Recent findings and future prospects for water quality impacts from catastrophic wildfires in California

Cliff Dahm

Professor Emeritus, University of New Mexico

Former Delta Lead Scientist, Delta Science Program

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Recent Findings and Future Prospects for Water Quality Effects from Catastrophic Wildfires in California, USA

Clifford N. Dahm*[1], Denise D. Colombano[2], Randy A. Dahlgren[3]

ABSTRACT

Global change affects the forests and wildlands of California through rising temperatures, earlier snowmelt, more rain and less snow, greater vapor-pressure deficits, and forest dieback, resulting in increased frequency, size, and severity of wildfires. California has experienced its eight largest wildfires since 1932 in the period from 2018 to 2024. The largest fire to date (August Complex Fire) occurred in 2020—a year in which 1.7 million ha or 4% of California's land area burned—and burned 418,000 ha. These mega-quality impairments responding linearly with the percentage of the watershed area burned, and responding exponentially as burn severity increases. Vegetation recovery is key to the duration of water-quality effects, and short-term, post-fire weather dictates actual water-related effects. Urban areas are hot spots for the production and transport of water pollutants such as sediments, heavy metals, mercury, nutrients, and toxic organic compounds. Water-treatability challenges after wildfire include short-term odor and taste, increased sediment and turbidity, and

