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# Changes in Snow Water Equivalent in the Sierra Nevada: A Comparative Analysis of Climate Projections and Modeling Techniques

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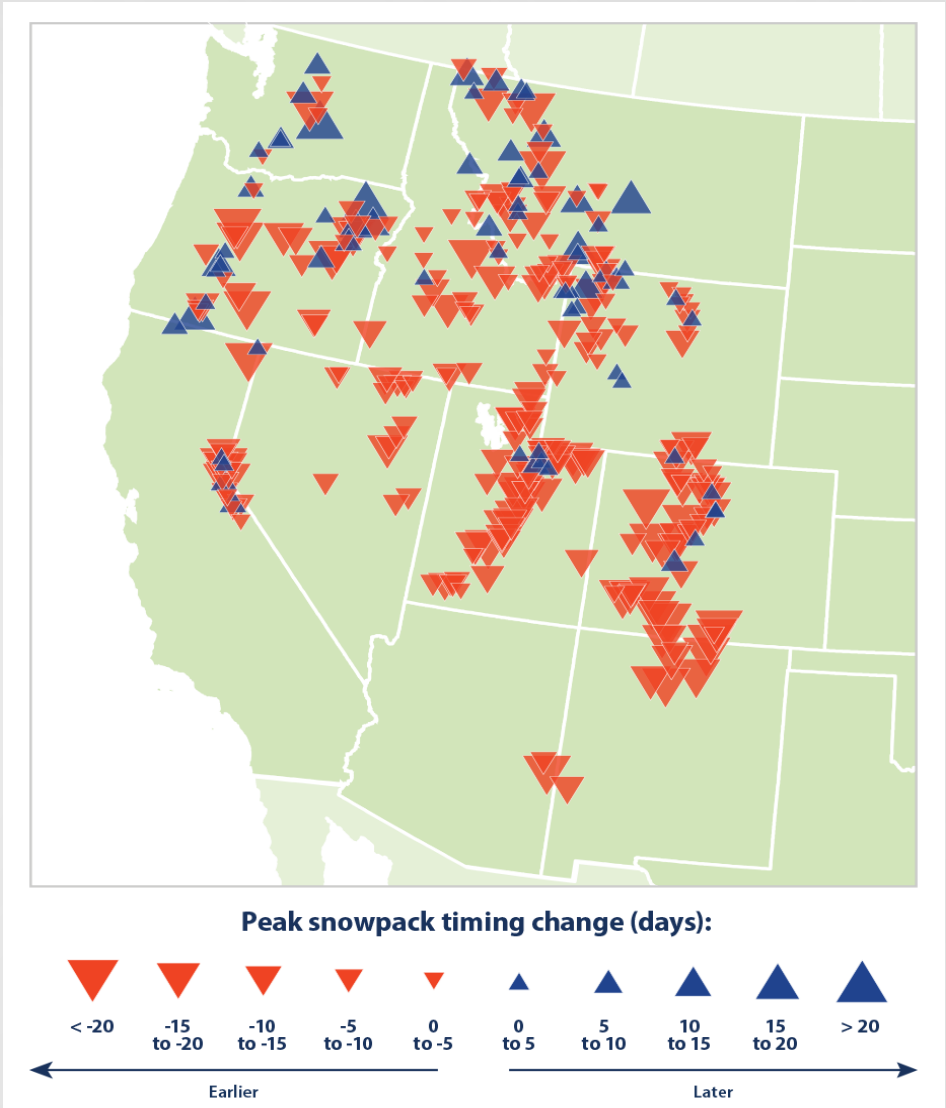
# Introduction

- Mountain snowpack, especially in the Sierra Nevada, is a vital **freshwater reservoir** for the Western U.S., storing winter precipitation and releasing it as **runoff** during spring and summer.

- However, 80% of monitoring sites show a **decline** in **snowpack** and **earlier melt**, reducing summer water availability and increasing the risk of winter flooding.

- This trend is projected to **worsen** throughout the 21st century, with significant **losses** in SWE and **shifts in peak SWE timing**, alters water availability patterns.

- These changes in snowpack dynamics **impact** not only water supply, but also agriculture, ecosystems, recreation, and tourism.




**Change in Peak Snowpack Timing in the Western United States, 1982–2023**

*(https://www.epa.gov/climate-indicators/climate-change-indicators-snowpack#ref5)*

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# Objectives

1. **Evaluate Future SWE Projections:** Examine SWE projections for the Northern and Central Sierra Nevada under future climate conditions, as utilized in the California Department of Water Resources' (DWR) Delivery Capability Report (DCR).

