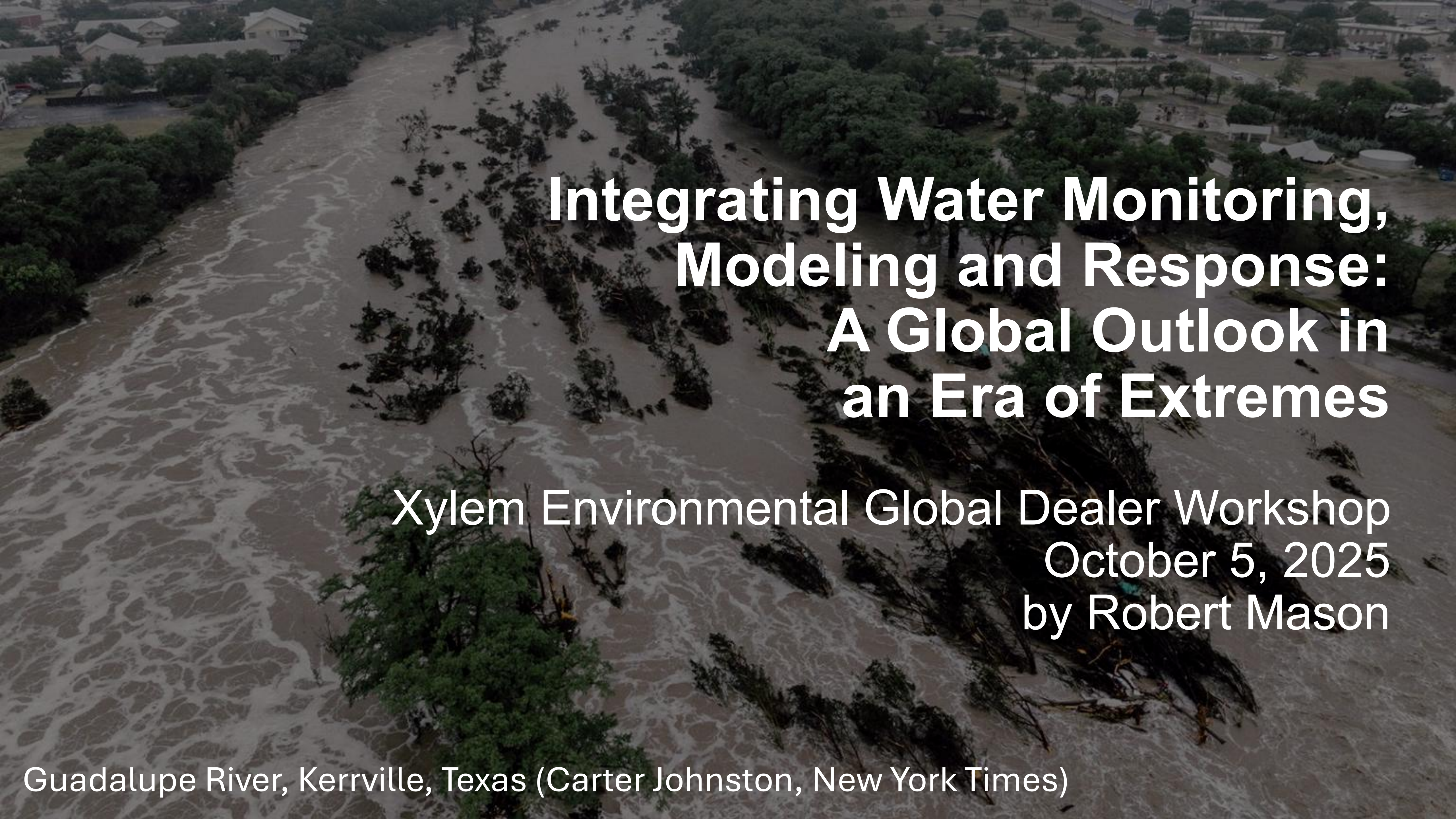
Integrating Water Monitoring, Modeling and Response: A Global Outlook in an Era of Extremes

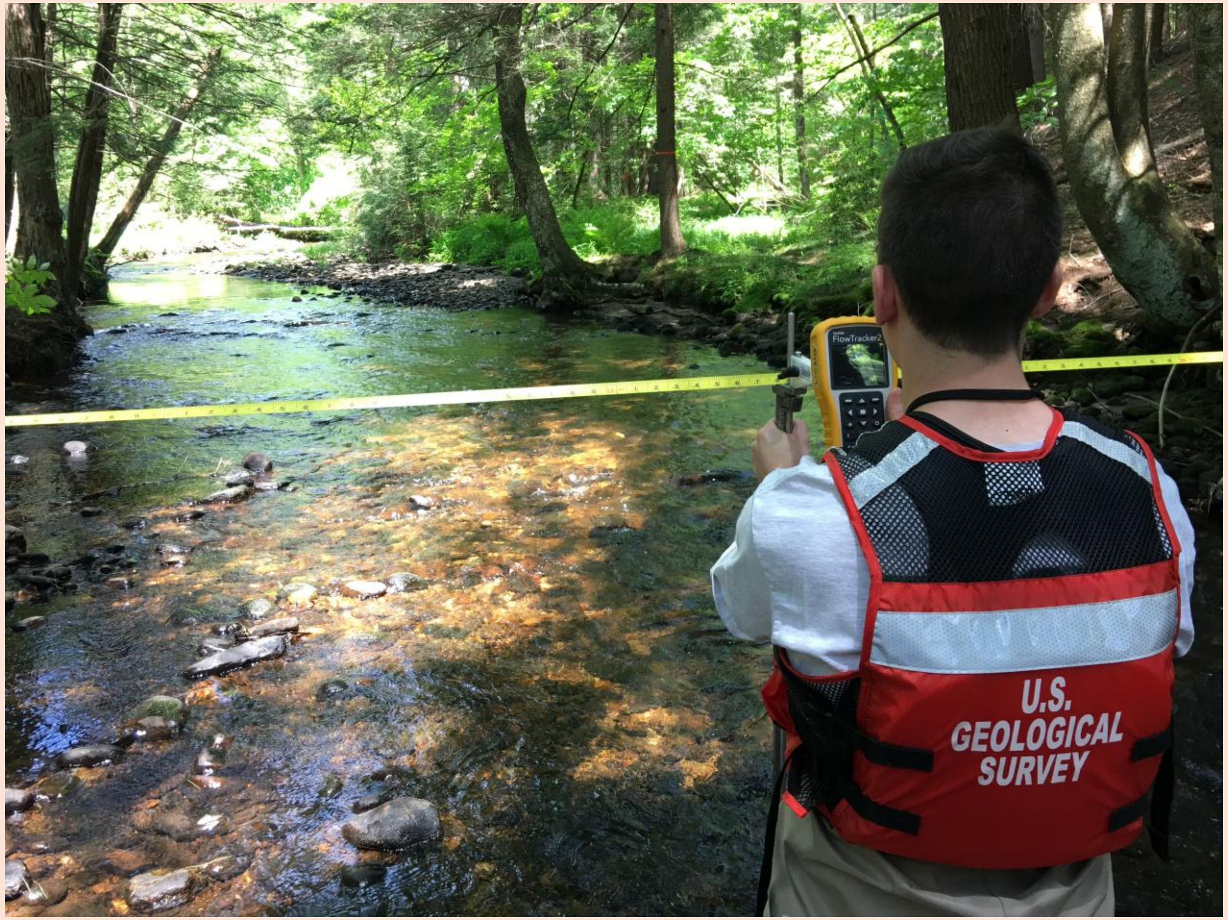
Xylem Environmental Global Dealer Workshop
October 5, 2025
by Robert Mason



Guadalupe River, Kerrville, Texas (Carter Johnston, New York Times)

Outline

- Global water outlook
- Are we entering an era of extremes?
- Recent evolution of streamflow monitoring
- Water hazard monitoring
- Selected instrumentation developments



The Global Water Outlook

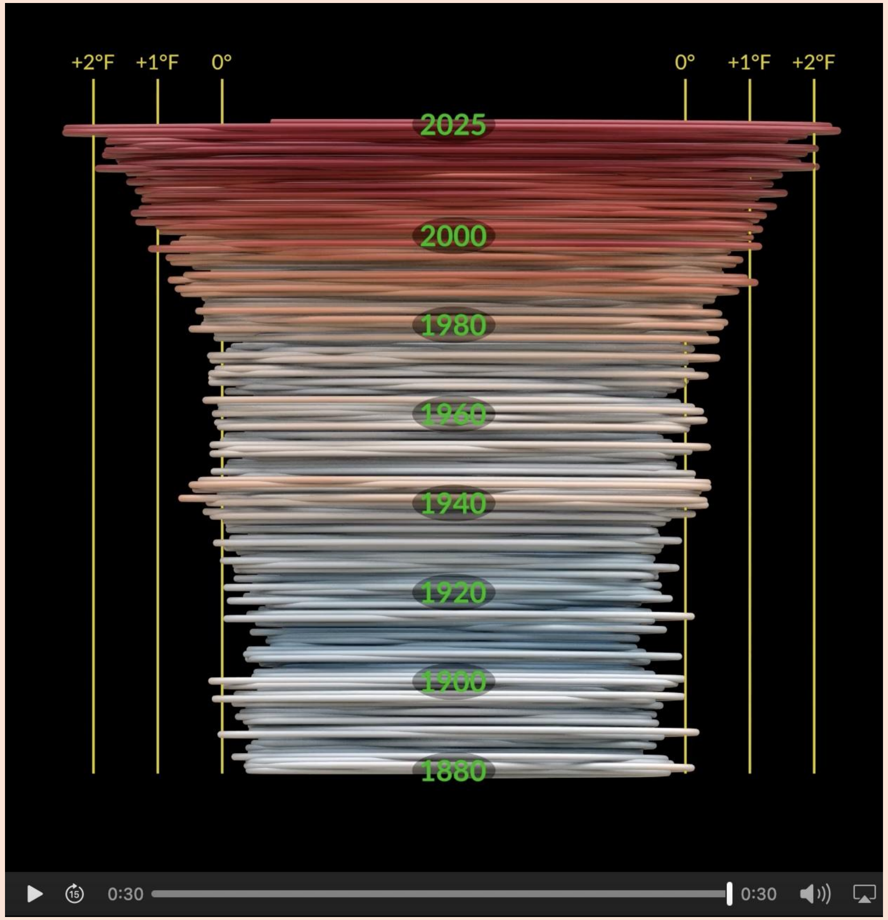
- 8.1 Billion people
- Drinking water and drought: According to the United Nations UNICEF and WHO:
  - 2.1 Billion people lack access to water that is reliably available, accessible on-premises, and free from contamination
  - Approximately 4 billion experience severe water shortage for a month each year.
  - URL: https://www.who.int/news/item/26-08-2025-1-in-4-people-globally-still-lack-access-to-safe-drinking-water---who--unicef
- Flooding:
  - 1.8 Billion people face inundation risk of at least 6 inches from the 1-percent chance flood (URL: https://hdl.handle.net/10986/34655)
  - According to FEMA 3 percent of the U.S. population live within the 1-percent chance floodplain (URL: https://hdl.handle.net/10986/34655)
  - According to First Street approximately 14.6 million properties are within the 1-percent chance flood

https://www.usgs.gov/media/images/earth-image-space
Image by NASA

Do we live in an era of Extremes or is the Water-Disaster Stew just heating up?

