Issue 18, Volume 2, November 2025

Chill To Spill: Unlocking Yosemite's Water Flow

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ACKNOWLEDGEMENTS

This was written for the University of California, Merced's Environmental Engineering faculty, California Data Exchange Center (CDEC), the Airborne Snow Observatory (ASO), NOAA's National Weather Service, and the Merced Irrigation District (MID) for providing openly accessible data resources. Special thanks to Professor Erin Hestir for supporting student use of remote sensing tools and hydrologic analysis techniques.

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ABSTRACT

Flooding and irrigation uncertainty in the Upper Merced River watershed present serious challenges for water managers and farmers. This project investigates how snowmelt, precipitation, and dam operations interact to influence river overflow and water availability ,especially near Yosemite National Park,. By comparing a dry water year (2022) with a wet year (2023), the project combines remote sensing data, streamflow records, and dam release patterns to model potential flood risks and seasonal irrigation supply. High-resolution snow data from the Airborne Snow Observatory (ASO) [1], which uses LiDAR to measure snow water equivalent (SWE), revealed significant snowpack differences between years. ENVI software was used to visualize snowmelt rates using band math and custom color lenses, while precipitation records from the National Oceanic and Atmospheric Administration (NOAA) [3] and river flow data from the California Data Exchange Center (CDEC) [2] helped map hydrological trends. Dam operation reports from the Merced Irrigation District (MID) [4] were manually compiled into an operational timeline. Results showed that although 2023 had greater SWE, the melt was slower and better regulated by MID dams, reducing immediate flood risk. In contrast, 2022's lower snowpack melted rapidly, overwhelming limited flow controls. These findings support the adoption of more adaptive irrigation planning and early-warning systems tied to snowmelt dynamics. While the model remains simplified, it demonstrates how open-source data and remote sensing tools can enhance regional water management, especially under intensifying climate variability.

Keywords—*snowmelt, Merced River, dam operations, remote sensing, precipitation, flood risk, water resources, irrigation planning, ENVI*

1. INTRODUCTION

As climate change accelerates towards a hotter environment, snow-dependent watersheds across the western United States are facing increased uncertainty in regards to precipitation. Warmer winters, shifting precipitation patterns, and extreme weather events have disrupted traditional water availability patterns, making it more difficult to predict flooding events or ensure timely irrigation. The Upper Merced River watershed, located near Yosemite National Park in California, is a key real world example in this broader environmental transformation. The region relies heavily on snowpack from the Sierra Nevada for seasonal water supply, yet variability in snowmelt and precipitation, compounded by human-managed dam operations, complicates forecasting and planning.

Recent studies have shown that snowmelt timing is shifting earlier in the season [5], and that rivers across California are experiencing higher peak flows in spring, with more frequent extremes [6]. Meanwhile, dam management strategies have had mixed success at mitigating these changes, especially in years of either exceptional drought or surplus precipitation. There remains a need to integrate remote sensing technologies with traditional hydrological data to build better models for managing these complex systems.

This project aims to assess how snowmelt, precipitation, and dam operations jointly influence water availability and flood risks in the Merced River watershed. The hypothesis is that years with higher snowpack, when coupled with concentrated spring precipitation and delayed dam releases, significantly increase the risk of overflow, while lower-snow years may lead to more rapid, unbuffered snowmelt and short-term flooding. By analyzing data from both a dry year (2022) and a wet year (2023), this project seeks to create a simple but informative predictive model that can support irrigation planning and flood mitigation in a warming world.

2. METHODOLOGY

2.1. Study Area

The project focuses on the Upper Merced River watershed, located near Yosemite National Park, California, identified by the Hydrologic Unit Code (HUC) 18040008. This region includes high-elevation snow accumulation zones in the Sierra Nevada and downstream agricultural and urban areas reliant on the Merced River for irrigation and water storage. The watershed is influenced by seasonal snowmelt, variable precipitation, and dam operations managed by the Merced Irrigation District (MID) [4].

2.2. Image Data and Pre-Processing

Snow data was obtained from the Airborne Snow Observatory (ASO) [1], which uses LiDAR and imaging spectrometry to generate high-resolution snow depth and Snow Water Equivalent (SWE) data. Datasets from 2022 (dry year) and 2023 (wet year) were downloaded from ASO's public repository. Images were imported into ENVI 5.6 for analysis. A linear 2% stretch was applied to enhance contrast, and band math was used to calculate SWE differences between March and April for each year (expression: b1 - b2). A rainbow color ramp was applied to visualize snowmelt rate, and a blue-scale ramp was used to highlight snow depth distribution.

