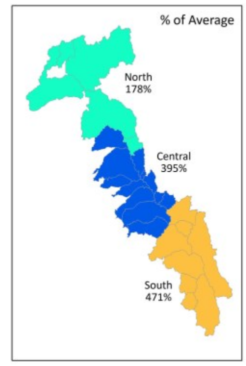
Real-Time Spatial Estimates of Snow-Water Equivalent (SWE)

Sierra Nevada Mountains, California
May 30, 2023



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Summary of current conditions

The regional summary map above shows the mean SWE above 5000' elevation for three major regions of the Sierra Nevada, percent of average is calculated from a long-term average of 2001-2021. As of May 30, percent of average SWE is highest in the south (471%), then central (389%) and lowest in the north (178%). This snow year has produced sporadic percent of averages, especially in low-elevation areas, and will be higher than historical averages. **NEW this year, scroll down for comparison maps of CU SWE versus ASO SWE**. Detailed SWE maps (in JPG format) and summaries of SWE (in Excel format) by individual basin and elevation band accompany the report and are publicly available on our website **here**.

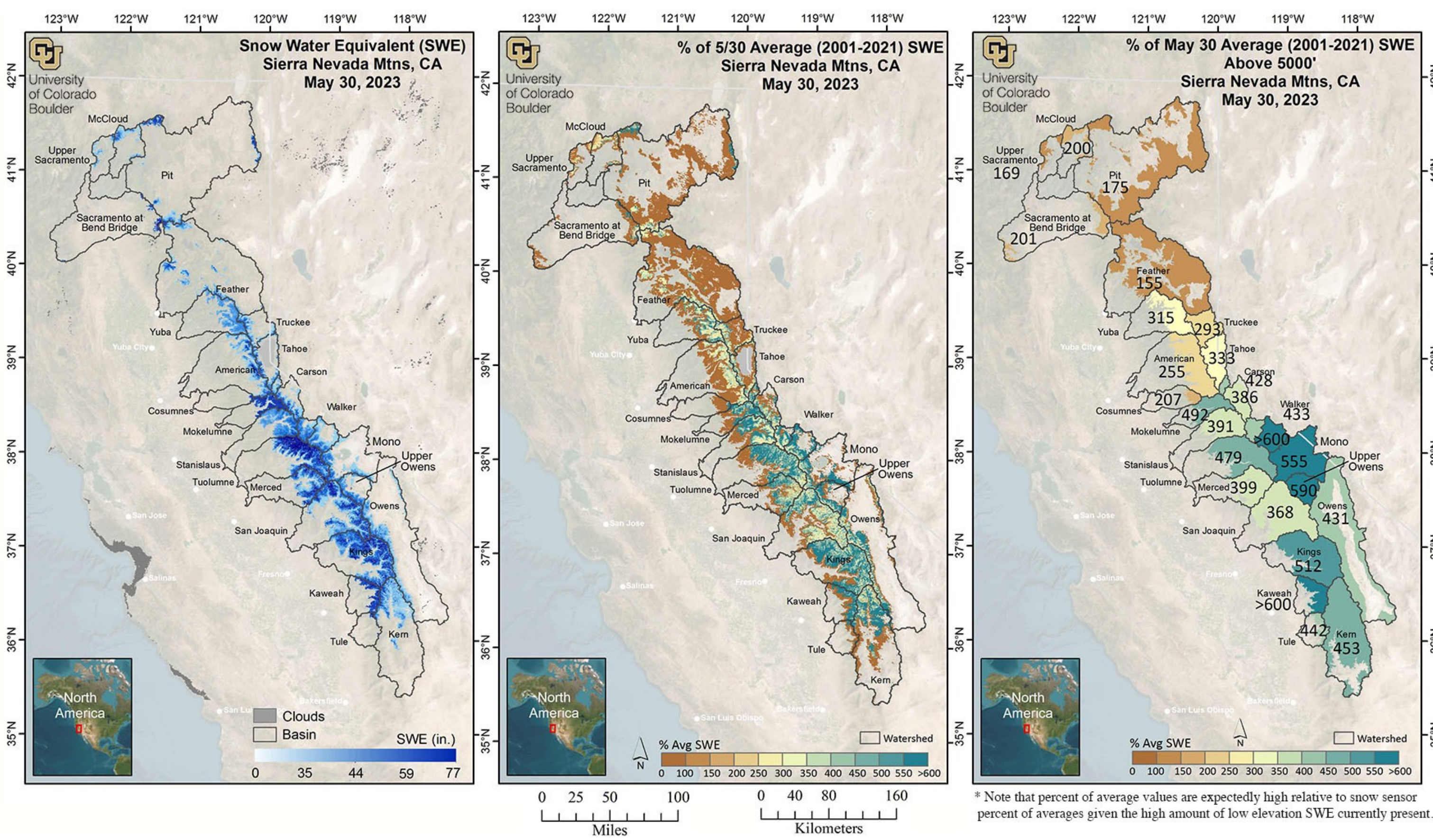

Figure 1. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts for May 30, 2023 (left), and percent of average (2001-2021) SWE for May 30, 2023 for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

Location of Reports and Excel Format Tables

https://www.colorado.edu/instaar/research/labs-groups/mountain-hydrology-group/sierra-nevada-swe-reports

About this report

This is an experimental research product that provides near-real-time estimates of snow-water equivalent (SWE) at a spatial resolution of 500 m for the Sierra Nevada in California from mid-winter through the melt season. The report is typically released within a week of the date of data acquisition at the top of the report. A similar report covering the Intermountain West is available and is distributed to water managers in Colorado, Utah and Wyoming.

The spatial SWE analysis method for the Sierra Nevada uses the following data as inputs:

- In-situ SWE from all operational CA and NV snow pillow sensor sites and CoCoRaHS SWE values when available and applicable
- MODSCAG fractional snow-covered area (fSCA) data from recent cloud-free MODIS satellite images
- Physiographic information (elevation, latitude, upwind mountain barriers, slope, etc.)
- Historical daily SWE patterns (1985-2016) retrospectively generated using historical MODSCAG data and an energy-balance model that back-calculates SWE given the fSCA time-series and meltout date for each pixel.
- Satellite-observed daily mean fractional snow-covered area (DMFSCA).

For more details on the estimation method see the *Methods* section below. Please be sure to read the *Data Issues / Caveats* section for a discussion of persistent challenges or flagged uncertainties of the SWE product.

Data availability for this report

87 snow pillow sites in the Sierra Nevada network were recording SWE values out of a total of 128 sites, 41 were offline, and 24 were recording zero (shown in black, red and yellow, respectively, in Figure 5, left map).

The value of spatially explicit estimates of SWE

Snowmelt makes up the large majority (~60-85%) of the annual streamflow in the Sierra Nevada. The spatial distribution of snow-water equivalent (SWE) across the landscape is complex. While broad aspects of this spatial pattern (e.g., more SWE at higher elevations and on north-facing exposures) are fairly consistent, the details vary a lot from year to year, influencing the magnitude and timing of snowmelt-driven runoff.

SWE is operationally monitored at over a hundred and thirty snow pillow sensor sites spread across the Sierra Nevada, providing a critical first-order snapshot of conditions, and the basis for runoff forecasts from the CA DWR, NRCS, and NOAA. However, conditions at snow pillow sites (e.g., percent of normal SWE) may not be representative of conditions in the large areas between these point measurements, and at elevations above and below the range of the sensor sites. The spatial snow analysis creates a detailed picture of the spatial pattern of SWE using snow sensors, satellite, and other data, extending beyond the snow sensor sites to unmonitored areas.

Interpreting the spatial SWE estimates in the context of snow pillows

The spatial product estimates SWE for every pixel where the MODSCAG product identifies snow-cover. Comparatively, snow sensor samples 8-20 points per basin within a narrower elevation range. Thus, the basin-wide percent of average from the spatial SWE estimates is not directly comparable with the snow sensor basin-wide percent of average. A better comparison might be made with the % of average in the elevation bands (Table 2) that contain snow sensor sites.