- Floods, droughts, spills –SEEM more frequent, larger, more impactful, and ARE more visible
- Climate change –More atmospheric moisture, more intense precipitation
- Larger, more dense, more vulnerable populations especially along coasts, wildland-urban interface
- Aging infrastructure –Increasingly subject to failure
- Flat or reduced budgets for observing, modeling, planning
- Increased expectations for accurate forecasts; rapid, reliable warnings; and immediate recovery to normal

Is the Earth's troposphere warming?

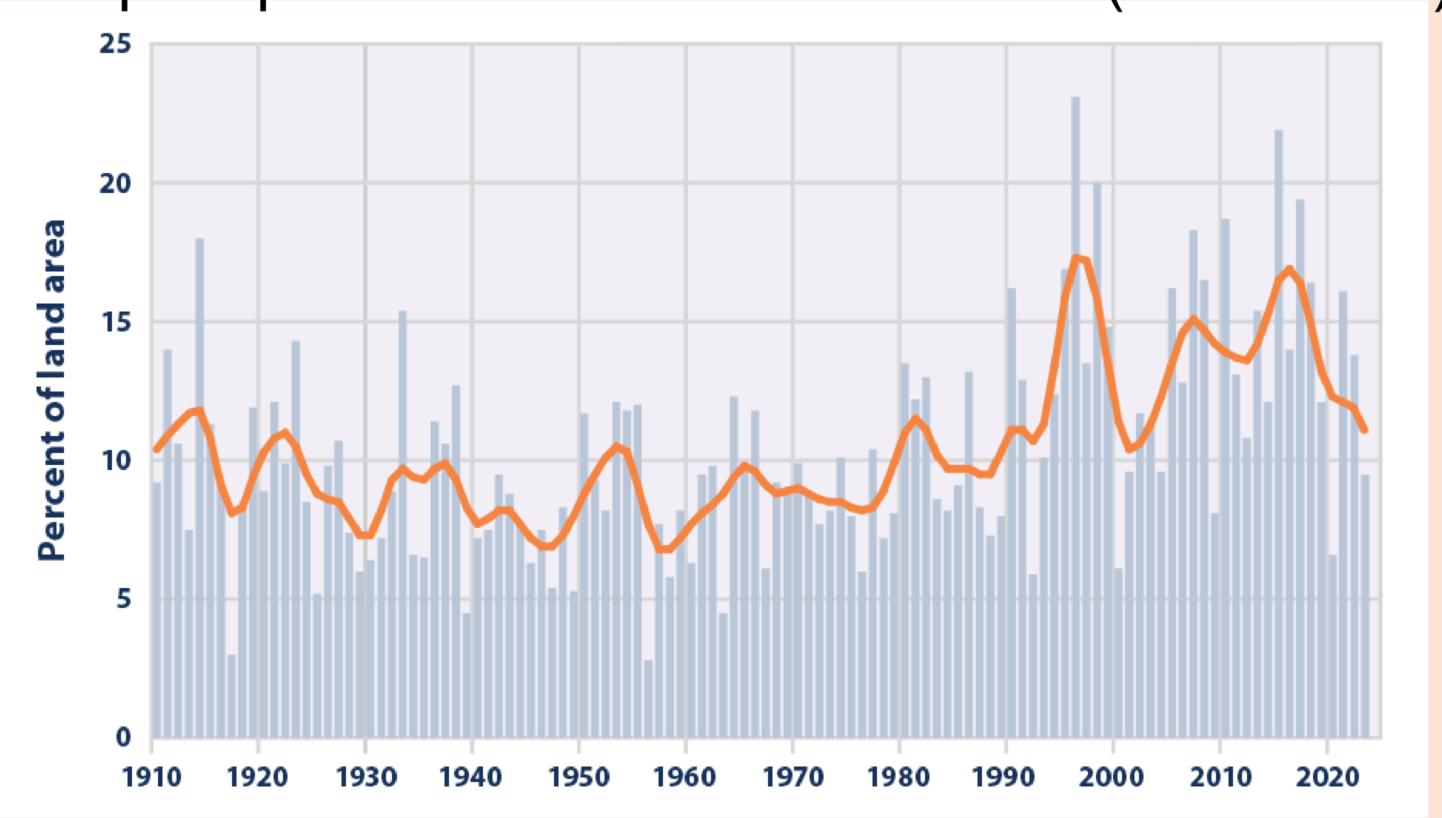


The NASA Climate Spiral (1880-2024)
https://svs.gsfc.nasa.gov/vis/a000000/a005100/a005190/GISTEMP_Spiral_English_degF_2160p60.mp4

Is rainfall more extreme?

- Thermo driver -Clausius-Clapeyron relation holds that warmer air can hold 7-percent more moisture for each ˚C ignoring availability limitations
- A warmer atmosphere can't hold what dry land can't release
- Warmer troposphere may also drive stronger storm dynamics such as uplift and downdraft that will pull moisture from more distant sources

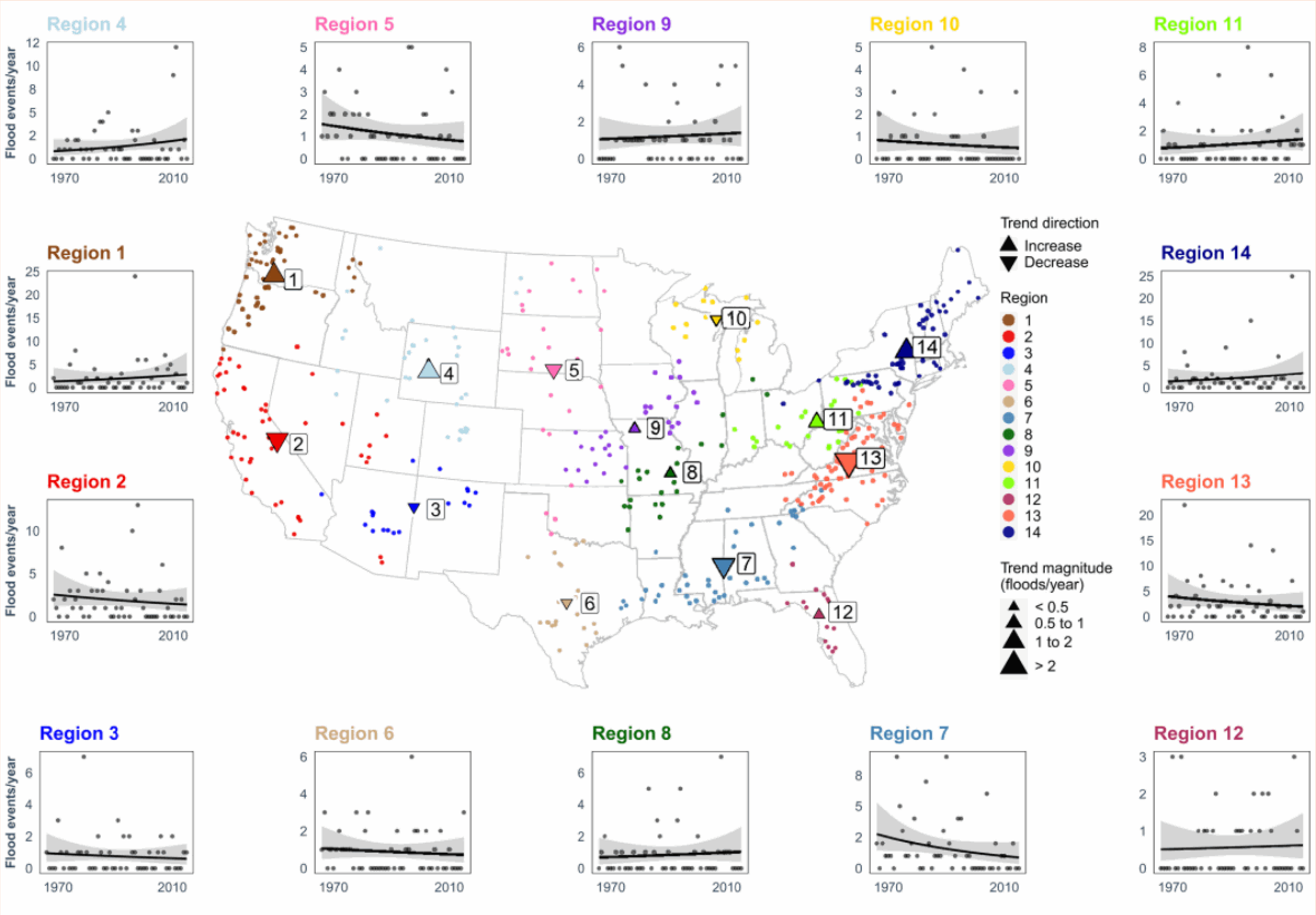
Area experiencing extreme one-day precipitation in the Continental US (1910-2023)



