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The Technical Newsletter of the National Stream and Aquatic Ecology Center

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Hydropower Development Presents Unique Challenges for Protecting Streams

The Forest Service encourages hydropower production where it is compatible with National Forest purposes, while ensuring that the planning, construction, and operation of hydropower projects protect and effectively utilize National Forest System (NFS) lands and resources (FSM, 2003). However, integrating the operation of hydropower facilities with other resource management objectives, especially those related to stream and riparian habitats, can be challenging. The Forest Service plays a strategic role in hydropower development, helping to ensure the needs of power generation are compatible with environmental, and recreational objectives.

The Federal Energy Regulatory Commission (FERC) authorizes the occupancy and use of federal lands for the purposes of hydropower generation under the Federal Power Act. Operating licenses for most non-federal hydropower facilities are issued by FERC with terms lasting from 30 to 50 years, with many facilities around the country operating under their 2nd or 3rd license. Currently, there are approximately 250 authorized

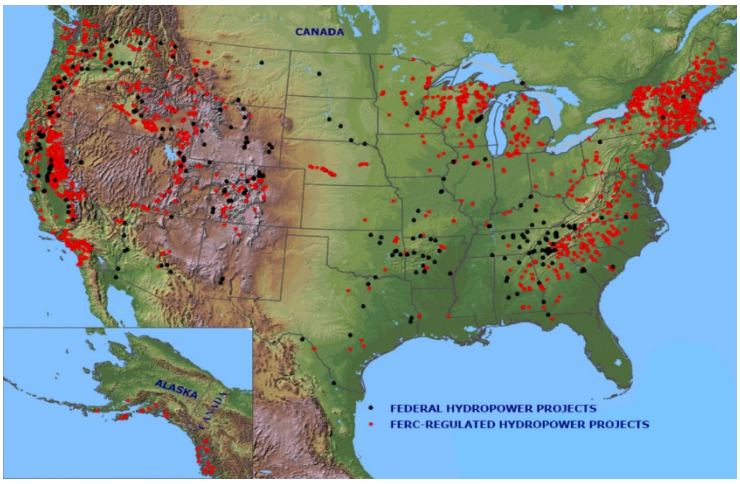

Figure 1: Locations of hydropower projects regulated by the Federal Energy Regulatory Commission (FERC) in the continental U.S. and Alaska.

StreamNotes is an aquatic and riparian systems publication with the objective of facilitating knowledge transfer from research & development and field-based success stories to on-the-ground application, through technical articles, case studies, and news articles. Stream related topics include hydrology, fluvial geomorphology, aquatic biology, riparian plant ecology, and climate change.

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facilities operating on NFS lands, affecting resources over thousands of stream miles (Figure 1). Ecological effects are generally related to the size of a facility, the number of facilities located in sequence along a single stream or within a stream network, and on the timing and magnitude of power-generating flows. Opportunities to implement mitigation measures typically occur during the renewal of FERC-issued licenses for existing facilities.

The potential long-term ecological costs of widespread hydropower development can be contrasted with the societal benefits – hydropower facilities on NFS lands represent about 20% of the total national hydropower generating capacity, enough to supply electricity to more than 20 million homes. Additionally, reservoirs associated with many facilities often provide storage for vital drinking water and irrigation systems, and frequently support highly-valued recreational opportunities. Active engagement by the Forest Service in FERC's licensing process is critical to ensure the continued operation of these facilities addresses all resource management objectives.

Figure 2: A hydroelectric powerhouse located at the base of a dam on the Clackamas River, near Mt. Hood National Forest, Oregon.

Eco-Hydrologic Effects

Hydropower turbines are typically installed in a powerhouse near the base of a dam, or rely on water transported through conduits from an upslope reservoir (Figure 2). Hydropower projects, by design, alter the frequency, timing, magnitude and duration of flows. Downstream impacts are to the bypass reach (the section of stream between the reservoir and the powerhouse return), as well as downstream reaches. Altered flow regimes can have a range of physical and biological impacts (Poff et al. 1997), with typical hydrologic effects including reductions in flow volumes, loss of flow variability (including the loss of large-magnitude floods), shifts in annual peak discharge timing, and changes in water quality (such as temperature and dissolved oxygen). The presence of these facilities can also result in interruptions in the transport of sediment, large wood, and particulate organic material. Over typical operating lifetimes, these impacts can lead to significant geomorphological and ecological changes in downstream channels and riparian corridors, presenting unique challenges to managers seeking to mitigate the impacts of on-going operations.