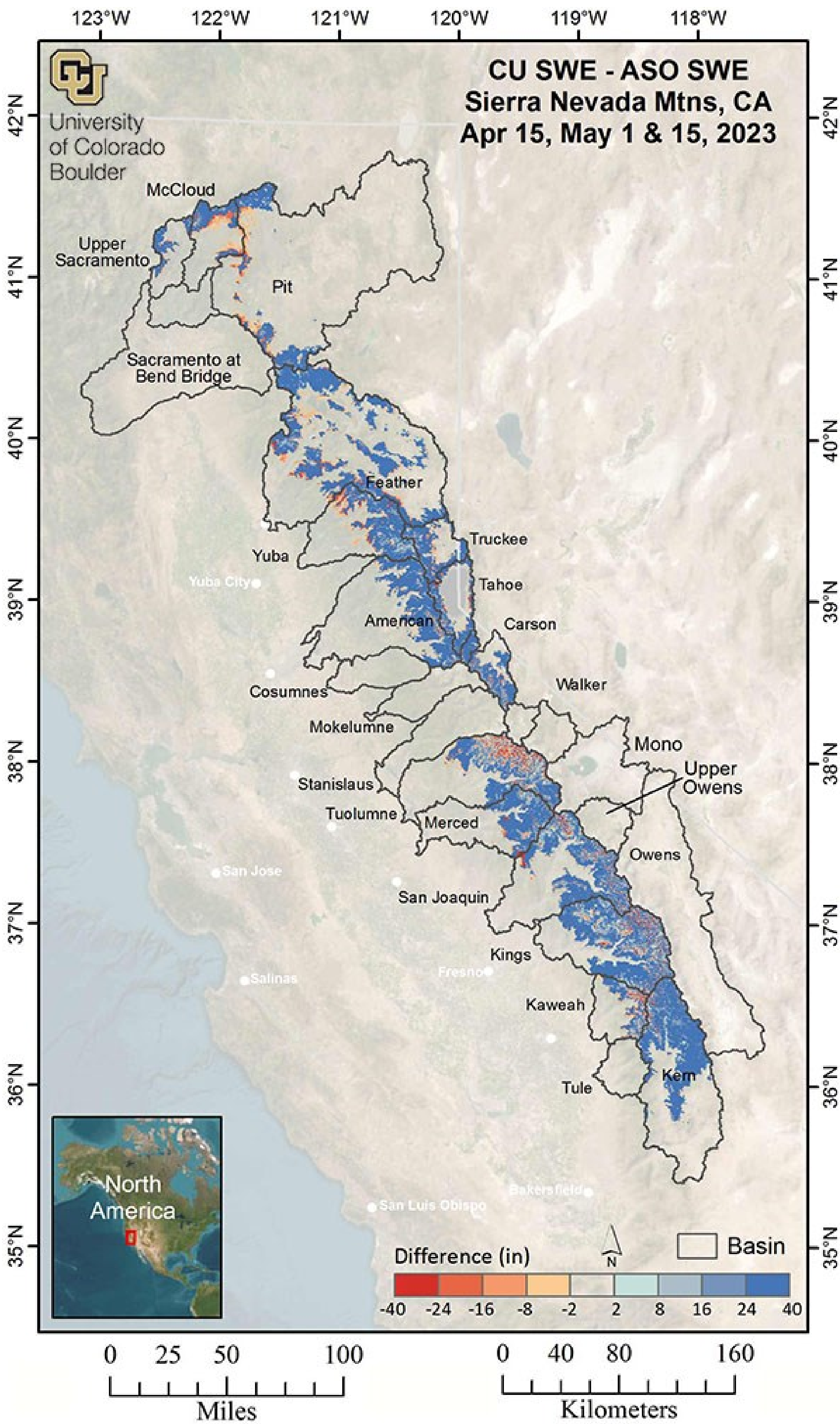

Figure 2. Comparison to ASO, Sierra Nevada. The difference in SWE amounts between the April 15 and May 1 and 15, 2023 CU SWE model run and Airborne Snow Observatories (ASO) lidar-derived SWE are shown for available basins. Red colors show where CU SWE is lower than ASO SWE and blue colors show where CU SWE is higher than ASO SWE. The CU SWE model runs are only for areas above 5000’, so any snow imaged by ASO below 5000’ will show up as light red colors. This map will be updated as new ASO data becomes available.

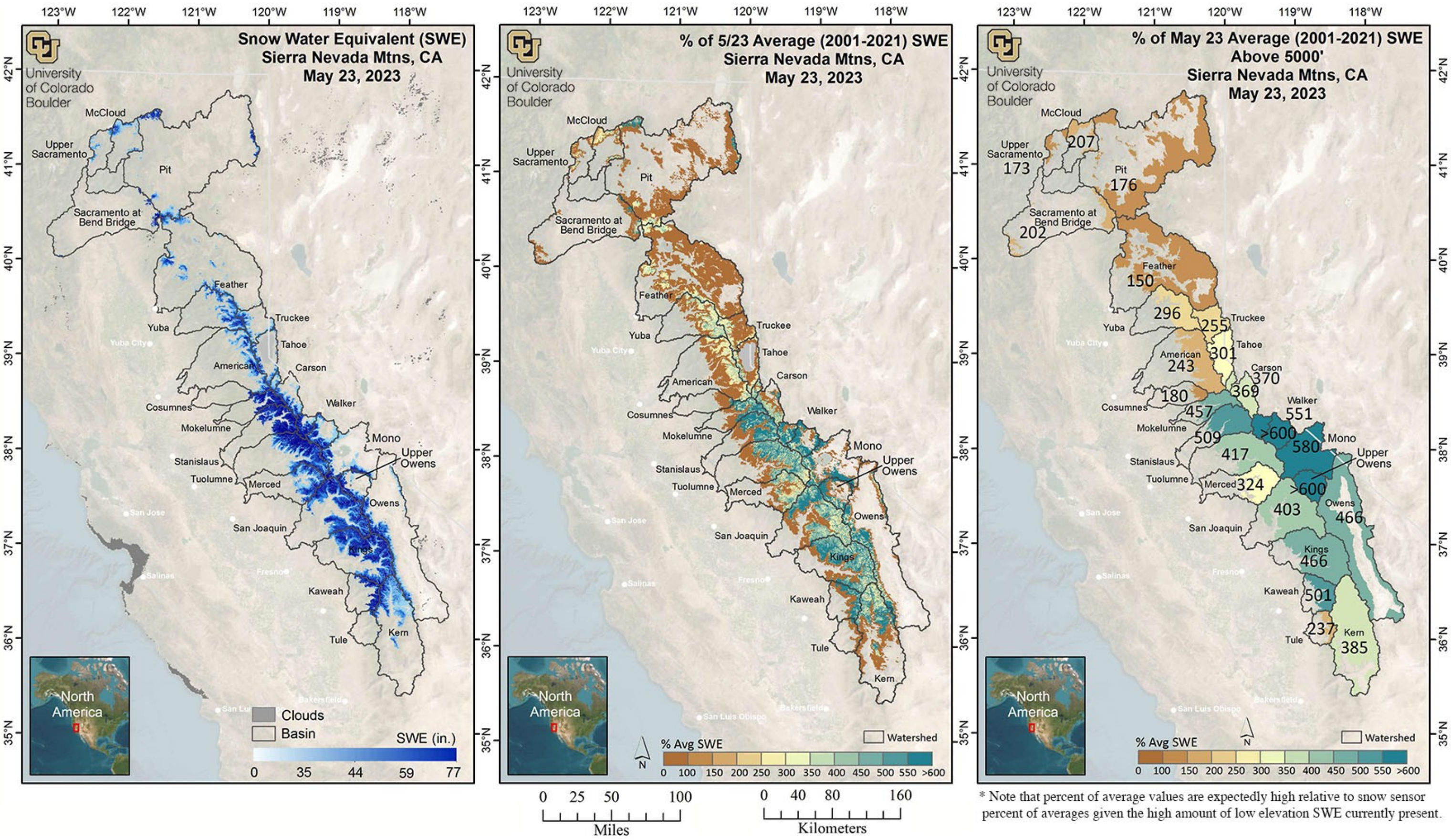

Figure 3. Estimated SWE and % of Average SWE across the Sierra Nevada. SWE amounts for May 23, 2023 (left), and percent of average (2001-2021) SWE for May 23, 2023 for the Sierra Nevada, calculated for each pixel (middle) and basin-wide (right). Basin-wide percent of average is calculated across all model pixels >5000' elevation.