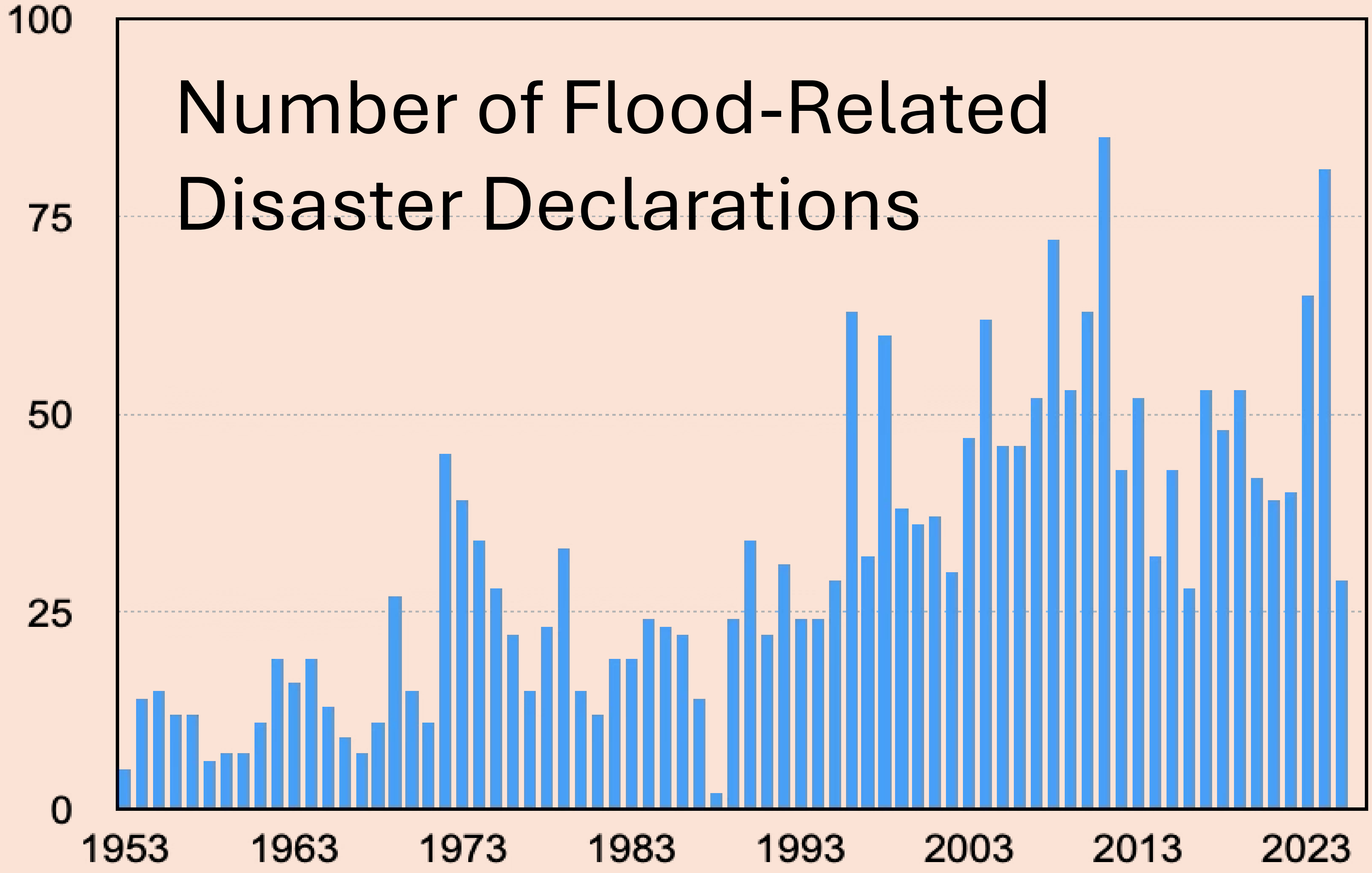
https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation

Are Floods increasing?

- Mixed results
- Increases in Northwest, Midwest, North Pacific
- Decreases in Southeast



https://doi.org/10.1029/2021WR030480



https://www.fema.gov/disaster/declarations

Disasters with 1,000 or More Fatalities, 1900-2023

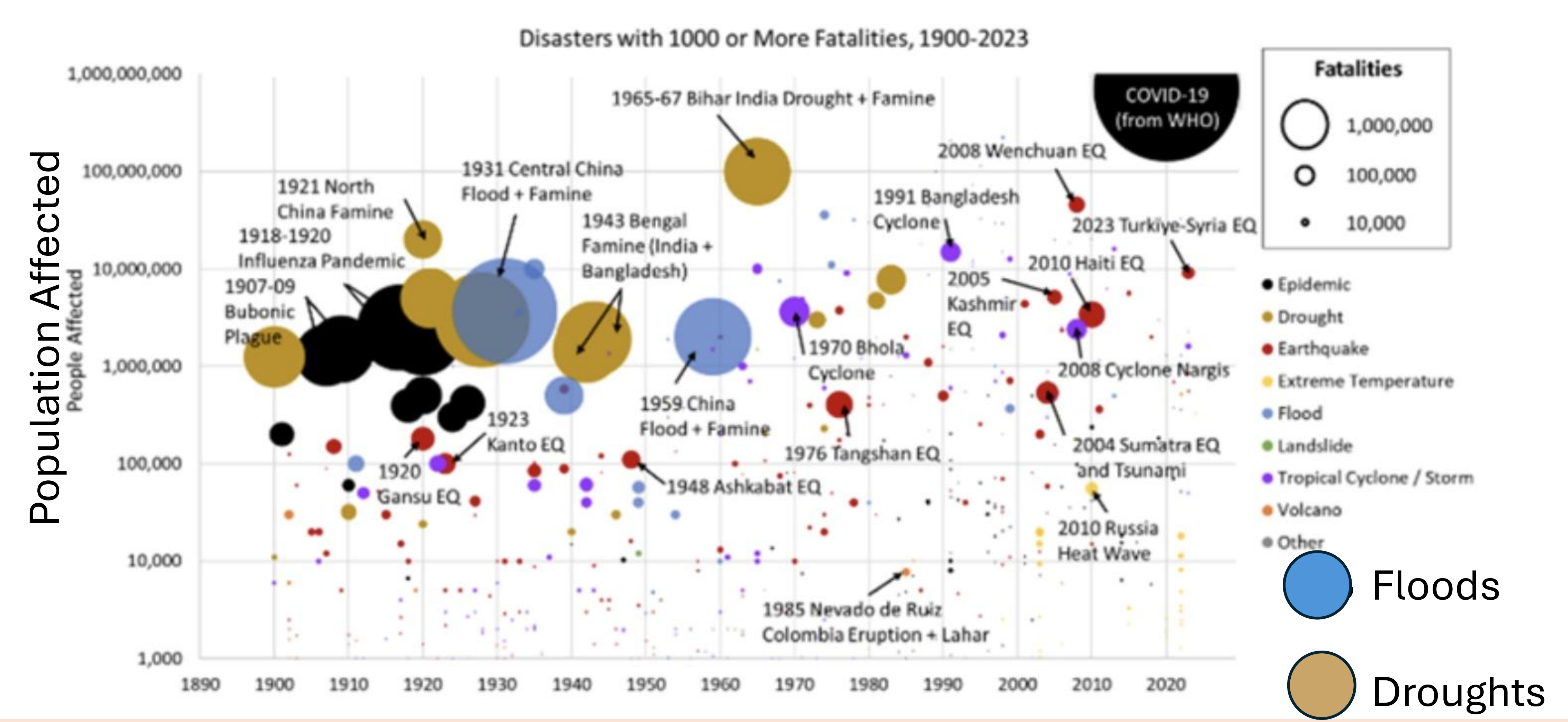
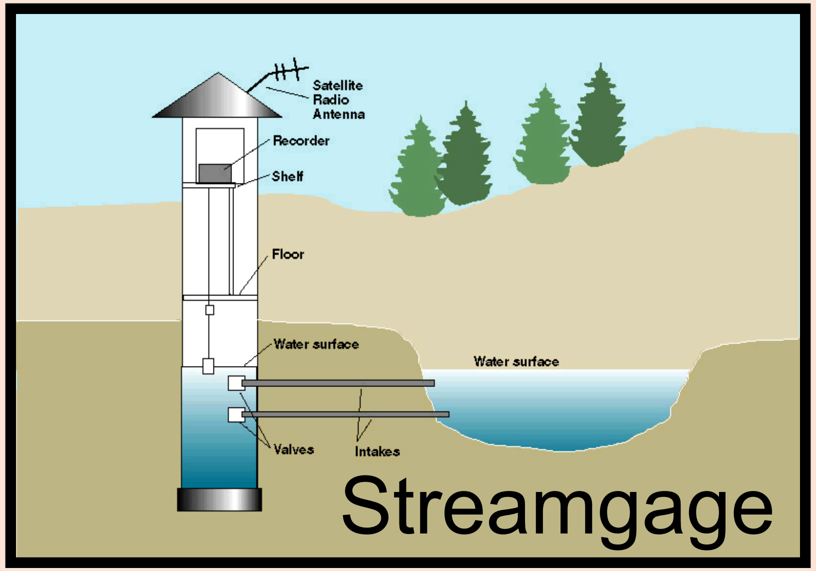
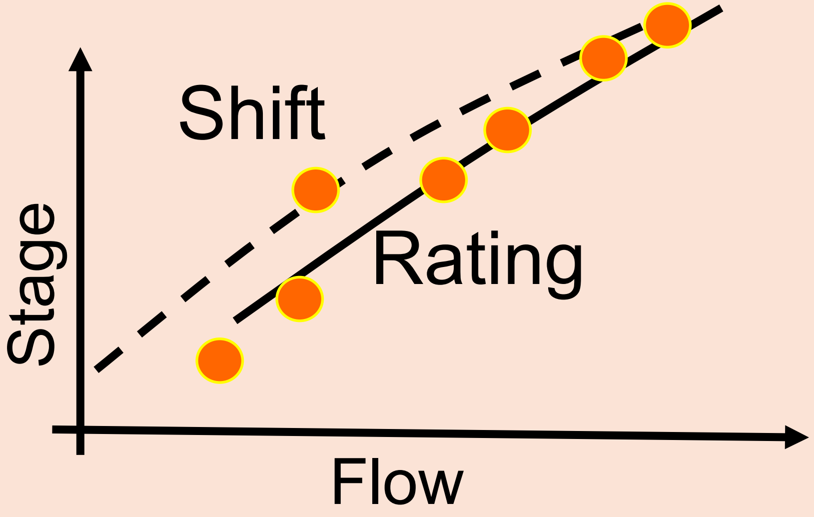