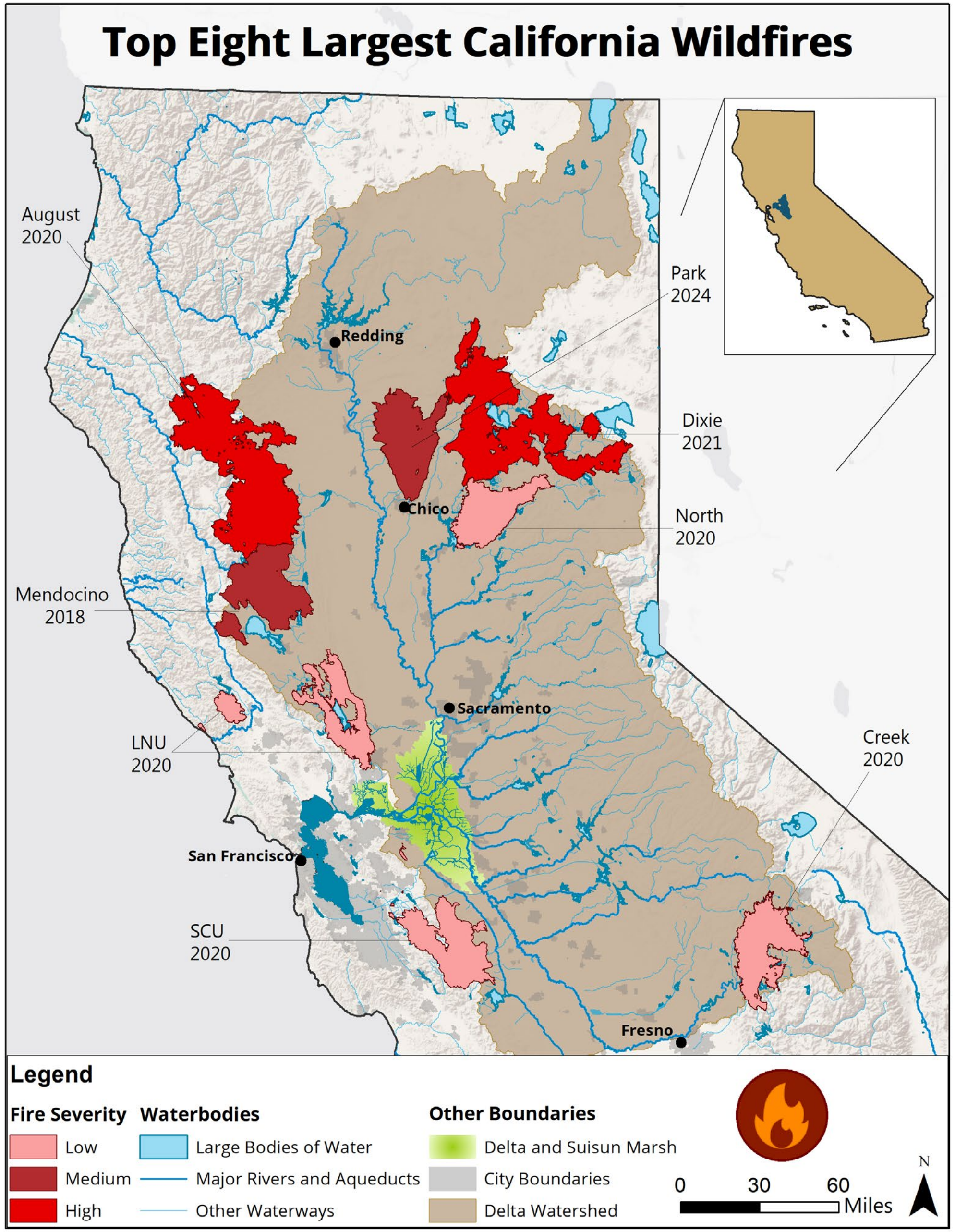

Table 1 Eight largest mega-fires in California recorded history; all eight of these wildfires have occurred in the Delta watershed since 2018 (see Figure 1). The total area burned by these eight mega-fires is 1,176,000 hectares. *Source: CALFIRE.*

Fire name	Date	Counties	Hectares
August Complex	Aug 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, Colusa	418,000
Dixie	Jul 2021	Butte, Plumas, Lassen, Shasta, Tehama	389,000
Mendocino Complex	Jul 2018	Colusa, Lake, Mendocino, Glenn	186,000
Park	Jul 2024	Butte, Plumas, Shasta, Tehama	173,900
SCU Lightning Complex	Aug 2020	Stanislaus, Santa Clara, Alameda, Contra Costa, San Joaquin	160,500
Creek	Sep 2020	Fresno, Madera	154,000
LNU Lightning Complex	Aug 2020	Napa, Solano, Sonoma, Yolo, Lake, Colusa	147,000
North Complex	Aug 2020	Butte, Plumas, Yuba	129,100

