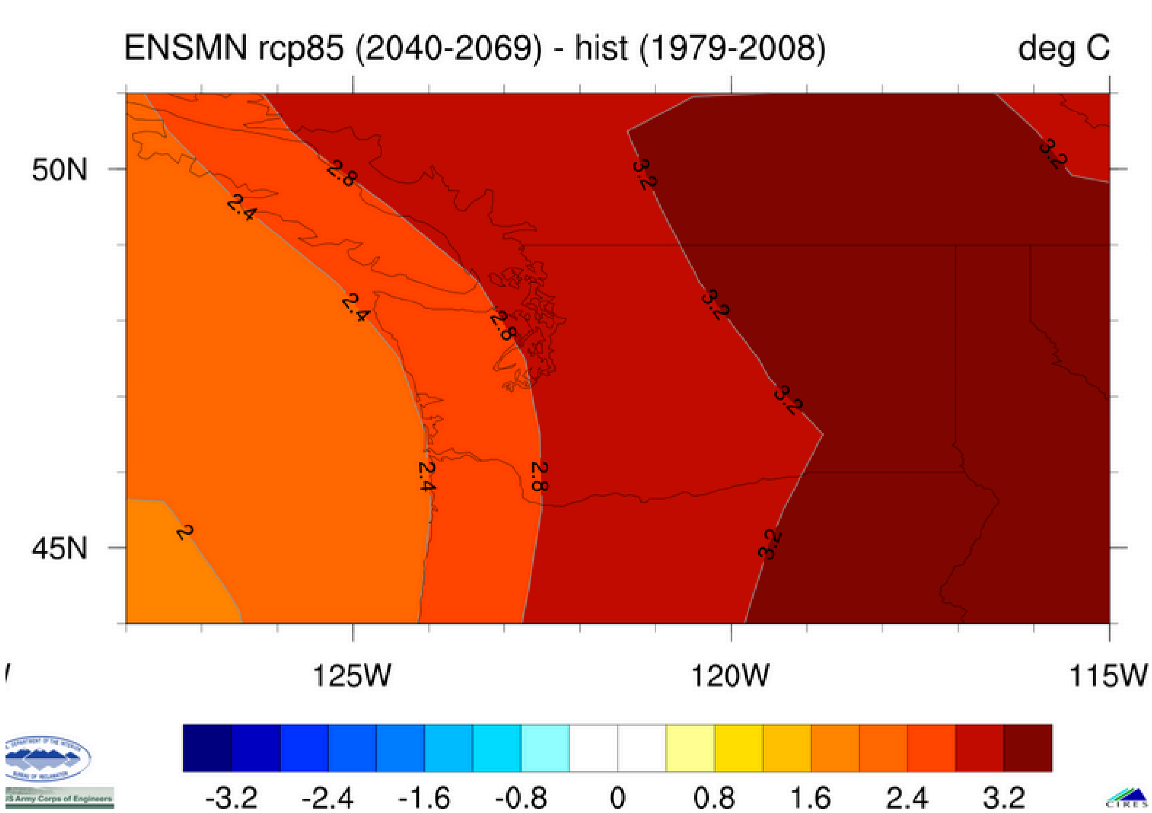


Figure 1b. As in Figure 1a, but for the season of June through August.

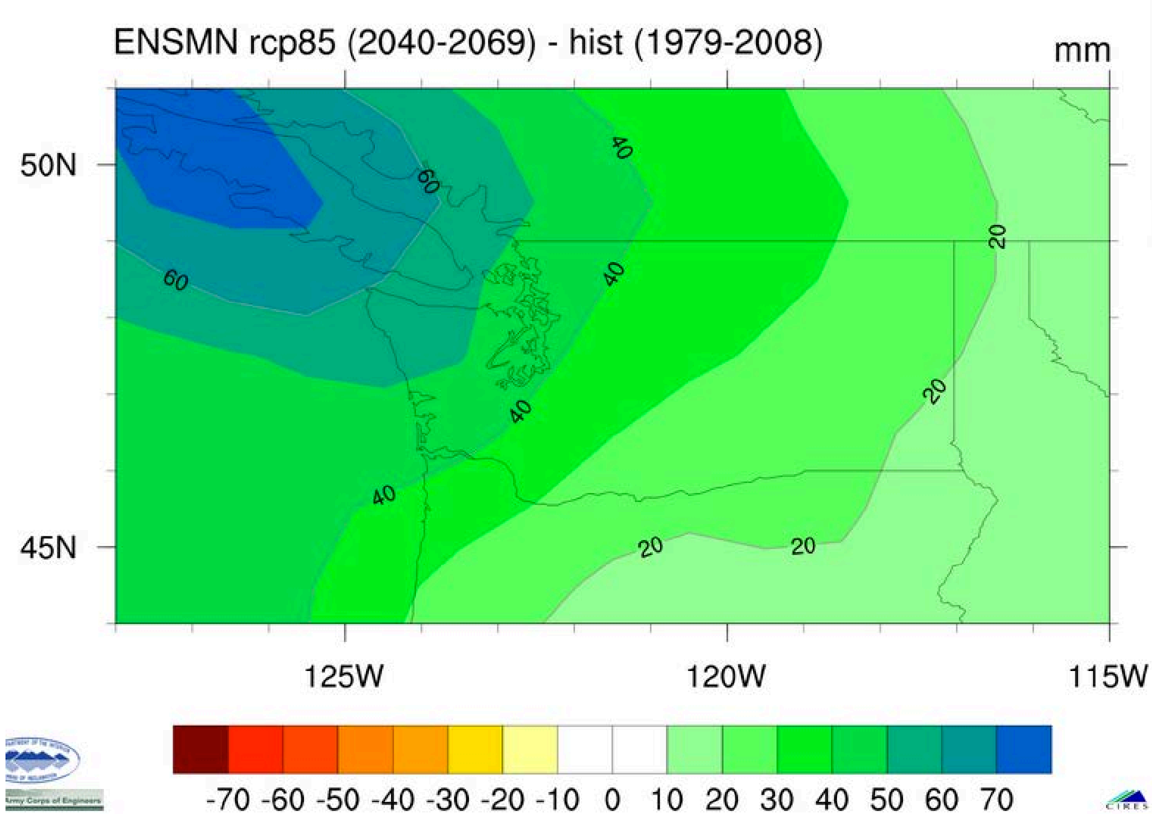


Figure 2a. Ensemble-mean change in November through January modeled precipitation (mm) from the period of 1979-2008 to the period of 2040-2069 under the RCP8.5 pathway.

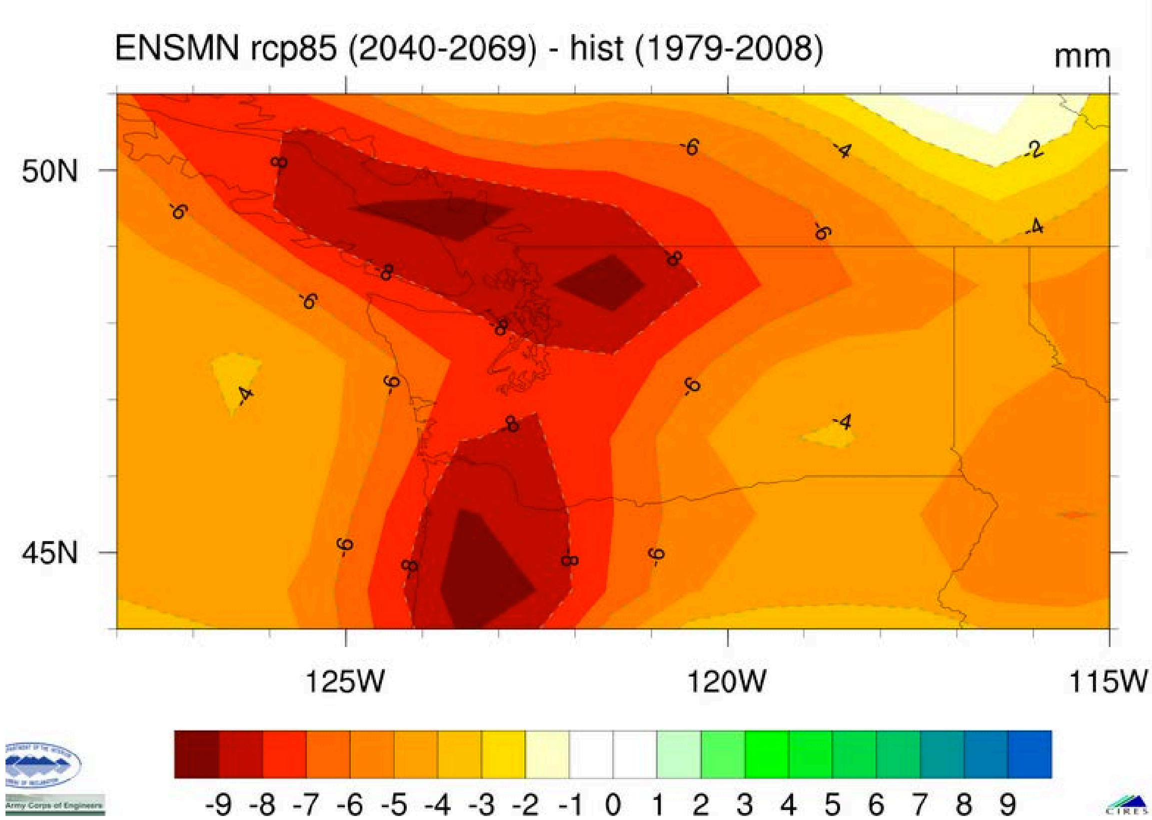


Figure 2b. As in Figure 2a, but for the season of June through August.

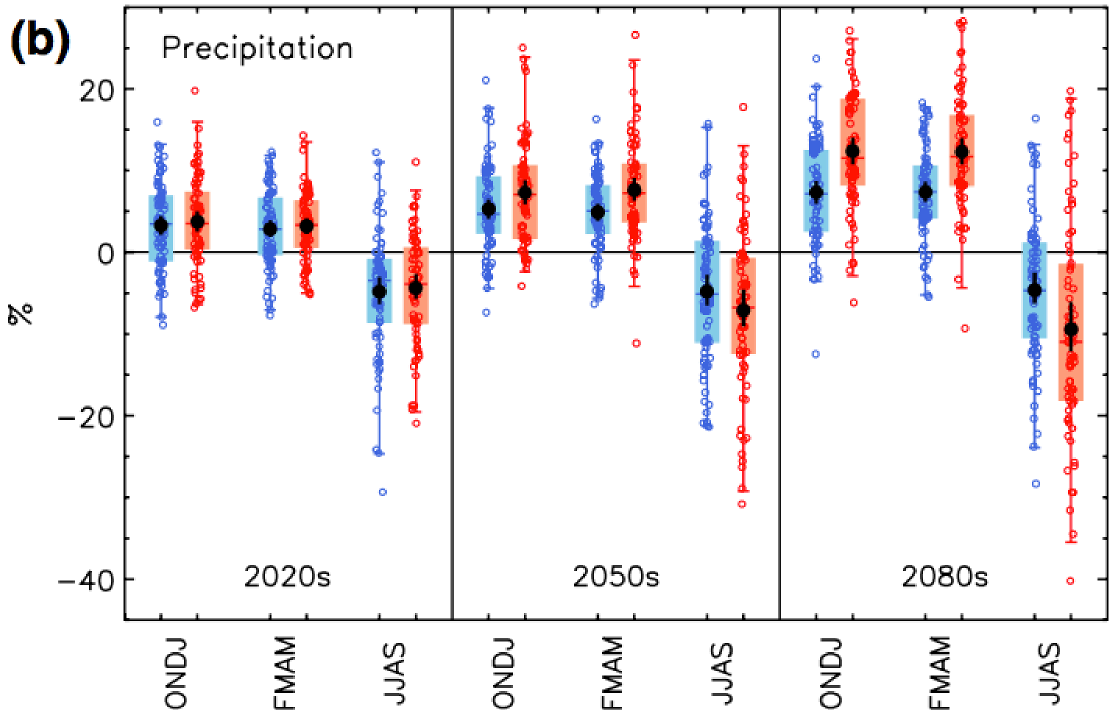


Figure 3 Change in 30-year averages of seasonal precipitation between 1970–1999 and three future periods: 2010– 2039 (2020s), 2040–2069 (2050s), and 2070–2099 (2080s), for the Columbia Basin above Bonneville Dam for the RCP4.5 (blue) and RCP8.5 (red) scenarios. *Open circles* show individual CMIP5 simulations (all available ensemble members) and the *box* and *whiskers* show inner quartiles and inner 95th percentiles, respectively. *Black circles* and *vertical black lines* show the mean of all simulations and the 95th percentile confidence limits on the mean, respectively (from Rupp et a. 2016).

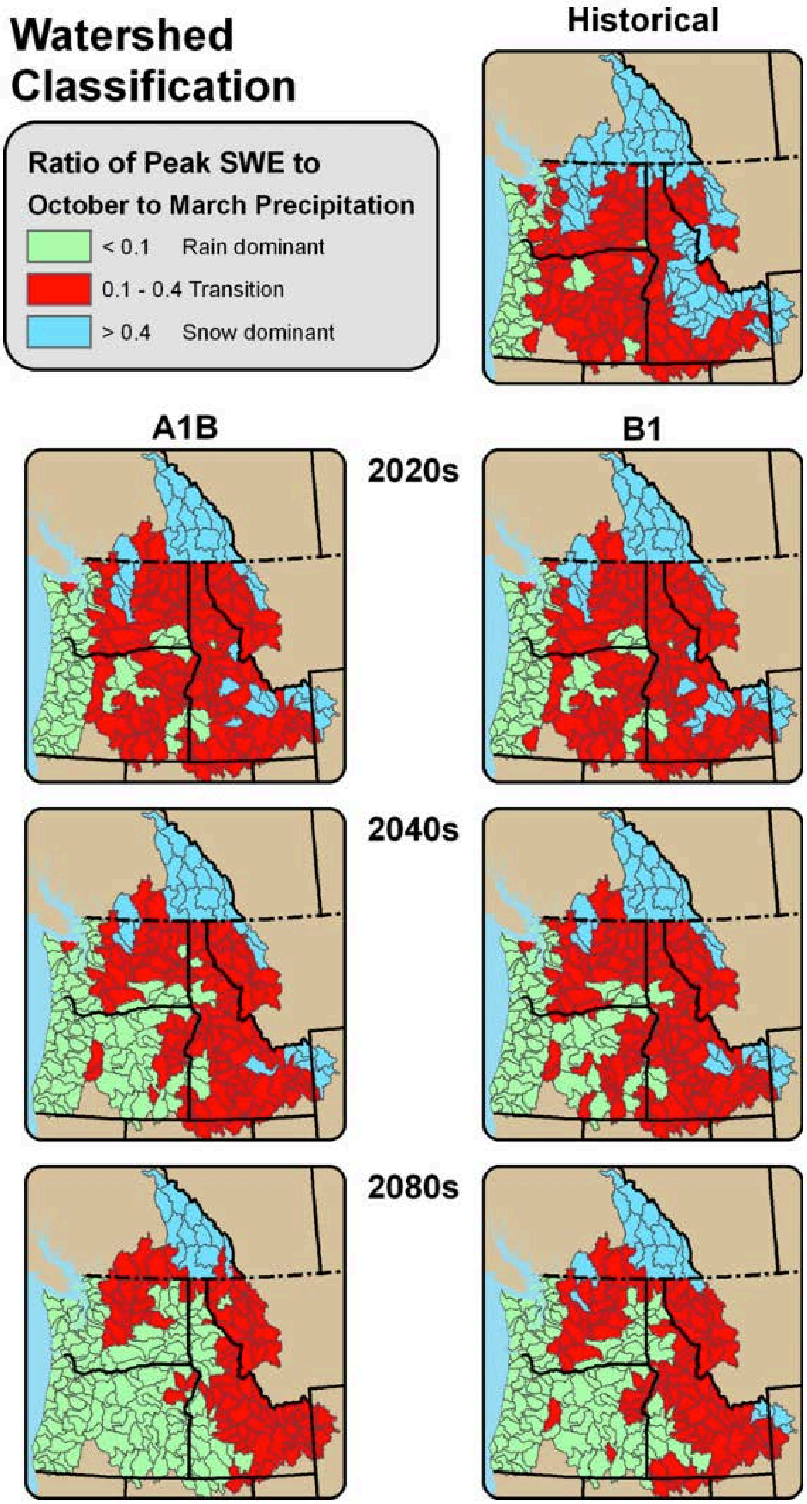


Figure 4. Average ratios of modeled peak snow water equivalent to total precipitation during the season of October-March. The model simulations under the A1B scenario feature higher CO2 concentrations than those under the B1 scenario (from Tohver et al 2014).