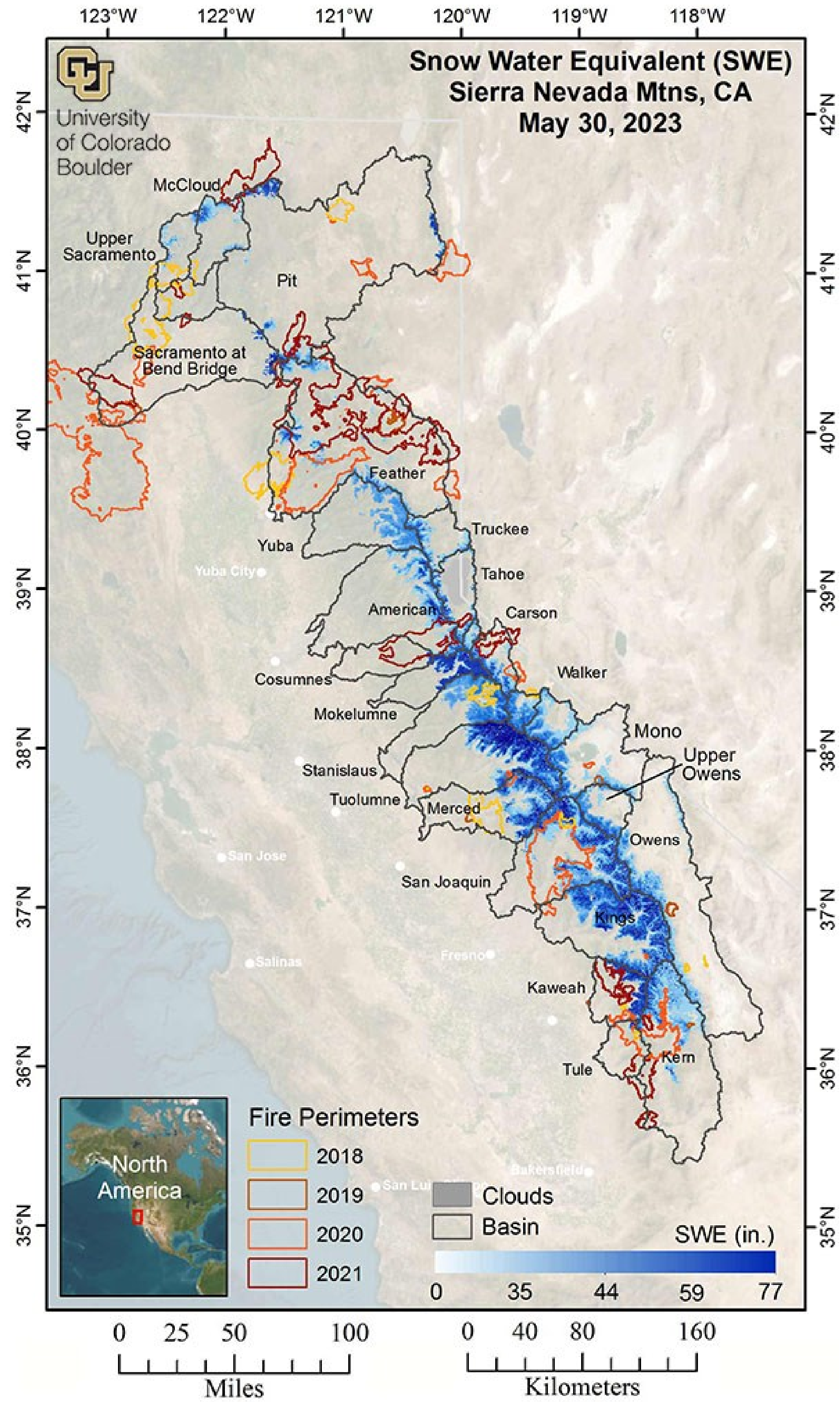

Figure 4. Estimated SWE with Fire Perimeters, Sierra Nevada. SWE amounts for May 30, 2023 are shown with fire perimeters from 2018-2021 (colored from yellow to red).

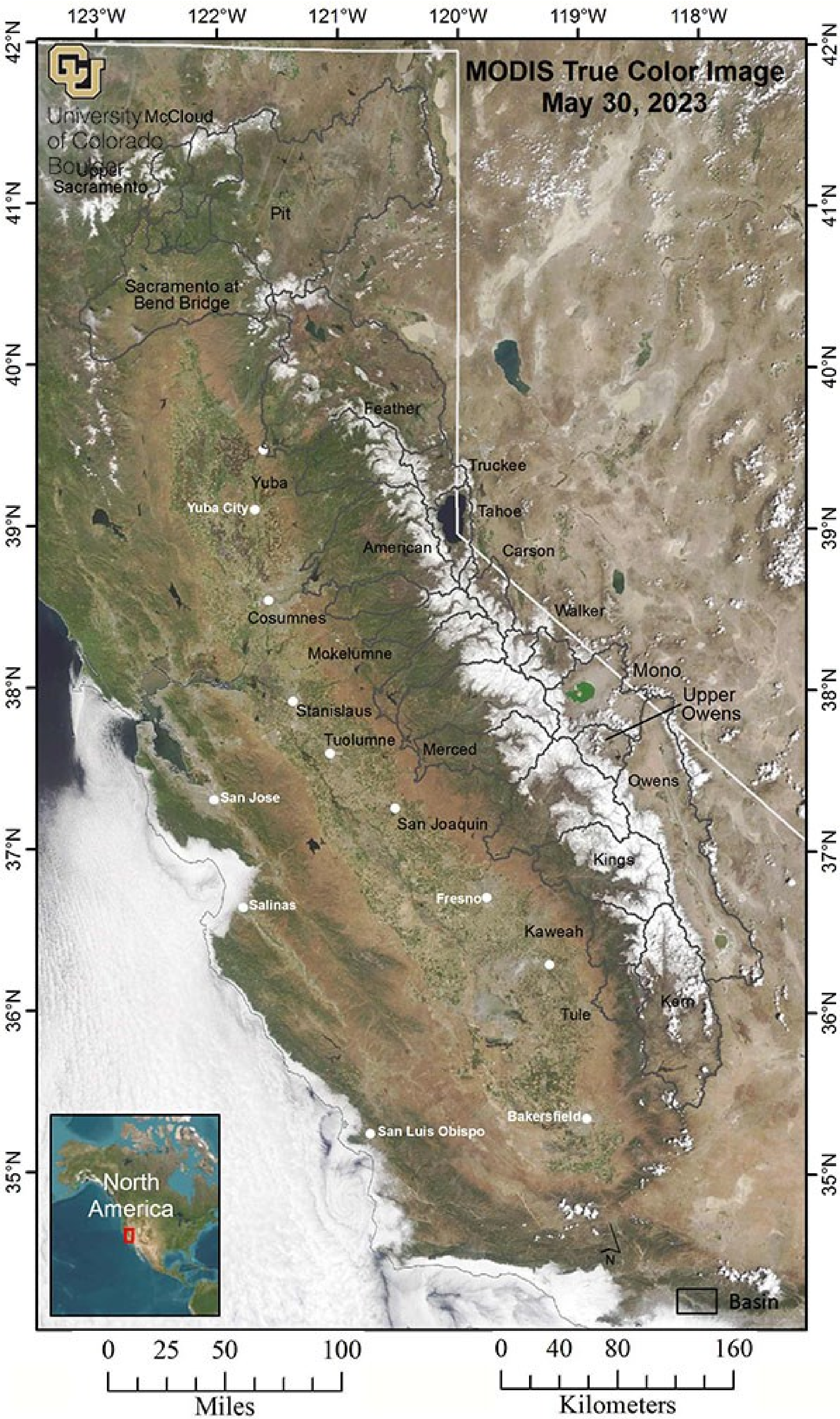

Figure 5. MODIS image, Sierra Nevada. A mostly cloud-free true color MODIS image, showing the image that used for the May 30, 2023 regression model run.

