Real-Time Snow Water Equivalent (SWE) Simulation
April 8, 2011
Intermountain West

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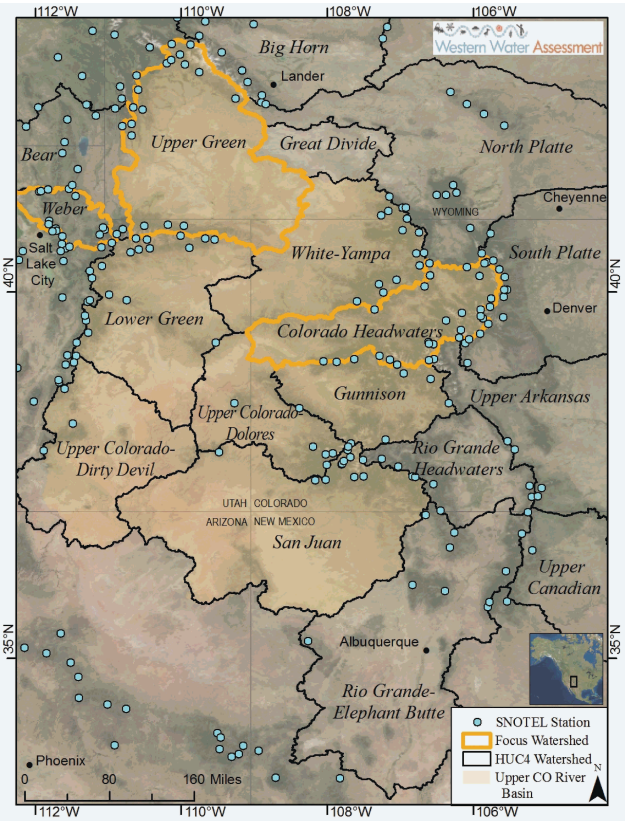
Abstract
273 snow sensors in the Intermountain West network were recording snow out of a total of 306 sensors. The locations of sensors that aren't recording snow (shown in yellow in Figure 4, right map) are lower elevation, southern latitude, and a few that are offline in other strategic locations. Overall, SWE depths have increased at the highest elevations but decreased at the lower elevations and snow extent has mostly decreased between April 1 and April 8.

Introduction
We are developing a real-time SWE estimation scheme based on historical SWE reconstructions between 2000-2012, a real-time MODIS/MODSCAG image (Painter et al., 2009), and daily in-situ SWE measurements for the Intermountain West (Molotch, 2009; Molotch and Margulis, 2008; Molotch and Bales, 2006; Molotch and Bales, 2005; Molotch, et al., 2004; Guan et al., 2013; and Schneider and Molotch, 2013). Real-time SWE can be released on a weekly basis during the maximum snow accumulation/ablation period.



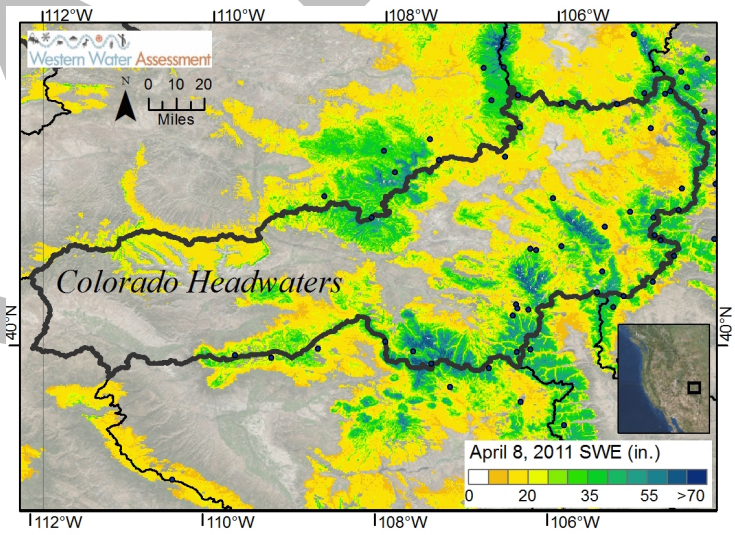


Figure 2. April 8, 2011 spatial SWE shown for the Colorado Headwaters, CO watershed.

Figure 1. Location map showing hydrologic unit (HUC) 4 watersheds in black, focus watersheds in orange, SNOTEL stations in cyan, and the Upper Colorado River basin in tan.