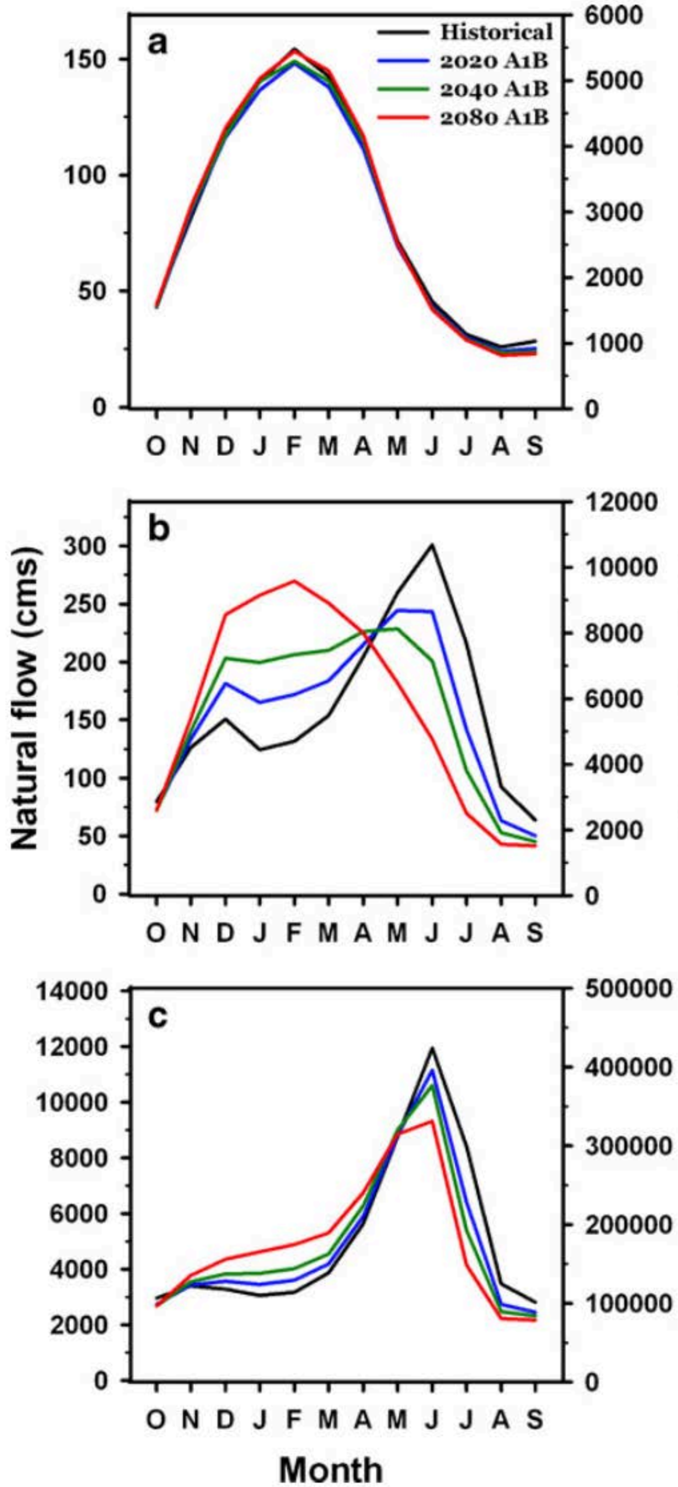


Figure 5. Projected average monthly streamflows using the A1B scenario for three watersheds: (a) Chehalis River at Porter, (b) Yakima River at Parker, and (c) Columbia River at The Dalles. The changes expected by the 2020s, 2040s, and 2080s are represented by the blue, green, and red traces, respectively (from Elsner et al. 2010).

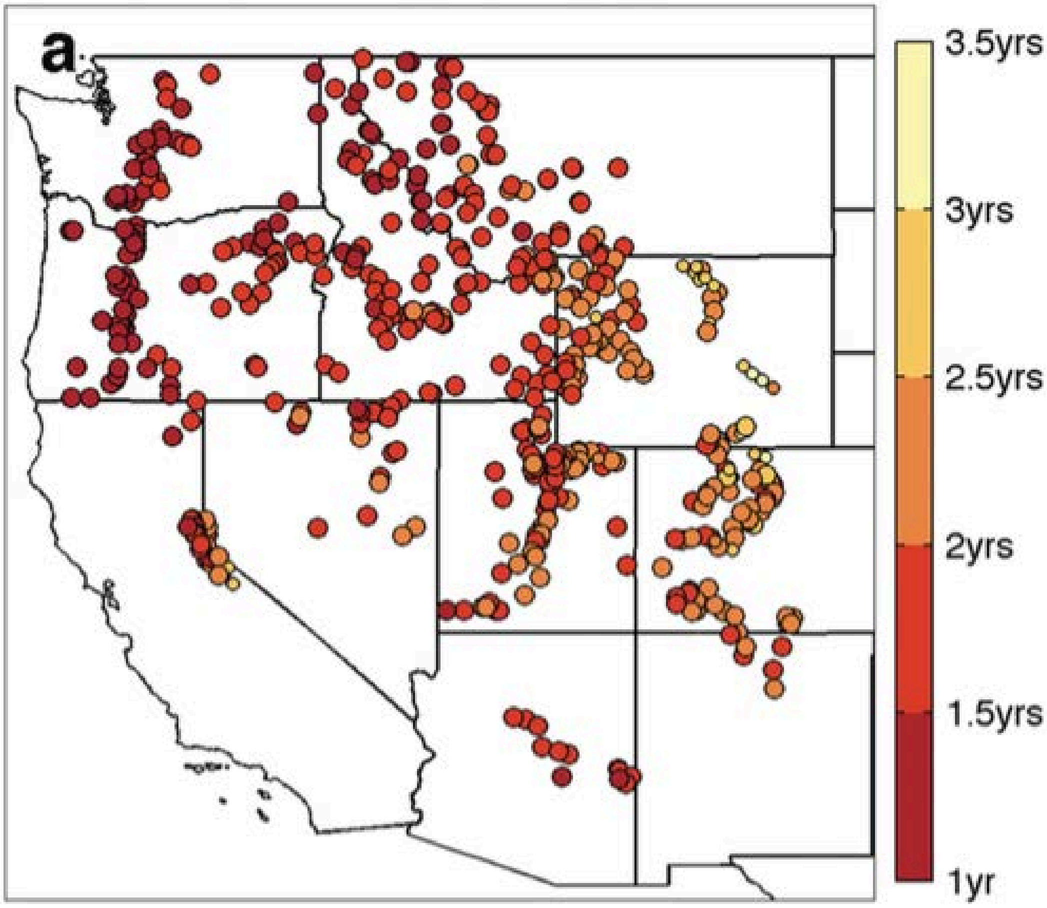


Figure 6. Mean return intervals of low-snowfall years (defined as the 25th percentile for the historical period of 1950-2005) during the period of 2040-2069 based on ensemble-mean model simulations under RCP8.5.

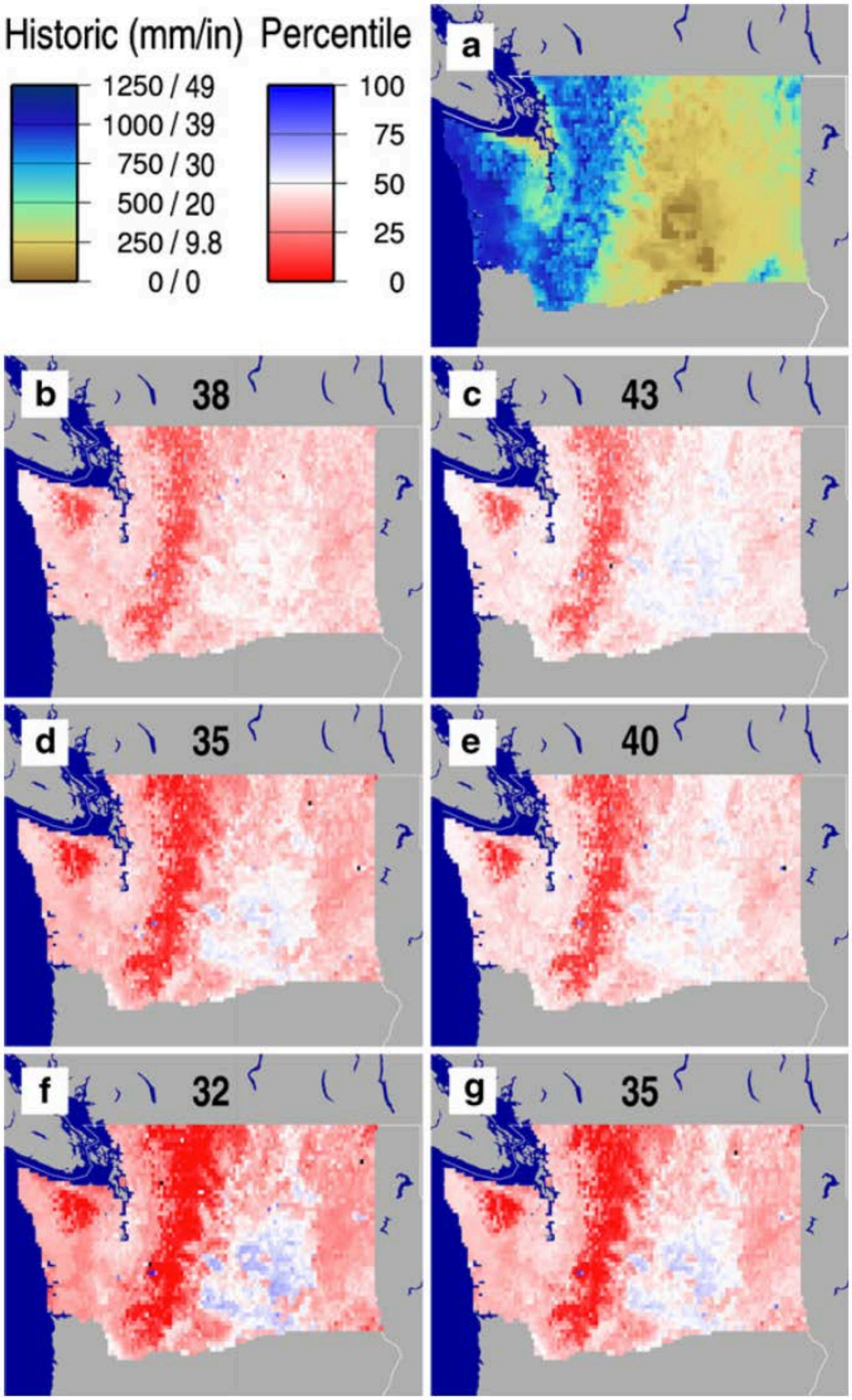


Figure 7. Projected change in 1 July soil moisture as a percentage of simulated historical mean values for the 2020s (b and c), 2040s (d and e) and 2080s (f and g). The left and right columns of projections are using the A1B and B1 scenarios.

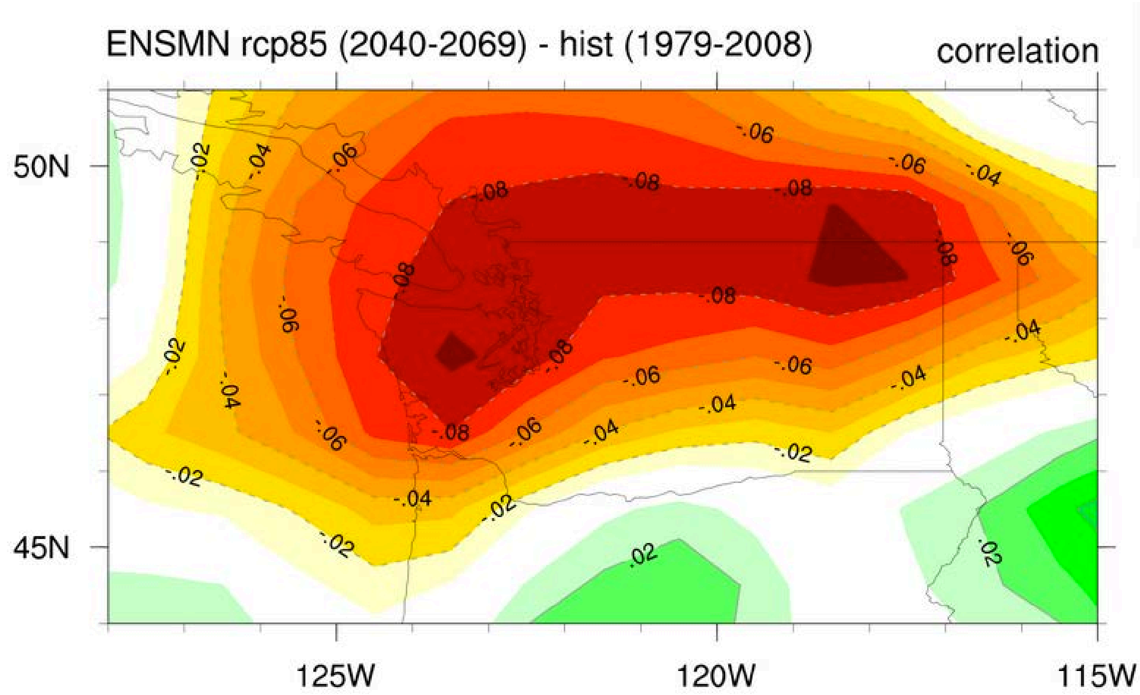


Figure 8. Ensemble-mean change in modeled 1-year lag correlation in annual precipitation from the period of 1979-2008 to the period of 2040-2069 under RCP8.5. See text for details.