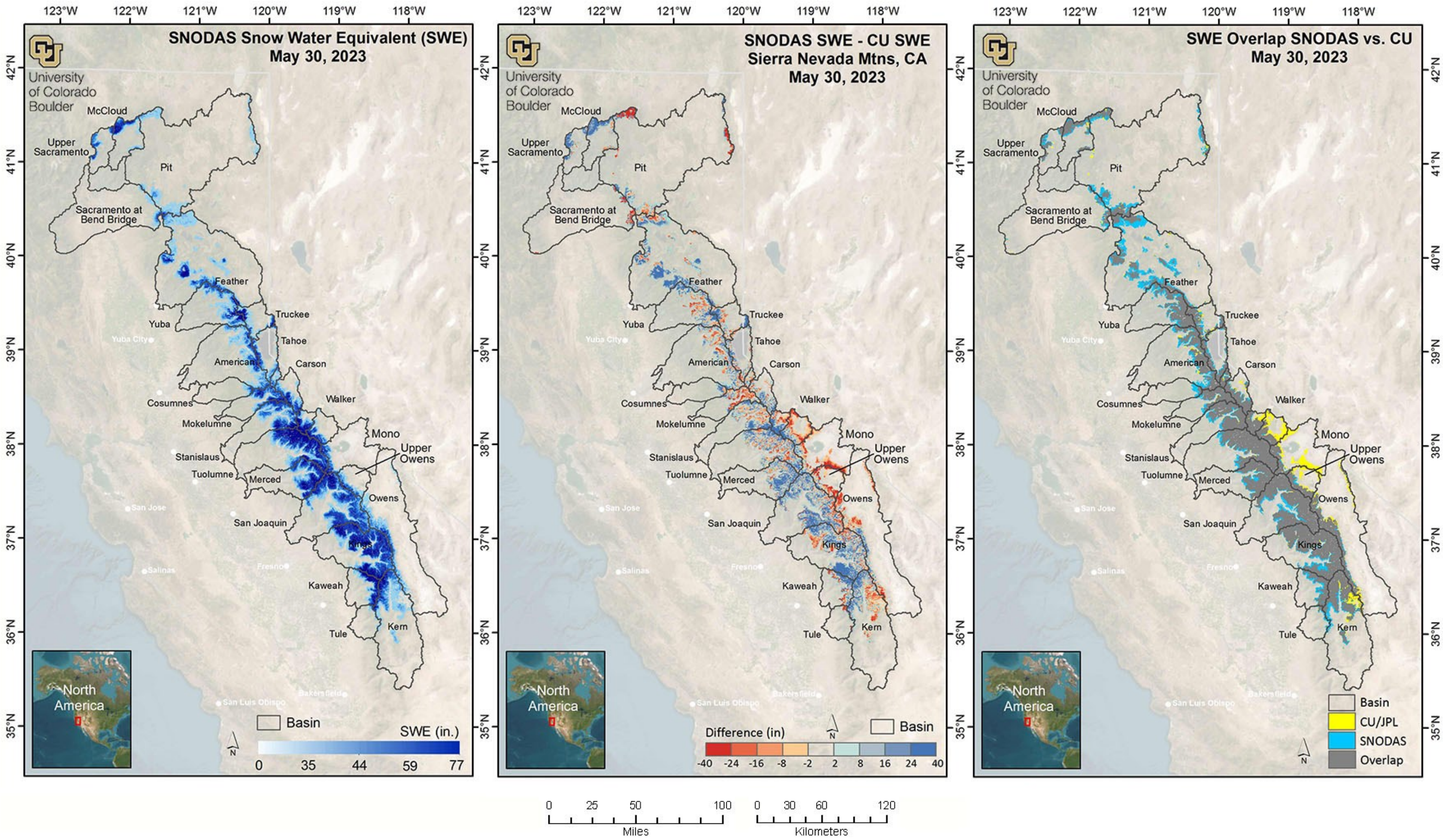

Figure 6. Comparison of CU regression SWE product and SNODAS SWE for the Sierra Nevada. The map on the left shows estimated SWE for May 30th from the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) SNOw Data Assimilation System (SNODAS). The middle map shows the difference between the May 30th SNODAS SWE estimate and CU regression SWE estimate. Red pixels denote areas where SNODAS SWE is less than CU SWE and blue pixels show areas where SNODAS SWE is higher than CU SWE. Light blue areas in low elevations are below 5000' where the CU SWE model doesn't calculate SWE estimates. The map on the right shows the snow-cover extent of SNODAS and CU SWE estimates. Yellow pixels show where the location of CU snow extends beyond the location of the SNODAS snow extent. Blue pixels show where the SNODAS snow extends beyond the CU snow extent. Gray areas indicate regions where both products agree on the snow-cover extent.

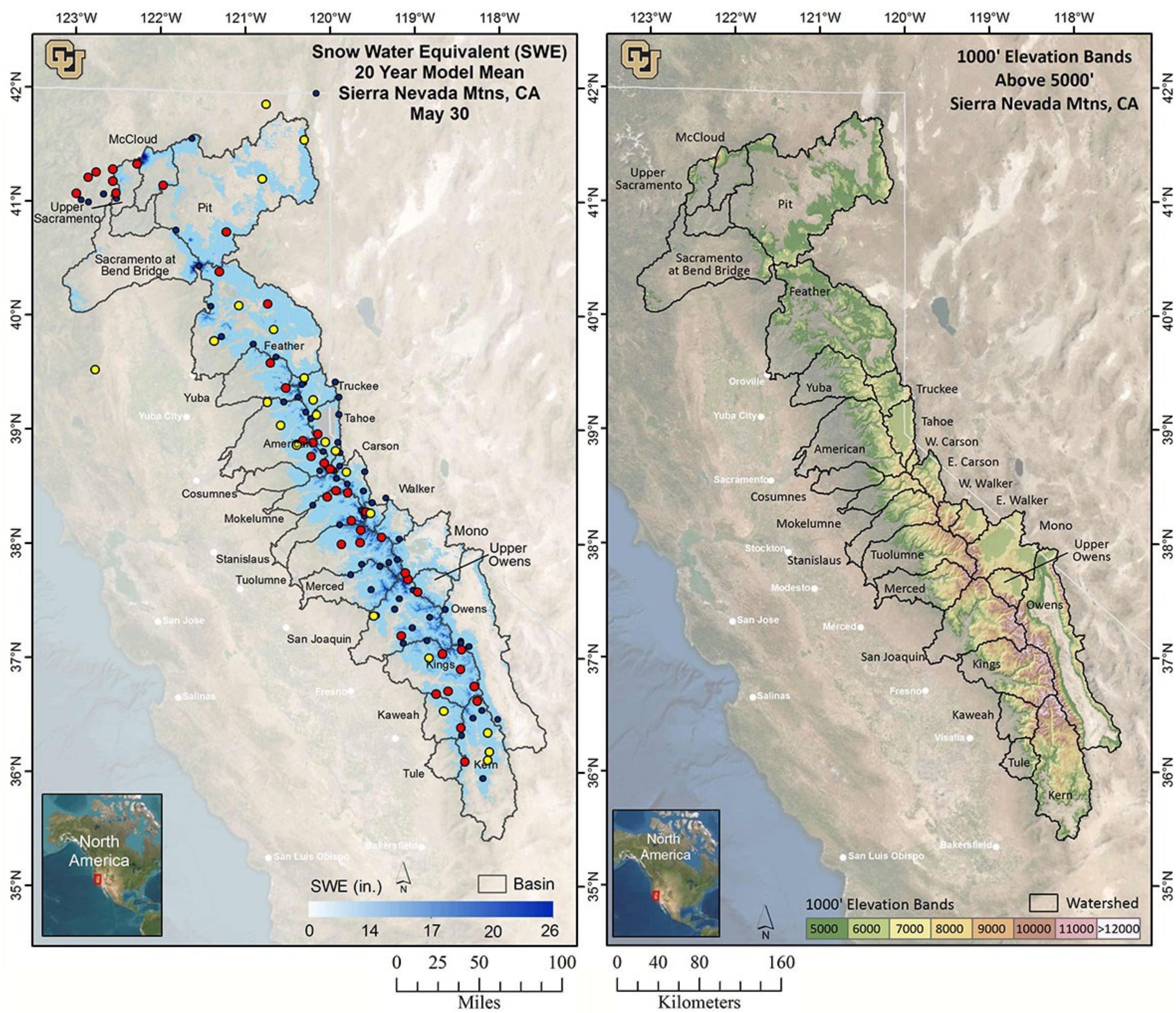

Figure 7. Historical average May 30th and Elevation Bands for the Sierra Nevada. Average SWE (2001-2021) for May 30th (left), and the Banded Elevation map (right) identifies basins used in this report (black boundaries) and 1000' elevation bands (colored shading) that match those used in Table 1 and Table 2. Map on left shows snow pillow sensor sites recording SWE on May 30th (black), sites that were offline are shown in red, and sites recording zero are shown in yellow. CoCoRaHS observations are shown in green. Note the average SWE map is using a different color ramp than the modeled SWE map shown in Figure 1.