Many hydropower facilities operate as "run-of-the-river" in which power-generating outflows are managed to equal inflows. However, in contrast to other non-fossil fuel energy sources such as wind and solar, hydropower facilities that include adequate reservoir storage may also provide a unique contribution to an electrical grid by increasing generation during periods of high demand. Short-term increases in electricity demand (typically during the evenings and on very hot days) can be met by passing additional water through turbines. The duration of these peaking flows can sometimes be measured on sub-hourly time scales, and can lead to channel incision and streambank instability, with associated negative ecological effects. Sharp changes in discharge may occur during dry season months when these types of events rarely occurred naturally, with consequences for aquatic organism migration cues. In the past, operators commonly employed the equivalent of a simple on-off switch to control discharges needed to meet peak demands, resulting in extraordinarily steep rising and recession rates in downstream reaches. More recently developed hydropower operating schedules often attempt to avoid such rapid changes.

The most common ecological effects of hydropower operations are well-documented in the literature (e.g. Cushman, 1985; Bain et al. 1988; Freeman et al. 2001). These effects include entrainment of aquatic organisms in turbines; changes in species composition caused by cold water discharge from the reservoir hypolimnion; reductions in, or elimination of fish passage; riparian encroachment into

dewatered stream channels; promotion of invasive species; and disturbances to reproductive cycles in aquatic organisms, such as amphibians that rely on appropriately-timed peak flows and recession rates. Specific local effects of hydropower facilities can vary significantly. These effects are often poorly understood and confounded with other stressors.

Mitigation Measures

Opportunities to mitigate the negative effects of hydropower facilities on NFS lands occur when these facilities renew their licenses with FERC. During the licensing process, the Forest Service can request that the licensee (i.e. the operator) collect information or conduct studies to improve the overall understanding of facility effects on NFS lands and resources. For example, these studies may focus on improved understanding of flow alterations, the quality of downstream habitat available for adult and juvenile fish species in relation to instream flows, geomorphological characteristics of downstream reaches, and recreational use patterns related to the facility (such as whitewater rafting, fishing, and camping). The duration of these studies is typically 1 year, and their scope may be subject to FERC approval. The results, along with other information collected during the licensing process, are then used to develop agency-prescribed mitigation measures. These measures become an integral part of the updated operating conditions specified in the FERC license. They can take many forms, including prescriptions for the frequency, magnitude, timing, and duration of instream flow releases, or targeted releases that coincide with fish migration periods, restrictions on ramping and recession rates and reservoir fluctuations, augmentation of gravel and woody material supplied to downstream reaches, and timing of recreational flows for a local boating community. Fish and wildlife management agencies may require new fish passage (Figure 3). Scientifically-informed measures are essential since these measures typically remain in place for the duration of the new license.

Figure 3: Soda Spring Hydroelectric Project on the Umpqua National Forest, Oregon. The dam was modified with fish ladder and screening facilities to allow safe passage of anadromous and resident fish up and downstream. The facilities were upgraded in 2012 as per the FERC licensing in 2003. Photo courtesy of Pam Sichting, USDA Forest Service.

Under the Federal Power Act, federal land management agencies have the authority to place mandatory conditions in FERC licenses necessary for the protection and utilization of their reservations. These conditions specify the mitigation measures to be undertaken by the licensee. A licensee may propose alternative conditions, which the land management agency must accept if the evidence shows they provide adequate protection of the Federal reservation and cost significantly less to implement. Licensees also have the legal right to challenge the factual basis for any agency condition in a trial-type hearing. Federal agencies, including the Forest Service, typically seek agreement with facility operators and other state and federal agencies on any mandatory conditions before they are transmitted to FERC for inclusion in a new license. This is a fundamental step for minimizing stakeholder conflict, and ensuring consideration of the needs for power generation, water supplies, recreational opportunities, and environmental protection.

The process of developing mitigation measures that meet the needs of power generation and other resource management objectives can be complicated. The resource conditions against which mitigation measures will be evaluated must first be clarified. For example, upstream reaches flowing into the reservoir may present a suitable reference (i.e. historical) flow condition, assuming no other disturbances and that discharge has been measured for a sufficient period. However, climate, valley type, channel slope and other stream characteristics upstream from a facility are often substantially different in downstream corridors, especially at higher elevations. Channel morphology, bedload characteristics, and aquatic and riparian communities downstream

may also have changed relative to historic conditions due to the presence and operations of the facility. These types of legacy effects must be sufficiently understood and accounted for if mitigation measures are to result in successful ecological outcomes. For example, target downstream flow conditions that mimic conditions in upstream reaches would not be expected to produce similar ecological outcomes in an altered channel. Other facilities located along the same stream corridor (or in the same stream network) may similarly influence the intended ecological outcomes of mitigation measures. Mitigatory flow conditions intended to improve fish habitat may be of limited benefit if migration pathways for these species are blocked downstream by other facilities or diversions.