Appendix B. Analysis of the Standardized Precipitation Index

DATE: 28 February 2017

TO: Jeff Marti, WA State Department of Ecology (ECY)

FROM: Office of the Washington State Climatologist (OWSC)

SUBJECT: Results from analysis of SPI drought thresholds

As part of the Drought Task Force convened by ECY, the OWSC has conducted analysis of thresholds that could be used towards declaring drought in Washington state. Current statute includes a quantitative definition of drought. Specifically, when water supply is at or below 75% of normal for a particular region of the state, or projected to fall below that threshold, that region can be considered to be in drought. The analysis carried out by the OWSC was designed to evaluate that threshold, considering the historical record and a common index used to signify drought, the Standardized Precipitation Index (SPI).

The SPI was developed in Colorado in the early 1990s, and is now considered to be the global standard index to identify meteorological drought by the World Meteorological Organization. The index uses only precipitation and is standardized using the mean over the period of record and the standard deviation for the same period. Large negative (positive) values of this index signify extremely dry (wet) periods; values near zero indicate close to normal conditions. A value of -1 usually signifies the beginning of drought and as the index becomes more negative, indicates increasing severe and infrequent conditions. The strengths of the SPI include the ability to identify dry and wet periods on multiple time scales (weekly to annual), ease of use and availability, and consistent interpretation from place to place. A major weakness is that the SPI is only a precipitation index. Since it does not account for temperature and precipitation type (rain versus snow), it relates only indirectly to streamflow.

Monthly precipitation totals for each of the 10 climate divisions of Washington state during the years of 1895-2016 were used to compute the SPI on the time scales of 1, 3, 6, 9 and 12 months. The number of occurrences of each value of SPI was used to estimate mean return periods for the historical period, and the results are summarized below.

A value of 75% of normal precipitation corresponds with different values of SPI, which depends on the magnitude of the variability relative to the mean. In Washington state, there tends to be greater relative variability during the dry season and east of the Cascade crest. In specific terms, the SPI associated with 75% of normal precipitation for a period of 1-month ranges from roughly -0.2 for eastern WA climate divisions in summer to -0.7 for western climate divisions during early winter. The relative variability in precipitation also decreases with time scale, implying that the 75% threshold corresponds with a smaller magnitude of the SPI for 1 month than for longer periods. From a statewide perspective, and considering 3-month totals, the 75% threshold is equivalent to a SPI of about -1 for November through January and a SPI of -0.45 for June through August. A value of -1 for the SPI occurs about every 4 years for each climate division, with minimal differences in the return periods between shorter (1-month) and longer (12-month) time intervals. The SPI threshold of -1 represents precipitation that is one standard deviation below normal, and is often used to specify drought. More information on how the severity of a drought relates to the SPI is available in a report for the state of Colorado (see Table 1: http://cwcb.state.co.us/water-management/drought/Documents/StateDroughtMitPlan2013/AnnexDDroughtMonitoringIndices.pdf).

The time series of SPI values were examined in the context of WA droughts in recent past decades. The SPI values for WA were consistent across time scales in showing drought in 2001 and 2005. Conversely, the SPI did not provide as clear of a signal for the onset of the more temperature-based droughts of 1992 and 2015. In particular, the statewide 3-month and 6-month values of the SPI dropped below -1 in June 2015, well after it was evident that water supplies would be an issue across much of WA state.

Overall, the 3-month SPI appears to be a suitable index for signifying precipitation-type droughts in WA. It effectively averages out the usual month-to-month fluctuations in precipitation, while still providing reasonably early detection of accumulating deficits. Moreover, there is more consistency between neighboring climate divisions in the 3-month (and longer) SPI than in the 1-month SPI, with a tendency for the western and eastern WA climate divisions to group separately.

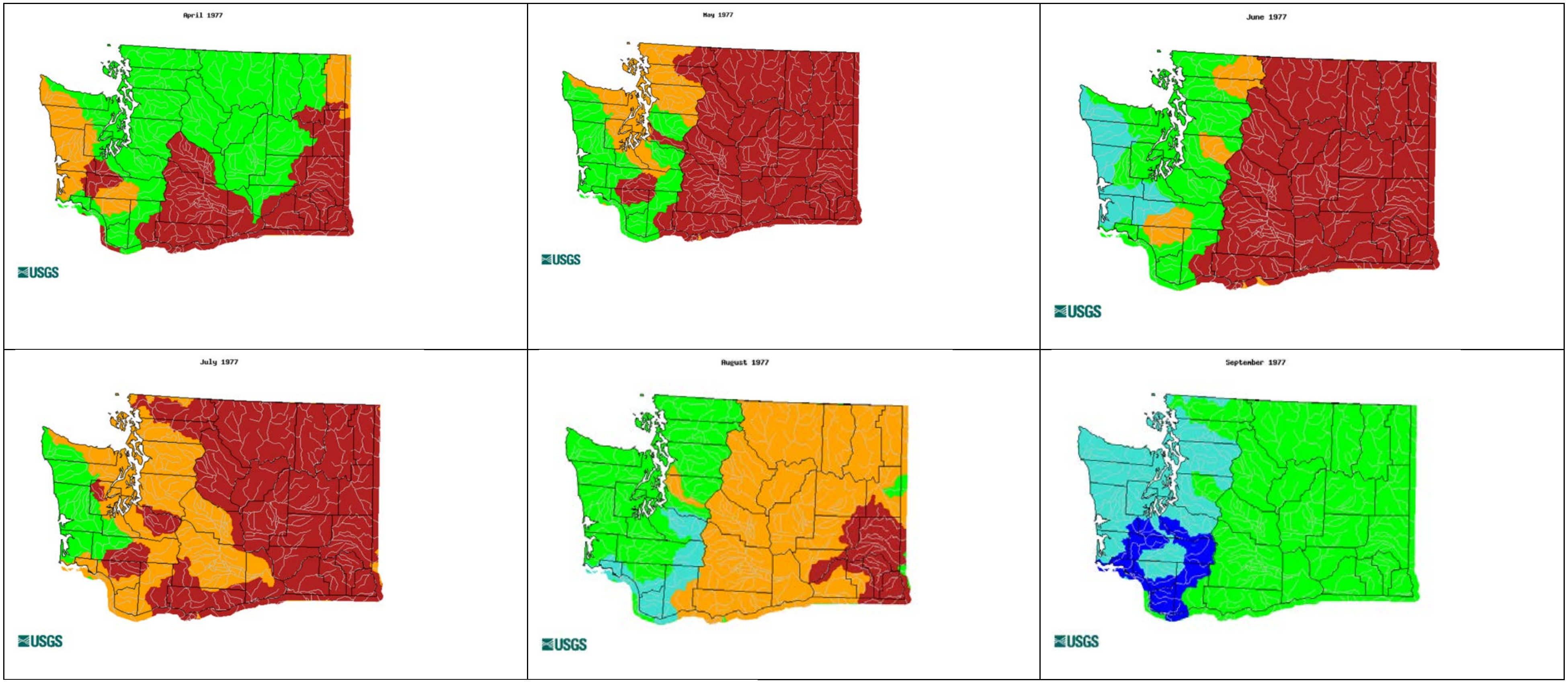
In summary, analysis carried out by the OWSC suggests that a value of -1 for the 3-month SPI would constitute a logical definition for declaring precipitation-driven droughts in WA state at the advisory level. It bears emphasizing that other factors, namely temperature, snowpack and reservoir levels, are important and sometimes dominant in terms of water supplies, and that the SPI should be used in conjunction with other information in declaring the onset and termination of drought conditions.

Nicholas Bond

Karin Bumbaco

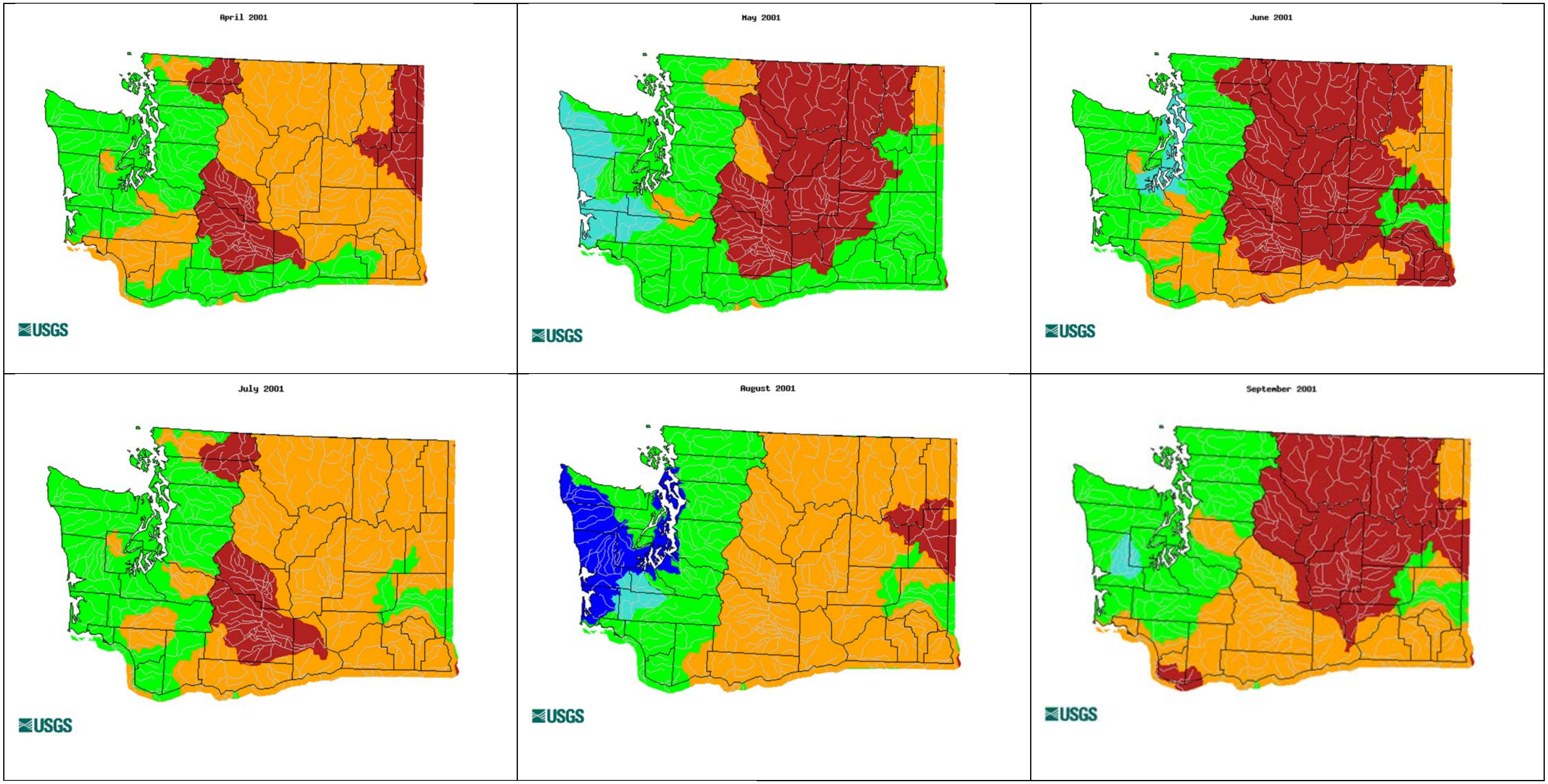
Appendix C. Runoff Patterns in Statewide Drought Years

Runoff Patterns Apr – Sept 1977



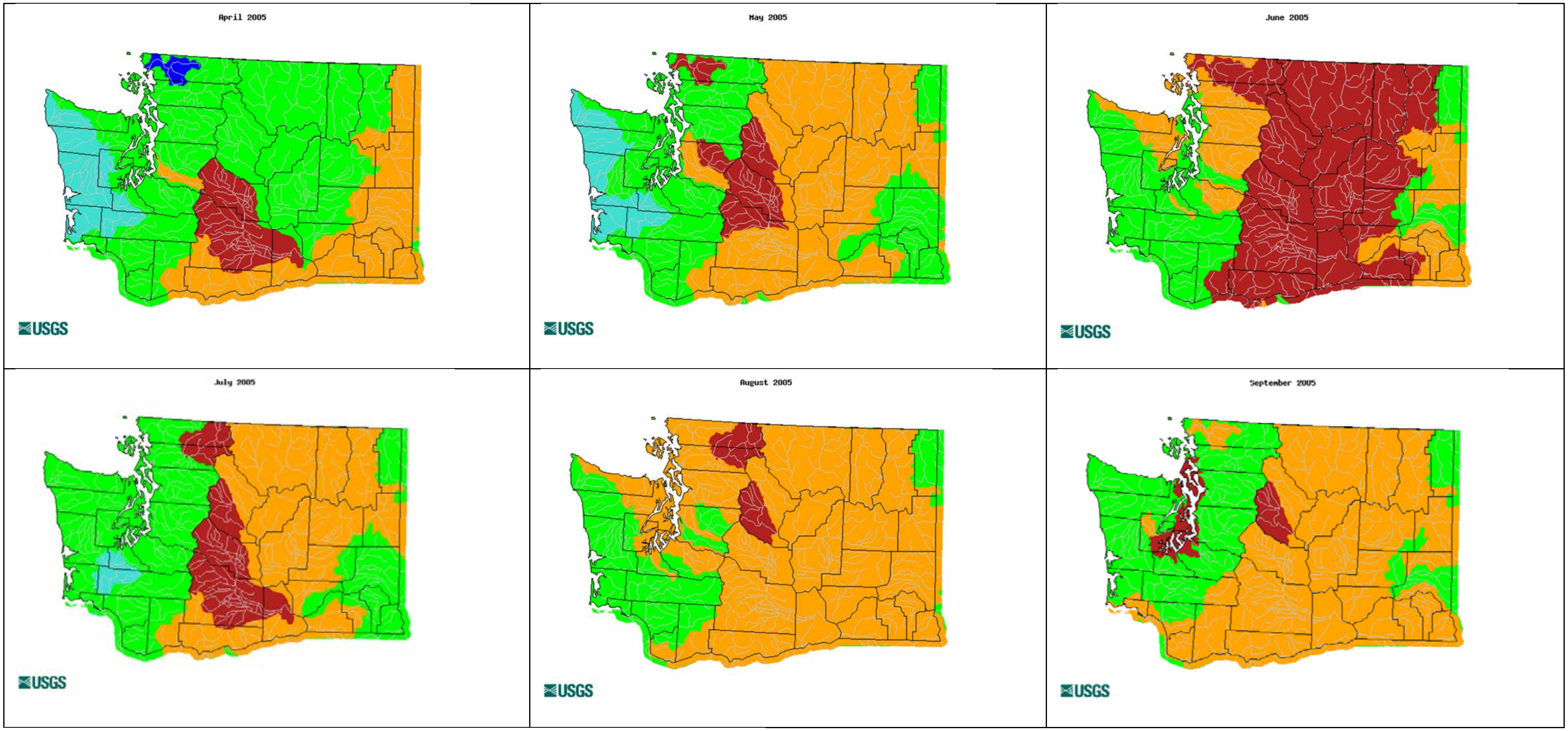
Explanation - Percentile classes							
Low	<10	10-24	25-75	76-90	>90	High	No Data
	Much below normal	Below normal	Normal	Above normal	Much above normal		