2.3. Streamflow and Precipitation Data

River flow data were obtained from the California Data Exchange Center (CDEC) using station ID: MST (Merced River near Stevinson) [2]. These records included hourly discharge values, used to analyze the timing and magnitude of flow changes.

Precipitation data were collected from NOAA's National Weather Service [3], using archived monthly records for the Merced area. Historical precipitation trends for both 2022 and 2023 water years were compiled into Microsoft Excel for comparative visualization.

2.4. Dam Operation Data

Operational data was sourced from the Merced Irrigation District (MID) and the California State Water Resources Control Board [4]. A spreadsheet was developed to approximate monthly dam release volumes based on qualitative release information and irrigation demand indicators.

2.5. Image Analysis

ENVI's raster tools were used to process and analyze the ASO snow data. SWE difference layers were generated for both years and compared visually and quantitatively to identify spatial variability in melt timing. Areas of rapid melt were highlighted using color gradients.

2.6. Data Analysis and Statistics

Comparative graphs were created in Microsoft Excel to explore correlations between snowmelt rates, precipitation intensity, river outflow, and dam operations across both water years. Basic statistical measures (mean, rate of change, peak values) were used to quantify inter-annual variability and identify leading indicators of overflow conditions.

3. Results

3.1. Snow Depth Patterns

ASO snow depth maps from March and May 2022 show low accumulation and near-total melt by early May, while 2023 maps reveal deep, extensive snowpack in March with sustained snow cover into mid-May [1].

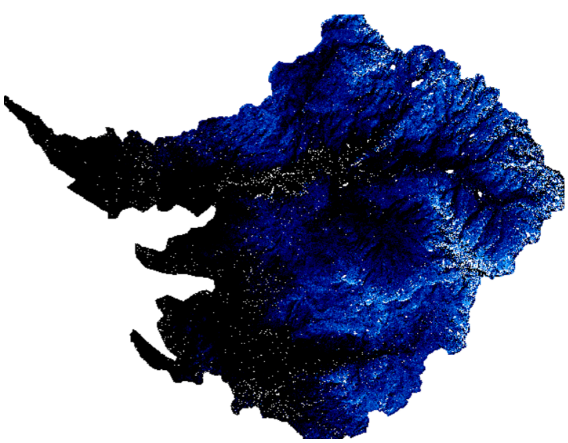

Figure 1. Snow Depth — March 2022 (ASO 3m resolution)
Shallow, patchy snow was observed across the Upper Merced watershed.

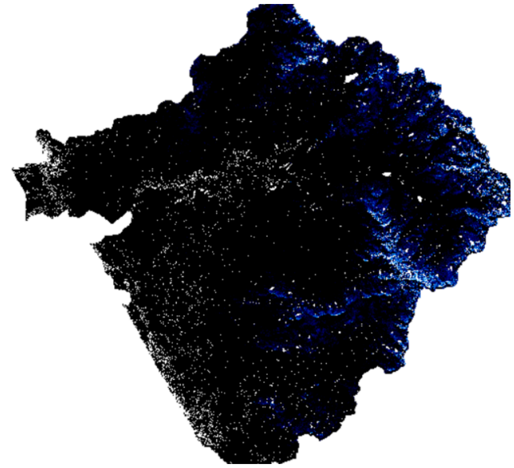

Figure 2. Snow Depth — May 2022 (ASO 3m resolution)
Snow is largely gone across all elevations by May 2.

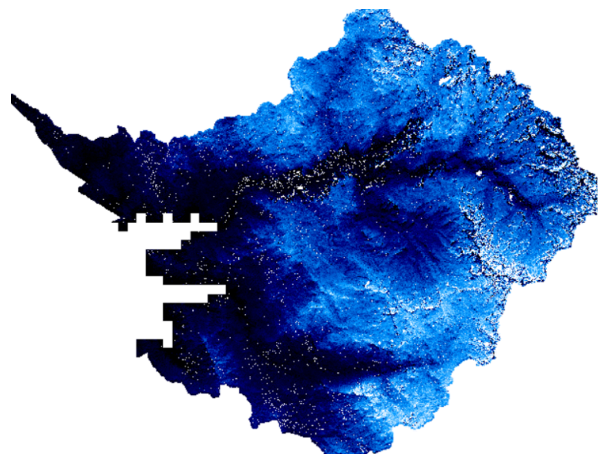

Figure 3. Snow Depth — March 2023 (ASO 3m resolution)
Significant accumulation across the entire basin, especially above 7,000 ft.