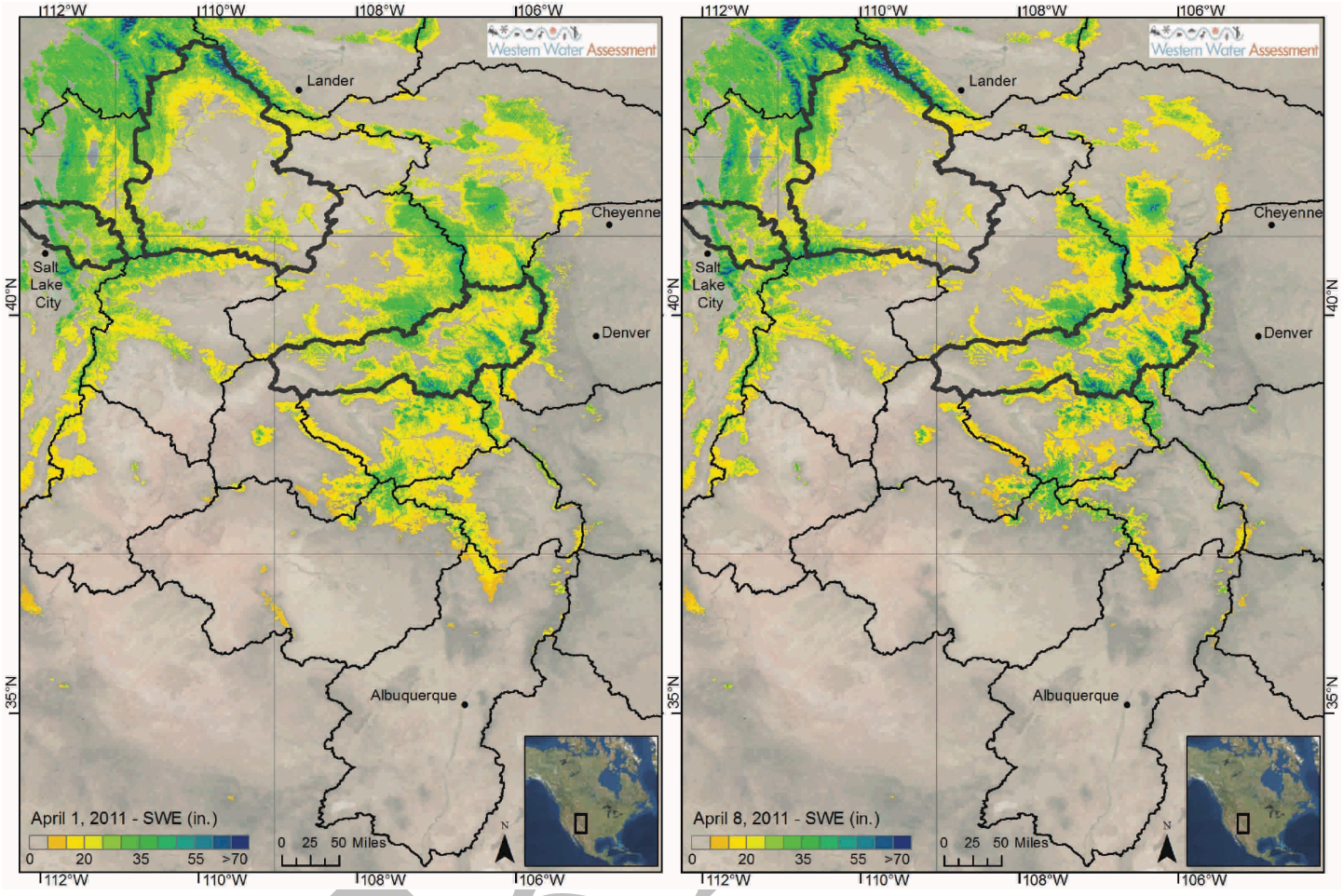


Figure 3. SWE amounts for April 1, 2011 are shown on the left and for April 8, 2011 are shown on the right. SWE depths have increased at the highest elevations but decreased at the lower elevations and snow extent has mostly decreased in the intervening week between images.