Runoff Patterns April – Sept 2001



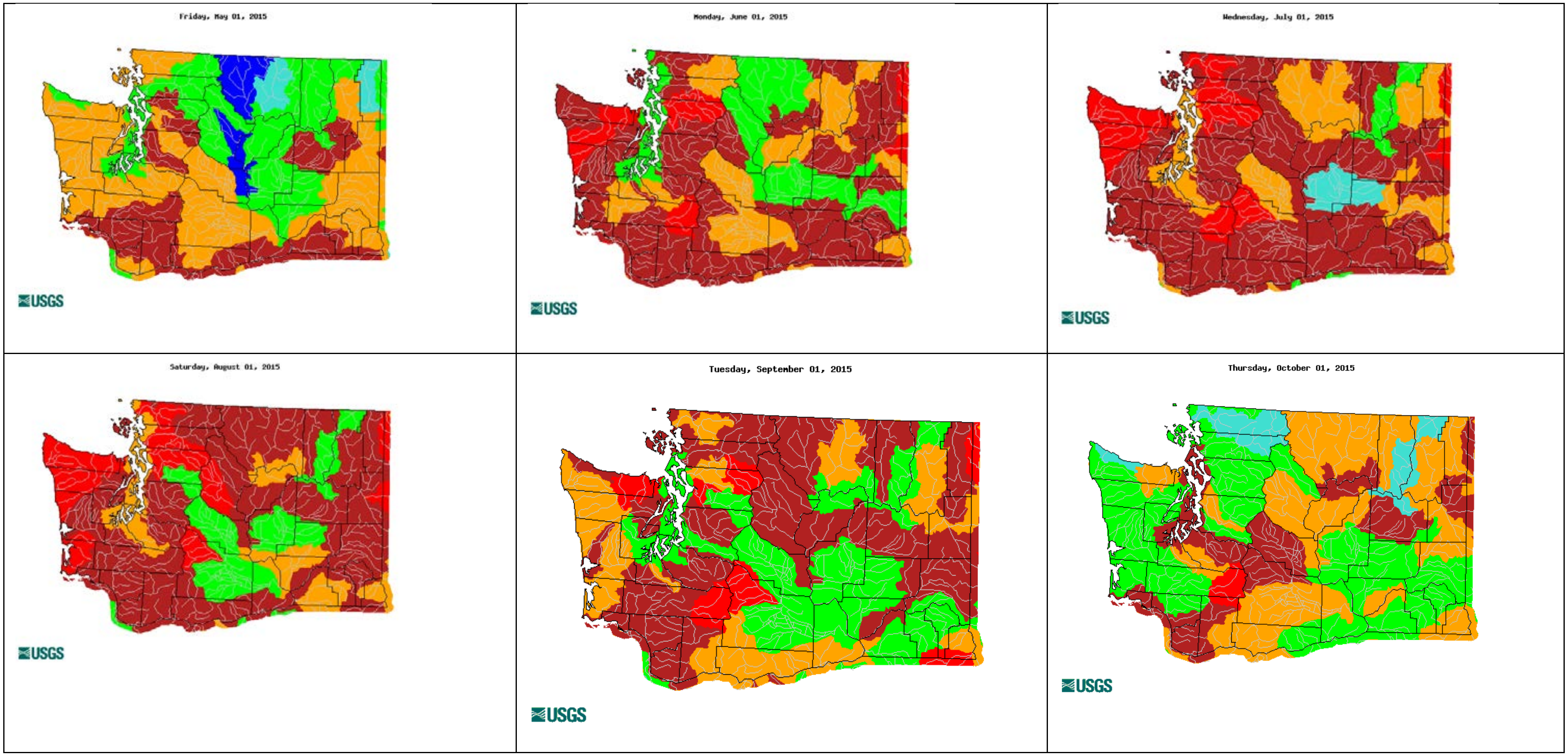
Explanation - Percentile classes							
Low	<10 Much below normal	10-24 Below normal	25-75 Normal	76-90 Above normal	>90 Much above normal	High	No Data

Runoff Patterns April – Sept 2005



Explanation - Percentile classes							
Low	<10 Much below normal	10-24 Below normal	25-75 Normal	76-90 Above normal	>90 Much above normal	High	No Data

Runoff Patterns April – Sept 2015



Explanation - Percentile classes

Low	<10	10-24	25-75	76-90	>90	High	No Data
	Much below normal	Below normal	Normal	Above normal	Much above normal		

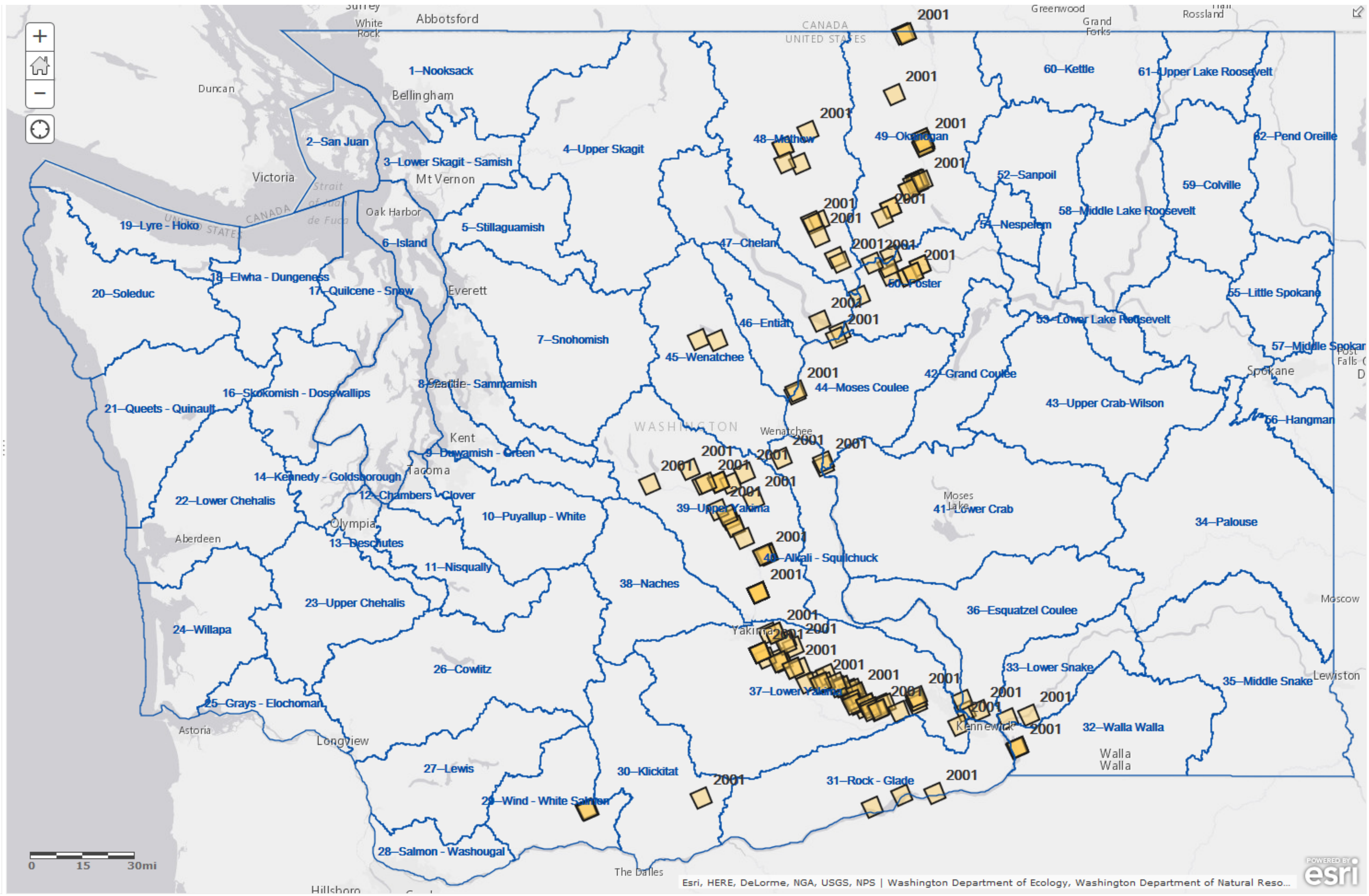


Figure 25 Emergency Drought Permit Authorizations 2001 (169 total)

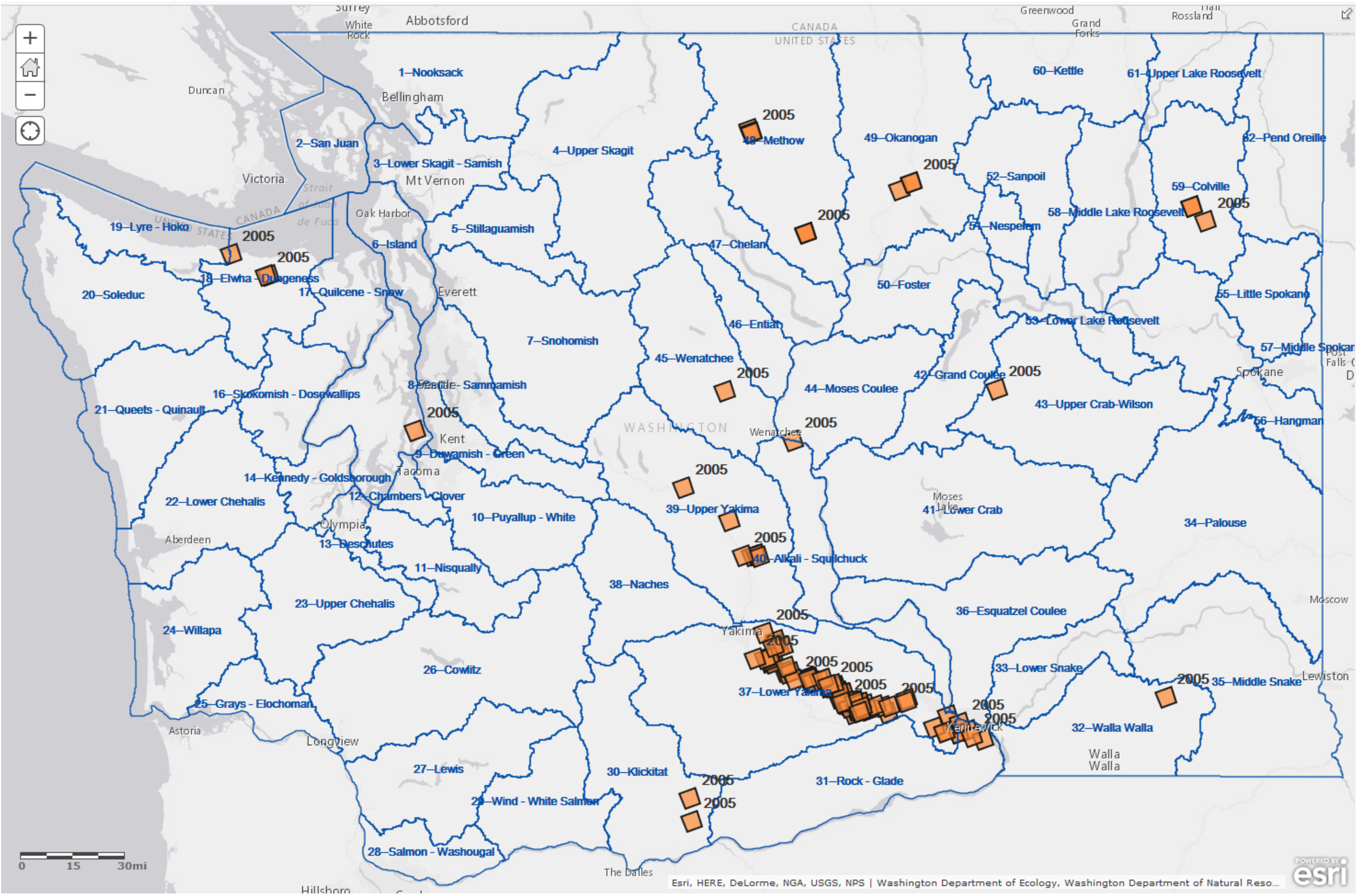


Figure 26 Emergency Drought Authorizations 2005 (119 total)