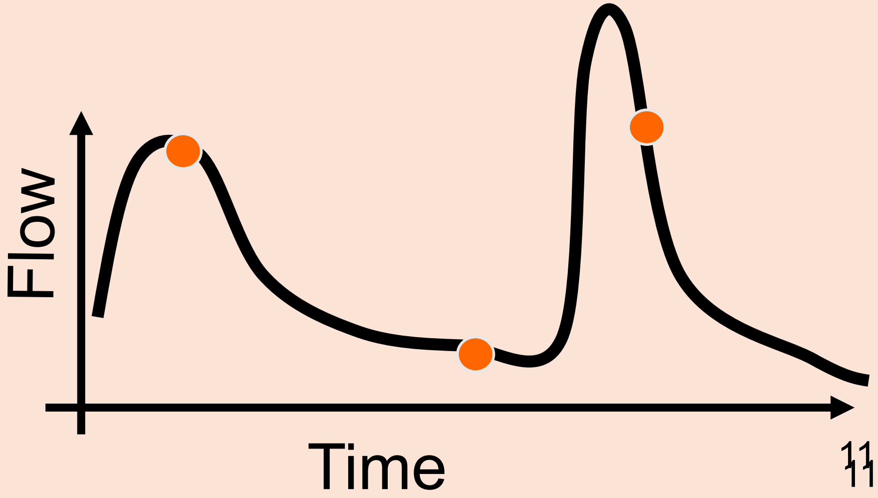
Figure 1 of 2025 Global Assessment Report on Disaster Risk Reduction
https://www.undrr.org/gar/gar2025

The "Traditional" Streamgaging Process



Flow measurement





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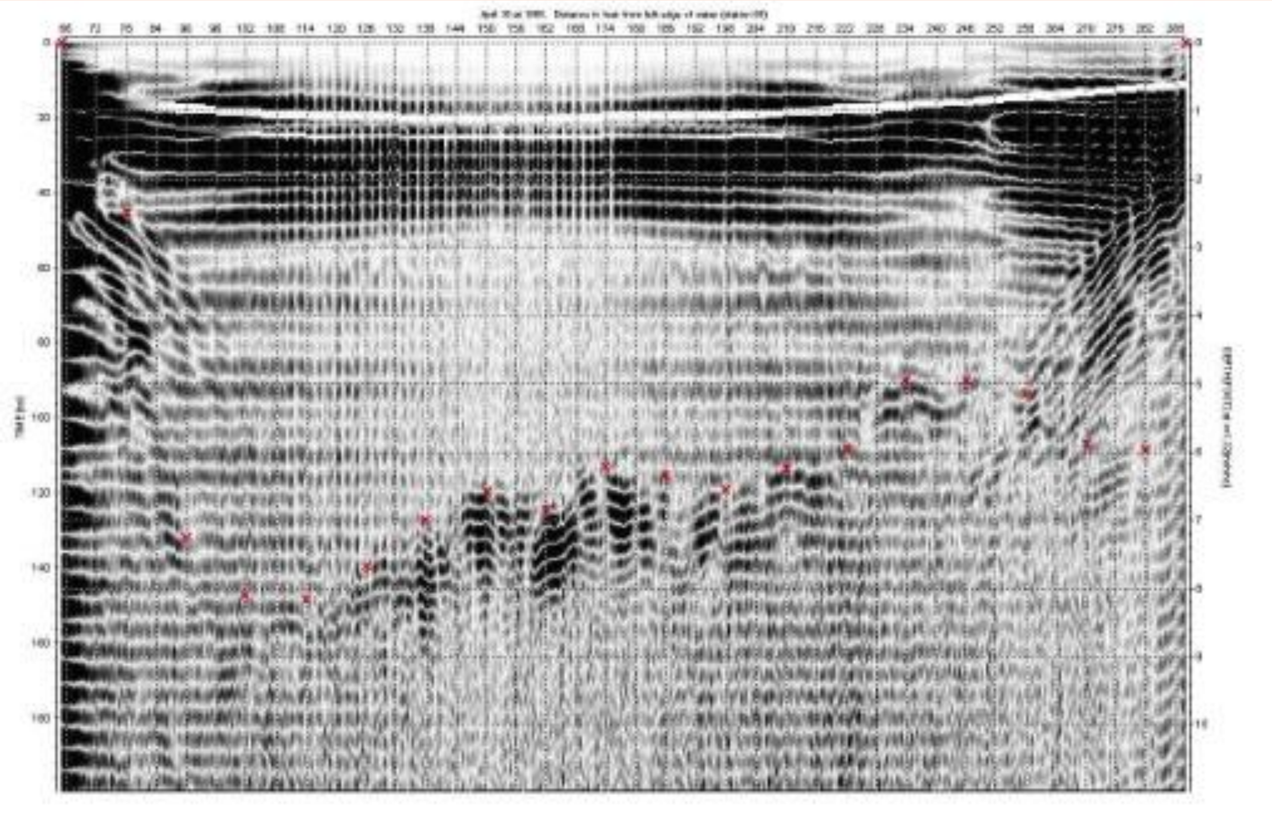
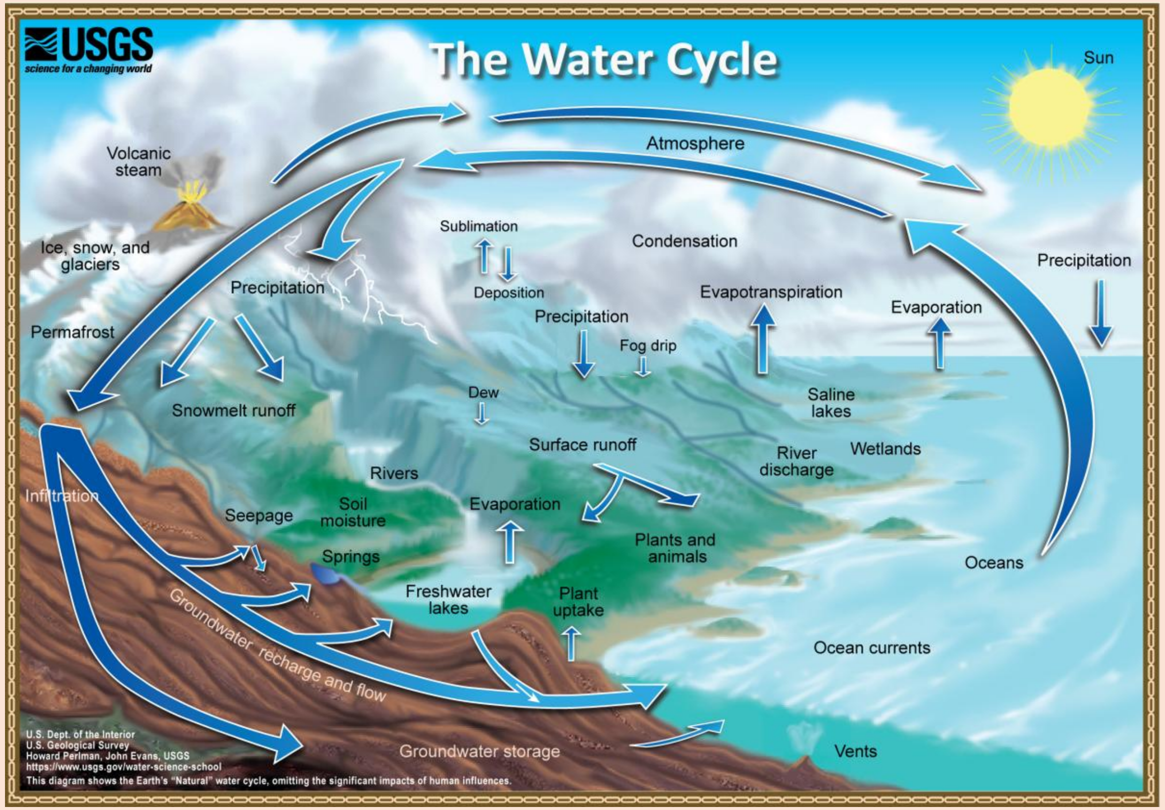
USGS Hydro 21 NonContact Flow Measurement

Bragg-scatter surface-velocity radar antenna and ground-penetrating radar, San Joaquin at Vernalis, CA (2002)



Ground-penetrating radar channel cross-section output (conductance in excess of 200us/cm limited effectiveness

What's Next?



Expanded List of Parameters

- Streamflow and velocities
- Evapotranspiration
- Snowpack
- Soil moisture
- Water temperature
- DO, pH, florescence

Multiple and diverse platforms

- In situ point monitoring and sampling
- Remote controlled and autonomous aerial, surface and, underwater vehicles
- Remote sensing

Emphasize water-related parameters needed to enable integrated hydrologic modeling for reliable and relevant water predictions

https://www.usgs.gov/mission-areas/water-resources/science/integrated-water-prediction-iwp.