Discussion

Figure 1 shows the model domain overlaid with the Colorado River Basin, watersheds, and SNOTEL sensors. Figure 2 shows April 8, 2011 spatial SWE shown for the Colorado Headwaters, CO watershed. Figure 3 shows SWE amounts for April 8, 2011 and for April 1, 2011. On April 8, 2011, snow depths increased at the highest elevations. 306 snow sensors in the Intermountain West network were operational and 273 were recording snow. For comparison in 2012, a very dry year, 306 were operational and 243 recorded snow on April 8th, and in 2008, a fairly average year, 270 were operational and 252 recorded snow on April 8th. Note the locations of sensors that aren't recording snow (shown in yellow in Figure 4, right map) are lower elevation sensors, lower latitude, and a few that are offline in other strategic locations, so calculations from sensors alone do not accurately calculate SWE for each watershed. Figure 4 (left) shows the 12-year-modeled percent of average SWE for April 8, 2011 for the snow-covered area and (right) is the mean 12-year-modeled percent of average for April 8, 2011 shown as an average by watershed for all model pixels above 6000' elevation. Note that spatial SWE watershed averages are much lower than those calculated using SNOTEL snow sensors (see Table 1). Each snow sensor produces one SWE point value

whereas the spatial SWE allows for areal calculations, every square foot above 6000' elevation in the watershed is used to calculate the spatial SWE mean. Table 1 shows mean spatial and SNOTEL SWE and mean 12-year-modeled percent of average spatial and SNOTEL SWE for 4/8/2011, mean spatial and SNOTEL SWE for 4/1/2011, change in spatial and SNOTEL SWE between 4/1/2011 and 4/8/2011 as summarized for each watershed above 6000' elevation. Figure 5 is the graph that corresponds to Table 1. Table 2 shows mean spatial and SNOTEL SWE and mean 12-year-modeled percent of average spatial and SNOTEL SWE for 4/8/2011, mean spatial and SNOTEL SWE for 4/1/2011, change in spatial and SNOTEL SWE between 4/1/2011 and 4/8/2011, and area in square miles for each 1000' elevation band inside each focus watershed. Figure 6 is the graph that corresponds to Table 2.

