The Russian River Hydrometeorological Observing Network (RHONET) is a unique suite of high-resolution in situ and remote sensing observations deployed over 20 years to address both scientific and operational gaps in understanding, monitoring, and predicting weather and water extremes on the United States’ West Coast. It was created over many years by diverse organizations ranging from universities to federal, state, and local government agencies and utilities. Today, RHONET is a hybrid network with diverse observation sets aimed at advancing scientific understanding of physical processes driving extreme precipitation and runoff in the region.

The evolution of this unique observing network represents the diverse range of challenges and approaches taken in the Russian River basin.

Terrain base maps of (a) the existing RHONET in the Russian River watershed and the immediate surrounding areas and (b) its development throughout the HMT, Habitat Blueprint, and FIRO epochs. The thick boundaries demarcate the Lake Mendocino subwatershed. The colors represent different (a) networks and (b) epochs. Inset maps show the same within the Lake Mendocino area. (top right) The California map displays the location of the Russian River watershed in California.
to deal with one of the most variable hydroclimates in the nation, in one of the most populous and productive states. However, there remains a need for comprehensive documentation of the evolution and the current state of this unique observing network, which has benefited hydrometeorological science and operations.

**Geography and hydroclimatology of the Russian River basin**

The Russian River drains an area of 1,485 mi² (3,846 km²) across parts of Sonoma and Mendocino Counties in Northern California. This part of California has a Mediterranean climate characterized by warm and dry summers and cool and wet winters, with ~80% of the precipitation occurring between November and March. Atmospheric Rivers (ARs) are responsible for the heaviest rainfall and most of the flood damage in the region and have increasingly become dominant contributors to California water resources and extremes. The process-based understanding enabled by densely instrumented watersheds, such as the Russian River, is invaluable in understanding the detailed life cycle of ARs after they make landfall. Furthermore, the mountainous terrain of the Russian River basin favors orographic precipitation processes that are problematic for operational radar coverage of shallow nonbrightband rain that accounts for 12%–15% of the total precipitation. Therefore, in situ monitoring of precipitation and surface and subsurface waters with high spatial and temporal resolution is essential for hydrologic applications in the region.

The basin-mean water year (WY) total precipitation is as low as 623 mm (WY 2014) and as high as 2,097 mm (WY 1983). It averages 1,131 mm over WYs 1982–2018. There is high variability in the region’s hydroclimate relative to the rest of the United States, with interannual variations as well, illustrating the need for long-term continuous monitoring systems with high spatial density.

**Four epochs of hydrometeorological sensor-network evolution in California**

1) **CALJET and PACJET.** The California Land-Falling Jets Experiment (CALJET) and Pacific Land-Falling Jets Experiment (PACJET) were a series of wintertime field campaigns predating the era of automated and real-time observations, taking place across the West Coast in 1997–98 and 2000–04, respectively. Both experiments were early hydrometeorological observation efforts predating the era of automated and real-time observations.

2) **NOAA Hydrometeorological Testbed (HMT).** In this epoch, permanent automated observation stations were installed and maintained and reported directly to users via telemetry. The instruments were installed sporadically over the period from...
(a) HMT Potter Valley Central site with air temperature, relative humidity, precipitation, soil temperature, and moisture measurements. CW3E (Center for Western Weather and Water Extremes) has also deployed a disdrometer, a weighing rain gauge, GPS-Met, and several additional instruments (not shown). (b) CW3E telemetered soil moisture probe installation at Deerwood during the 2017 field campaign. (c) CW3E precipitation gauge at the Magruder Ranch in the Potter Valley area. (d) CW3E stream gauging site at Boyes Creek. (e) ARO 449-MHz wind profiler at UC Davis BML. Image by the California Department of Water Resources (CADWR). (f) Map showing the locations of the five sites in the Russian River watershed.
2005 to 2016 in the Russian River watershed area. The enhanced capabilities of HMT-West enabled atmospheric scientists to investigate the role of ARs in creating flood-producing heavy precipitation, and they motivated a follow-on HMT-Legacy project focused on California’s water and emergency management needs for weather and river forecasters and water managers.

3) NOAA Habitat Blueprint. NOAA’s Habitat Blueprint was designed to help restore and maintain healthy coastal and marine habitats by building on existing programs and adding new projects to address future priorities. During this epoch, in 2012, one of the projects awarded to the Russian River Focus Area was aimed at improving frost predictions and protection methods for vineyards.

4) FIRO. The Forecast-Informed Reservoir Operations (FIRO) Program, launched in 2015 as a 5-yr program, is a principal example of a research and operations partnership, in which meteorologists, hydrologists, civil engineers, biologists, economists, and decision-makers from various academic institutions and government agencies collaborate to achieve and optimize a water storage and distribution management goal. FIRO-2 was launched in summer 2019 as a follow-on effort including its applications in some other watersheds.