Drone-based streamflow, bathymetry, land elevation, and water quality measurements
High-throughput, high-performance satellite telemetry
Visible light and thermal imaging cameras for measuring streamflow, water quality, and temperature
USGS
Two way wireless communication to office and other nearby stations
Meteorological, shallow groundwater, and soil moisture monitoring to support water budget modeling
Mobile monitoring with autonomous underwater vehicles and surface gateway
..,22.3,
112.4,..
..,56.7,
10.98,..
In-situ monitoring of water quality, eDNA, and emerging contaminants
USGS NextGen Water Monitoring
https://www.usgs.gov/mission-areas/water-resources/science/next-generation-water-observing-system-ngwos

NextGen Principals*

- Expand hydrologic parameters of interest and focus on hydrologic model inputs needed for relevant, actionable predictions
- Parametric consistency –Consistent results, “fit-for-purpose” methodology with stated uncertainty
- Methodological transparency –No black boxes
- Utilize, integrate multiple sensors to characterize stream and QW
- Leverage expanding platform availability
- Integrate and speed workflows from gage to page
    - Minimize touchpoints/maximize automation
    - Program instruments with interactive screens; Correlate with more easily monitored parameters -i.e., the humble stage-flow rating
    - Use AI/ML to quantify or categorize optical or spectral images and patterns
    - National Dashboard to communicate results with maps and charts

*As understood by Mason

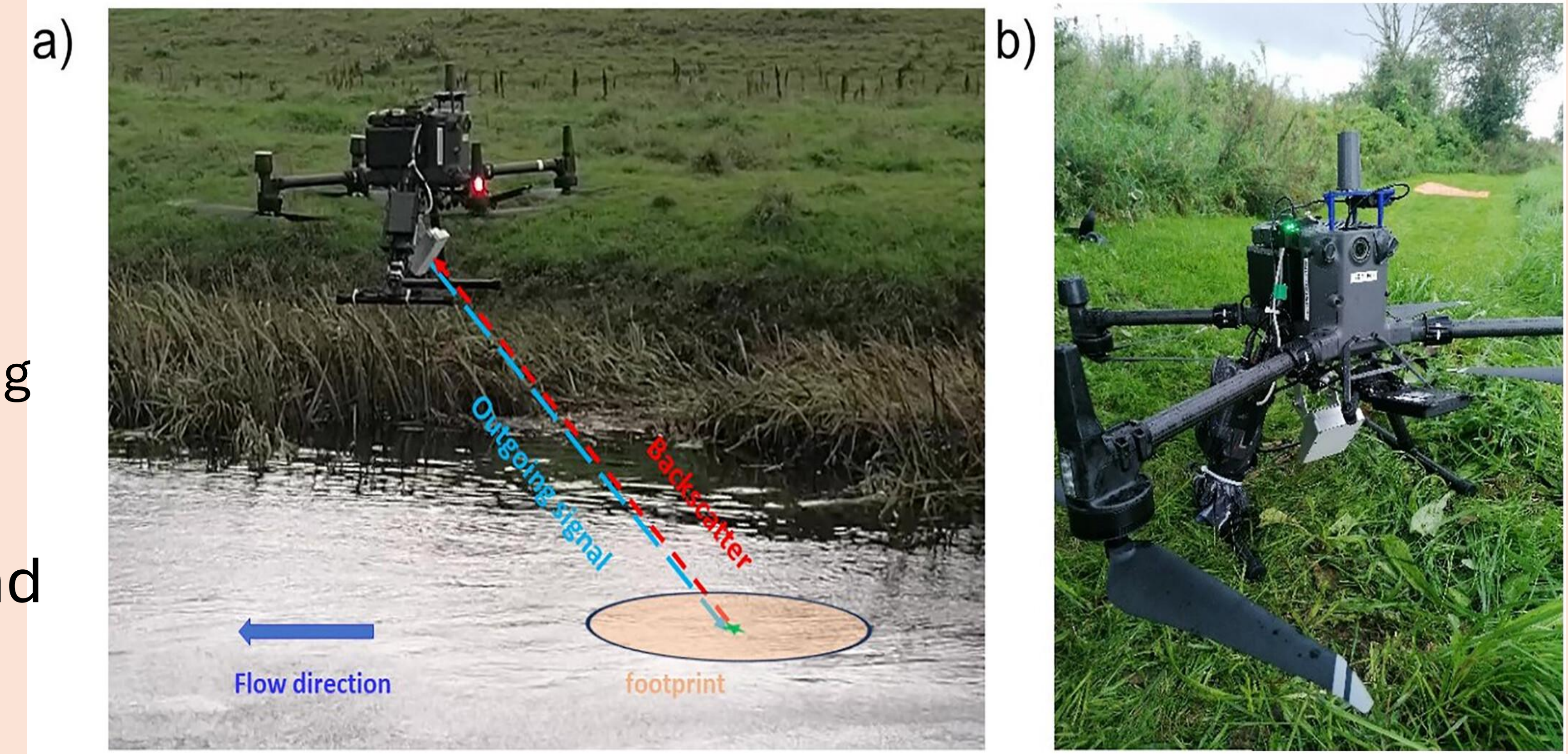
Monitoring Water Hazards in an Era of Extremes*

	Observation Needs	Methods
✓ Riverine flood flows and inundation	Stage, flow, volumes, timing	ADCPs, Camera-based PIV, Doppler radar, drones, remote sensing
Water-quality transport	Chemical concentrations and distributions across channel	In situ sensing, spectral tracking, autonomous vehicles remote sensing
✓ Small streams and Flash floods (post-wildfire runoff)	Threshold detection, speed, rate of rise	Non-contact-stage sensing, cameras, pattern recognition
Storm surge	Water-levels, waves, salinity	In situ water levels, Lidar, PIV
Pluvial floods	Depths, rates of rise	Stage monitoring, cameras and remote sensing
Spills	Chemical concentrations and distributions across channel	Mobile in situ sensing, cameras, spectral analysis
✓ Harmful Algae Blooms	Concentrations, distributions,	e-DNA and spectral analysis
Invasive species	Detection, population indicators	e-DNA

*Water hazards present risks to life, property, or degradation of natural resources.

Riverine flooding –Doppler and GPR

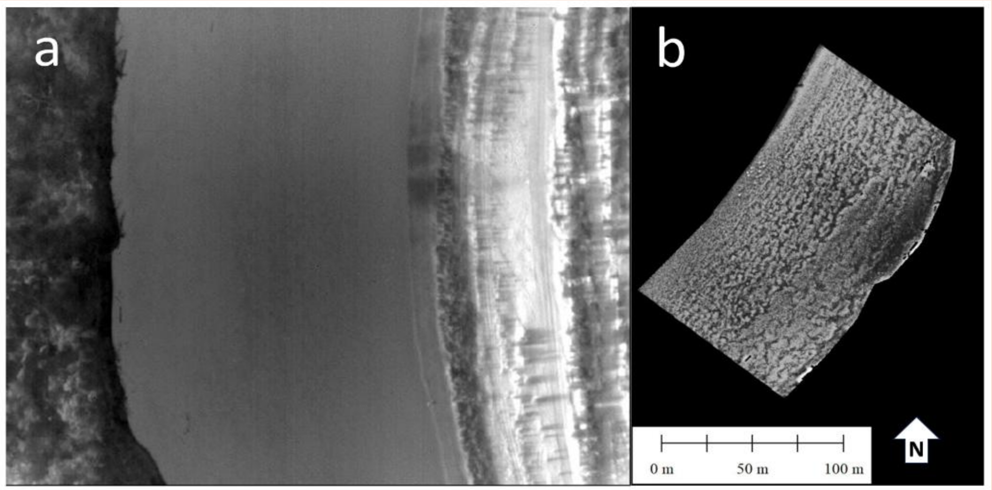
- Q=VA !!!
- Velocity -Doppler radar
- Bathymetry
  - Ground-penetrating radar
  - Green lasers
- Corrections for wind and overturning currents

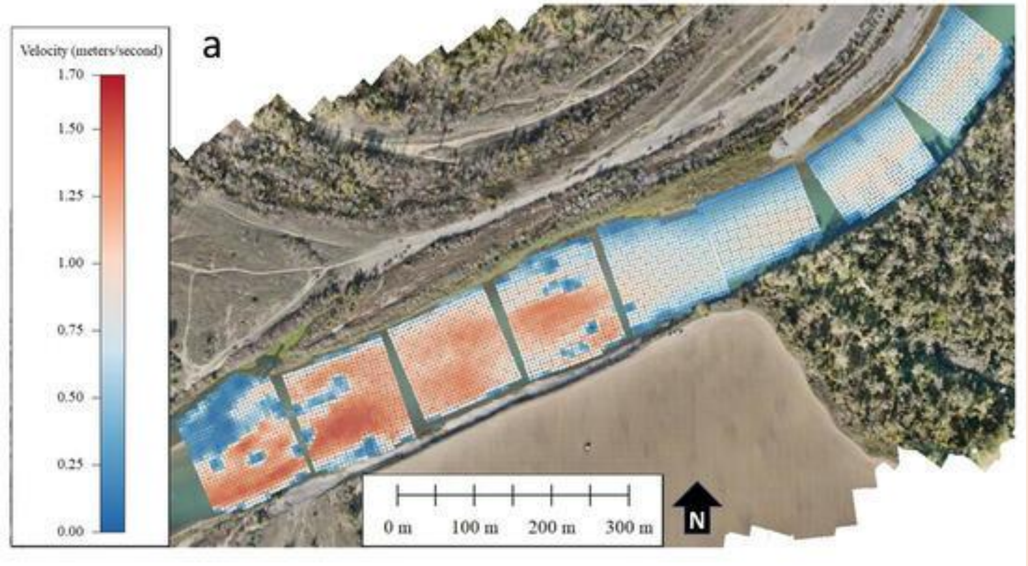


Water Resources Research, Volume: 60, Issue: 11, First published: 15 November 2024, DOI: (10.1029/2024WR037375)
Provided by Daniel Wennerberg