The factors complicating the development of mitigation measures are somewhat simplified because the baseline conditions referred to under National Environmental Policy Act analyses during licensing are the current conditions, not the conditions in place before a reservoir and/or a hydropower facility were constructed. This definition also influences the formulation of the investigative studies utilized during the licensing process to help guide the development of mitigation measures. In other words, these studies are often directed more toward an improved understanding of only current conditions. Typically, the targets for, and the benefits of mitigation measures similarly refer to expected improvements over current conditions.

Future Concerns

In the next 15 years, the number of hydroelectric projects undergoing licensing across Federal lands is expected to increase substantially (Figure 4). New hydropower development is also expected during this period, including an expected increase in the number of pumped-storage facilities. These energy storage facilities pump water to a higher-elevation reservoir when electricity demand is low, and release this stored water through turbines during period of high demand; this design can provide significant advantages in electricity markets compared to conventional hydropower facilities, while also presenting unique resource impacts. Widespread installation of new hydropower facilities onto existing, non-powered dams is also expected.

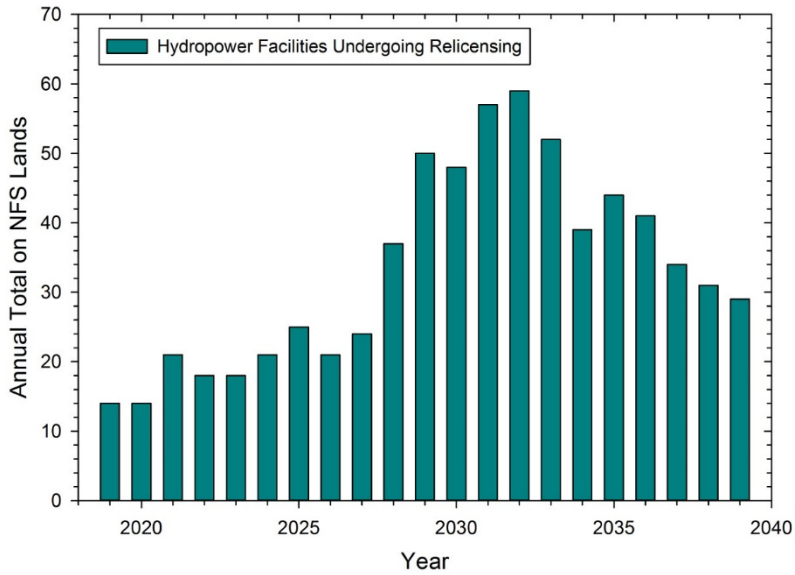

Figure 4: The number of hydropower facilities on NFS lands scheduled to undergo licensing through FERC will increase significantly over the next two decades.

The implications of climate change for hydropower generation have been explored in recent literature (Kopytkovskiy et al. 2015; Boehlert et al. 2016; Cherry et al. 2017). Regulatory agencies have started to consider how to facilitate adaptation of local operations to climate change in ways that continue to balance environmental needs with those of power generation and water supplies. For example, the non-stationarity in hydrologic conditions produced by a changing climate (Milly et al. 2008) may require new approaches to defining the baseline against which ecological outcomes are measured during FERC licensing. Other climate change adaptation strategies can be complex, and depend on many factors such as the expected severity or duration of drought events (particularly in relation to reservoir capacity), and on the presence of listed species that are dependent on managed flow regimes. Licensees often develop hydrologic simulation models that link climate variables, inflows, and target outflows to reservoir fluctuations and power generation. These simulation models can indicate the extent to which target outflows are compatible with power generation, and provide an important opportunity to investigate how the relationships between reservoir inflows, target outflows, and power generation may change under future climate scenarios. In some locations, paleo-climate data derived from tree rings or other proxies may help to define the range of conditions that should be simulated during licensing (Ho et al. 2017).

Management Implications

- Detailed land management plans are needed to ensure the desired conditions for impacted resources are clearly defined.
- Before a license proceeding begins, all available information needed for documenting the existing resource conditions in and around a facility should be compiled, and any information gaps identified.
- Dedicated teams of interdisciplinary specialists, program managers, and line officers who are trained in FERC licensing processes are needed to ensure both the societal benefits of hydropower development and successful mitigation of environmental impacts.
- On-going changes in climate, electricity markets, downstream water demands, and other factors are likely to affect future hydropower development and operations, with implications for aquatic resource conditions.

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Notices and Technical Tips

- **Direct technical assistance from applied scientists at the National Stream and Aquatic Ecology Center** is available to help Forest Service field practitioners with managing and restoring streams and riparian corridors. The technical expertise of the Center includes hydrology, fluvial geomorphology, riparian plant ecology, aquatic ecology, climatology, and engineering. If you would like to discuss a specific stream-related resource problem and (if needed) arrange a field visit, please contact a scientist at the Center or David Levinson, the NSAEC program manager.