Research and operational benefits

Creation of rich hydrometeorology datasets provides valuable information for stakeholders, water and emergency management operations, and research and development. From the research perspective, data from this network and others capture the diversity of the associated watershed or region and are a key component in addressing gaps in technology and/or hydrometeorological understanding. This is especially true in this region as NWS’s radars are frequently blocked at low levels, where significant precipitation may be occurring. Important advances in understanding the relationship of antecedent soil moisture to runoff generation in flood-prone areas have also been made possible using these monitoring legacy networks.

The diversity of the observations within these rich networks also supports cross-disciplinary approaches to hydrometeorological modeling challenges in calibration, verification, and physical-process parameterization development. Operational sectors are further supported by the network information to create interagency strategic plans related to water resource management, sanitation, and emergency response coordination for drought, floods, and fires.

Real-time stream gauge data, such as those from USGS and Sonoma Water’s OneRain, are used to coordinate and manage reservoir releases to meet minimum instream flows in the Russian River as required by the State Water Resource Control Board. These instream flows support water supply, recreation, and ecosystems, particularly endangered salmonids. In addition, data produced by the dense instrumentation in the Russian River Watershed help assess postfire hazards (as with the devastating wildfires of 2017) due to ARs, such as debris flows, flash floods, and increased risk of flooding. Similarly, advances in forecasting AR events benefit wastewater system operators to better prepare for addressing sewer overflows and minimizing their impacts (e.g., deployment of crews and equipment).

Conclusions and recommendations

The research and operational benefits of RHONET are realized through improved data collection and integrated observations from all sources of information, from the atmosphere to the surface and subsurface. In FIRO, for example, RHONET is a critical piece of “enhanced monitoring,” providing support for modeling efforts to better parameterize physical processes. Important lessons emerging from the Russian River watershed are transferable to others. For instance, small-scale landscape heterogeneity can be significant, and we need to strive for representative measurements in different soil types, slope, and elevation.

Over the long term, RHONET and similar networks are beneficial in helping to identify the dominant physical processes and their variabilities at different spatial and temporal scales, in addition to providing optimal monitoring strategy. Such networks can also capture systemic changes due to external perturbations, such as fires and floods, and ultimately enhance operational capabilities.
Finally, it is important that utilities, research agencies, and others involved in developing and maintaining observational networks coordinate and form relationships with entities typically involved with emergency response and public safety to share critical information, especially during times of need. Maintaining adequate funding for such observation networks and operations is crucial to ensure reliable communication and emergency response during extreme events.

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**METADATA**

**BAMS:** What would you like readers to learn from this article?

**Edwin Sumargo (University of California, San Diego):** Hydrometeorological observations on the U.S. West Coast underwent rapid development from almost exclusively seasonal field campaigns to including remote sensing and telemetered networks in the last three decades. This development is a multiagency effort to advance scientific understanding and observational capability for extreme precipitation and flood events, particularly with atmospheric rivers. Our article is intended to tell not only a story about the network development but also about the lessons learned in the process that can be applied in other regions or watersheds.

**Anna Wilson (University of California, San Diego):** I hope the article gives readers an appreciation that observations are critical for a wide variety of applications—including monitoring, hazard preparedness, and forecast improvement, among many others. I also hope it is clear how essential robust and long-term partnerships are for the success of high-density observation networks.

**BAMS:** How did you become interested in the topic of this article?

**ES:** RHONET offers a suite of high spatial- and temporal-resolution observations that allows for various scientific studies and hydrologic operations in the region we see today. However, how this unique network had started and developed through the years needed proper documentation, which we now have.

**AW:** I have been interested in in situ observations in general since I first was an undergraduate participating in the maintenance of a remote rain gauge network in and near the Great Smoky Mountains National Park. There is so much we can learn about physical processes from consistent, high-quality monitoring. Beyond the data, the history of RHONET and its evolution is fascinating to document. I am grateful to have met the community of the Russian River and gotten firsthand experience on how dedicated people there are to the long-term health of the river and the agriculture, economy, and ecosystems supported by the watershed.

**BAMS:** What surprised you the most about the work you document in this article?

**ES:** The enthusiasm of water scientists, operators, and managers across the board, as reflected in the collaborative environment that has brought us to our current state. Without this I would not even be able to imagine having such a robust and diverse observation network.

**AW:** The most surprising part of this work was the dedication of so many participants, over such a long time, to keep up and continue enhancing this network. The extensive, diverse collaborator network includes academic institutions; federal, state, and local government agencies; and diverse stakeholders. The amount of effort behind the network is nontrivial, and the benefits continue accumulating.

**BAMS:** What was the biggest challenge you encountered while doing this work?

**ES:** Our current scientific understanding and operational capabilities in the region owe their success to the rich history behind the instrumentation efforts. In turn, we are challenged to do our best to tell a truthful and compelling story from different institutional angles in a journal article.

**AW:** The station installations were the biggest challenge (and also the most satisfying!). We had to be extremely cognizant of fire safety, and worked in temperatures exceeding 110 degrees Fahrenheit at times. We always had a team member with a fire backpack, strictly enforced water breaks, and kept up a canopy at all times so that we were in shade while working.