2. **Estimate Changes in Peak Snowpack Timing:** Assess potential shifts in the timing of peak snowpack under future climate scenarios.

3. **Compare Model Outputs:** Compare SWE outputs from the VIC model used in DCR 2023 with results from high-resolution, state-of-the-art climate models (e.g., Beltran-Peña et al., 2024).

# What is SWE

Snow water equivalent is the amount of water contained within the snowpack. It can be thought of as the depth of water that would result if the entire snowpack were to melt.

# Approach

**Step 01: VIC Model simulation (Baseline, LOC50, LOC75, and LOC95)**

**Step 02: Calculating weighted daily SWE for each grid**

**Step 03: Sum the weighted SWE for all the grids for each day**

**Step 04: Daily weighted areal average SWE time series generation**
Compute weighted areal average SWE for each day across the entire region. Timespan: 100 years

**Step 05: Identifying the maximum weighted areal average SWE and corresponding date for each water year**

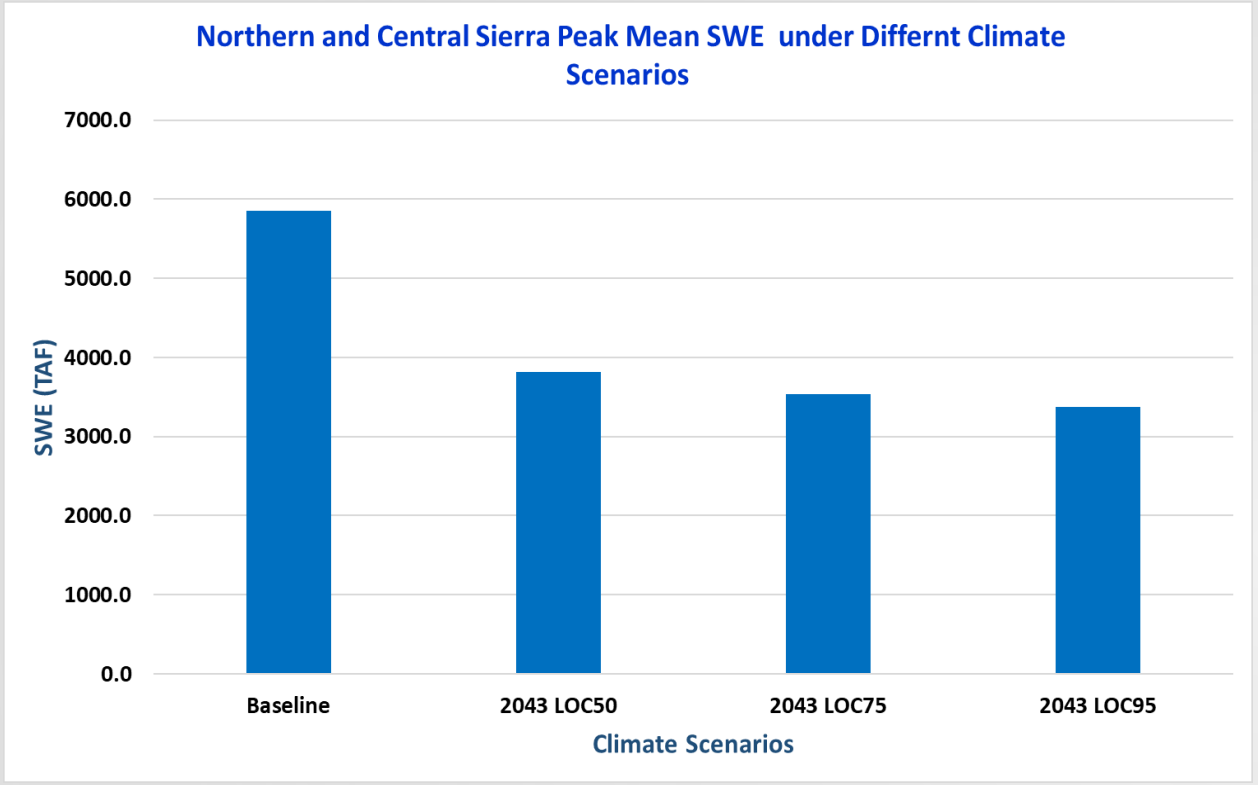