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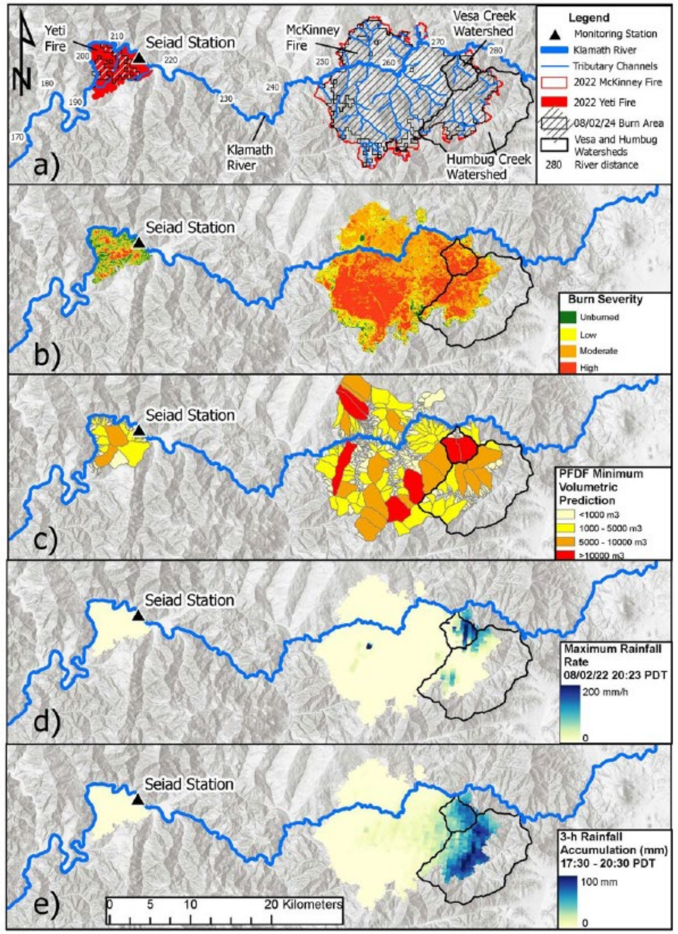
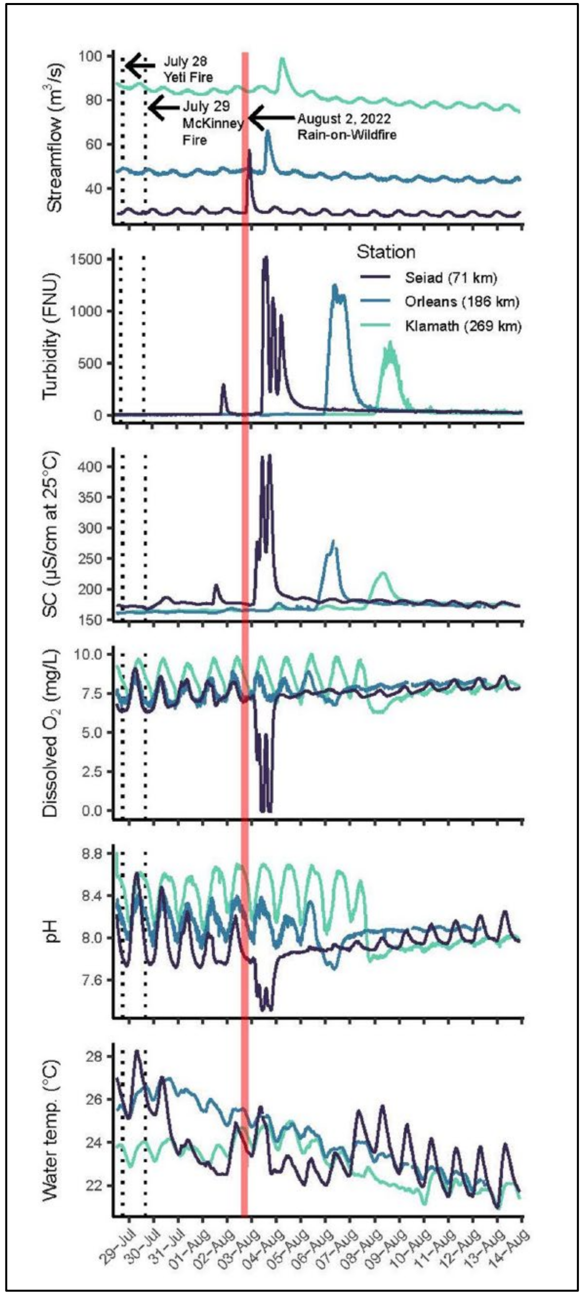
2022 McKinney rain-on-wildfire event, dissolved oxygen sags, and a fish kill on the Klamath River, California

Jennifer A. Curtis[1]✉, Grant S. Johnson[2], Josh D. Cahill[3], Laurel Genzoli[4], Cliff N. Dahm[5], Liam N. Schenk[6] & John R. Oberholzer[2]