Methods

The spatial SWE estimation method is described in Yang, et al. (2022) and Schneider and Molotch (2016). The method uses linear regression in which the dependent variable is derived from the operationally measured in situ SWE from all online snow pillow sensor sites in the domain. The snow pillow sensor SWE observations are scaled by the fractional snow-covered area (fSCA) across the 500 m pixel containing that snow pillow sensor site before being used in the linear regression model. The fSCA is a combination of a near-real-time cloud-free MODIS satellite image which has been processed using the MODIS Snow Cover and Grain size (MODSCAG) fractional snow-covered area algorithm program (Painter, et al. 2009) and the Snow Today fSCA image when necessary (Rittger, et al. 2019, https://nsidc.org/snow-today).

The following independent variables (predictors) enter into the linear regression model:

- Physiographic variables that affect snow accumulation, melt, and redistribution, including elevation, latitude, upwind mountain barriers, slope, and others. See Table 1 in Yang, et al. (2022) for the full set of these variables.
- The historical daily SWE pattern (1985-2016) retrospectively generated using historical MODSCAG data, and an energy-balance model that back-calculates SWE given the fractional Snow-Covered Area (fSCA) time series and meltout date for

each pixel. See Margulis, et al. (2016) for details. (For computational efficiency, only one image during the 1985-2016 period that best matches the real-time snow pillow-observed pattern is selected as an independent variable.)

- Satellite-observed daily mean fractional snow-covered area (DMFSCA) derived from Rittger, et. al., 2019 data.

The real-time regression model for this date has been validated by cross-validation, whereby 10% of the snow pillow data are randomly removed and the model prediction is compared to the measured value at the removed snow pillow stations. This is repeated 30 times to obtain an average R-squared value, which denotes how closely the model fits the snow pillow data. During development of this regression method, the model was also validated against independent historical SWE data collected in snow surveys at 9 locations in Colorado, and an intensive field survey in north-central Colorado. Data utilized to generate this report change to optimize model performance. To maintain consistency across the historical record, the percent of average values are based on our baseline algorithm and therefore there can be discrepancies between absolute SWE values and corresponding percent of averages.

Data Issues/Caveats for* May 30, 2023 *– IMPORTANT – READ THIS!

- ANOMALOUS SNOW PATTERNS – Anomalous snow years or snow distributions may cause SWE error due to the model design to search for similar SWE distributions from previous years. If no close seasonal analogue exists, the model is forced to find the most similar year, which may result in error.
- PERCENT OF AVERAGE CALCULATIONS - Data utilized to generate this report change to optimize model performance. To maintain consistency across the historical record, the percent of average values are based on our baseline algorithm and therefore there can be discrepancies between absolute SWE values and corresponding percent of averages.
- MODELING METHODS - We work to generate the best SWE estimates for each reporting date. Our methods can change from one report to another. Sometimes data changes between reports is an artifact of method changes.
- MISSING SWE VALUES - Data omitted due to inconsistencies with independent SWE estimates.
- CLOUD COVER – Cloud cover can obscure satellite measurements of snow-cover. While careful checks are made, occasionally the misclassification of clouds as snow or *vice versa* may result in the mischaracterization of SWE or bare-ground.

List of All Known Data Issues/Caveats

- NEW AVERAGE CALCULATIONS – Average calculations are based on 2001-2021 model values, this includes the drought years (2012-2016) which brings our overall average SWE down considerably, thereby increasing percent of averages.
- RECENT SNOWFALL – There are occasionally problems with lower-elevation SWE estimates due to recent snowfall events that result in extensive snow-cover extending to valley locations where measurements are not available. This scenario results in an over-estimation of lower- elevation SWE.
- LIMITED SNOW PILLOW DATA – When snow at the snow pillow sites melts out, but remains at higher elevations, the model tends to underestimate SWE at the under-monitored upper elevations. This issue typically occurs late in the melt season, resulting in less accurate SWE prediction at higher elevations compared to earlier in the snow season.
- CLOUD COVER – Cloud cover can obscure satellite measurements of snow-cover. While careful checks are made, occasionally the misclassification of clouds as snow or *vice versa* may result in the mischaracterization of SWE or bare-ground.
- LOW LOOK ANGLE – When a satellite does not pass directly over a region but the area is still included within the satellite sensor's field of view, this is referred to as a low "look angle". The resulting image has lower effective resolution – this "blurry" MODSCAG data still contains useful information but may lead to overestimation of SWE near the margins of the snow-cover extent.
- POOR QUALITY SNOW SENSOR DATA – Although data QA/QC is performed, occasional sensor malfunction may result in localized SWE errors.
- ANOMALOUS SNOW PATTERNS – Anomalous snow years or snow distributions may cause SWE error due to the model design to search for similar SWE distributions from previous years. If no close seasonal analogue exists, the model is forced to find the most similar year, which may result in error.
- DENSE FOREST COVER – Dense forest cover at lower elevations where snow-cover is discontinuous can cause the satellite to underestimate the snow-cover extent, leading to underestimation of SWE.
- MISSING SWE VALUES - Data omitted due to inconsistencies with independent SWE estimates.
- PERCENT OF AVERAGE CALCULATIONS - Data utilized to generate this report change to optimize model performance. To maintain consistency across the historical record, the percent of average values are based on our baseline algorithm and therefore there can be discrepancies between absolute SWE values and corresponding percent of averages.
- MODELING METHODS - We work to generate the best SWE estimates for each reporting date. Our methods can change

from one report to another. Sometimes data changes between reports is an artifact of method changes.

Table 1. Estimated SWE by basin. *The basin-wide SWE values and averages, are across all pixels at elevations >5000'. Shown are May 23rd percent of May 23rd average SWE, May 30th percent of May 30th average SWE (between 2001-2021 as derived from the regression model), May 23rd mean SWE, May 30th mean SWE, May 30th percent of snow-covered area, May 30th water volume (acre-feet), the area (mi²) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), May 23rd snow pillow data, and May 30th snow pillow data for those areas collected, summarized for each basin. The last column shows May 30th mean SWE from SNODAS*.*

Basin	5/23/23 % 5/23 Avg.	5/30/23 % 5/30 Avg.	5/23/23 SWE (in)	5/30/23 SWE (in)	5/30/23 % SCA	5/30/23‡ Vol (af)	Area (mi2) > 5000'	5/23/23 Pillows	5/30/23 Pillows	5/30/23 SNODAS* (in)
Upper Sacramento§	173	169	17.3	14.6	65.1	99,287	127.8	16.0 (1)	8.7 (1)	30.3
McCloud§	207	200	21.6	19.1	74.5	181,003	178.0	NA	NA	36.8
Pit§	176	175	4.2	3.8	10.8	461,321	2286.8	14.0 (4)	9.3 (4)	3.0
Sac at Bend Bridge	202	201	13.1	11.7	22.8	151,782	243.8	NA	NA	8.6
Feather§	150	155	5.8	4.9	16.9	593,976	2,267.8	29.3 (5)	16.5 (5)	9.4
Yuba§	296	315	24.3	21.0	64.7	620,383	554.0	42.8 (2)	34.3 (2)	27.4
American§	243	255	16.9	14.5	48.4	654,001	847.8	23.7 (10)	14.8 (8)	16.9
Cosumnes	180	207	7.9	7.0	14.1	35,326	94.3	NA	NA	11.8
Mokelumne	457	492	37.5	32.1	59.8	572,081	334.2	54.7 (1)	51.0 (1)	28.3
Stanislaus	509	391	40.9	24.4	65.3	764,710	588.2	57.5 (3)	49.1 (3)	29.5
Tuolumne§	417	479	35.8	33.8	65.6	1,730,649	960.4	43.3 (2)	28.3 (3)	38.1
Merced§	324	399	26.3	25.2	68.1	760,417	565.4	48.0 (3)	36.5 (3)	35.0
San Joaquin§	403	368	33.7	24.3	64.0	1,646,604	1,272.5	37.1 (8)	27.8 (8)	31.3
Kings§	466	512	37.8	31.8	70.2	2,133,320	1,258.3	NA	33.6 (2)	39.5
Kaweah§	501	>600†	30.3	25.9	50.5	448,948	325.4	0.0 (1)	0.0 (1)	32.7
Tule	237	442	5.6	6.3	10.2	48,110	142.8	NA	NA	6.0
Kern§	385	453	10.7	8.1	27.8	753,296	1,745.8	28.2 (8)	17.5 (7)	9.4
Truckee	255	293	12.7	11.3	39.7	268,805	447.5	16.1 (5)	12.4 (5)	14.4
Tahoe	301	333	19.2	16.5	49.0	293,977	333.8	24.6 (7)	14.7 (6)	16.9
W Carson	370	428	27.6	24.0	80.5	89,867	70.2	48.9 (2)	40.9 (2)	22.4
E Carson	369	386	18.8	15.1	46.4	307,558	380.9	31.7 (5)	23.9 (5)	17.9
W Walker	551	433	46.1	29.7	75.4	300,464	189.7	52.0 (3)	47.9 (2)	37.6
E Walker	>600†	>600†	25.6	17.8	54.2	352,970	371.2	36.4 (1)	32.5 (1)	13.9
Mono	580	555	10.7	7.9	23.0	443,610	1,059.1	NA	NA	5.0
Upper Owens	>600†	590	20.8	15.1	37.0	317,792	393.4	NA	NA	9.1
Owens	466	431	9.3	6.2	17.0	611,621	1,854.5	25.6 (5)	17.7 (5)	5.0

§ Data in all ASO-collected basins have been bias-corrected using ASO data and therefore the SWE changes might not represent snowmelt but rather an update to the SWE estimates based on airborne data.