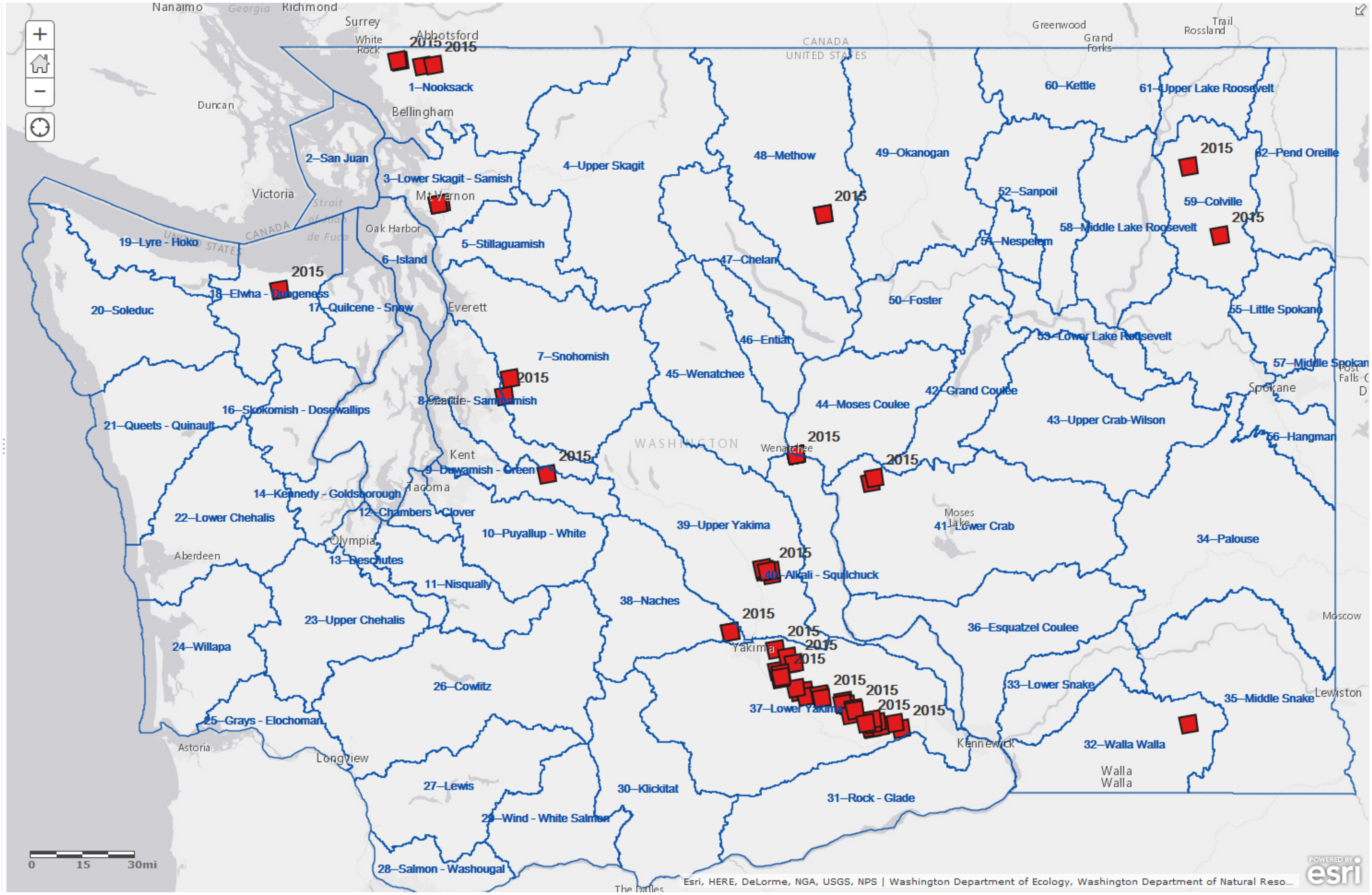
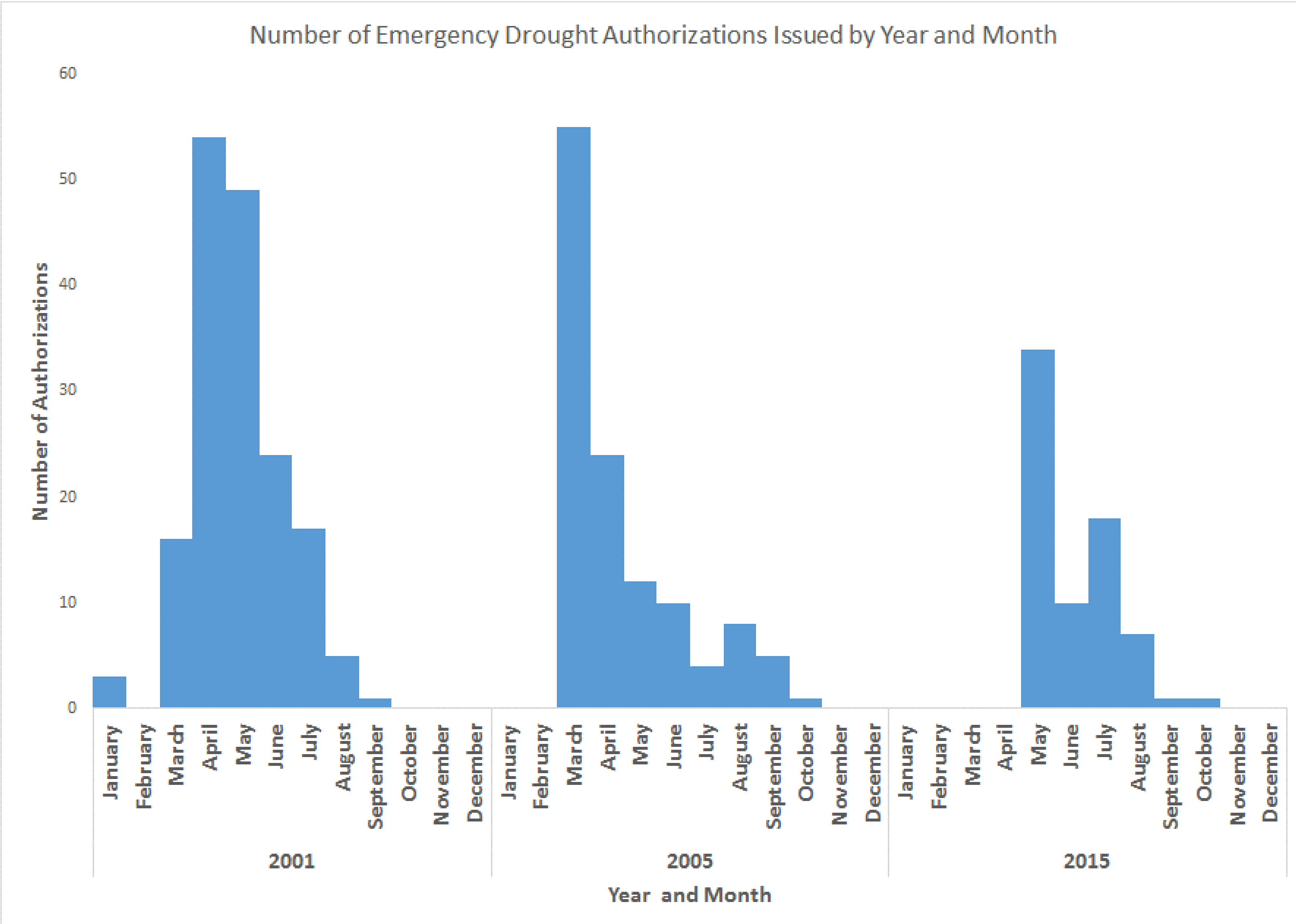


Figure 27 Emergency Drought Authorizations 2015 (71 total)



Number of Emergency Drought Authorizations Issued by Year and Month
Number of Authorizations
60
50
40
30
20
10
0
January
February
March
April
May
June
July
August
September
October
November
December
2001
2005
2015
Year and Month

Appendix D: Analysis of Drought Vulnerability and Adaptive Capacity.

Excerpt from University of Washington Drought Project, 2007.

Vulnerability

Vulnerability, in this study, will be defined as the susceptibility of a water user, a region, or a sector to drought hazard. Severity of drought hazards is based on the duration, magnitude, and spatial extent of drought impacts. Vulnerable sectors will be identified based on results of the impacts assessment performed in Phase 1 of this project. Vulnerability will consider two main factors: (1) frequency and severity of previous drought impacts, and (2) likelihood and severity of future drought impacts. In addition, adaptive capacity and the ability to mitigate impacts will be considered in the assessment of vulnerability.

North West

Agriculture

Prior impacts of drought to the agricultural community were described as minor. The primary challenge in meeting crop demands during drought occurs due to limitations of existing irrigation systems. Representatives from this sector with less robust irrigation systems are the most vulnerable to this type of drought impacts. Farmers may enhance their ability to cope with drought by predicting increasing plant demands in advance and making existing irrigation systems more robust.

When making decisions regarding row crops, one farmer reported planting crops in soils that have better moisture retention properties when drought is expected, though this is not likely to be a viable option for some farmers.

Dairy farmers in the region are affected by increased costs for feed. Production of feed onsite can also be reduced. Dairy farmers have limited capacity to adapt to increases in feed prices.

Golf courses in the region are especially vulnerable to use restrictions in cases where water is obtained from a purveyor. Golf courses have a considerable amount of adaptability when dealing with water shortage, including prioritizing watering locations, altering watering methods, and modifying horticultural practices. Interviewees from the golf course industry report that golfers are more accepting of dry hard grass than flooded soggy turf, further enhancing adaptive capacity of courses. The primary impact reported from droughts is over-watering, which is under the complete control of the golf course.

M&I

No interviewees reported drought impacts to the M&I sector.

Environment

The environmental sector is vulnerable to impacts caused by low stream flows. No interviewees identified significant environmental impacts during previous droughts. Challenges in meeting fish demands can occur during drought, and will be magnified by extractions from surface water.

Central West

Agriculture

The green industry reports severe impacts from drought during previous years. In this unique case, the green industry is most vulnerable to the expectation of drought by customers during the spring rather than actual shortages during the summer. The green industry feels that they cannot exert control on operations of municipal supply. When drought is anticipated, they can increase efforts to ensure that potential customers form their water supply expectations on accurate information, rather than on perceptions (from the media).

Because nurseries plant much of their product several years in advance, they have limited adaptive capacity other than scaling back onsite operations when reduced sales are expected. Retail nurseries and residential landscape companies may adapt to drought by reducing labor costs and purchasing. These labor and purchasing reductions have secondary impacts within the community.

Golf courses in the region are especially vulnerable to use restrictions in cases where water is obtained from a purveyor. Golf courses have a considerable amount of adaptability when dealing with water shortage, including prioritizing watering locations, altering watering methods, and modifying horticultural methods. Interviewees from the golf course industry report that golfers are more accepting of dry hard grass than flooded soggy turf, further enhancing the adaptive capacity of courses. The primary impact reported from droughts is over-watering, which is under the complete control of the golf course.

M&I

The primary impact of drought on water purveyors is economic losses from reduced sales during use restrictions. Suppliers have some ability to adapt to these potential economic losses by creating reserve funds and modifying water management strategies to reduce the necessity for use restrictions. Management strategies cited by interviewees include using a dynamic rule curve, altering maintenance schedules, and optimizing the combined use of water sources. M&I water users are affected by use restrictions during drought. They may adapt to these conditions by changing their practices to ones that require less water, including gardening with drought tolerant plants.

Environment

The environmental sector is vulnerable to impacts of drought during all seasons of the year. Flexibility of the environmental sector is limited. Impacts can be reduced by increasing monitoring and maintenance of fish devices and using manual methods to transport fish. In some controlled watersheds environmental advisory boards have been formed to enhance coordination between M&I operations and fisheries demands. Coordinating supplemental flows from reservoirs with fish needs is another way the environmental sector adapts to drought.

South West/Olympic Peninsula

Agriculture

Prior impacts of drought to the agricultural community in the southern portion of this region can be described as minor. The primary challenge in meeting crop demands for southern irrigators occurs due to limitations of existing irrigation systems. Representatives from this sector with less robust irrigation systems are the most vulnerable to this type of drought impact. Farmers may enhance their ability to cope with drought by predicting increasing plant demands in advance, and making existing irrigation systems more robust. Adaptive capacity of smaller farms is limited because of less ability to finance new projects. Irrigation districts in the northern portion of this region have reported some significant impacts from drought. The primary cause for these impacts is low stream flows. Farmers of cruciferous row crops, which are planted the previous fall and grown for seed, are drought tolerant and rarely impacted. Farmers of hay and alfalfa and farmers of perennial fruit trees have the least flexibility to respond to drought conditions because these crops are permanent and they require significant amounts of water late in the season to produce quality crops. In some cases decisions can be made to increase flexibility; farmers can decide not to plant additional fields or not to increase acreage of perennial crops when drought is expected.

Dairy farmers in the region are affected by increased feed costs or decreased feed production. Operations that rely solely on purchased feed are most vulnerable to impacts from drought, and also have extremely limited ability to adapt. Many dairy farmers in this region produce their own feed and are have more flexibility in their own operations to avoid increased costs. One method for reducing potential impacts is to leave alfalfa crops intact for another season, instead of rotating fields to corn.

Golf courses in the region are especially vulnerable to use restrictions in cases where water is obtained from a purveyor. Golf courses have a considerable amount of adaptability when dealing with water shortage, including prioritizing watering locations, altering watering methods, and modifying horticultural methods. Interviewees from the golf course industry report that golfers are more accepting of dry hard grass than flooded soggy turf, further enhancing adaptive capacity of courses. The primary impact reported from droughts is over-watering, which is under the complete control of the golf course.

M&I

No impacts of drought were reported in the M&I sector. Vulnerability of this sector to drought is currently low. Vulnerability to drought is likely to increase in areas experiencing population growth. Difficulty in procuring additional water rights has been identified in one location.

Environment

Some impacts to migrating fish have been reported in the Dungeness River, where irrigation reduces natural flows during the migration period. Flexibility exists to confront this problem. Coordinated irrigation reductions have proven to be effective at providing necessary flows for returning adults to migrate upstream.

North Central

Agriculture

According to Weekly Drought Reports produced by the Washington Department of Ecology, several rivers in the North Central region, including the Wenatchee, Okanogan, Stehekin, Entiat, Chiwawa, and Similkameen Rivers, reported record-low daily stream flows during the 2005 growing season. Several of these rivers recorded daily record-low flows in multiple months. Despite these record-low river levels, growers of tree fruit reported only minimal impacts from drought. One interviewee reported that 2005 proved that water supply in the region is less vulnerable to drought than he had thought. Growers did face challenges meeting water demand during the 2005 drought. Some water use restrictions were imposed. This indicates that the agricultural sector is vulnerable to drought impacts during more extreme droughts. This vulnerability may increase as growth in the region increases. Tree fruit growers in the region have some capacity to adapt to water shortage. Options for reducing demand include increasing watering efficiency, widening weed control strips, alternating watering from one side of trees to another, limiting irrigation in the spring to reduce foliage development thereby reducing water demand in the summer, using heat reflective spraying, and removing marginal blocks of trees.

Dairy farmers in the region are affected by increased feed costs or reduced feed production. Operations that rely solely on purchased feed are most vulnerable to impacts from drought, and also have extremely limited ability to adapt. Dairy farmers that produce their own feed are less susceptible to drought impacts and have more flexibility in their own operations to avoid increased costs. In the North Central region one method for reducing potential impacts from water restrictions is to plant more drought tolerant forage crops.

Beef cattle ranchers reported experiencing some impacts from drought, including rangeland water supplies running dry before forage runs out and increased feed costs. Ranchers have some flexibility in range operations which allows adaptation to drought conditions. Herd size can be cut back to stay within the reduced carrying capacity for given range conditions, herd rotation can be increased (at increased costs), water can be supplied by truck (cattle are often inaccessible by truck), and production schedules can be altered.

M&I

No impacts were reported by the M&I sector; however, the water intake for the city of Cashmere was reported to be dangerously close to running out of water coverage. This indicates that future droughts could affect M&I supply in the region. Modification of intake levels or obtaining alternative supplies during extreme drought may be difficult and time consuming.

Environment

Impacts to fish have been reported in the North Central Region during previous droughts. These impacts include increased stress and in some years hundreds of returning Summer Chinook Salmon and Sockeye Salmon perish before spawning. The adaptive capacity of the environmental sector is increased in years where emergency drought funds are made available. Impacts to fisheries can be reduced by more intensive monitoring and management of fish devices. Monitoring can also be performed on known problem areas in the river in order to identify stranded fish. Water can also be bought back from agricultural users returning some of the natural flow to rivers. When temperatures below Osoyoos Lake become high and tributaries of the Okanagan are dewatered, adaptive capacity decreases significantly.

South Central

Agriculture

The agricultural sector in the South Central region is highly vulnerable to drought impacts. In 11 of the past 35 years water supply from the Yakima Project has not fully met the demands of irrigated agriculture. According to an interviewee, the Yakima Project was able to provide 42 percent of normal water supply to proratable water users in 2005. This is the third lowest final proration estimate in the last thirty years; however, preliminary proration estimates in March of 2005 predicted only 34 percent of normal water supply for proratable users, which would have been the lowest proration in 35 years. Inability to meet agricultural demands in the Yakima Project has led to a variety of impacts to junior (proratable) water right holders. Impacts vary from farm to farm. Proratable users who farm hay or alfalfa realized fewer cuttings. Those that grew tree fruit reported reduced quality, and in some cases entire crops were lost. In general operations growing exclusively apples have the least adaptive capacity. Apples require very large amounts of water in every season: to protect from frost in the spring, to produce fruit, and to protect fruit from heat and sun during the hottest summer days. When proration is low growers may struggle to keep the orchard alive; production of high quality crop is even more challenging. On the other end of the spectrum, diverse operations have more flexibility, for example a farmer of tree fruit, wine grapes, and row crops is flexible in several ways. Firstly, wine grapes require three to four times less water than apples, so when proration is low, water from the grapes can be used to help insure tree fruit quality. In addition, row crop fields can be left fallow to concentrate water on the most profitable crops or those that represent the largest investment (fruit trees are usually both). In some cases a certain section of trees may produce a variety of fruit that is only marginally marketable. In these cases growers may opt to remove the marginal block of trees to conserve water for more marketable fruit. Growers can also invest in more efficient irrigation systems.

In addition to methods of managing water within farming operations, official drought declaration enables proratable users to apply for approval to transfer water between irrigation units on their own land, to lease water rights from others on a temporary basis, and for emergency water rights to drill new groundwater wells or reactivate existing emergency ground water wells. Farmers may also purchase extra land to fallow during drought years and transfer water to acreage with more valuable production.