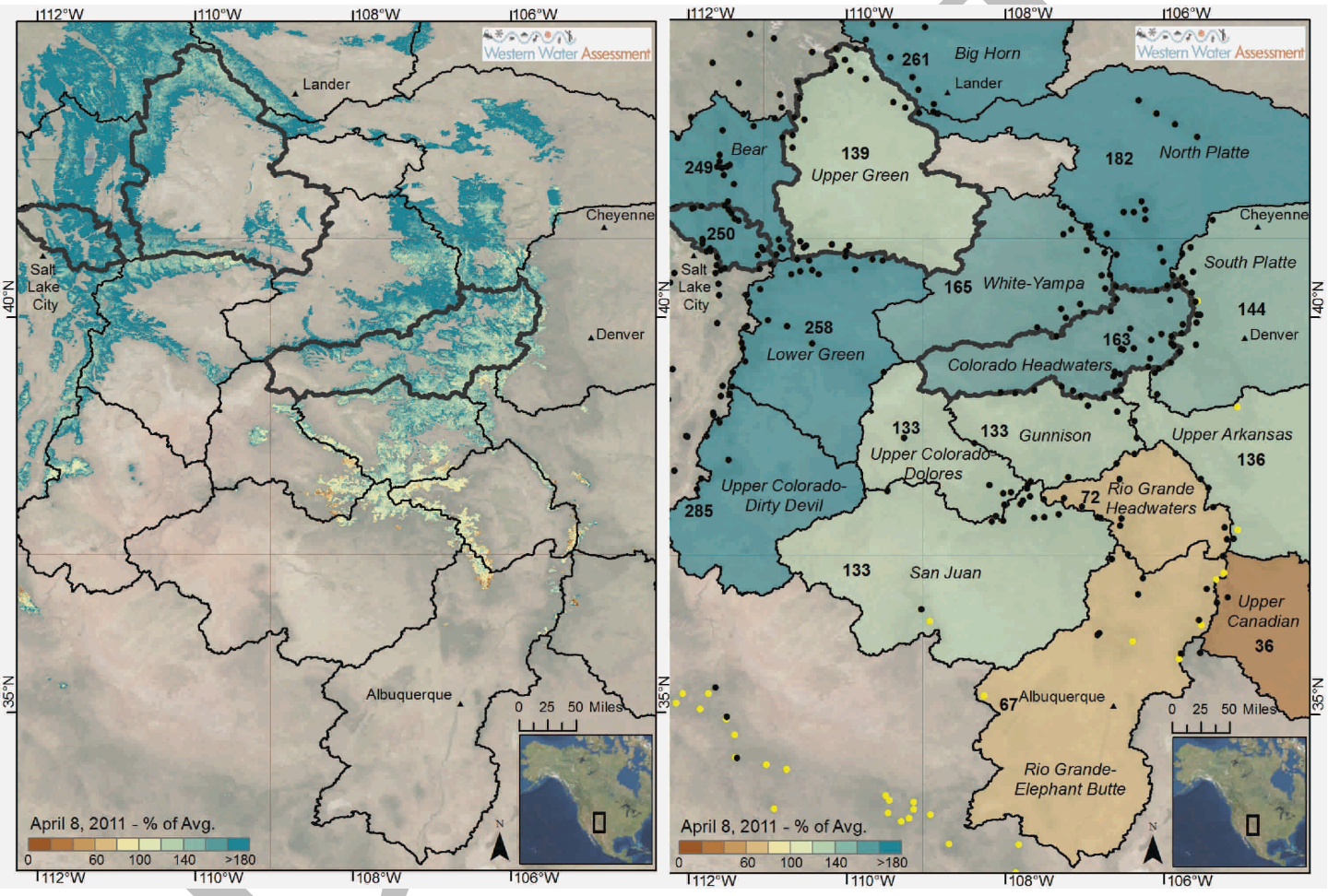


Figure 4. Percent of average SWE for April 8, 2011 for the Intermountain West (shown on left) and by watershed (shown on right). Watershed percentages are calculated for all model pixels above 6000' elevation. SWE snow sensors that had snow on April 8, 2011 are shown in black and sensors that had no snow are shown in yellow.

Methods

Results for the date of April 8, 2011 are based on April 8, 2011 data from 306 in situ SWE measurements distributed across the Intermountain West, one cloud-free Moderate Resolution Imaging Spectroradiometer (MODIS)/Terra snow covered area daily cloud-free image which has been processed using the MODIS Snow Cover And Grain size (MODSCAG) fractional snow covered area algorithm program (Painter, et. al. 2009, snow.jpl.nasa.gov) and one reconstructed SWE image.

Relative to snow stations and the NWS SNODAS product, the spatial reconstructed SWE product correlates strongly with full natural flow, especially late in the snowmelt season (Guan, et. al. 2013).
Table 1. All calculations are for elevations above 6000'. Shown are mean spatial and SNOTEL SWE and mean percent of 12-year-modeled average spatial and SNOTEL SWE for 4/8/2011, mean spatial and SNOTEL SWE for 4/1/2011, and change in spatial and SNOTEL SWE between 4/1/2011 and 4/8/2011 for each watershed.

	4/8/11 % of Avg to Date		4/8/11 SWE (in)		4/1/11 SWE (in)		4/1-4/8 Change SWE (in)	
Watershed	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL
Bear	248.75	174.78	20.06	28.47	22.42	27.24	-2.36	1.23
Big Horn	260.92	127.52	12.27	13.74	12.16	12.89	0.11	0.85
Colorado Headwaters	163.46	140.55	14.45	21.03	17.03	20.86	-2.58	0.17
Gunnison	133.43	130.75	9.66	19.26	12.28	19.51	-2.62	-0.25
Lower Green	258.39	156.44	8.82	18.83	9.84	19.63	-1.03	-0.80
North Platte	182.34	148.91	6.49	27.67	11.02	26.84	-4.53	0.84
Rio Grande Headwaters	71.98	88.38	3.17	8.72	4.34	9.12	-1.17	-0.39
Rio Grande-Elephant Butte	67.31	60.77	0.27	4.23	0.39	4.40	-0.11	-0.17
San Juan	133.38	97.28	1.37	15.05	1.89	16.19	-0.52	-1.14
South Platte	143.74	136.84	2.91	16.43	4.24	16.35	-1.33	0.08
Upper Arkansas	135.81	82.00	2.70	7.87	2.81	7.97	-0.11	-0.10
Upper Canadian	36.39	12.86	0.10	0.60	0.05	2.90	0.05	-2.30
Upper Colorado-Dirty Devil	285.32	146.57	2.30	12.03	2.35	12.75	-0.05	-0.72
Upper Colorado-Dolores	133.02	98.25	2.86	12.55	3.88	13.72	-1.02	-1.17
Upper Green	139.21	146.82	7.77	20.77	9.09	20.05	-1.33	0.73
Weber	250.32	158.24	21.54	29.24	22.36	28.31	-0.82	0.93
White-Yampa	165.10	147.62	7.64	29.39	10.60	28.77	-2.96	0.62

Figure 5. Graph that corresponds to Table 1 above.