- **Human Activities Create Corridors of Change in Aquatic Zones**

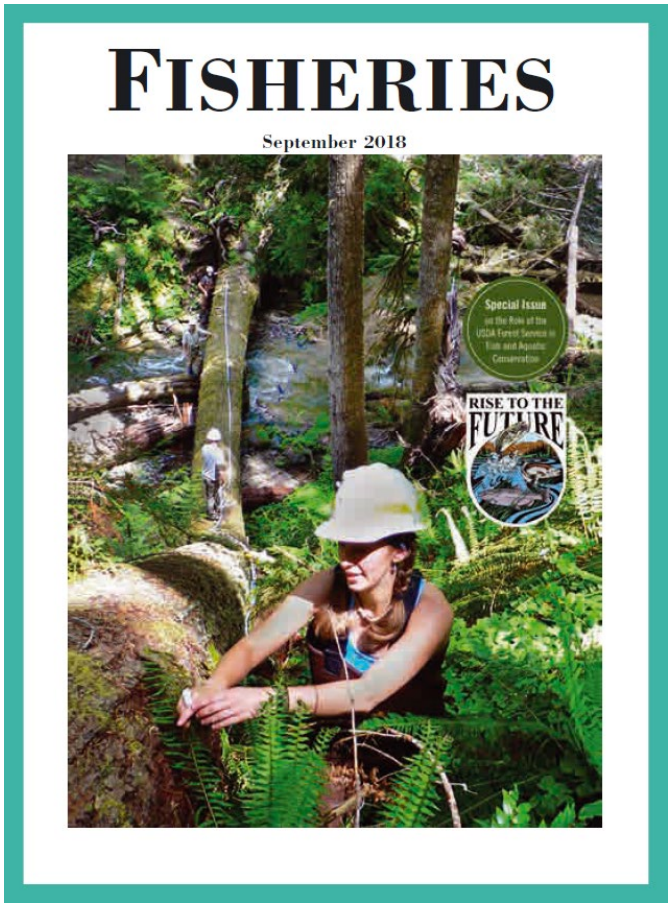
  A recent American Geophysical Union EOS article discusses how human activities are changing the characteristics of aquatic zones across the planet.

  Humans have been disturbing Earth's landscape ever since we began constructing simple dwelling structures in the Paleolithic (400,000–500,000 years ago). The pace accelerated with the invention of the wheel in the middle Holocene (5,000–7,000 years ago), which enabled humans to travel farther and faster.

  But humans haven't been changing land only since antiquity. With the construction of the first man-made canal prior to the Iron Age some 3,600 years ago, we started to control the flow of water for agricultural practices and began perturbing Earth's hydrologic system [Bishop et al., 2017]. This "replumbing" of Earth's surface, recently referred to as anthroturbation [Zalasiewicz et al., 2014], rapidly expanded during the Industrial Revolution (beginning in about 1800 CE) and the "Great Acceleration" (about 1950 CE). The pattern of hydrological landscape modification—or replumbing—continues to this day.

- The **September issue of Fisheries**, a publication of the American Fisheries Society, is a special issue dedicated to the stewardship of fish and aquatic resources on National Forests and Grasslands.

  Did you know the U.S. Forest Service, an agency of the U.S. Department of Agriculture, plays a vital role in stewarding the nation's fish and aquatic resources? In fact, the agency has a robust fish and aquatic ecology program that employs over 325 fisheries biologists and aquatic ecologists across the country. In this special edition of Fisheries, we aim to better acquaint you with the Forest Service's important contributions to aquatic conservation and to introduce our newly up-dated Rise to the Future: National Fish and Aquatic Strategy. This updated strategy builds upon 30 years of lessons learned while implementing the previous strategy and charts a course to address current and future challenges. In this issue, we highlight how the agency contributes to the conservation of fish and aquatic resources for the benefit of the American people. We also show you the individual faces of several Forest Service employees who make a difference everyday through their work. We hope you come away with a greater appreciation of the Forest Service's role as a leading conservation agency, locally, regionally, nationally, and even globally.



Overview of the 2018 Water Year: Drought Develops Across the Western U.S.

Widespread drought developed across the western U.S during the 2018 water year. At the beginning of the water year, which began on October 1, 2017, much of the U.S. was near-normal or abnormally dry (D0) with respect to drought classification, as illustrated on the October 3, 2017 U.S. Drought Monitor (Figure 5). Portions of Montana and the Dakotas were experiencing severe, extreme and exceptional (D2-D4) drought, as well as the Big Island of Hawaii (not shown), but otherwise very little of the U.S. was categorized in moderate or higher drought (D1 or above). Unfortunately the conditions changed dramatically over the course of the 2018 Water Year, with severe to exceptional drought developing across large areas of the western U.S. by the end of September 2018 (Figure 6). As a result, much of the western U.S. experienced a variety of impacts due to the developing drought.