† Deep, and particularly low-elevation snow in areas that typically are snow-free can report exceptionally high percent of average for this date because the mean 2001-2021 regression-derived SWE for that area is low or 0.

‡ For volume totals above Shasta Lake add Upper Sac, McCloud and Pit volumes. For volume totals above Bend Bridge add Upper Sac, McCloud, Pit and Sac at Bend Bridge volumes.

* This is a comparison to the SNODAS (SNOw Data Assimilation System) nationwide product from the National Weather Service.

Table 2. Estimated SWE by basin and elevation band. *The basin-wide SWE values and averages, are across all pixels at elevations >5000'. Elevation bands begin at 5000' and extend past the highest point in the basin. Note that the area of the highest 2-5 bands is typically much smaller than the lower bands. Shown are May 23rd percent of May 23rd average SWE, May 30th percent of May 30th average SWE (between 2001-2021 as derived from the regression model), May 23rd mean SWE, May 30th mean SWE, May 30th percent of snow-covered area, May 30th water volume (acre-feet), the area (mi^2) inside each basin that contains data pixels (not including cloud-covered pixels, lakes or other satellite no data pixels), May 23rd snow pillow data, and May 30th snow pillow data for those areas collected, summarized for each 1000' elevation band inside each basin. The last column shows May 30th mean SWE from SNODAS*.*

Basin	Elevation Band	5/23/23 % 5/23 Avg.	5/30/23 % 5/30 Avg.	5/23/23 SWE (in)	5/30/23 SWE (in)	5/30/23 % SCA	5/30/23‡ Vol (af)	5/30/23 Area (mi2)	5/23/23 Pillows	5/30/23 Pillows	5/30/23 SNODAS* (in)
Upper Sacramento§	5000-6000'	160	164	11.4	9.5	50.4	36,753	72.5	16.0 (1)	8.7 (1)	21.7
	6000-7000'	198	187	22.3	18.2	80.2	37,578	38.6	NA	NA	40.0
	7000-8000'	195	181	29.2	24.8	95.9	11,979	9.1	NA	NA	41.0
	8000-9000'	173	178	35.0	34.0	92.8	5,564	3.1	NA	NA	46.8
	9000-10,000'	129	146	34.7	38.7	90.0	4,323	2.1	NA	NA	53.5
	10,000-11,000'	103	104	34.5	35.1	88.4	2,348	1.3	NA	NA	53.5
	> 11,000'	78	37	25.1	11.8	66.0	743	1.2	NA	NA	47.3
McCloud§	5000-6000'	216	243	13.7	12.4	64.0	69,895	105.7	NA	NA	24.9
	6000-7000'	249	245	27.5	24.5	86.4	57,161	43.7	NA	NA	51.4
	7000-8000'	223	220	38.4	36.5	97.2	27,669	14.2	NA	NA	56.7
	8000-9000'	205	177	45.1	38.2	97.4	13,781	6.8	NA	NA	60.3
	>9,000'	160	125	42.6	34.1	86.6	5,708	3.1	NA	NA	63.4
Pit§	5000-6000'	72	70	0.8	0.8	2.5	63,462	1,569.5	33.2 (1)	21.1 (1)	1.0
	6000-7000'	180	182	7.1	6.3	19.7	187,459	555.2	11.3 (2)	8.0 (2)	5.4
	7000-8000'	281	297	-	20.7	56.3	153,766	139.1	0.2 (1)	0.0 (1)	13.7
	>8,000'	420	436	-	45.3	88.6	51,526	21.3	NA	NA	16.2
Sac at Bend Bridge	5000-6000'	94	97	3.5	3.1	7.4	27,030	163.7	NA	NA	3.7
	6000-7000'	258	262	24.7	21.9	45.0	71,033	60.9	NA	NA	12.9
	>7,000'	317	294	-	-	82.2	36,960	14.1	NA	NA	32.0
Feather§	5000-6000'	72	77	1.9	1.7	6.9	119,804	1,354.1	48.5 (1)	34.8 (1)	7.4
	6000-7000'	190	192	9.7	8.1	27.5	337,394	784.5	27.0 (3)	16.0 (3)	10.9
	7000-8000'	251	260	22.1	19.4	56.7	129,263	124.7	17.3 (1)	0.0 (1)	21.6
	8000-9000'	285	266	39.0	31.6	77.8	7,515	4.5	NA	NA	25.3
Yuba§	5000-6000'	95	149	4.3	4.9	19.0	53,098	202.7	NA	NA	10.6
	6000-7000'	336	390	29.5	27.2	87.0	332,817	229.2	42.8 (2)	34.3 (2)	29.3
	7000-8000'	358	310	47.5	35.8	98.5	224,533	117.6	NA	NA	50.8
	8000-9000'	352	265	61.2	41.7	96.8	9,935	4.5	NA	NA	81.3
American§	5000-6000'	24	28	0.6	0.6	4.6	10,139	312.6	0.9 (3)	0.0 (3)	2.5
	6000-7000'	207	243	13.8	12.4	58.3	185,718	280.5	40.8 (1)	34.2 (1)	14.9
	7000-8000'	311	324	34.3	29.5	89.3	276,012	175.2	29.5 (4)	19.0 (3)	34.6
	8000-9000'	344	320	-	42.3	96.1	159,064	70.4	37.5 (2)	27.1 (1)	40.8
	9000-10,000'	323	275	-	47.3	91.5	23,069	9.1	NA	NA	39.3
Cosumnes	5000-6000'	1	2	0.0	0.0	0.1	113	62.5	NA	NA	3.2
	6000-7000'	208	246	13.5	11.9	26.3	15,844	24.9	NA	NA	23.5
	7000-8000'	532	589	-	52.6	96.1	19,369	6.9	NA	NA	46.8
Mokelumne	5000-6000'	16	21	0.3	0.3	1.2	1,384	87.9	NA	NA	1.0
	6000-7000'	390	501	21.1	18.8	41.5	67,543	67.3	NA	NA	18.8
	7000-8000'	557	>600†	57.9	50.3	94.3	242,998	90.7	NA	NA	43.2
	8000-9000'	475	470	65.9	55.3	97.7	235,206	79.7	54.7 (1)	51.0 (1)	48.0
	9000-10,000'	399	376	65.3	54.1	90.6	24,950	8.6	NA	NA	43.8
Stanislaus	5000-6000'	19	17	0.3	0.2	0.9	946	111.7	NA	NA	0.4
	6000-7000'	492	497	23.9	14.7	47.3	109,192	139.3	28.0 (1)	10.2 (1)	17.1
	7000-8000'	>600†	495	53.2	31.1	90.2	250,643	151.2	NA	NA	37.9
	8000-9000'	527	367	65.8	38.3	98.3	242,298	118.6	83.3 (1)	78.7 (1)	47.3
	9000-10,000'	456	314	71.8	44.0	97.2	126,255	53.8	61.2 (1)	58.4 (1)	52.5
	10,000-11,000'	396	298	70.9	48.7	91.0	34,442	13.3	NA	NA	55.1
	> 11,000'	363	286	68.5	50.2	84.8	934	0.3	NA	NA	65.1