Irrigation districts also have some capacity to adapt to drought conditions. Districts made up of proratable users may choose to purchase extra water from non-proratable districts, especially in situations where the proratable farmers produce more valuable crops or cases where the proratable farmers grow perennial crops. Districts may also chose to shut down irrigation operations for short periods in order to conserve water for later in the summer when water is more essential for crop development. During the 2005 drought, one proratable irrigation district was able to purchase enough water from senior districts to supply its users with approximately 49-51 percent of normal water supply rather than the normal 42 percent proration realized by proratable users who didn't obtain extra water. Trading was also used by this district during the 2001 drought, but with less success. In 2001 approximately 42-43 percent of normal supply was delivered rather than the 37 percent that would have been delivered otherwise.

Dairy farmers in the region are affected by increased feed costs or reduced feed production. Operations that rely solely on purchased feed are most vulnerable to impacts from drought, and also have extremely limited ability to adapt. Dairy farmers that produce their own feed are less susceptible to drought impacts and have more flexibility in their own operations to avoid increased costs. In the South Central region one method for reducing potential impacts from water restrictions is to plant more drought tolerant forage crops.

Beef cattle ranchers reported experiencing some impacts from drought including rangeland water supplies running dry before forage runs out and increased feed costs. Ranchers have some flexibility in range operations which allows adaptation to drought conditions. Herd size can be cut back to stay within the reduced carrying capacity for given range conditions, herd rotation can be increased (at increased costs), water can be supplied by truck (cattle are often inaccessible by truck), and production schedules can be altered.

Dryland farmers in the South Central region also experience impacts from droughts when crops don't receive adequate rain. Impact to dryland farmers may be increased if nitrogen is applied that plants can't consume due to drought. Dryland farmers have some adaptive capacity for dealing with drought. For example, quantities of nitrogen applied to crops are based on expectations for available moisture during the growing season. If more nitrogen is applied than the plant can use based on available water then investment in fertilizer is lost; if the crop cannot make use of all available water due to nitrogen deficiency, then potential yield is lost. With accurate predictions of available moisture during a growing season, farmers can avoid lost fertilizer investments or lost crop yields. In the South Central region, various dryland crop cycles are used depending on average precipitation. In some cases, a winter wheat summer fallow two-year rotation is used; in other cases, a three-year winter wheat, spring wheat, summer fallow rotation is used. Other rotations combinations are also possible, but most dryland operations in Washington State include at least one rotation of winter wheat. Depending on available moisture in the soil before planting and seasonal moisture expectations, this planting cycle can be modified to reduce impacts of drought. During winter wheat rotations, fall nitrogen applications can be reduced and, if winter moisture is higher than expected, crops can be side dressed with additional nitrogen in the spring (this practice increases application costs). Spring crop rotations can be skipped if soil moisture and precipitation expectations are too low. Dryland farmers may also place lands that perform poorly during dryer conditions into the Conservation Reserve Program. In most cases, the ability of dryland farmers to adapt to drought conditions depends on accurate determination of existing soil moisture and predictions of available precipitation during the growing season. In cases where production is extremely low, farmers may chose not to harvest if operation costs of the combine will be larger than revenue from wheat sales.

M&I

No M&I impacts were reported by interviewees. Vulnerability of the M&I sector can be expected to increase as populations in the South Central region grow.

Environment

The environmental sector experiences impacts from unnatural flows and reduced base flows on all years; these impacts are greatly magnified during drought. The environmental sector has some ability to adapt to drought conditions. This ability is enhanced by drought declarations, which make additional funding available to fisheries personnel for mitigation of impacts.

Fisheries organizations can reduce drought impacts by increasing monitoring and maintenance of fish devices, such as ladders and screens, in the system. Monitoring of trouble locations can also be increased to enhance ability to respond to stranded fish. Fish can be transported and fisheries personnel can make appropriate decisions regarding whether to allow fish migration into areas that a may become dewatered later in the fall. A Systems Operation Advisory Committee (SOAC) has been established in the South Central region to advise operations of the Yakima Project on issues regarding fish. This organization makes recommendations to the USBR on flows that should be maintained during different seasons. These recommendations include recommendations for artificial spring freshets, minimum summer base flows, recommended flows during fall spawning that determine access of spawning fish to areas outside the main channel, and winter flows required to prevent redds from being dewatered.

East

Agriculture

Agriculture in the East region is highly vulnerable to drought. Dryland farming operations in general are particularly vulnerable, as the water supply for these crops comes directly from precipitation. Impact to dryland farmers may be increased if nitrogen is applied that plants can't consume due to drought. Dryland farmers have some adaptive capacity for dealing with drought. For example, quantities of nitrogen applied to crops are based on expectations for available moisture during the growing season. If more nitrogen is applied than the plant can use based on available water then investment in fertilizer is lost; if the crop cannot make use of all available water due to nitrogen deficiency, then potential yield is lost. With accurate predictions of available moisture during a growing season, farmers can avoid lost fertilizer investments or lost crop yields. In the East region, various dryland crop cycles are used depending on average precipitation. In some cases, a winter wheat summer fallow two-year rotation is used; in other cases, a three-year winter wheat, spring wheat, summer fallow rotation is used. Other rotations combinations are also possible, but most dryland operations in Washington State include at least one rotation of winter wheat. Depending on available moisture in the soil before planting and seasonal moisture expectations, this planting cycle can be modified to reduce impacts of drought.

During winter wheat rotations, fall nitrogen applications can be reduced and, if winter moisture is higher than expected, crops can be side dressed with additional nitrogen in the spring (this practice increases application costs). Spring crop rotations can be skipped if soil moisture and precipitation expectations are too low. Dryland farmers may also place lands that perform poorly during dryer conditions into the Conservation Reserve Program. In most cases, the ability of dryland farmers to adapt to drought conditions depends on accurate determination of existing soil moisture and predictions of available precipitation during the growing season. Several interviewees stated that El Niño years have proven to be warmer and dryer, so dryland farmers may adapt to drought by responding appropriately to the ENSO signal. This includes reduced nitrogen fertilizer application during El Niño years.

Irrigated operations in the East region are only slightly vulnerable to drought. Irrigated farming operations receive surface water from the Columbia Basin project or other smaller irrigation projects. Some pump water directly from small tributaries. Others irrigate with water pumped from groundwater. No interviewees reported impacts from supply restrictions or groundwater drawdown. The main impacts reported from irrigated farming operations were increased costs to pump water. These operations can also be vulnerable to reductions in crop quantity or quality if water supply is unable to meet demands from evapotranspiration on extremely dry years. Farmers that don't have a high percentage of perennial crops have some adaptive capacity. Crops placed within one irrigation unit can be diversified so that large amounts of water are required at different times in each field within the irrigation unit. For example, an irrigation unit that supplies water to five fields may limit potato production to two of those fields because potatoes require very large quantities of water during tuber development.

M&I

The M&I sector is not particularly vulnerable to drought in the East region. No interviewees identified any physical impacts of water shortage, such as water use restrictions. Walla Walla and Moses Coulee/Foster Creek WRIA's reported restrictions of growth in the region; however, this may be an appropriate response to water supply limitations that have been identified. Growth restrictions will help limit vulnerability of the M&I sector.

Environment

The environmental sector is affected on most years due to stream dewatering. These impacts are magnified by drought, which indicates medium vulnerability. The environmental sector has some ability to adapt to drought conditions. This ability is enhanced by drought declaration, which makes additional funding available to fisheries organizations for mitigation of impacts. Fisheries organizations can reduce drought impacts by increasing monitoring of streams, particularly problem locations. This can enhance the ability of this sector to respond to stranded fish. Fish can be transported and fisheries personnel can make appropriate decisions regarding whether to allow fish migration into areas that may become dewatered later in the fall. When low spring flows are affecting outmigration of juvenile fish, coordinated irrigation reductions can provide artificial freshets aiding fish migration and reducing impacts to fish.

Power

Because river flow is the primary fuel for hydropower producers in the state, hydropower producers will always be vulnerable to drought; however, from dealing with past droughts, hydropower producers have developed strategies making the sector better equipped to adapt to drought conditions. Some of the vulnerability of hydropower producers to drought stems from quantities agreed upon in sales agreements. In a worst case scenario, when supply agreements can't be met, power must be purchased on the open market. In 2001 the cost of purchasing replacement power was compounded by inflated market prices for electricity.

Using results of flow modeling simulations and climate forecasts, water managers in the hydropower sector can make decisions that make hydropower producers less vulnerable to impacts from drought similar to those experienced in 2001. If less flood control space is necessary managers may decide to keep more water in reservoirs during the spring. Water may be purchased from irrigators in order to ensure better flows for generation. Electricity may be bought back from the direct service industry (DSI buyback). DSI buyback makes large quantities of electricity available to meet supply agreements during drought. Other production units may be paid to turn generators on or alter generation schedules to produce electricity for lower prices than those available on the open market.

Impacts to fisheries and hydropower generation potential are often inseparable. Many power producers have established agreements to sacrifice power generation in order to provide more water over spillways for downstream fish migration. The cost of this spilled water is magnified during drought when power must be purchased to meet supply commitments. Hydropower producers have several methods for dealing with fish flow requirements during drought to decrease vulnerability. During drought, water managers may decide to pool more water in the spring and summer to increase fuel supply for the winter. This may mean that fish flow requirements are not met, in which case fish capture and transport below the dams is increased.

Recreation

Many recreation industries in the state depend on adequate supply of water to meet the demands of their operations. This report focuses on the ski industry, which requires adequate snow pack to open operations and to attract customers. Low snow pack results in reduced visits and can have large impacts on profit, making the ski industry extremely vulnerable to drought. The ski industry has limited adaptive capacity. The primary method used by ski area operators is to minimize staffing and reduce operations. One interviewee indicated that early season hiring is minimized during times of uncertain supply to reduce vulnerability. Ski areas may also be opened on a limited capacity to reduce vulnerability, e.g. opening only one restaurant rather than five when snow pack is low.

Appendix E. Mutual Aid

(first page only – full document available from the

Water/Wastewater Agency Response Network at wawarn.org)

Mutual Aid and Assistance Agreement for Washington State for Intrastate Water/Wastewater Agency Response Network (WARN)
As of: 04/13/09

This Agreement ("Agreement") is made and entered into by public water and wastewater utilities that have executed this Agreement.

ARTICLE I
PURPOSE

Recognizing that emergencies may require aid or assistance in the form of personnel, equipment, and supplies from outside the area of impact, the signatories hereby establish an Intrastate Network for Mutual Aid and Assistance (the "Network"). Through the Network, Members (as further defined in this Agreement) may coordinate response activities and share resources during emergencies.

ARTICLE II
DEFINITIONS

A. Authorized Official – An employee or officer of a Member agency that is authorized to:

1. Request assistance;
2. Offer assistance;
3. Decline to offer assistance;
4. Decline to accept offers of assistance, and
5. Withdraw assistance under this Agreement.

B. Emergency – A natural or human-caused event or circumstance causing, or imminently threatening to cause, loss of life, injury to person or property, human suffering, significant financial loss, or damage to environment. For example, Emergencies may include fire, explosion, flood, severe weather, drought, earthquake, volcanic activity, spills or releases of oil or hazardous material, contamination, utility or transportation emergencies, disease, blight, infestation, civil disturbance, riot, intentional acts, sabotage and war that are, or could reasonably be beyond the capability of the services, personnel, equipment, and facilities of a Member to fully manage and mitigate by itself.

C. Member – Any public agency which provides supply, transmission or distribution of water; or collection, conveyance or treatment services of storm water or waste water that executes this Agreement (individually a "Member" and collectively the "Members"). The Members are further classified as follows:

1. Requesting Member – A Member who requests aid or assistance under the Network.
2. Responding Member – A Member that responds to a request for aid or assistance under the Network.

D. Period of Assistance – The period of time when a Responding Member

Appendix F. Yakima Basin Drought Wells MOA

Supplemental Memorandum of Understanding among the Yakama Nation and United States Bureau of Reclamation and Washington State Department of Ecology related to Surface Water Transfer Activities during the FY 2015 Drought

I. INTRODUCTION

This Memorandum of Understanding (MOU) is entered into by the Yakama Nation (Yakama), United States Bureau of Reclamation (Reclamation), and Washington State Department of Ecology (Ecology) for the purposes stated below.

II. PURPOSE AND SCOPE

A. Purpose

The parties agree that there is need to supplement the Memorandum of Agreement dated August 12, 1999, under Section VI of that agreement, for the purpose of addressing issues associated with the drought of 2015. This supplemental agreement will identify actions to be taken by the parties with respect to surface water transfer proposals and the issuance of emergency ground water permits this year. The general terms of the state's Yakima drought response strategy were discussed among Reclamation, Ecology, and Yakama staff on March 16, April 16, May 13, and May 18, 2015.

III. PROVISOS

A. All provisos in the original MOA shall apply under this supplemental agreement.

B. None of the information used or actions taken by the parties during this drought emergency shall be introduced as evidence by the parties in court, and resolution of water transfer proposals within this agreement will have no bearing upon resolution of similar transfer proposals during subsequent water short years or upon permanent transfer proposals. Nonetheless, a party to this MOU will not be restrained in any way from any action regarding evidence introduced by third parties to effectively defend a party's interest. Provisions within this supplemental agreement will apply only to the resolution of selected water transfer actions and emergency ground water permit actions associated with the 2015 drought. Approval shall not be used as evidence of nor waive any argument concerning future proposed permanent or temporary transfers under either applicable Federal law or contract or state law, including RCW 90.03.380. The use of the procedure for approval here is also not intended by any party to be a concession as to the appropriate procedures for transfers in the future.

MITIGATION STRATEGY

A. Background

Kittitas Reclamation District (KRD), Reclamation and Ecology have agreed to work together to provide supplemental water from Reclamation owned/KRD maintained irrigation facilities to enhance fisheries during the 2015 drought. KRD proposes to deliver and release the water to the creeks and Ecology will manage that flow through the lower reaches of each stream. A combined 10 cfs from KRD's Yakima River point of diversion at Easton will be conveyed to five streams crossed by the KRD main canal: Tucker Creek, Big Creek, Little Creek, Spex Arth and Tillman Creek.

Yakima Tieton Irrigation District (YTID), Reclamation, and Ecology are also working together to provide supplemental water from Reclamation owned/ YTID maintained irrigation facilities to enhance fisheries to the South Fork of Cowiche Creek during the 2015 drought. YTID can convey and release approximately 2 cfs to the South Fork.

The state has completed a reverse auction to obtain water rights, which is targeting tributaries upstream of the City of Yakima in both the Naches and Yakima River systems. The purpose of the reverse auction is to lease water primarily to improve instream flows for fisheries.

The state is proposing to administer a program of emergency ground water permits to allow certain water users primarily within the Kittitas Reclamation District and Roza Irrigation District to utilize ground water sources as an emergency supplemental supply of water during the 2015 season. The pumps will be metered and Ecology will perform routine site visit, periodic monitoring of electrical and flow meters to quantify water usage. Therefore, the volume of ground water to be withdrawn under the emergency groundwater permits during the 2015 irrigation season will be verified.

The Roza-Sunnyside Board of Joint Control proposes the capture and reuse of up to approximately 15 cfs of water. Under this proposal, as much as 2500 acre-feet of the captured water is proposed for transfer from Sunnyside Valley Irrigation District (SVID) to the Roza Irrigation District (RID).