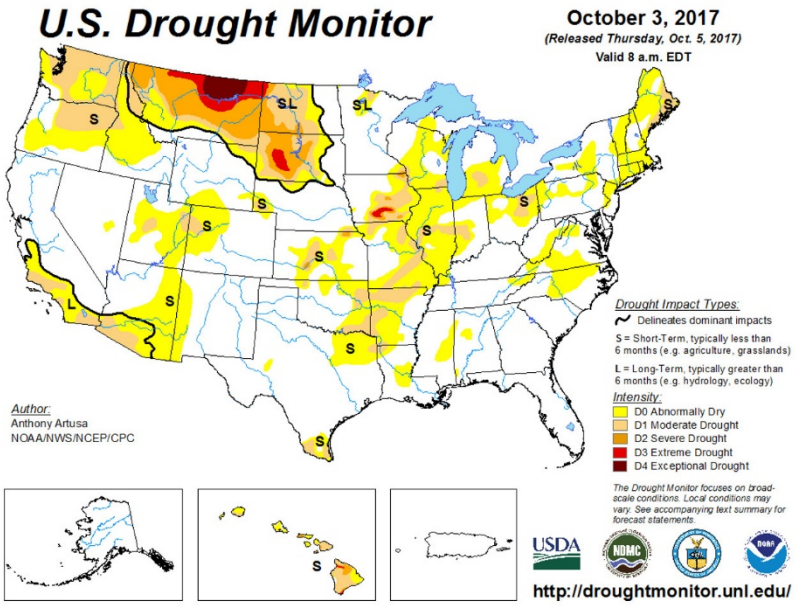


Figure 5: Drought conditions across the contiguous U.S. on October 3, 2017, at the start of the 2018 Water Year (Source: U.S. Drought Monitor).

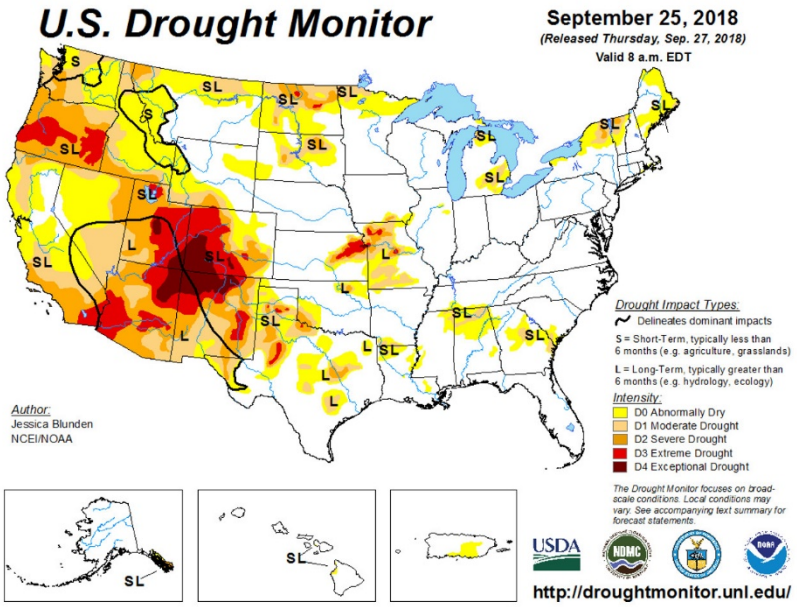


Figure 6: Drought conditions across the contiguous U.S. on September 25, 2018, at close to the end of the 2018 Water Year (Source: U.S. Drought Monitor).

Precipitation

Total annual precipitation accumulations were well-below normal, as illustrated by the percent of the 30-year average (1981-2010) for the 12-month period covering the 2018 Water Year (Figure 7). The observed deficits were much below average throughout the western U.S., with some areas having their record driest water year. Most of the precipitation deficits developed during the winter (Dec.-Feb.) and spring (Mar.-May), but many areas also experienced below normal rainfall during the summer months (Jun-Aug) of 2018.

In California, which started the water year with precipitation surpluses from a much wetter-than-average 2017, the entire state received below normal precipitation in 2018. Table 1 shows the percent of average precipitation for California hydrologic regions covering the 2018 Water Year, with all regions having experienced below-normal rain and snowfall. Many regions of the state were exceptionally dry, with much of Southern California receiving half or less of their average annual precipitation. The south coast region had the lowest percent of normal, with 36% of the 50-year mean,

while the Colorado River region was the next lowest with 42% of the long-term average. Overall, for the 2018 Water Year the statewide average was 73% of the 50-year base period mean, and a significant decline following the wet 2017 Water Year.