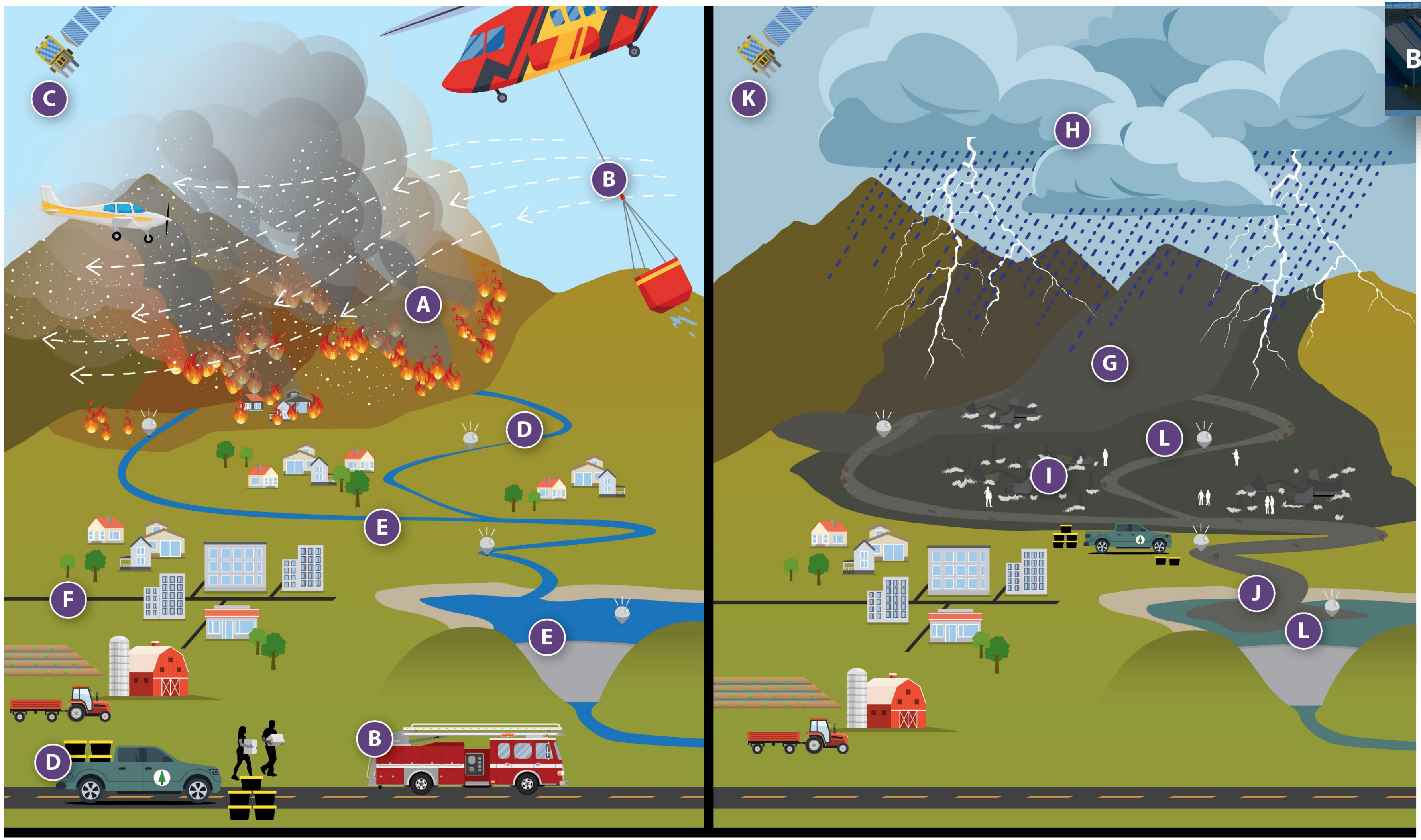
The longitudinal propagation of water-quality and ecological impairments in rivers during and after wildfires remain poorly understood. In Northern California, the 2022 McKinney Fire burned 243 km^2 of the Klamath National Forest, with 83% of the burned area classified as moderate to high severity. During the active wildfire, a high-intensity monsoonal rain event triggered sediment-laden flooding and runoff-initiated debris flows, causing extreme water-quality impairments and a 95 km fish kill zone along the main-stem Klamath River. This rain-on-wildfire event produced a flood wave that outpaced a sediment pulse, diminishing the dilution effect of the floodwaters. A network of high-frequency water-quality sensors recorded water-quality impairments that propagated 296 km downstream. Impairments at the nearest monitoring station, situated 71 km downstream from the fire perimeter, included dissolved oxygen sags to zero (anoxia) for 5.25 h, turbidity spikes exceeding 1000 FNU, a doubling of specific conductance from 175 to 415 µS/cm (at 25 °C), and pH anomalies of 0.5 units from 7.8 to 7.3. This novel rain-on-wildfire event triggered the first flush of fire-scar material during an active wildfire, resulting in water-quality impairments unprecedented in the historical monitoring data for the river spanning 2012 to 2022. This study provides new insights into the potential role of rain-on-wildfire events in generating extreme downstream water-quality and ecological impairments in a more fire-prone future.