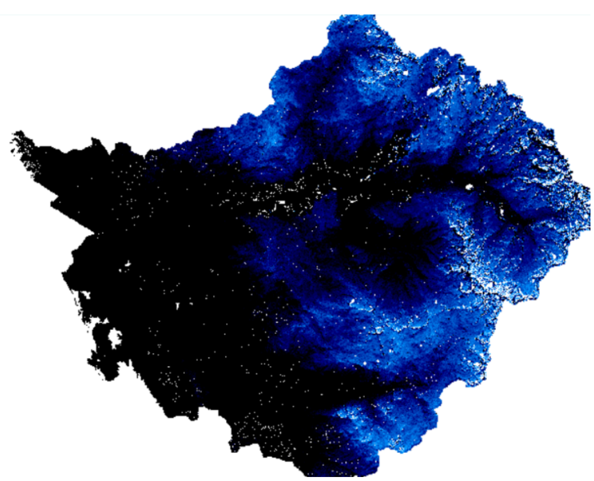

Figure 4. Snow Depth — May 2023 (ASO 3m resolution)
Snow persists at upper elevations; melt is slower than in 2022.

3.2. River Discharge

Hydrographs from the MST gauge show 2022 peaking quickly in late March at 114 CFS, dropping to 13 CFS by the end of May. In contrast, 2023 discharge rapidly rose past 6,000 CFS in March and remained high into May [2].

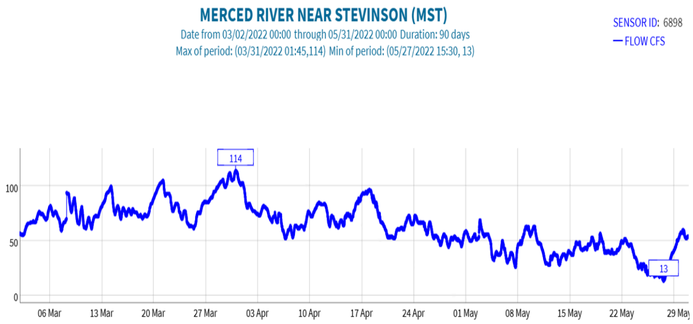

Figure 5. Hourly River Flow — March to May 2022 (MST Station)
Sharp peak and steep drop reflect rapid, unregulated melt.

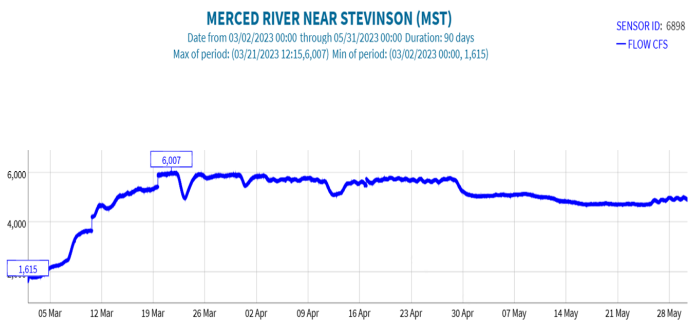

Figure 6. Hourly River Flow — March to May 2023 (MST Station)
Sustained high flows linked to prolonged snowmelt and dam control.

3.3. Precipitation and Dam Release Trends

The 2023 precipitation in March was more than four times greater than in 2022 [3]. MID dam outflows in 2023 averaged 5,800–7,000 CFS across spring months, whereas 2022 rarely exceeded 1,000 CFS [4].

Table 1. Monthly Precipitation and Average Dam Outflows (Spring 2022 vs. 2023)

Month	Precip. 2022 (mm)	Precip. 2023 (mm)	Dam Outflow 2022 (CFS)	Dam Outflow 2023 (CFS)
March	0.82	4.36	1899.88	5807.00
April	0.75	0.03	419.66	6956.00
May	0	0.77	870.68	6099.00

3.4. Snowmelt Timing and Intensity

SWE difference rasters (March to April) show that 2022 experienced a sharp and localized snow loss, while 2023 exhibited a more gradual melt across a broader elevation range. This trend is confirmed by heat-based melt rate maps from ENVI: 2022 had high-intensity melt zones concentrated in mid-elevations, while 2023's melt was lower-intensity but spatially widespread.