Basin	Elevation Band	5/23/23 % 5/23 Avg.	5/30/23 % 5/30 Avg.	5/23/23 SWE (in)	5/30/23 SWE (in)	5/30/23 % SCA	5/30/23‡ Vol (af)	5/30/23 Area (mi2)	5/23/23 Pillows	5/30/23 Pillows	5/30/23 SNODAS* (in)
Tuolumne§	5000-6000'	2	3	0.0	0.0	0.2	209	179.6	NA	NA	0.3
	6000-7000'	235	379	7.7	7.9	32.6	62,039	147.2	NA	NA	13.8
	7000-8000'	461	>600†	33.7	33.9	82.7	284,461	157.3	43.0 (1)	31.4 (1)	39.0
	8000-9000'	484	557	54.0	51.5	95.5	474,450	172.8	NA	10.0 (1)	52.3
	9000-10,000'	455	485	63.0	58.4	97.2	572,349	183.8	43.7 (1)	43.3 (1)	66.2
	10,000-11,000'	394	403	61.7	55.7	92.5	270,800	91.1	NA	NA	63.3
	11,000-12,000'	299	304	49.4	44.4	79.9	60,801	25.7	NA	NA	49.1
	> 12,000'	245	209	44.7	35.5	67.3	5,539	2.9	NA	NA	42.2
Merced§	5000-6000'	4	10	0.0	0.0	0.2	170	75.2	NA	NA	0.0
	6000-7000'	139	283	4.2	4.7	21.9	20,561	82.6	NA	NA	6.7
	7000-8000'	309	495	19.5	20.4	77.1	154,031	141.9	34.0 (1)	24.4 (1)	30.8
	8000-9000'	371	453	38.6	37.0	95.9	245,818	124.6	55.0 (2)	42.6 (2)	49.9
	9000-10,000'	366	396	48.2	44.2	99.1	206,977	87.9	NA	NA	59.7
	10,000-11,000'	314	333	51.7	48.3	96.9	102,824	39.9	NA	NA	65.4
	11,000-12,000'	254	237	49.3	42.1	87.6	26,440	11.8	NA	NA	62.3
	> 12,000'	184	193	42.0	42.0	81.9	3,596	1.6	NA	NA	59.4
San Joaquin§	5000-6000'	0	2	0.0	0.0	0.0	45	144.4	NA	NA	0.0
	6000-7000'	198	226	4.8	2.3	14.4	23,392	186.8	16.5 (2)	1.9 (2)	5.4
	7000-8000'	404	370	20.7	11.6	53.4	137,675	222.2	39.2 (4)	30.6 (4)	22.2
	8000-9000'	485	400	43.2	27.5	91.0	297,474	203.0	NA	NA	42.7
	9000-10,000'	448	372	52.9	36.8	97.6	405,866	207.1	61.2 (1)	55.1 (1)	51.1
	10,000-11,000'	404	368	57.1	44.6	95.6	384,607	161.7	45.8 (1)	41.0 (1)	53.2
	11,000-12,000'	370	369	58.1	50.3	88.3	319,130	119.0	NA	NA	42.8
	12,000-13,000	308	340	51.9	51.5	75.2	74,087	27.0	NA	NA	32.2
	> 13,000	291	384	45.9	55.4	65.1	4,327	1.5	NA	NA	22.6
Kings§	5000-6000'	0	0	0.0	0.0	0.0	6	101.2	NA	NA	0.0
	6000-7000'	167	334	3.1	2.8	12.2	20,618	136.8	NA	NA	2.1
	7000-8000'	499	>600†	20.5	18.0	59.6	169,739	176.8	NA	NA	19.2
	8000-9000'	529	>600†	39.6	33.7	85.4	396,947	221.0	NA	0.0 (1)	47.8
	9000-10,000'	511	540	50.9	42.2	94.6	499,298	221.7	NA	67.2 (1)	59.4
	10,000-11,000'	475	501	57.0	48.2	94.2	494,466	192.2	NA	NA	59.4
	11,000-12,000'	436	438	61.2	50.2	88.8	416,110	155.3	NA	NA	54.7
	12,000-13,000	383	387	57.6	48.6	80.2	127,535	49.2	NA	NA	45.7
	>13,000'	368	334	51.8	39.2	64.4	8,600	4.1	NA	NA	35.4
Kaweah§	5000-6000'	0	0	0.0	0.0	0.0	0	61.4	NA	NA	0.0
	6000-7000'	78	136	1.6	1.4	3.9	4,376	60.7	0.0 (1)	0.0 (1)	4.4
	7000-8000'	541	>600†	24.2	21.3	48.7	70,670	62.2	NA	NA	23.9
	8000-9000'	>600†	>600†	51.1	44.0	89.4	135,314	57.7	NA	NA	49.1
	9000-10,000'	543	>600†	60.7	51.4	96.5	119,391	43.6	NA	NA	71.3
	10,000-11,000'	491	533	67.1	56.2	96.1	92,787	31.0	NA	NA	74.7
	>11,000'	444	460	68.2	56.4	92.1	26,410	8.8	NA	NA	70.2
Tule	5000-6000'	0	0	0.0	0.0	0.0	0	55.2	NA	NA	0.0
	6000-7000'	2	13	0.0	0.1	0.1	234	41.6	NA	NA	0.4
	7000-8000'	107	226	4.3	5.4	9.5	7,690	26.8	NA	NA	8.1
	8000-9000'	403	>600†	28.9	33.8	52.4	26,367	14.6	NA	NA	25.2
	9000-10,000'	548	>600†	58.6	57.2	94.7	13,819	4.5	NA	NA	55.5
Kern§	5000-6000'	0	0	0.0	0.0	0.0	0	257.9	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	357.8	NA	NA	0.0
	7000-8000'	27	30	0.2	0.1	0.8	2,247	338.7	0.0 (1)	0.0 (1)	1.1
	8000-9000'	362	510	7.9	5.8	27.3	100,542	325.8	18.5 (3)	9.2 (3)	6.3
	9000-10,000'	503	>600†	24.5	19.2	76.4	198,248	193.2	36.6 (1)	26.7 (1)	19.3
	10,000-11,000'	458	536	38.2	30.4	94.6	215,568	133.1	39.3 (2)	34.0 (2)	33.2
	11,000-12,000'	390	390	45.1	33.6	89.7	169,634	94.8	54.5 (1)	NA	44.6
	12,000-13,000	338	291	43.6	28.7	75.5	58,551	38.2	NA	NA	37.9
	>13,000'	311	250	39.8	25.1	62.2	8,506	6.3	NA	NA	23.7