River Flows –Streamflow velocity from thermal turbulence

- Clear, shallow water
- Requires temp difference between river and air (night time)
- Multispectral thermal camera
- Extensive processing to identify turbulence structures
- ORByT feeware available
- Need field acquired depth datasets to train AI/ML

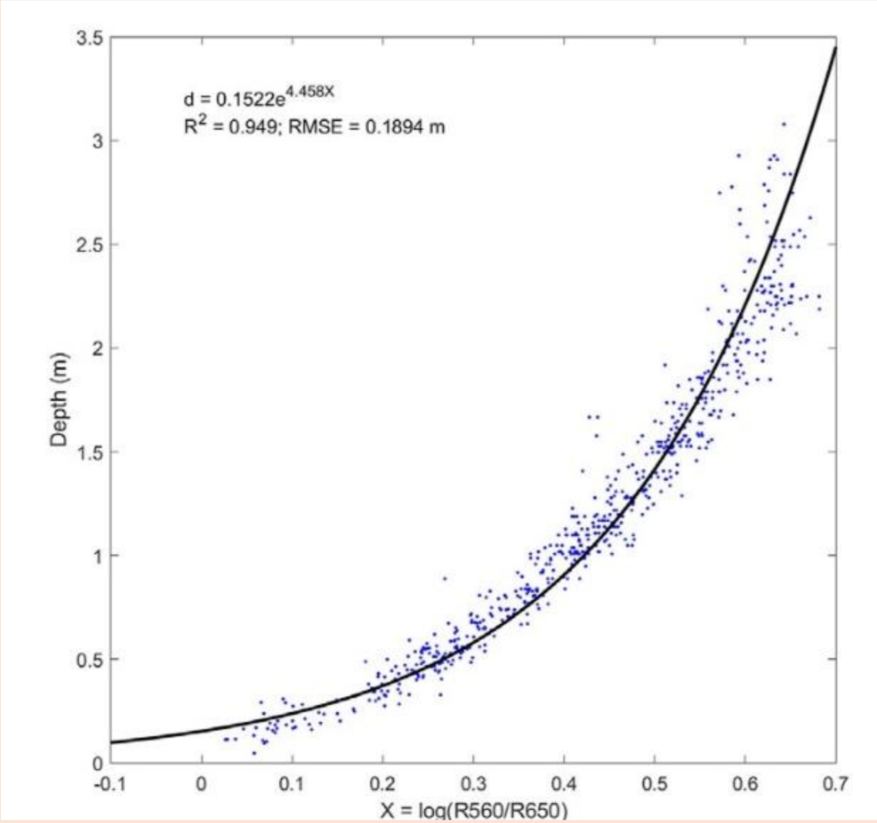


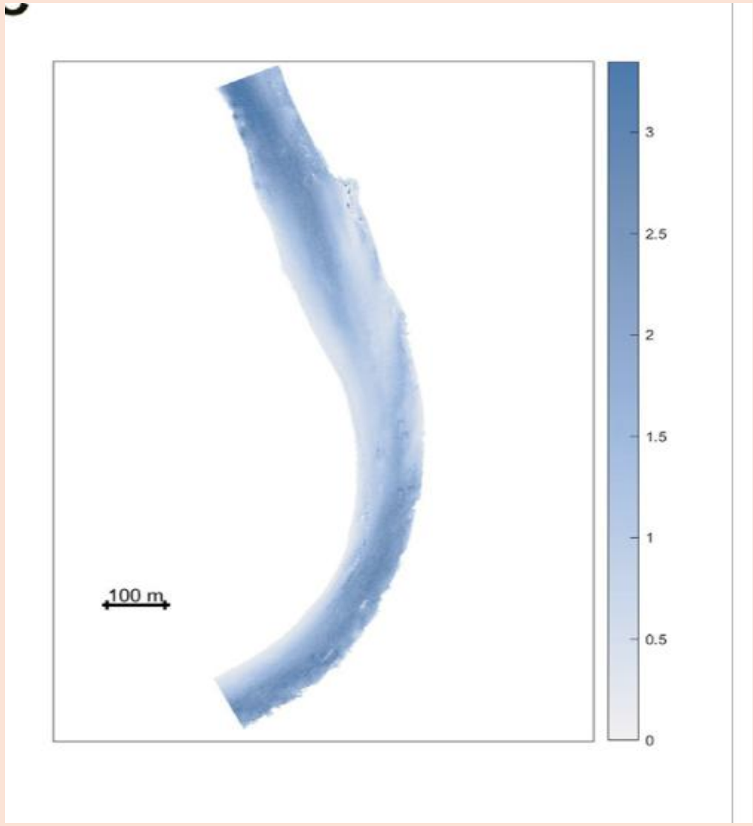


Legleiter and others, 2024 https://doi.org/10.3390/rs16244746

River Flows –Bathymetry from multispectral imagery

- Optimal Band Ratio Analysis
- Calibrated against field depth data to yield relation between reflectance and depth
- Uses variations in the rate at which solar radiation is attenuated as it propagates through the water
- Clear, relatively shallow water
- Optical River Bathymetry Toolkit (ORByT)

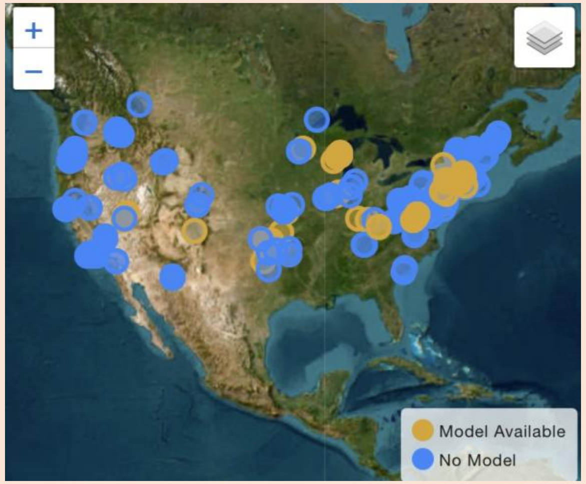


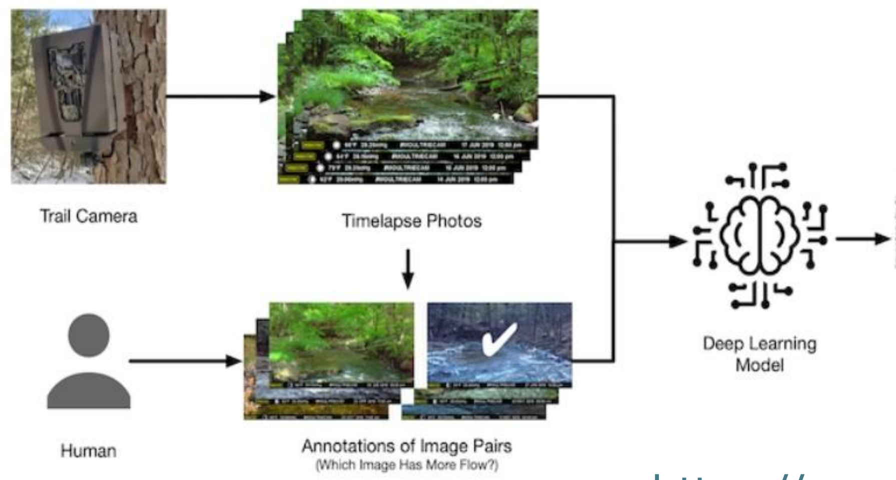


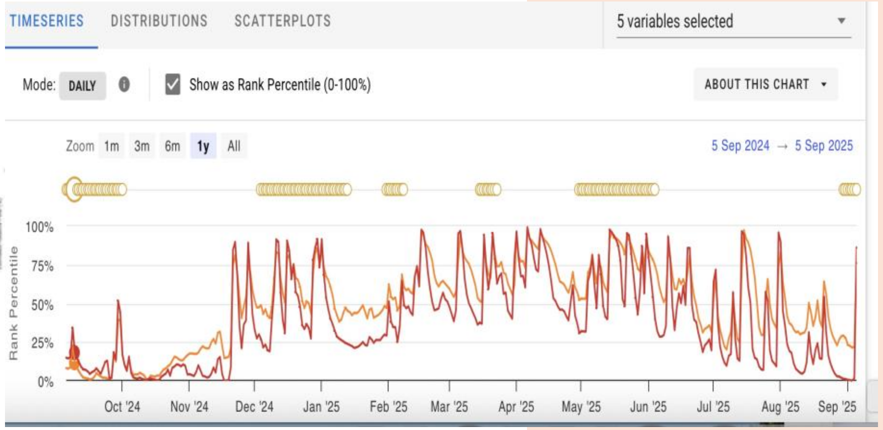
Legleiter and Harrison, 2024, doi: 10.3389/frsen.2024.1305991

USGS FlowPhoto -Small streams/Flash floods

- The Flow Photo Explorer (FPE) is an integrated database, machine learning, and data visualization platform for monitoring streamflow and other hydrologic conditions using timelapse images
- Relative flow, habitat characteristics, ecosystem health
- Flash flood/debris flow warning/bed mobilization?