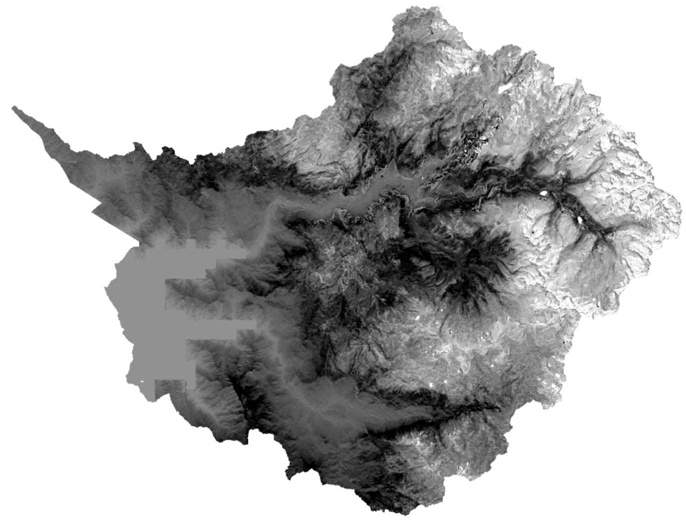

Figure 7. SWE Difference Map — 2022 (March to April)
Rapid SWE decline is shown in dark zones at mid elevations.

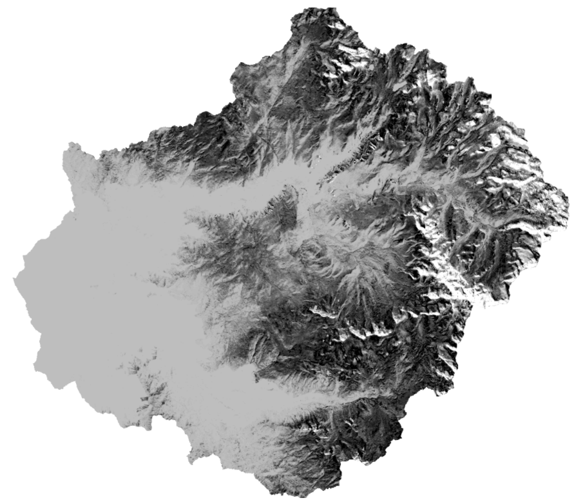

Figure 8. SWE Difference Map — 2023 (March to April)
More gradual melt across elevations; slower loss of SWE.

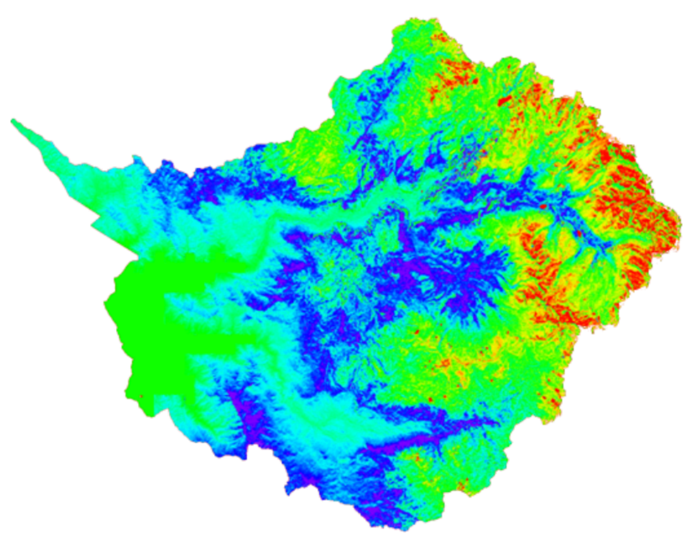

Figure 9. Snowmelt Rate Map — 2022 (Heat Map)
High-intensity melt concentrated in small areas, early peak.

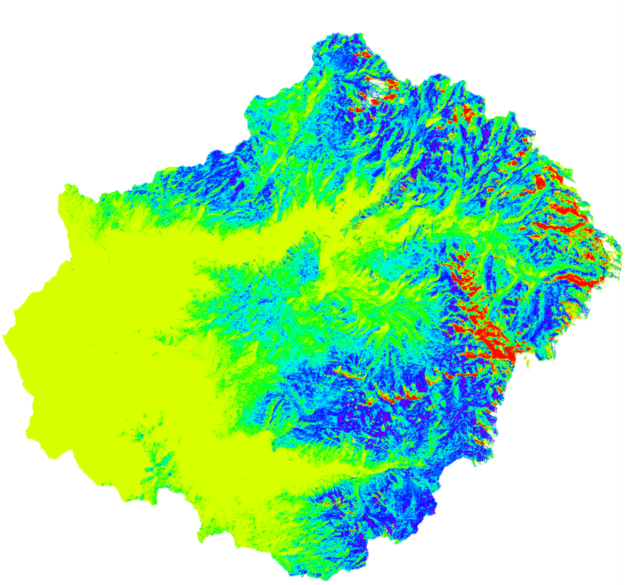

Figure 10. Snowmelt Rate Map — 2023 (Heat Map)
Lower melt intensity sustained across broader regions.