Snowpack

The observed precipitation deficits that developed during the winter of 2017-2018 extended into the spring of 2018. These deficits led to low snowpack across the western U.S., with many locations across the Sierra Nevada, southern Cascades, and the central and southern Rockies experiencing pronounced snow drought. The term snow drought is defined as a period of abnormally low snowpack for the time of year, reflecting either below-normal cold-season precipitation (dry snow drought) or a lack of snow accumulation despite near-normal precipitation (warm snow drought), caused by warm temperatures and precipitation falling as rain rather than snow or unusually early snowmelt (Cooper et al. 2016; Harpold et al. 2017).

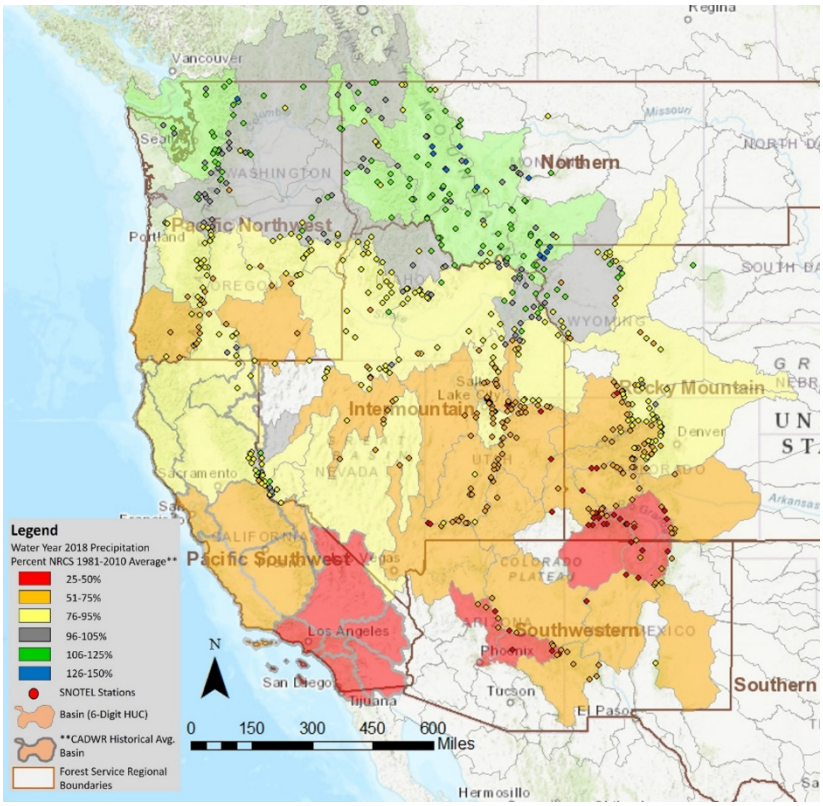


Figure 7: Percent of average precipitation for the 2018 Water Year (Oct. 2017 to Sep. 2018), relative to the 1981-2010 base period at SNOTEL sites across the western U.S. Data source: USDA/NRCS Water and Climate Center.

The dearth of snowpack across western watersheds was evident on the April 1, 2018 (Figure 8) with the Snow Water Equivalent (SWE) measurements at SNOTEL sites. April 1st is often used for determining expected runoff, since

Table 1: Hydrologic region summary of precipitation accumulated for the period Oct. 2017 to Sep. 2018 for California, with percentages determined relative to a 50-year base period (1966-2015). Source data: California Cooperative Snow Surveys.

		Basins Reporting			Stations Reporting			Percent of Historic Average		
Hydrologic Region	Hydro Region Weight	Basins	Sep	Oct-Sep	Stations	Sep	Oct-Sep	Sep	Oct-Sep	Water-Yr
NORTH COAST	0.27	5	5	5	20	10	10	31.6%	76%	76%
SAN FRANCISCO BAY	0.03	2	2	2	6	3	3	4.4%	70%	70%
CENTRAL COAST	0.06	3	3	3	10	6	6	.6%	58%	58%
SOUTH COAST	0.06	3	3	3	14	8	8	.4%	36%	36%
SACRAMENTO RIVER	0.26	5	5	5	42	22	22	.2%	87%	87%
SAN JOAQUIN RIVER	0.12	6	3	3	25	10	10	5.8%	74%	74%
TULARE LAKE	0.07	5	5	5	29	27	26	49.3%	69%	69%
NORTH LAHONTAN	0.04	3	3	3	13	7	7	1.1%	93%	93%
SOUTH LAHONTAN	0.06	3	3	3	17	8	8	10.6%	51%	51%
COLORADO RIVER	0.03	1	1	1	6	3	3	2.3%	42%	42%
STATEWIDE weighted average	1.00	36	33	33	182	104	103	13.7%	73%	73%

this is typically close to the peak snowpack before the melt-season begins in spring. Despite some SNOTEL sites receiving above normal SWE, specifically in northern Idaho, Montana and northern Wyoming, much of the western U.S. was below normal relative to the 1981-2010 average. The SWE on April 1, 2018 was also below normal across sites in southern Alaska and Panhandle region of the state. Similar to conditions across the western U.S., low snowpack and water deficits were exacerbated due to warmer-than-average temperatures and early runoff (i.e., warm snow drought) in spring 2018.