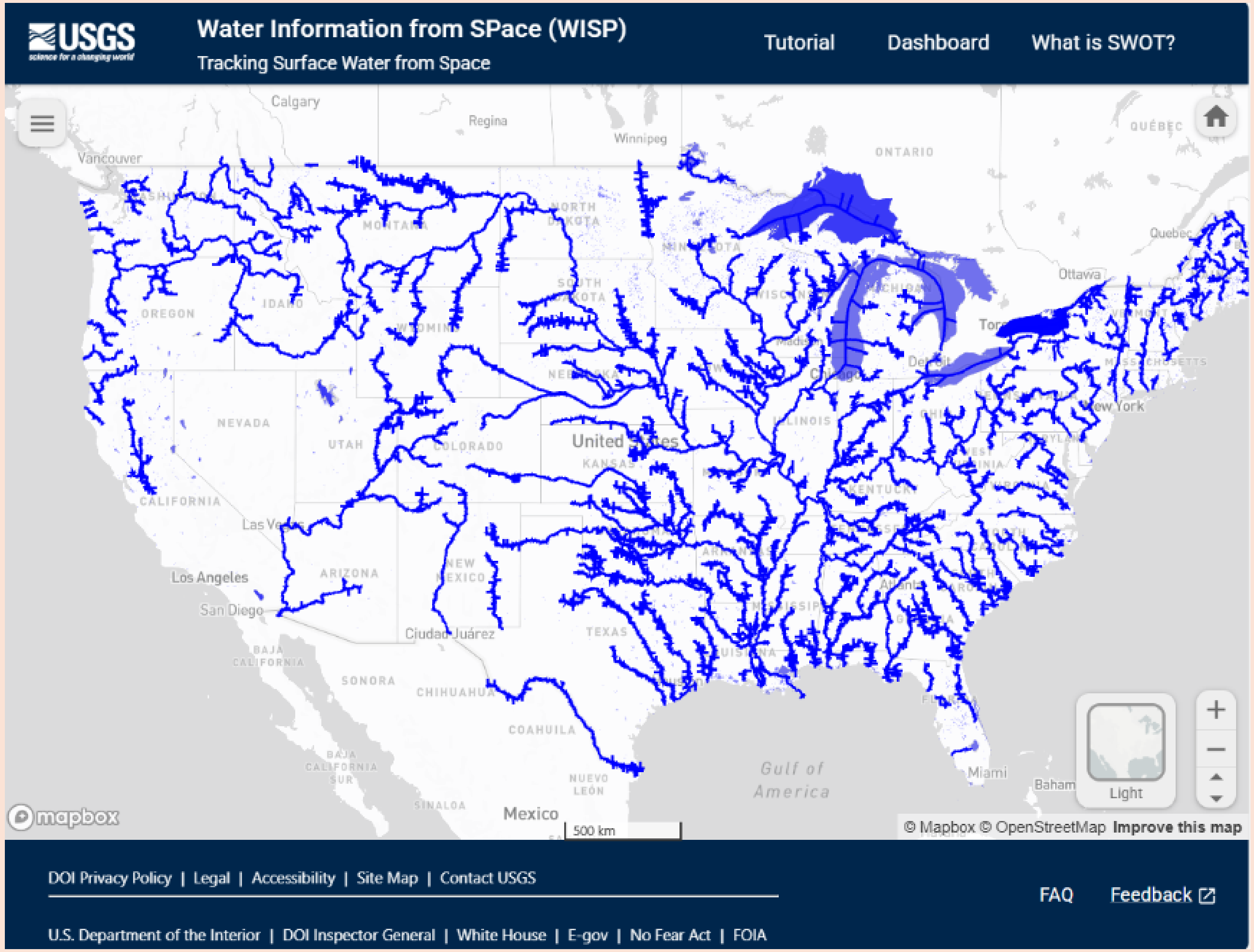


https://www.usgs.gov/apps/ecosheds/fpe/#/

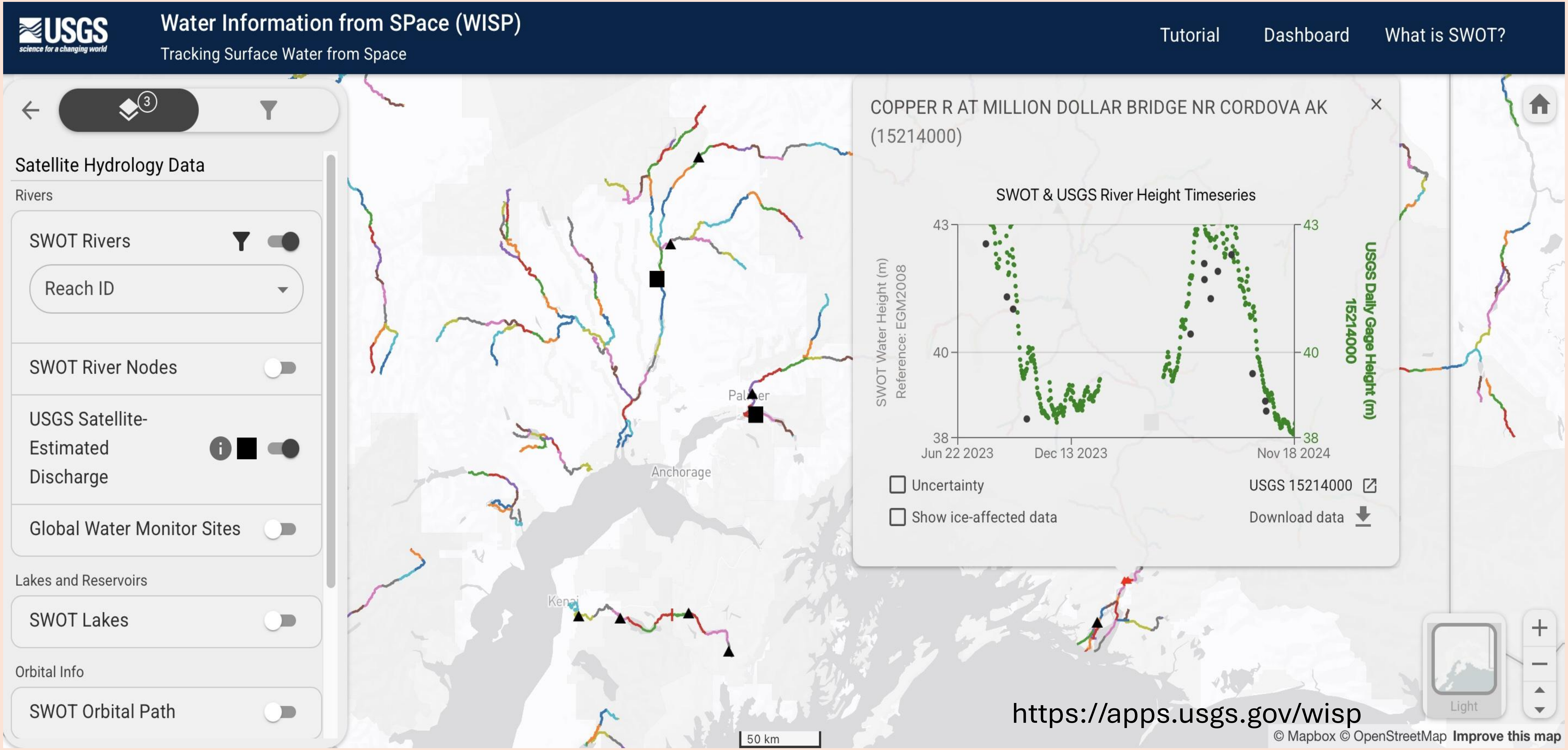
HIVIS https://apps.usgs.gov/hivis/

River flows –Remote Sensing

- NASA SWOT
  - Stream water elevations, slopes
  - 90 m resolution, 21 day return period
- USGS WISP
  - Piggy-backs on several satellite systems
  - Provides concurrent SWOT and USGS gage readings