Keywords Wildfire, Water quality, Flood wave, Sediment, Dissolved oxygen, Fish kill





USGS station number	USGS station name	Karuk Tribe and Yurok Tribe station name	Distance upstream from the river mouth (km)	Distance downstream from Humbug Creek (km)	Drainage area (km^2)	Mean annual streamflow (m^3/s)
11520500	Klamath River at Seiad Valley	Klamath River near Seiad Valley	211	71	17,980	76
11523000	Klamath River at Orleans	Klamath River near Orleans	96	186	21,950	140
11530500	Klamath River near Klamath	Klamath at Turwar	13	269	31,340	280



- **A.** Active fire zone with extreme winds
- **B.** Fire fighting efforts
- **C.** Remote sensing monitoring
- **D.** In situ monitoring
- **E.** Vulnerable downstream aquatic ecosystems
- **F.** Infrastructure protection
- **G.** Post-fire burn scar
- **H.** Active thunderstorm
- **I.** Burned wildland urban interface (WUI)
- **J.** Downstream water quality effects
- **K.** Post-fire remote sensing monitoring
- **L.** Post-fire in situ monitoring

Key points on wildfire impacts on the Delta watershed…

- Wildfires are inevitable in arid and semi-arid wildlands worldwide, including the Delta watershed.
- Concurrently, global climate change is adversely affecting wildfire dynamics at global scales, with a clear and strong response of larger and more intense wildfires in California.

Key points on wildfire impacts on the Delta watershed…

- The **eight largest wildfires** in California since 1932 have all occurred from **2018 to 2024**, and the burn scars from these wildfires are all at least partially within the Delta watershed.
- The area burned by these eight wildfires total 1.18 million hectares **(~3%** of California's total land area).

Key points on wildfire impacts on the Delta watershed…

- **Reducing the intensity and size** of wildfires is key to protecting the quality of water resources in California,
- In a rapidly changing climate (e.g., warmer, and drier conditions) the recovery of forest ecosystems from wildfire in California is becoming progressively more difficult.

Key points on wildfire impacts on the Delta watershed…

- The **recovery of water quality** from wildfire is largely a function of the speed of **vegetative regrowth**.
- Water-quality impairments generally respond linearly with the percentage of the watershed area burned, and exponentially as burn severity increases.

Key points on wildfire impacts on the Delta watershed…

- Urban areas and wildland-urban interfaces (WUIs) are **hot spots for organic contaminants and heavy metals** that impair water resources and affect water treatment.
- Many of these contaminants are **transported downstream** in solution or attached to sediment particles.

Key points on wildfire impacts on the Delta watershed…

- Forest and fire management can help reduce potential threats to humans, infrastructure, and nature.
- **Traditional ecological knowledge** of fuel management plays a crucial role in future forest management.

Research needs on wildfire impacts...

- Atmospheric deposition of **small particles linked to smoke** from wildfires is an important topic for future research in the Delta watershed, because they affect both humans and ecosystems.
- Human-health effects and effects on sensitive high-elevation lakes and reservoirs deserve special attention.

Research needs on wildfire impacts…

- **Severe water-quality impairment** is commonly linked to strong precipitation events that generate **spates and debris avalanches** that occur soon after the wildfire has ended.

Research needs on wildfire impacts…

- **Continuous *in situ* measurements** enhance documentation of the severity and duration of episodic pulses of flow on water quality.
- Highly responsive water-quality parameters amenable to continuous monitoring methods are dissolved oxygen (DO), turbidity, conductivity, pH, temperature, DOC, chlorophyll, and some dissolved nutrients.

Research needs on wildfire impacts…

- **Measurements of initial stormflows** after mega-fires have recently deployed *in situ* DO probes that continuously measure DO concentrations.
- **Strong DO sags**, sometimes to anoxia, have been documented.
- More of these types of studies are crucial to understand water quality and biological responses after mega-fires in California.

Research needs on wildfire impacts…

- Few studies have examined post-mega-fire exports of **trace element concentrations** and forms from forested catchments.
- The duration and pattern of elevated trace element concentrations in streams, rivers, and reservoirs **is needed to determine the longevity** of post-mega-fire water-quality impairment.

Research needs on wildfire impacts…

- Until quite recently, **dissolved organic carbon (DOC)** was rarely measured in streams and rivers affected by mega-fires.
- Limited data led to the conclusion that DOC effects from large wildfires were minor, but recent studies conclude that, in initial storm events after major wildfires, DOC increases.
- There is still much to learn about DOC dynamics and their effects on the formation of disinfection byproducts during water treatment.

Research needs on wildfire impacts...

- **Reservoirs** appear to play a key role in ameliorating downstream water-quality effects after catastrophic wildfire, but rigorous reservoir studies are **currently limited** in California and worldwide.

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