Widespread Drought Develops

As a result of the below-normal precipitation and snowpack during the winter and spring, combined with the warmer-than-average temperatures, widespread drought conditions developed and reached the severe, extreme and exceptional (D2-D4) classifications by the end of the 2018 water year (Figure 6). The worst drought conditions developed across much of the Southwest, Great Basin and Southern Rockies, although severe to extreme (D2-D3) drought also developed across Oregon, western Washington and North Dakota.

To further illustrate the widespread nature and extent of the drought that developed in 2018, Figure 9 shows the U.S. Drought Monitor change map for the 12 month period covering October 3, 2017 to October 2, 2018. The worst drought conditions, those areas with a 3, 4 or 5 class degradation as analyzed by the U.S. Drought Monitor, developed across the Four-Corners region (Arizona, Colorado, New Mexico and Utah), and extending westward into Nevada and across most of Oregon. In contrast, a 3-4-5

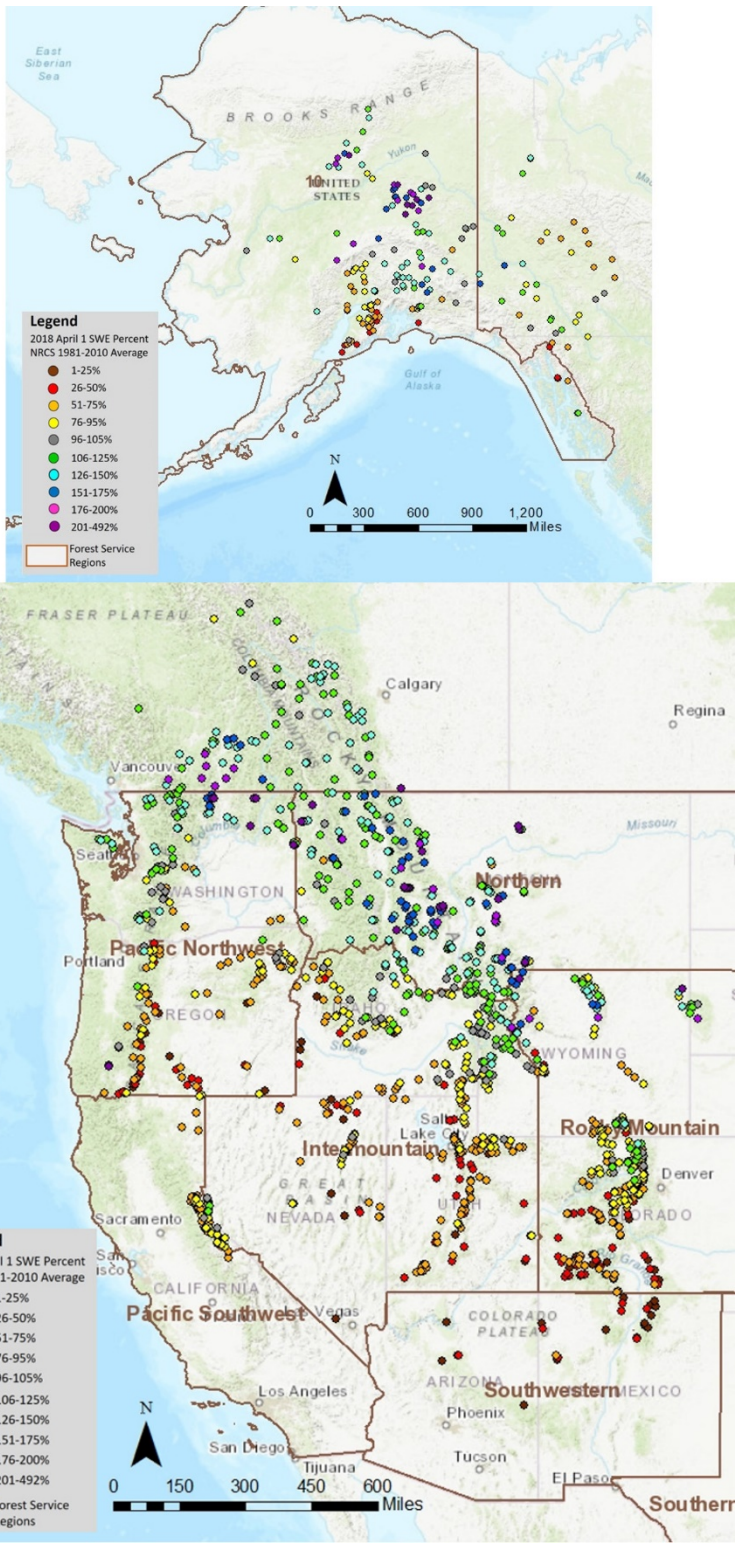


Figure 8: Percent of average Snow Water Equivalent (SWE) on April 1, 2018, relative to the 1981-2010 base period, at SNOTEL sites in Alaska (top) and the western U.S. (bottom). Data source: USDA/NRCS Water and Climate Center.

class improvement in drought conditions occurred across Montana during the 2018 water year.

A broad range of impacts were associated with the drought during the latter part of the 2018 water year. One of the worst of these impacts were the many large fires experienced across the western U.S., with severe to extreme fire danger and the numerous large fires that developed during the summer months in conjunction with the widespread drought conditions (see National Interagency Fire Center for more information on the 2018 fire season).

As far as water resource impacts, very low streamflow levels were observed across western Colorado, northern New Mexico and Utah, with reports of wells running dry and water hauling operations needed in south-central Colorado. In southwest Colorado, the Animas River near Durango recorded its lowest flows in its 107-year record at the end of the 2018 water year. In New Mexico, the natural flows of the Rio Grande dried up in July, but the river was kept flowing due to water