The water pumped from the Sunnyside Drains would be used by SVID if not for this proposed transfer. The total water supply available (TWSA) would not be reduced by the proposed transfer from SVID to RID. Because the pumps will be metered, actual quantities can and will be verified.

The state recognizes the substantial public interest associated with water quality standards compliance in the lower Yakima River and the need to ensure that the Yakama's time immemorial right to instream flows for fisheries is protected.

B. Strategy

The parties agree that the guiding principle during the current drought is to use all the available tools to manage the Yakima River basin for the benefit and protection of all the basin's resources, including both instream and out of stream uses of water within the limits of law and existing water rights.

The 2015 drought response strategy applies to off-reservation emergency groundwater well use and surface water right transfers between off-reservation entities. Any requests for transfers within the reservation or emergency groundwater well use on the Reservation must be approved by the Yakama Tribal Council. Any requests for transfers from an on-reservation source to an off-reservation entity must be approved by the Yakama Tribal Council before being forwarded to the state for its consideration.

Ecology will manage its emergency ground water well permit program to ensure that effects to the Yakima River will be mitigated in the long term and that permitting actions will not reduce TWSA in the current year. Ecology agrees to acquire water for placement into trust to benefit instream flows in the Yakima River and its tributary streams.

The water pumped from the Sunnyside Drains would not be used by SVID if not for the emergency drought actions. The proposed transfer of a portion of the captured return flow from SVID to RID would reduce Yakima River flows downstream of Sunnyside Dam. Because the pumps will be metered, actual quantities can and will be verified.

Water leases of up to 5,000 acre feet from fallowed ground in SVID will be transferred to Roza Irrigation District. That water would have been used by SVID if not for the water transfer and the total water supply available will not be reduced as a result of the transfer.

Acquisition of water to replace the net flow reduction in the lower Yakima River would ensure that the public's interests are protected and the Yakama's rights are not harmed by the state's approval of the transfer. Ecology agrees to work with Reclamation and Yakima Nation and acquire water to replace the water lost to that reach of the river. In doing so, we agree to the following approach to guide the acquisition of replacement water:

The objectives:

1) Ecology, in consultation with the Yakama Nation and Reclamation, will seek to lease or purchase water for in-time, in-place, and in-kind mitigation this year or;

2) If water cannot reasonably be acquired to accomplish #1, Ecology, in consultation with the Yakama Nation and Reclamation, pursue alternative means to acquire water that provides in-time benefits upstream and which is of equal or greater benefit ecologically. Ecology will implement the agreed strategy.

If the parties agree that water is not reasonably available to meet either #1 or #2 above, Ecology will either acquire water rights to be placed into the State Trust Water Rights Program for instream flow purposes or provide funding based on the market value of the water to the YRBWEP Acquisition Fund for replacement water and/or habitat. The parties will jointly list, analyze, and select other long-term and sustainable acquisition options. Land and/or water acquisitions will be jointly evaluated for longer-term ecological benefits and will be implemented by Reclamation.

Ecology, Reclamation and the Yakama will:

Implement the agreed strategy as soon as possible after its selection or as soon as fund transfer is completed, whichever occurs first.

Nothing herein is intended to quantify, diminish, or define the Yakama's water rights nor serve as an admission as to instream flows in the Yakima Basin. All other terms of the original Memorandum of Agreement shall remain in force and effect and are incorporated herein by reference.

This amendment to the original MOA shall apply only during the year 2015. Any action taken by Reclamation to implement measures pursuant to this Agreement is contingent upon any necessary compliance with relevant Federal laws, including but not limited to the Endangered Species Act.

Maia D. Bellon
Director
Department of Ecology
Date:__________________________

Dawn Wiedmeier
Columbia-Cascades Area Manager
US Bureau of Reclamation
Date:__________________________

JoDe L. Goudy
Chairman, Tribal Council
Yakama Nation
Date:__________________________

Appendix G. Communication

Overview

The Washington State Drought Contingency Plan lays out a multi-agency response to drought or potential drought conditions. As the state's water resource manager, the Department of Ecology facilitates the declaration process and leads the response - but close coordination with other state agencies is vital for response success, including communications.

This chapter provides guidance on how to develop and deliver strong, synchronized communications in the event of a drought advisory or emergency declaration in Washington State.

Lessons learned from 2015

Washington has experienced a handful of water-short years in recent memory, but 2015 stands out as the most severe. Here are high-level lessons learned from our experiences communicating during that year:

- Drought does not impact everyone equally
- Coordination among the state family and close partners is critical
- People want to know what we are doing and how they can get relief

These lessons, and others, are woven into this chapter.

Communications summary

Here's a look at the actions and communications associated with water supply communication:

	Actions	Communications
Water supply updates (year round)	Ecology regularly convenes the Water Supply Advisory Committee (WSAC) to review conditions and anticipate potential problems Ecology continues its drought mitigation efforts	Ecology updates its website, blog and social media based on WSAC findings Other state agencies are involved in communications, as necessary Highlight successful projects or plans that increase drought resilience (e.g. Office of Columbia River work)
Stage 1 – Advisory (regional or statewide)	Ecology issues an advisory for the affected area(s) Involved state agencies have heightened awareness and increased preparation Involved agencies may begin mobilizing resources and preparing for drought response actions Ecology invites water users who anticipate hardships to petition for assistance with drought preparedness/ response actions	Ecology convenes the drought communication coordination team Ecology leads the effort to communicate about existing conditions and forecasted climate outlooks Coordinate communication with major water managers and affected governments (county, city and tribal) Tone: Concerned but not panicked; clear and conversational

	Actions	Communications
Stage 2 – Emergency declaration (regional or statewide)	Ecology issues a drought declaration for the affected area(s) Ecology activates systems for response as defined in the state's drought contingency plan Involved agencies mobilize resources	The drought communication coordination team (Ecology convenes this group, if advisory step is skipped) highlights information about relief efforts and how affected people can access resources Ecology continues communicating about existing conditions and forecasted climate outlooks; state agencies support Team coordinates communication with major water managers and affected governments (county, city and tribal) Tone: Calm, direct and empathetic

Coordination team

In the event of drought conditions, communications staff representing each involved state agency will meet regularly. Ecology will convene this team. Their work will involve:

- Discussion and decisions on roles, responsibilities and expectations
- Updates from each state agency on its preparation or response activities
- Discussion and decisions on communication goals, tactics and strategies
- Coordination of messages and messengers
- Reviewing each agency's audiences and strategies to reach target groups
- Identifying the best approaches for managing online content and media outreach
- Determine where information will be housed online
- Determine the lead on media outreach, including news releases and spokespeople
- Connecting with key stakeholders (cities, water districts, PUDs, irrigation districts, etc.) and their messaging
- Reviewing the impact of our communications - what's working and what's not

Members of this group will be responsible for channeling communications updates to and from their leadership teams. These internal updates could include:

- What other agencies (federal, state, county, local and tribal) are doing
- Big media stories or inquiries
- Stakeholder outreach for their respective state agency

Goals of multi-agency communication

- Remain a trusted source on water supply conditions
- Work as a singular state family

Objectives

- Keep audiences informed about current and forecasted water supply conditions
- Share information about resources and how to access them
- Coordinate and amplify messages
- Leverage agencies' unique relationships with stakeholders to reach target audiences

Audiences

The involved state agencies have relationships with specific audiences that could be utilized during a drought advisory or emergency declaration. Here are the audiences each agency is best at reaching during drought:

Department of Ecology

- Media
- Water rights holders
- Governor's Office
- Environmental groups

UW Office of State Climatologist

- Media
- State agencies
- Universities and agricultural groups for presentations

Washington State Conservation Commission

- Conservation districts (can reach all 45 directly via delivery.gov)
- Rural landowners

- Tribes (?)

Department of Agriculture

- Washington Water Resources Association
- Washington Tree Fruit Association
- Washington Grain Commission
- Western Washington Agricultural Association
- Washington Dairy Federation

Washington Department of Fish and Wildlife

- Audiences they reach best:
- Tribes (?)
- Recreational users of water bodies (?)
- Fishers

Department of Commerce

- Media
- Energy utilities
- Association of Washington Business
- Businesses (local, national)
- Local governments
- Community action agencies and related service providers

Department of Health

- Group B water systems
- General public

Department of Natural Resources

- Audiences they reach best:

Other critical audiences for drought communication include:

- Lawmakers, including the Joint Legislative Drought Task Force
- Residents
- On water systems
- On individual domestic wells
- Businesses
- City/county officials
- Other agency stakeholders
- Water Resource Advisory Committee members (Ecology)
- Tribes
- Internal agency staff and executives

Strategies

- Use plain talk
- No surprises: Be the first and best source of information on what's going on
- Implement a cohesive online strategy
- Encourage dialogue on social media
    - Consider sharing a hashtag
- Work with media to reach affected communities, including non-English-speaking communities
    - Translate as much as possible
- Partner closely with Ecology's regional communications managers, and - if possible - involve state agencies' regional communications staff

Tactics

Ecology will take the lead on external communication tactics but will need support from other state agencies. Each agency will handle its own internal communication and messaging to its stakeholders. All communications - internal and external - will be discussed (and coordinated, as appropriate) during drought communication coordination team meetings.

- Communications plan and talking points
- Media outreach
    - Issue news releases, as necessary (coordinate roles among state agencies)
    - Clearly set "lanes" when answering reporter questions
    - Work with diverse media outlets
- Blog posts
    - Water supply conditions and forecasts
    - What we're doing; how to access resources
    - Guest posts
- Website
    - Identify a strategy to share information online

  - Coordinate with state agencies on content and messages

- Social media
  - Share latest information and/or success stories
  - Advertise blog posts
  - Promote web page updates
  - Promote sister agencies' web pages, when appropriate
  - Engage and elevate regionals' and partner agencies' accounts

- Creative thinking
  - Podcasts, livestream interviews, etc.
  - Photo albums of impacts

Recommendations

Stay connected to water suppliers

In 2015, many residents were confused when Ecology declared a statewide drought but people saw water being used normally - local parks being irrigated, for example. Or citizens heard that "fish are flopping" in dry streams but saw neighbors refilling backyard pools. Confusion can arise when the state says one thing and people hear another message (or see contradictory behavior) elsewhere.

Many of these issues happened in areas served by municipal water suppliers. Coordination with key water management groups, especially municipalities and other water purveyors, can help avoid conflicting messaging. About 85 percent of water users in our state are connected to a water system. We need to clearly address how water system users are affected by an advisory or emergency declaration - or clearly state where they can learn about those impacts. Chances are, people using a water system will need to contact their local water supplier to get more information. This will require regular and open communication with water suppliers so we share consistent messages.

Note about large utilities: In the event of a drought advisory or emergency declaration, EWEC-level staff would contact the state's largest utilities (Seattle, Tacoma, Everett and the Pierce County regional system). Once communication is established, the drought communication coordination team will assist by:

- Opening dialogue about local messaging plans
- Identifying and discussing any potential conflicting messages

- Sharing messages and talking points
- Integrating communications, as appropriate (e.g. sharing quotes in news releases)
- Staying connected with utilities for the duration of the advisory/declaration
- Making adjustments, as needed

Call out impacted groups

Clearly and frequently specify who or what is most affected by drought conditions - irrigators, fisheries, drinking water suppliers, etc. This will help people quickly determine whether they'll be impacted.

Keep messages consistent

Ecology will take the lead on developing messages, but here are guiding principles for all involved agencies (and non-agency partners, as appropriate). We need to be consistent with our:

- Terminology
- Format
- Facts

Message coordination will occur through the drought communication coordination team.

Use plain talk and repeat definitions

A formal drought advisory or emergency declaration will need to be accompanied by plain talk communications (news release, web updates, social media, etc.) that address:

- When
- Where
- Who
- How bad

Don't assume the advisory or declaration language will be widely understood on its own. Studies show that many audiences do not understand the difference between warnings, watches, advisories, statements, etc. It's our job to clearly define what we mean and continue to define it for the duration of the advisory or declaration (or beyond).

Make impacts relatable

Technical or academic language like, "An anomaly of 1.5 degrees Celsius," is not something most audiences understand or relate to. Impacts need to be plain-talked and relevant.

When possible, connect impacts to the local level. This will help people understand what to expect in their community. When discussing impacts, share stories about what is being done to help those affected by drought conditions.

Acknowledge uncertainties

A drought's impact can vary widely, even in a small geographic area.

Research shows that emphasizing uncertainties and probabilities can provide helpful context. This could reduce the frustration that comes with forecast uncertainty. The drought communication coordination team could consider using terms like "best case," "worst case" and "most likely case" to describe the range of potential impacts to an area or community.

Work with Portland media in Southwest Washington

Portland media outlets reach into the southwest portion of Washington. If a drought advisory or emergency declaration is issued in this region, it'll be important to:

- Ask for guidance from southwest-based regional communicators (Ecology's or other state agencies') on how to best reach Portland media

- Intentionally include Portland media on news distribution lists

Coordinate with the Bureau of Reclamation

The U.S. Bureau of Reclamation is a co-water manager in the Yakima River basin, an important agricultural center for our state. Ecology worked closely with Bureau staff on response actions (the drought well program and Columbia drought insurance program) during the 2015 drought. This partnership will need to continue and include dialogue about messaging. Ecology's Central Regional Office communications staff could help build necessary connections.

Sample communications - more to come!

News releases

Governor Inslee declares drought for three Washington regions

March 13, 2015

OLYMPIA - Snowpack conditions across Washington state mountains are near record low levels, prompting Gov. Jay Inslee to declare a drought emergency for three key regions.

Watersheds on the Olympic Peninsula, east side of the central Cascade Mountains including Yakima and Wenatchee, and Walla Walla region will be hit hardest with drought conditions.

Snowpack is a mere 7 percent of normal in the Olympic Mountains. It ranges from 8 to 45 percent of normal across the Cascades, and is 67 percent of normal in the Walla Walla region.

"We can't wait any longer, we have to prepare now for drought conditions that are in store for much of the state," said Inslee. "Snowpack is at record lows, and we have farms, vital agricultural regions, communities and fish that are going to need our support."

An unusually warm winter has caused much of the precipitation to fall as rain, leaving mountain snowpack a fraction of normal. And a healthy snowpack is what would slowly feed rivers across the state and sustains farms and fish through the drier summer months.

"We've been monitoring the snow conditions for months now, hoping for a late-season recovery," said Washington Department of Ecology Director Maia Bellon. "Now we're gearing up to help provide relief wherever we can when the time comes. Hardships are on the horizon, and we're going to be ready."

Short and long-range weather forecasts are not expected to bring relief, calling for warmer and drier weather.

With snowpack statewide averaging 27 percent of normal, 34 of the state's 62 watersheds are expected to receive less than 75 percent of their normal water supplies.

Ecology has requested $9 million in drought relief from the legislature. The money would pay for agricultural and fisheries projects, emergency water-right permits, changes to existing water rights, and grant water-right transfers.

For now, water suppliers in the Seattle, Tacoma and Everett areas are in decent shape and are not projecting much hardship.

To track snow and watershed totals, Ecology is posting daily updates to its drought website - www.ecy.wa.gov/drought, and providing routine updates on Facebook and Twitter - search @ecologywa or #wadrought.