**Step 06: Peak mean SWE calculation**

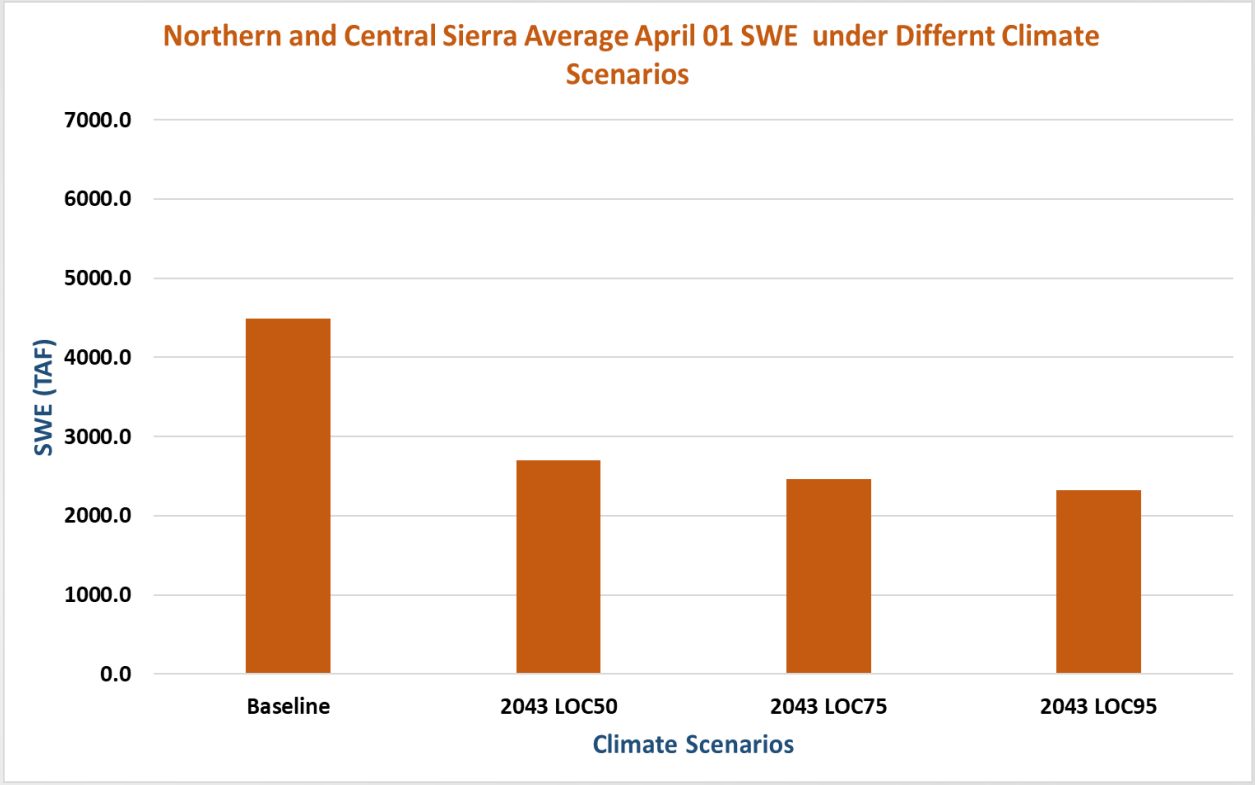
**Step 07: Estimation of April 01 average SWE**

# Climate Change Scenarios Used in DCR 2023

| Climate Change Scenarios (Level of Concern Percentile) | 2043 Change in Temperature | 2043 Change in Precipitation | 2043 Precipitation Intensification |
|---|---|---|---|
| 50th | 1.5° C | +1.5% | 11% |
| 75th | 1.7° C | +0.1% | 12% |
| 95th | 1.8° C | -1.8% | 13% |

# Change in SWE in the Northern and Central Sierra under different Climate Change Scenarios




| Scenarios | Northern and Central Sierra Mean Peak SWE (TAF) | Northern and Central Sierra Average April 01 SWE (TAF) | Change in Peak Mean SWE (TAF) | Change in Average April 01 SWE (TAF) |
|---|---|---|---|---|
| Baseline | 5852.9 | 4492.5 | | |
| 2043 LOC50 | 3820.0 | 2701.9 | -2033.0 | -1790.6 |
| 2043 LOC75 | 3534.0 | 2459.0 | -2318.9 | -2033.5 |
| 2043 LOC95 | 3377.8 | 2325.7 | -2475.1 | -2166.8 |