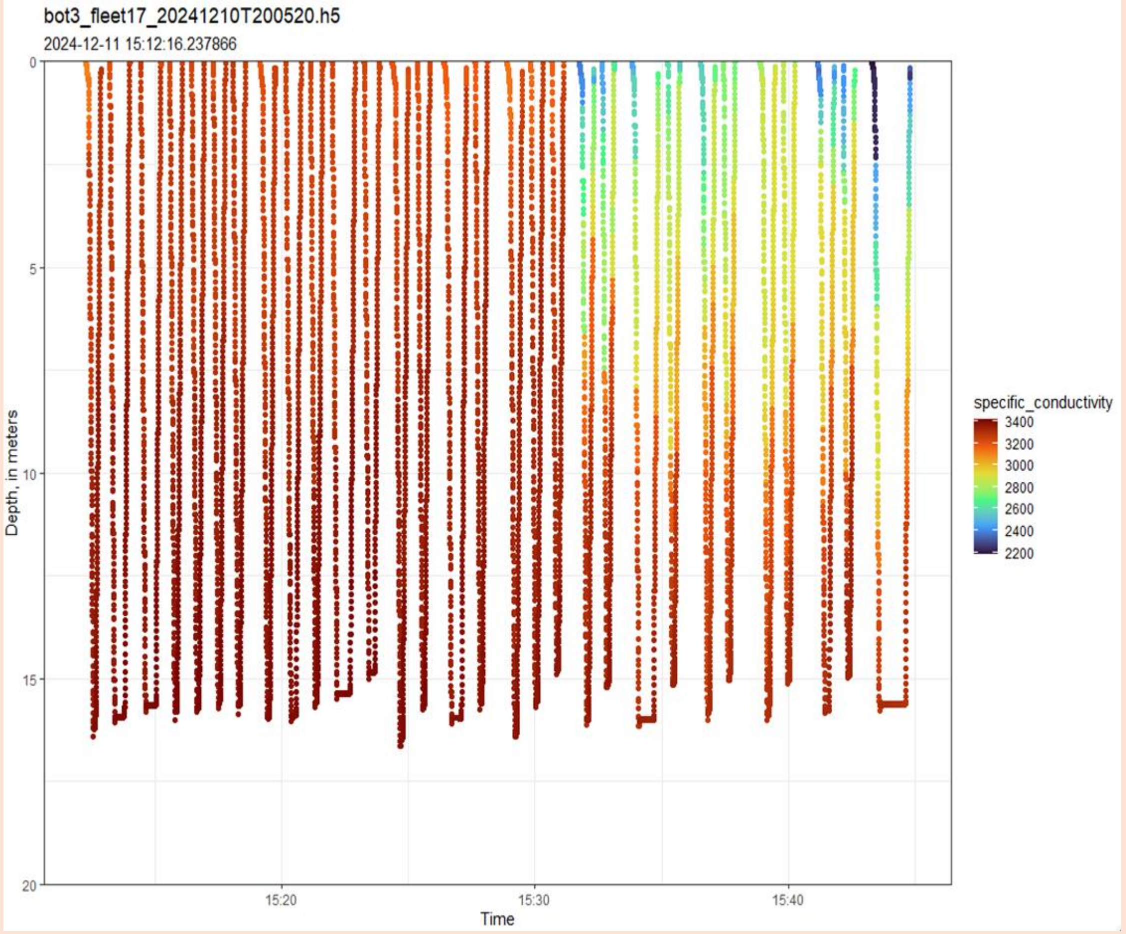
River flows –Remote sensing



https://apps.usgs.gov/wisp

Water-quality transport –Near field

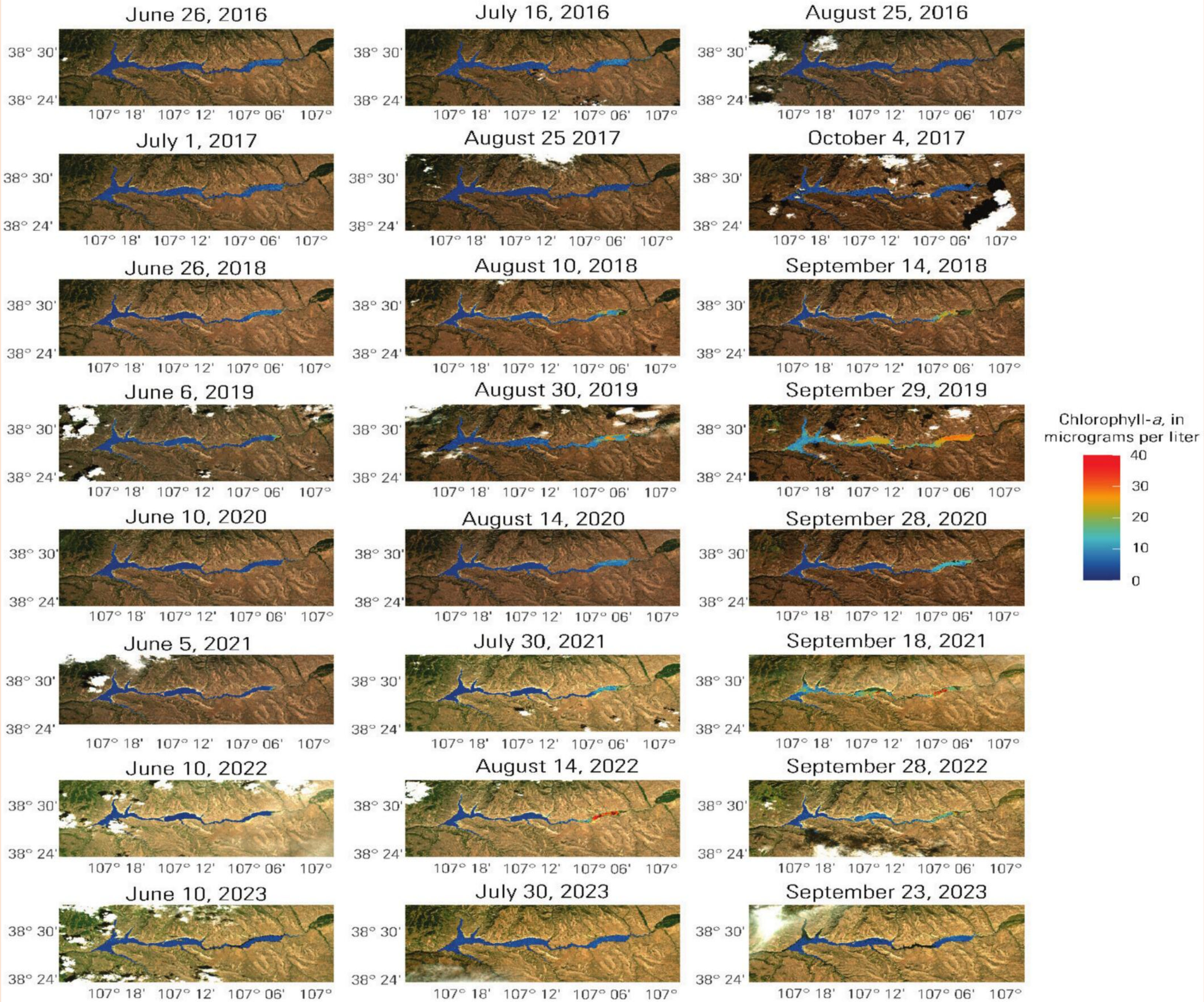
Autonomous Underwater Vehicle (AUV)



Autonomous Underwater Vehicle (AUV) salinity output

HABs -Remote Sensing of Chlorophyll a and Temperature to Support Algal Bloom Monitoring in Blue Mesa Reservoir, Colorado

J American Water Resources Assoc, Volume: 61, Issue: 4, First published: 11 August 2025, DOI: (10.1111/1752-1688.70038)



Conclusions

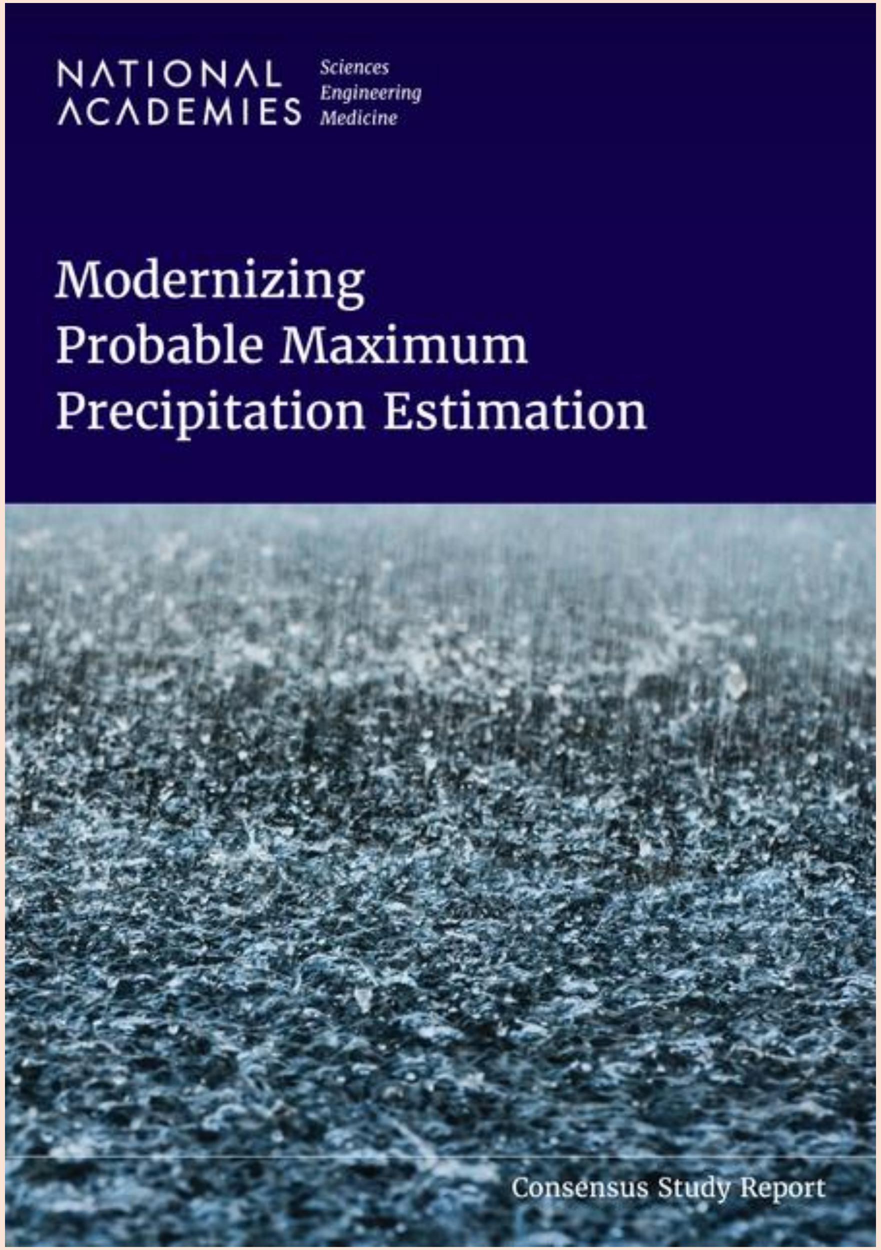
- Billions lack reliable, safe, and on-premises water or suffer inundation risks of 6 inches or more from the 1-percent chance flood
- The climate is warming; a warmer atmosphere is primed to hold more moisture, but changes in precipitation will depend on precipitation efficiencies driven by storm dynamics
- Water-related disaster fatalities have been drastically reduced but property damage is increasing persistently
- The USGS is addressing a broader suite of hydrologic issues and parameters with novel technologies, particularly camaras, radars, hyperspectral tools, and remote sensing and “fit-for-purpose” approach
- Bathymetry measurement and mapping, through rarely explicitly prioritized should be a key focus for methods development

Shameless self promotion

Extreme Rainfall in Mountainous Terrain: Modeling and observational challenges for warm-season precipitation

National Academy of Sciences Workshop
November 4, 2025

https://www.nationalacademies.org/event/45551_11-2025_extreme-rainfall-in-mountainous-terrain-modeling-and-observational-challenges-for-warm-season-precipitation



Questions?

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- *Walker, J.D. (2025).* ***Low-cost Streamflow Monitoring using Timelapse Imagery and Machine Learning Models.*** *Year 1 Final Report, USEPA Regional-ORD Applied Research Program (ROAR) Project #2554. Prepared for US Environmental Protection Agency Office of Research and Development. April 3, 2025. https://doi.org/10.5281/zenodo.15133342*

Selected software

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- Trivia Software for processing aerial images to river surface velocity vectors and discharge, journal article and open source software, https://onlinelibrary.wiley.com/doi/10.1002/rra.433
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