withdrawals from the San Juan-Chama Project. In addition, the New Mexico Department of Game and Fish are investigating a decline and die-off of brown and rainbow trout in the Pecos River east of Santa Fe possibly in relation to low flows and increased water temperatures. In Utah, the Governor's office declared a state of emergency due to drought in early October 2018, with record low streamflow reported on the San Juan River near Bluff, UT, and according to the most recent Utah Crop Progress and Condition Report (10/1/2018) stock water supplies are rated 67% and very short to short.

Finally, critical water resources in the western U.S. were also impacted by the worsening drought, with reservoir storage <50% of the period-of-record average reported in many reservoirs at the end of the 2018 water year. Below average reservoir storage was reported in Arizona, California, Colorado, New Mexico, Oregon and Washington, with the critical large reservoirs of the Lower Colorado River drainage basin below 50% full. Conditions across Arizona had declined to 47% of capacity statewide, as Lake Powell storage had decreased to 45% and Lake Mead was only 38% of capacity in early October 2018. In addition, the reservoirs that store water as part of the Salt River Project's system in central and southern Arizona were at 49% of capacity, with the Verde River system at 33% of capacity. Overall, the Arizona reservoir system declined 16% from a year ago as the drought worsened and expanded across the state.

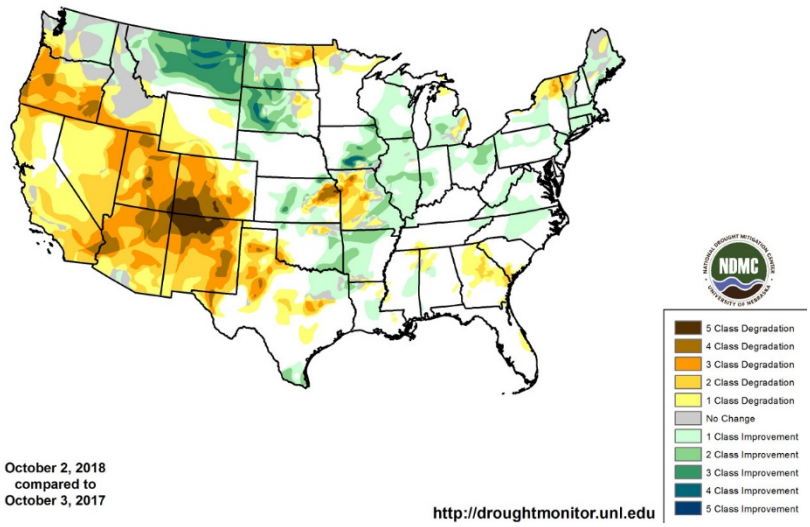


Figure 9: U.S. Drought Monitor condition class changes for the 12-month period covering October 3, 2017 to October 2, 2018 (Source: National Drought Mitigation Center, University of Nebraska- Lincoln).

Management Implications

- Large areas of severe, extreme, to exceptional drought developed across the Southwest and Four Corners region during the 2018 water year; drought conditions developed due to long-term precipitation deficits over the past 12-24 months, along with low snowpack related to snow drought during the winter and spring of 2018.
- The developing drought across the West and Intermountain regions resulted in widespread impacts, including numerous large fires, and low streamflow and reservoir storage.

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