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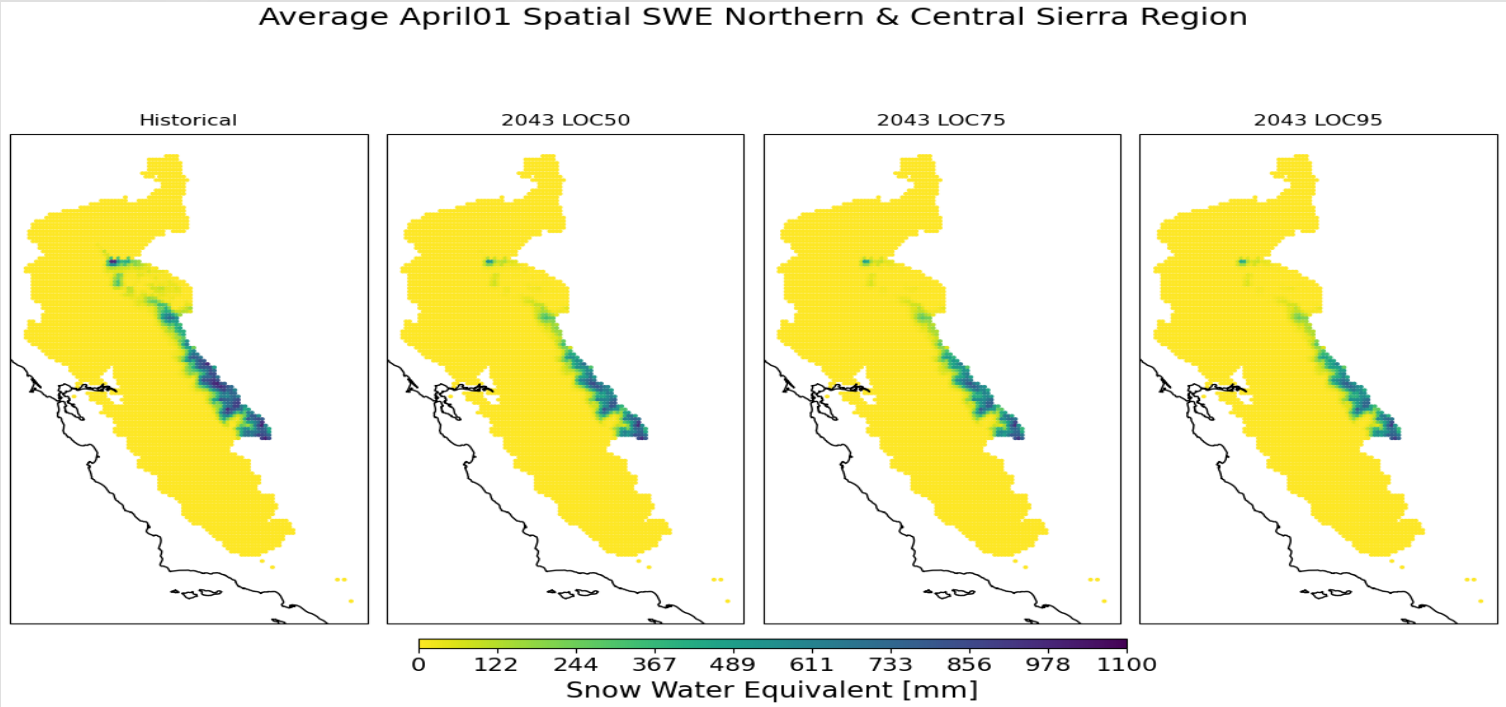