Basin	Elevation Band	5/23/23 % 5/23 Avg.	5/30/23 % 5/30 Avg.	5/23/23 SWE (in)	5/30/23 SWE (in)	5/30/23 % SCA	5/30/23‡ Vol (af)	5/30/23 Area (mi2)	5/23/23 Pillows	5/30/23 Pillows	5/30/23 SNODAS* (in)
Truckee§	5000-6000'	2	5	0.0	0.0	0.2	63	69.3	NA	NA	0.0
	6000-7000'	151	203	4.5	4.2	20.9	48,894	219.5	16.1 (5)	12.4 (5)	4.5
	7000-8000'	311	345	26.5	23.6	79.6	150,606	119.7	NA	NA	28.7
	8000-9000'	310	309	40.0	33.8	98.9	55,382	30.7	NA	NA	50.1
	9000-10,000'	281	272	37.6	31.0	99.3	13,132	8.0	NA	NA	60.1
	10,000-11,000'	245	251	36.9	32.6	95.2	728	0.4	NA	NA	61.4
Tahoe§	6000-7000'	108	141	2.6	2.3	10.2	16,111	130.2	17.2 (2)	12.8 (2)	3.6
	7000-8000'	311	376	20.7	18.8	61.4	113,309	113.0	27.9 (4)	15.1 (3)	20.5
	8000-9000'	352	362	39.7	33.2	93.7	129,421	73.0	26.3 (1)	17.3 (1)	30.6
	9000-10,000'	342	319	47.2	37.4	93.2	33,638	16.9	NA	NA	36.8
	10,000-11,000'	298	297	43.8	36.6	79.8	1,497	0.8	NA	NA	41.0
W. Carson§	5000-6000'	0	0	0.0	0.0	0.0	0	0.2	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	2.2	NA	NA	1.5
	7000-8000'	327	432	16.0	14.6	70.0	25,047	32.2	NA	NA	19.0
	8000-9000'	398	446	37.7	32.5	96.4	48,393	27.9	48.9 (2)	40.9 (2)	25.5
	9000-10,000'	376	387	47.8	40.3	92.6	15,123	7.0	NA	NA	31.1
	10,000-11,000'	408	402	49.3	39.0	84.5	1,305	0.6	NA	NA	39.2
E. Carson§	5000-6000'	0	0	0.0	0.0	0.0	0	49.9	NA	NA	0.0
	6000-7000'	3	2	0.0	0.0	0.4	30	77.8	0.0 (1)	0.0 (1)	0.4
	7000-8000'	300	388	9.7	8.2	38.7	45,506	104.1	NA	NA	11.6
	8000-9000'	411	438	35.5	28.9	90.3	156,491	101.5	39.7 (4)	29.9 (4)	32.0
	9000-10,000'	396	360	53.2	41.4	95.4	80,554	36.5	NA	NA	49.2
	>10,000'	348	299	55.2	42.5	92.2	24,977	11.0	NA	NA	48.9
W. Walker	6000-7000'	0	0	0.0	0.0	0.0	0	7.7	NA	NA	0.0
	7000-8000'	567	>600†	9.4	7.7	32.4	16,558	40.4	0.0 (1)	0.0 (1)	2.4
	8000-9000'	>600†	>600†	48.8	30.4	91.4	77,802	47.9	38.9 (1)	NA	29.4
	9000-10,000'	531	382	-	39.5	94.5	135,906	64.5	117.1 (1)	95.9 (1)	59.6
	10,000-11,000'	418	318	-	45.0	87.9	64,666	26.9	NA	NA	61.1
	> 11,000'	387	345	-	46.5	78.1	5,532	2.2	NA	NA	54.7
E. Walker	6000-7000'	16	546	0.0	0.1	0.3	238	57.4	NA	NA	0.0
	7000-8000'	>600†	>600†	6.9	5.7	32.5	35,614	117.6	NA	NA	0.9
	8000-9000'	>600†	>600†	32.5	21.8	80.3	111,886	96.2	NA	NA	9.2
	9000-10,000'	>600†	534	-	35.5	89.9	108,139	57.1	36.4 (1)	32.5 (1)	37.4
	10,000-11,000'	455	377	-	42.2	83.8	77,062	34.2	NA	NA	49.7
	>11,000'	387	364	-	43.1	73.9	20,031	8.7	NA	NA	45.6
Mono	6000-7000'	10	96	0.0	0.0	0.3	582	319.7	NA	NA	0.0
	7000-8000'	474	>600†	1.1	1.1	6.8	24,551	411.8	NA	NA	0.1
	8000-9000'	>600†	>600†	16.8	12.2	51.1	120,062	184.3	NA	NA	1.6
	9000-10,000'	>600†	>600†	-	33.5	88.8	115,508	64.6	NA	NA	21.4
	10,000-11,000'	494	408	-	42.3	86.1	108,587	48.1	NA	NA	47.0
	11,000-12,000'	377	357	-	45.4	73.6	63,561	26.2	NA	NA	44.9
	> 12,000'	300	327	47.1	45.9	65.7	10,758	4.4	NA	NA	39.2
Upper Owens	6000-7000'	0	0	0.0	0.0	0.0	0	66.0	NA	NA	0.0
	7000-8000'	>600†	>600†	3.2	2.5	10.6	20,139	149.0	NA	NA	0.5
	8000-9000'	>600†	>600†	33.1	22.3	64.9	95,155	79.9	NA	NA	11.0
	9000-10,000'	>600†	561	48.7	33.8	82.6	79,292	43.9	NA	NA	23.3
	10,000-11,000'	486	439	53.7	40.2	81.0	74,156	34.6	NA	NA	32.6
	11,000-12,000'	398	389	54.9	45.8	73.2	39,537	16.2	NA	NA	28.2
	> 12,000'	368	415	48.1	46.5	65.5	9,513	3.8	NA	NA	16.8
Owens	5000-6000'	0	0	0.0	0.0	0.0	0	446.6	NA	NA	0.0
	6000-7000'	0	0	0.0	0.0	0.0	0	358.7	NA	NA	0.0
	7000-8000'	35	77	0.1	0.0	0.5	766	333.1	NA	NA	0.1
	8000-9000'	215	313	1.5	1.0	5.3	10,262	185.7	NA	NA	1.5
	9000-10,000'	571	>600†	13.6	9.0	32.2	72,671	151.3	28.5 (3)	20.9 (3)	7.4
	10,000-11,000'	>600†	583	33.5	22.0	65.1	195,773	166.6	21.2 (2)	13.0 (2)	17.2
	11,000-12,000'	464	400	43.6	29.2	70.0	209,769	134.5	NA	NA	24.5
	12,000-13,000	371	312	43.8	29.7	65.4	106,914	67.4	NA	NA	21.6
	>13,000'	325	287	38.7	27.5	60.3	15,467	10.5	NA	NA	15.1

- Data omitted due to inconsistencies with independent SWE estimates.

§ Data in all ASO-collected basins have been bias-corrected using ASO data and therefore the SWE changes might not represent snowmelt but rather an update to the SWE estimates based on airborne data.

‡ For volume totals above Shasta Lake add Upper Sac, McCloud and Pit volumes. For volume totals above Bend Bridge add Upper Sac, McCloud, Pit and Sac at Bend Bridge volumes.

† Deep, and particularly low-elevation snow in areas that typically are snow-free can report exceptionally high percent of average for this date because the mean 2001-2021 regression-derived SWE for that area is low or 0.

* This is a comparison to the SNODAS (SNOw Data Assimilation System) nationwide product from the National Weather Service.

Location of Reports and Excel Format Tables

https://www.colorado.edu/instaar/research/labs-groups/mountain-hydrology-group/sierra-nevada-swe-reports

References and Additional Sources

Margulis, S. A., Cortés, G., Girotto, M., & Durand, M. (2016). A Landsat-Era Sierra Nevada Snow Reanalysis (1985–2015). *Journal of Hydrometeorology*, 17(4), 1203–1221, doi:/10.1175/JHM-D-15-0177.1

Molotch, N.P. (2009). Reconstructing snow water equivalent in the Rio Grande headwaters using remotely sensed snow cover data and a spatially distributed snowmelt model. *Hydrological Processes*, Vol. 23, doi: 10.1002/hyp.7206, 2009.

Molotch, N.P., and S.A. Margulis. (2008) Estimating the distribution of snow water equivalent using remotely sensed snow cover data and a spatially distributed snowmelt model: a multi-resolution, multi-sensor comparison. *Advances in Water Resources*, 31, 2008.

Molotch, N.P., and R.C. Bales. (2006). Comparison of ground-based and airborne snow-surface albedo parameterizations in an alpine watershed: impact on snowpack mass balance. *Water Resources Research*, VOL. 42, doi:10.1029/2005WR004522.

Molotch, N.P., and R.C. Bales. (2005). Scaling snow observations from the point to the grid-element: implications for observation network design. *Water Resources Research*, VOL. 41, doi: 10.1029/2005WR004229.

Molotch, N.P., T.H. Painter, R.C. Bales, and J. Dozier. (2004). Incorporating remotely sensed snow albedo into a spatially distributed snowmelt model. *Geophysical Research Letters*, VOL. 31, doi:10.1029/2003GL019063, 2004.

Painter, T.H., K. Rittger, C. McKenzie, P. Slaughter, R. E. Davis and J. Dozier. (2009) Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. *Remote Sensing of the Environment*, 113: 868-879.

Rittger, K., M. S. Raleigh, J. Dozier, A. F. Hill, J. A. Lutz, and T. H. Painter. 2019. Canopy Adjustment and Improved Cloud Detection for Remotely Sensed Snow Cover Mapping. Water Resources Research 24 August 2019. doi:10.1029/2019WR024914.

Schneider D. and N.P. Molotch. (2016). Real-time estimation of snow water equivalent in the Upper Colorado River Basin using MODIS-based SWE reconstructions and SNOTEL data. *Water Resources Research*, 52(10): 7892-7910. DOI: 10.1002/2016WR019067.

Yang, K., K. N. Musselman, K. Rittger, S. A. Margulis, T. H. Painter and N. P. Molotch. (2022). Combining ground-based and remotely sensed snow data in a linear regression model for real-time estimation of snow water equivalent. *Advances in Water Resources,* 160, 2022, 104075. DOI: 10.1016/j.advwatres.2021.104075