A pie chart summarizing snowmelt rate comparisons reinforces this finding: 2022 had faster melt despite less snow, contributing to a sharper discharge spike downstream.

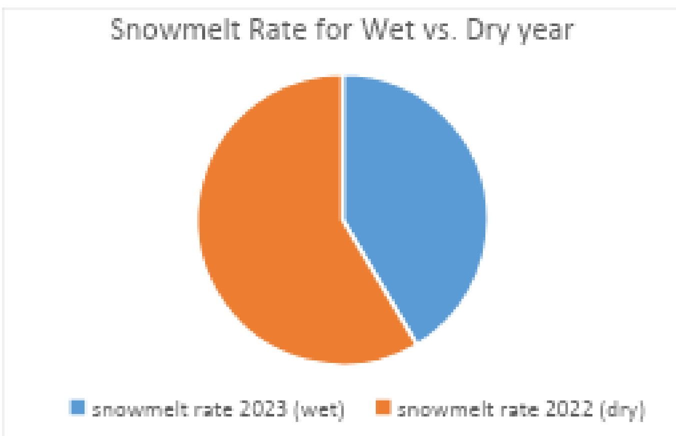

Figure 11. Estimated Snowmelt Rate Comparison — 2022 vs. 2023. Faster melt in 2022 produced short, intense runoff; 2023's slower melt allowed for better flow regulation.

4. Discussion

The results confirm the original hypothesis: faster snowmelt in low-snow years can be just as disruptive as high-snow years with slower melt. The 2022 water year had significantly less snow, but the rate of melt was much more abrupt [1]. Without much snow retained at elevation and with minimal dam release support [4], the system couldn't buffer the sudden runoff, leading to an early, high-risk flow surge [2].

By contrast, 2023 had an extremely high snowpack and more intense precipitation [3], but flow remained relatively stable due to a combination of slower melt and well-timed dam outflows [4]. This regulated response allowed the MST hydrograph to remain elevated but smooth [2].

These observations are built on prior research [5][6] by showing that high-resolution remote sensing, when paired with real-time stream and dam data, offers a useful toolkit for managing snowmelt-driven watersheds in the face of climate extremes.

5. Conclusion

This project shows that snowpack size alone doesn't determine flood risk; the speed of melting and timing of dam releases matter just as much. The dry 2022 year, with minimal snow and little dam regulation, saw a sharp spike in streamflow that dropped off quickly [2][4]. In contrast, the wet 2023 year, though much snowier and wetter [1][3], saw sustained but manageable flow thanks to a slower melt rate and active outflow control [4].

By combining ENVI-based snow depth and SWE data [1], streamflow records from CDEC [2], precipitation totals from NOAA [3], and MID dam operation estimates [4], this project creates a simplified but powerful model of seasonal runoff. These insights underline the importance of integrating remote sensing with hydrological and operational data to build more responsive water management systems in the face of climate change.

6. ACKNOWLEDGMENT

The author would like to thank the University of California, Merced's Environmental Engineering faculty for their guidance throughout this project, as well as the California Data Exchange Center (CDEC), the Airborne Snow Observatory (ASO), NOAA's National Weather Service, and the Merced Irrigation District (MID) for providing openly accessible data resources. Special thanks to Professor Erin Hestir for supporting student use of remote sensing tools and hydrologic analysis techniques.

REFERENCES

[1] Airborne Snow Observatory. "Merced Basin 2022–2023 Snow Depth & SWE Products." NASA JPL. [Online]. Available: https://data.airbornesnowobservatories.com/

[2] California Data Exchange Center (CDEC), "Station MST: Merced River near Stevinson," California Department of Water Resources. [Online]. Available: https://cdec.water.ca.gov/

[3] NOAA National Weather Service, "Merced Area Climate Data Archive," National Centers for Environmental Information (NCEI). [Online]. Available: https://www.ncei.noaa.gov/

[4] Merced Irrigation District. "Water Operations Reports and Irrigation Schedules." [Online]. Available: https://www.mercedid.org/

[5] Mote, P. W., Hamlet, A. F., Clark, M. P., & Lettenmaier, D. P. "Declining mountain snowpack in western North America." *Bulletin of the American Meteorological Society*, vol. 86, no. 1, pp. 39–49, 2005.

[6] Dettinger, M., & Cayan, D. "Drought and the California Delta: A Matter of Extremes." *San Francisco Estuary and Watershed Science*, vol. 12, no. 1, 2014.