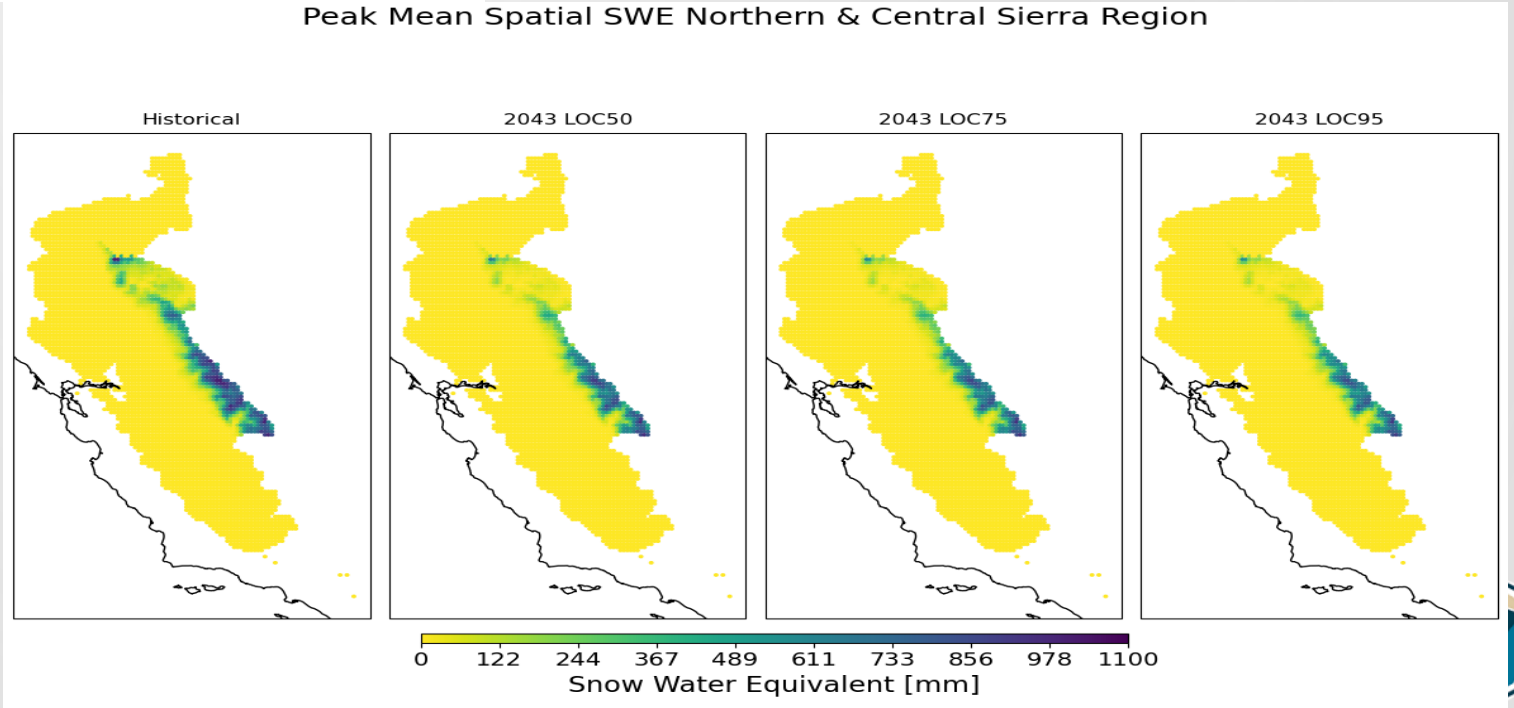
# Comparison of Average April 01 SWE vs. Peak Mean SWE across All Climate Change Scenarios