Emergency funds support three drought-relief projects

Projects in Eastern, Central and Western Washington help with water shortages

OLYMPIA - Emergency funding is going to support three drought-relief projects in Eastern, Central and Western Washington. The money will help pay for a new well in Stevens County, water conservation in Benton County, and protect spawning salmon in the Dungeness River on the Olympic Peninsula.

"We're moving quickly to support critical water supplies for communities, farmers and fish across the state who are enduring extreme hardships in this unprecedented drought," said Director Maia Bellon of the Washington Department of Ecology.

Ecology has approved three grants to help pay half the cost of projects that will bring much needed relief.

Stevens County Public Utility District will receive $47,000 to help drill a new well to replace the failing main production well of the Riverside Water System. The new well will help provide reliable drinking water to 385 residents. Declining groundwater levels have been reducing production from the existing well since October 2014.

Kennewick Irrigation District will receive $28,872 to help increase water conservation by 23,000 customers in Kennewick, Richland, West Richland, and incorporated Benton County. The district will advertise on TV and radio to increase awareness, and -hired a code enforcement officer to ensure compliance.

Jamestown S'Klallam Tribe will receive $74,430 to monitor and address fishing stranding and/or blockages. The effort will include acquiring and installing multiple temporary "diversion dams" in the Dungeness River that will concentrate flow to help spawning salmon migrate upstream. Flows in the Dungeness River are currently 35 percent of normal and 1.3 million pink salmon are expected to return this season. The tribe is working in cooperation with the Washington Department of Fish and Wildlife.

The money for these projects is coming from the $16 million approved by the 2015 Legislature to use over the next two years to help relieve drought hardships statewide.

Through the grant program, public entities such as cities, public utilities and irrigation districts can get help paying for developing alternative water supplies or deepening existing groundwater wells.

Additional applications for grant funding have been received, and Ecology is working quickly to review the applications. The agency expects to fund more drought-relief projects in the coming weeks.

Gov. Jay Inslee made the entire state eligible for drought relief funding when he declared a statewide drought May 15, 2015.

Application forms and information on qualifications for drought relief grants are available on Ecology's website: 2015 Drought Emergency Grant Program.

Blog posts

Friday, July 31, 2015

How bad is the drought? 2015 is shaping up to be the worst of Washington's statewide droughts

by Dan Partridge, communications manager, Water Resources

The U.S. Drought Monitor has now classified all but a smidgen of Washington state as being in a "severe" drought (99.99 percent) and says that more than 31 percent of our state is in an "extreme" drought.

It's the first time the state has reached these conditions in a decade.

Exposed rock and boulders at
Skykomish River Bridge
Photo: Seth Preston

Ginny Stern with the Washington Department of Health is a veteran of drought relief work. She says simply that this drought is "way worse" than the statewide droughts of 2001 and 2005.

The health department is seeing water systems starting to switch to emergency water supplies, driven by the demand for water created by 90-degree temperatures. In fact, the National Weather Service (NWS) reports that July has been the warmest month in recorded Seattle weather history dating back to 1890.

Next week, the health department will be sharing with county health directors a list of drinking water systems at risk of water shortages.

Stream flows, crop losses, fish issues are indicators of record drought

The impacts on our drinking water supplies are certainly not the only sign that 2015 is shaping up to be the worst drought in Washington modern history:

- Almost 80 of our streams and rivers are running at below normal or record low flows.
- The Walla Walla River went dry a week ago as measured by the USGS gauge near Touchet. This was caused both by the drought itself and by the large amount of water being diverted from the Walla Walla's tributaries to fight the Blue Creek fire.
- Ecology has curtailed the water use for almost 500 irrigators across the state to sustain stream flows. Some of these water rights date back to the 1800s.
- Crops are at risk of failure in areas where farmers have had to stop their diversions. In the Yakima Basin, that means orchards, hay and alfalfa crops on some 2,153 acres. In the Dungeness Basin, irrigators' choice to curtail water use from the Dungeness River because of low flows means they will lose their last cutting of hay.
- Record-breaking warm water temperatures from "the Blob" in the North Pacific Ocean are increasing harmful algae blooms, closing shellfish harvests and causing unfavorable conditions for salmon and other marine life in Puget Sound.

- The cities of Everett, Seattle and Tacoma have implemented the first stage of their water shortage response plans, which means they are asking customers to carefully manage their water use and make sure they are not wasting water.

- The state Department of Fish & Wildlife is closing areas to fishing or restricting fishing at an unprecedented rate: more than 40 closures so far this year. This is to relieve stress on fish already struggling with high water temperatures and low stream flows.

Ecology, partner agencies focused on drought response

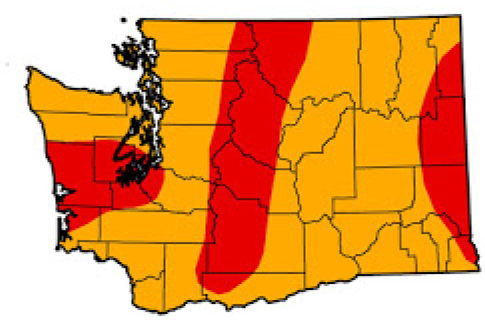
Ecology is working with the state departments of Health, Fish & Wildlife, Agriculture and Natural Resources to help relieve the hardships that are occurring due to water storages. Ecology will soon announce our first round of recipients for drought relief funds. Our grant program is supporting projects designed by cities, utilities and irrigation districts to help protect public health and safety from effects of the drought and to reduce economic or environmental impacts from water shortages. The Legislature authorized $16 million over the next two years for Ecology's drought relief work, including the grant program.

No relief from drought conditions on the horizon

And the hot weather driving these shortages shows no sign of relenting.

Neither the state weather forecast nor the West Coast outlook offer much hope of relief from the drought in the months ahead.

The August forecast calls for more hot and dry weather in Washington and the long-term forecast is calling for a strong El Niño weather pattern to continue into next year. If accurate, this will mean another low snowpack and another year of drought.



The U.S. Drought Monitor this week classified 99.99% of Washington state as being in a “severe” drought. The red swaths on the map show the 31% of the state classified as being in “extreme” drought.

Friday, August 21, 2015

Help us tell the story: Half of state in “extreme drought”

Send us your photos of dry river beds, fish kills, crop losses

By Dan Partridge, communications manager, Water Resources Program

The U.S. Drought Monitor now considers half of Washington to be in “extreme drought.” The entire state is classified as being in “severe drought.”

As fires rage in Eastern Washington and low stream flows are turning some rivers and streams into beds of bare rocks and boulders, it’s essential that we document the drought’s impacts and what’s being done to mitigate the hardships from those conditions. And we need your help to do that.

Find updates as they happen on our drought page.

This week, we posted a more streamlined Washington Drought 2015 Web page that provides links to the latest fire information, air quality alerts about smoke from the fires, and information about how the drought is impacting our communities, farms and migrating salmon. The page also allows you to track the work Ecology and our partners are doing to relieve the rapidly mounting hardships across the state. We are also spotlighting the water conservation work of our cities, towns and irrigation districts with a weekly blog series.

Story of the drought in pictures, charts and graphs

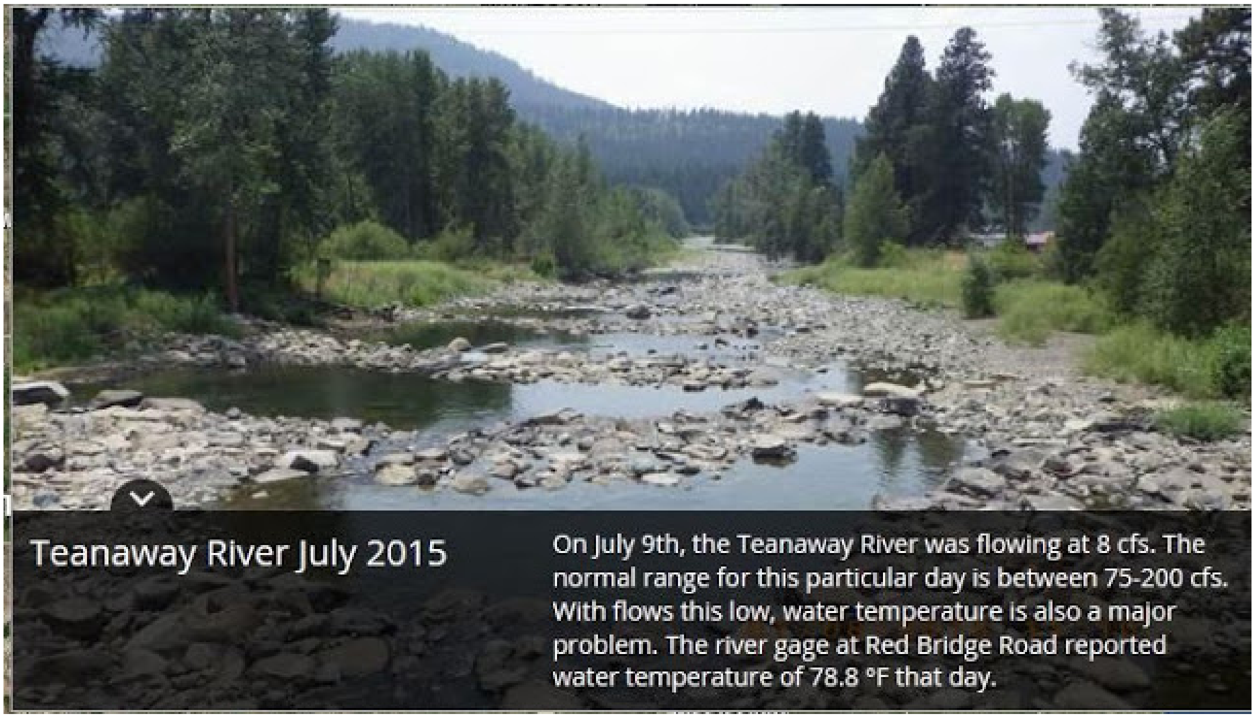
In conjunction with the new Web page, we have posted a Washington State 2015 Drought Photo Tour. At this site, you will find photos of scant snowpack, streams reduced to a trickle and charts and graphs that illustrate what is shaping up to be the state’s worst drought in modern history.

Submit your photos

Ecology is working with the state departments of Agriculture, Health and Fish & Wildlife to provide information, photos and analysis, but we also need the public’s help in documenting the impacts of the drought. If you see dry stream beds, wildlife struggling to get to water, fish stranded in shallow pools or crops dying in the fields, fill out this simple form and submit your photos for the Drought Photo Tour.

Your contribution will alert staff to conditions they may not be aware of and help us in our efforts to alleviate hardships across the state from a drought that shows no signs of subsiding soon.

Below is one of our stories of declining river flows:



Posted by Lynne Geller at 4:28 PM No comments:

Email ThisBlogThis!Share to TwitterShare to FacebookShare to Pinterest

Labels: drought, drought photos, Water Resources, water shortage

Videos

https://youtu.be/AyWifdwCD64

Photos

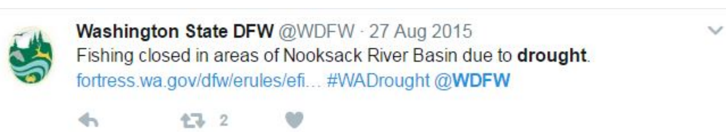
https://www.flickr.com/photos/ecologywa/albums/72157656690948883

https://www.instagram.com/ecologywa/

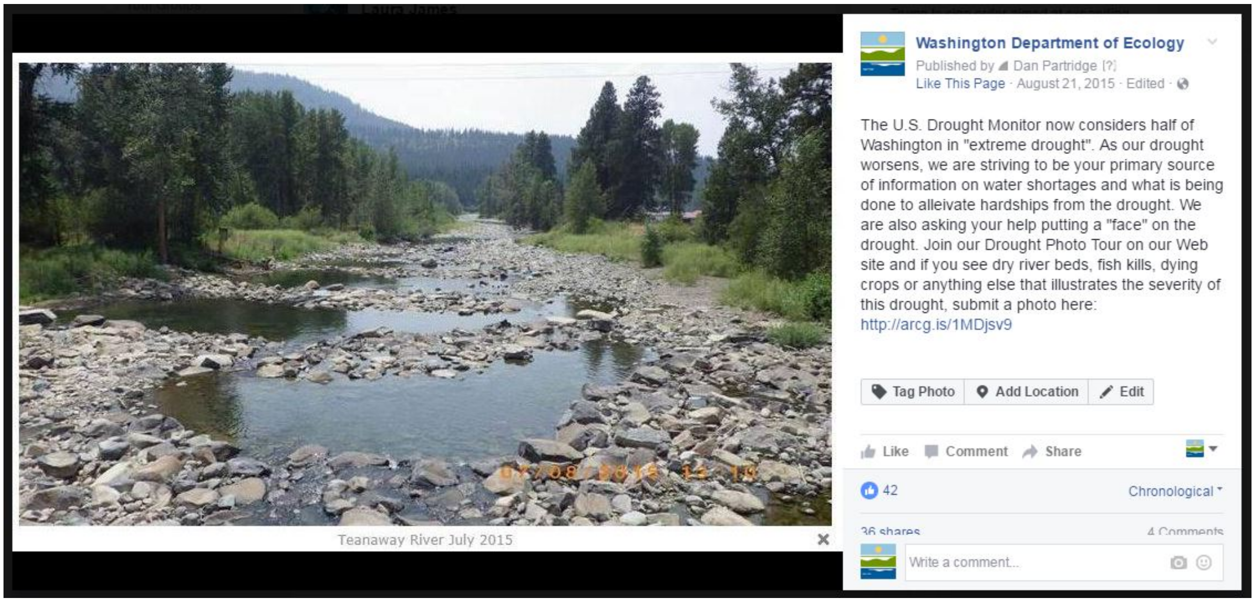

Director Maia Bellon
@maiabellon
We have to stick together and support one another as the drought deepens. #wadrought
U.S. Drought Monitor
50%
OF STATE
IN EXTREME DROUGHT
ecologywa
Follow
32 likes
88w
ecologywa In this together. #wadrought #washingtonstate #wawx #wawildfires
tacoma_ty Already stopped watering non-eatables
Log in to like or comment.

Tweets


WA Dept of Ecology
@EcologyWA
Follow
Washington's drought is shaping up to be the state's worst in modern history.
bit.ly/1M2rFtW
RETWEETS
19
LIKES
9
7:17 PM - 31 Jul 2015
19
9


Washington State DFW @WDFW · 27 Aug 2015
Fishing closed in areas of Nooksack River Basin due to drought.
fortress.wa.gov/dfw/erules/efi… #WADrought @WDFW
2

Facebook


Washington Department of Ecology
Published by Dan Partridge [?]
Like This Page · August 21, 2015 · Edited ·
The U.S. Drought Monitor now considers half of Washington in "extreme drought". As our drought worsens, we are striving to be your primary source of information on water shortages and what is being done to alleivate hardships from the drought. We are also asking your help putting a "face" on the drought. Join our Drought Photo Tour on our Web site and if you see dry river beds, fish kills, dying crops or anything else that illustrates the severity of this drought, submit a photo here:
http://arcg.is/1MDjsv9
Tag Photo
Add Location
Edit
Like
Comment
Share
42
Chronological
36 shares
4 Comments
Write a comment...
Teanaway River July 2015

Appendix H: Examples of Administrative Documents

The following administrative documents have been bundled as a separate file, for the purpose of providing examples and templates to refer to in future drought actions.