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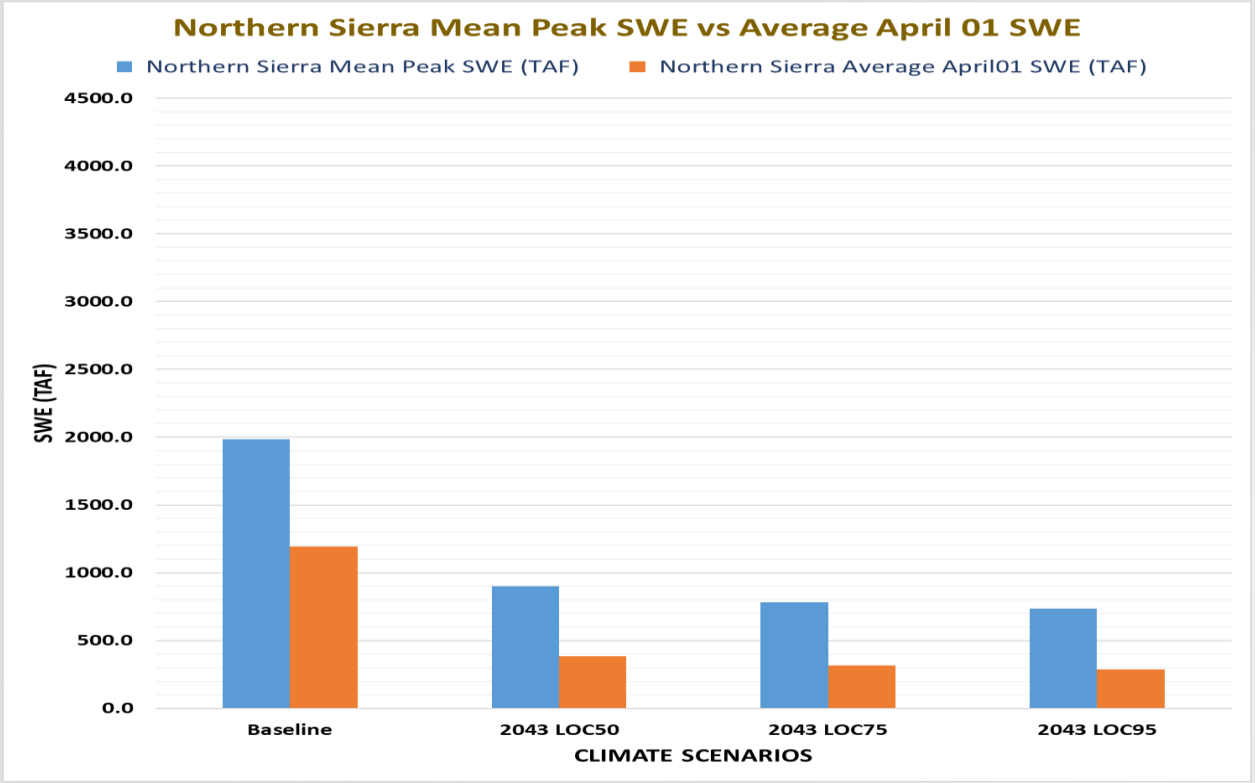
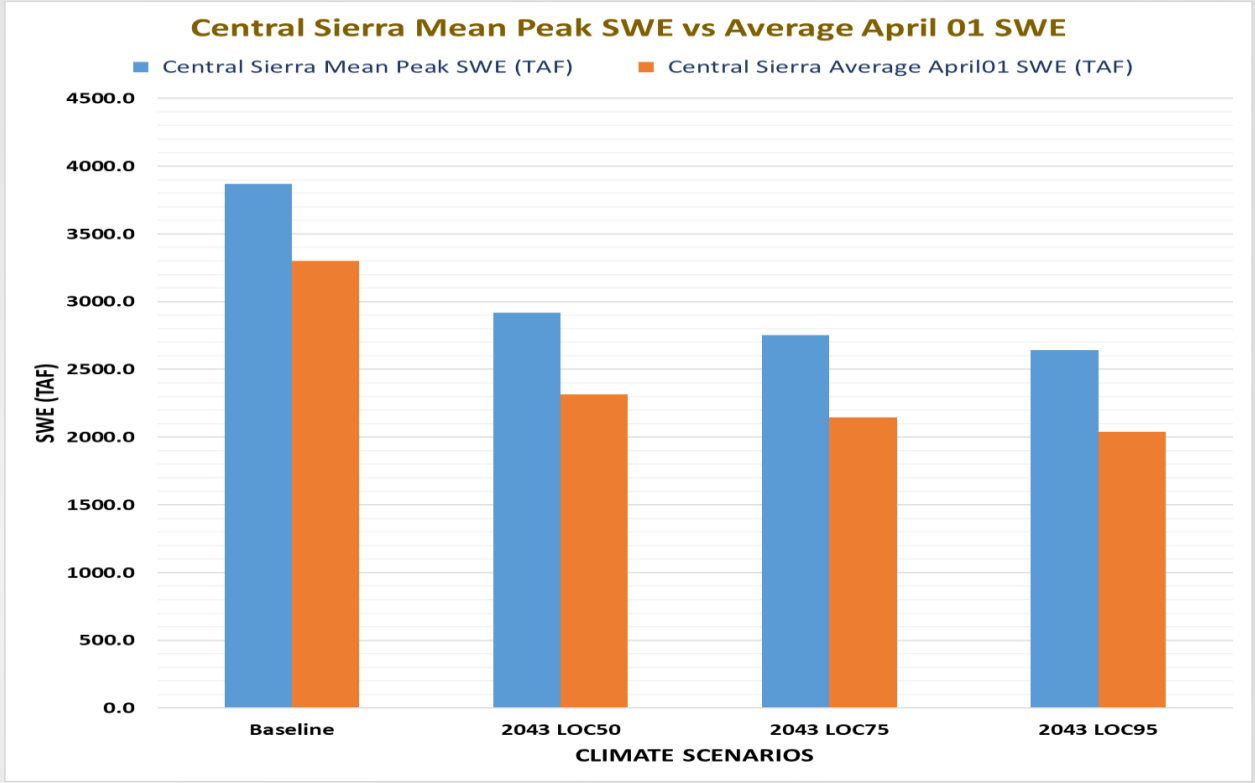
# Average April 01 SWE vs. Peak Mean SWE for different Climate Change Scenarios




| Scenarios | Northern Sierra Mean Peak SWE (TAF) | Northern Sierra Average April01 SWE (TAF) | Change (TAF) |
|---|---|---|---|
| Baseline | 1985 | 1194 | -791 |
| 2043 LOC50 | 901 | 385 | -515 |
| 2043 LOC75 | 783 | 315 | -468 |
| 2043 LOC95 | 736 | 285 | -450 |

| Scenarios | Central Sierra Mean Peak SWE (TAF) | Central Sierra Average April01 SWE (TAF) | Change (TAF) |
|---|---|---|---|
| Baseline | 3868 | 3298 | -570 |
| 2043 LOC50 | 2919 | 2317 | -603 |
| 2043 LOC75 | 2751 | 2144 | -607 |
| 2043 LOC95 | 2642 | 2040 | -602 |

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# Trend of SWE Change in the Northern and Central Sierra Under Climate Change Scenarios

| Regions | April 1st SWE (km3) | | April 1st SWE % Change | | Peak Mean SWE (km3) | | Peak Mean SWE % Change | |
|---|---|---|---|---|---|---|---|---|
| | B.-P. et al | DCR 2023 | B.-P. et al | DCR 2023 | B.-P. et al | DCR 2023 | B.-P. et al | DCR 2023 |
| **Historical (1984 - 2005)** | | | | | | | | |
| **Northern+Central** | 3.6 | 5.30 | | | 9.8 | 7.31 | | |
| **Northern Sierra** | 0.9 | 1.47 | | | 4.1 | 2.74 | | |
| **Central Sierra** | 2.7 | 3.83 | | | 5.7 | 4.57 | | |
| **(+)1.5degC for Both Studies** | | | | | | | | |
| **Northern+Central** | 2.0 | 3.33 | -44% | -37% | 5.9 | 4.71 | -40% | -36% |
| **Northern Sierra** | 0.3 | 0.48 | -67% | -67% | 2.4 | 1.11 | -41% | -59% |
| **Central Sierra** | 1.7 | 2.85 | -37% | -26% | 3.5 | 3.6 | -39% | -21% |
| **(+)2degC (paper) vs (+) 1.7 degC (DCR 2023)** | | | | | | | | |
| **Northern+Central** | 1.5 | 3.03 | -58% | -43% | 5.0 | 4.36 | -49% | -40% |
| **Northern Sierra** | 0.2 | 0.39 | -78% | -73% | 2.0 | 0.97 | -51% | -65% |
| **Central Sierra** | 1.3 | 2.64 | -52% | -31% | 3.0 | 3.39 | -47% | -26% |
| **(+)3degC (paper) vs (+) 1.8 degC (DCR 2023)** | | | | | | | | |
| **Northern+Central** | 0.8 | 2.86 | -78% | -46% | 3.4 | 4.17 | -65% | -43% |
| **Northern Sierra** | 0.0 | 0.35 | -100% | -76% | 1.2 | 0.91 | -71% | -67% |
| **Central Sierra** | 0.8 | 2.51 | -70% | -34% | 2.2 | 3.26 | -61% | -29% |

# Summary

## Decline in SWE

The study indicate significant declines in **April 1st SWE** as well as **Peak Mean SWE** across the Sierra Nevada, particularly under higher emissions scenarios.

## Shift in Peak SWE Timing

The timing of peak snowpack is projected to **shift away from the historical April 01 benchmark**, indicating a change in the seasonal distribution of runoff.

## Regional Differences

While both the Northern and Central Sierra show SWE decline, **the Northern Sierra exhibits greater losses** in both April 1 SWE and Peak Mean SWE—indicating higher vulnerability in that subregion.

## Model Agreement with Variations

While VIC and high-resolution models agree on general SWE decline trends, magnitude and spatial variability differ.