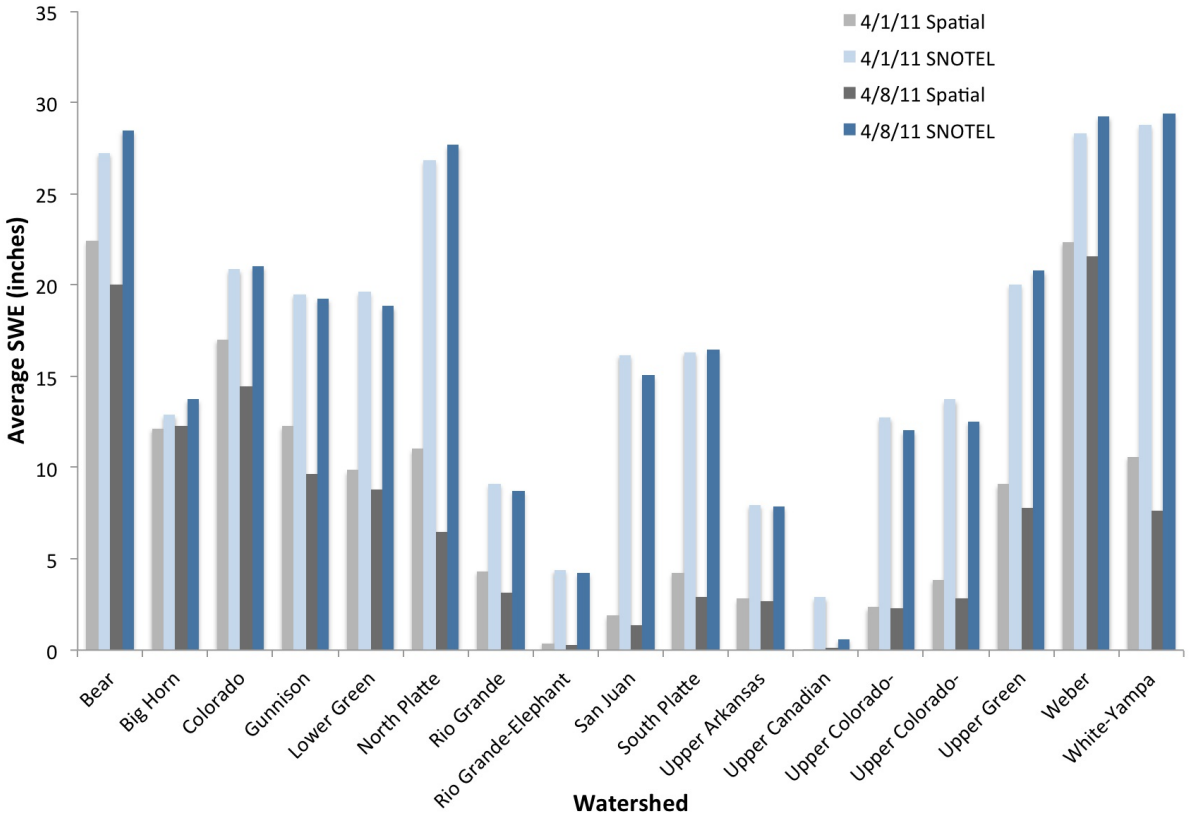
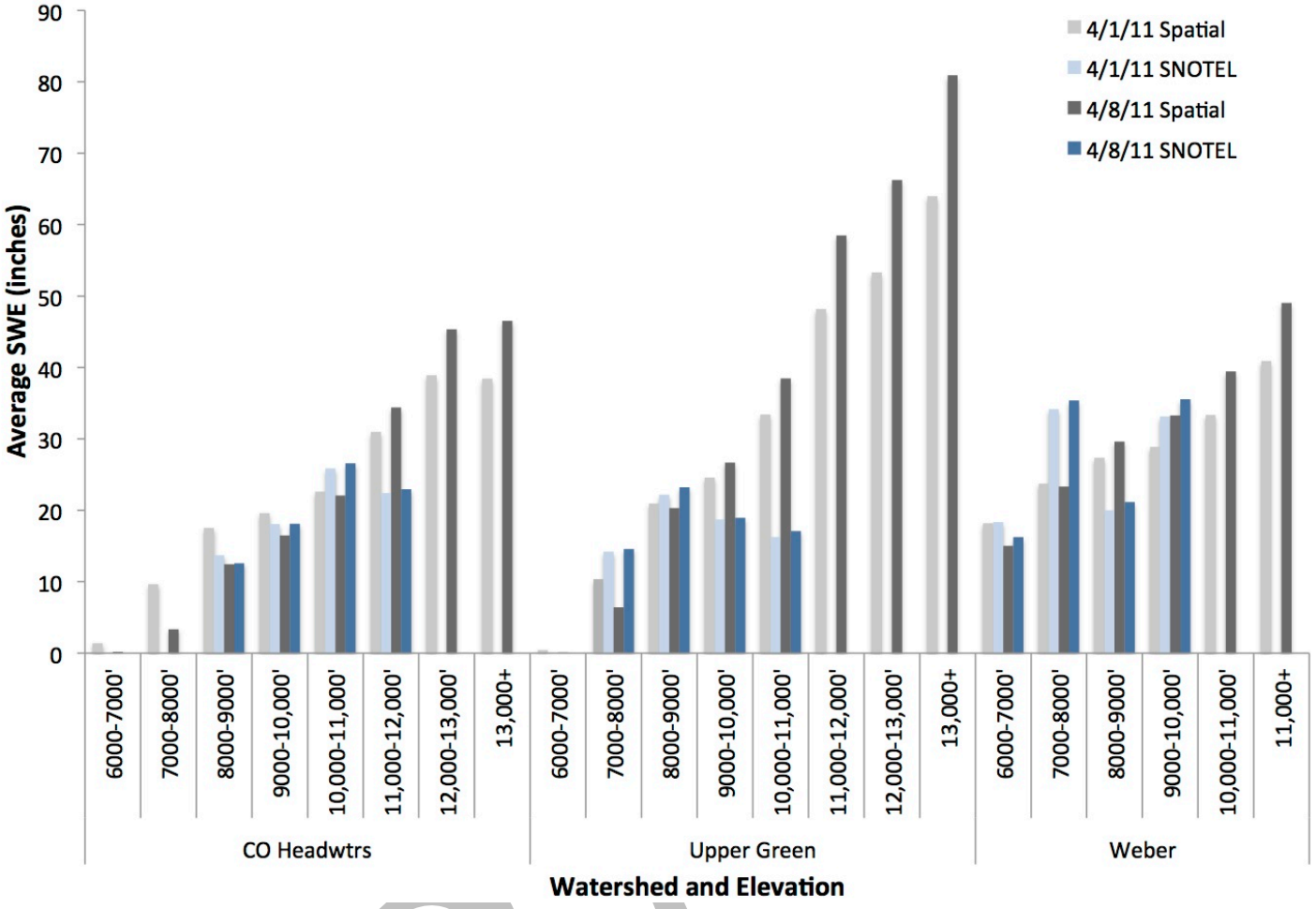


Table 2. Mean spatial and SNOTEL SWE and mean 12-year-modeled percent of average spatial and SNOTEL SWE for 4/8/2011, mean spatial and SNOTEL SWE for 4/1/2011, change in spatial and SNOTEL SWE between 4/1/2011 and 4/8/2011, and area in square miles for each elevation band inside each focus watershed.

Watershed	Elevation	4/8/11 % Avg to Date		4/8/11 SWE (in)		4/1/11 SWE (in)		4/1-4/8 Change SWE (in)		Area
		Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL	Spatial	SNOTEL	Sq Mi
CO Headwtrs	6000-7000'	31.64	**N/A**	0.19	**N/A**	1.39	**N/A**	-1.21	**N/A**	1,732.4
	7000-8000'	105.47	**N/A**	3.35	**N/A**	9.65	**N/A**	-6.30	**N/A**	2,293.2
	8000-9000'	167.09	158.41	12.46	12.58	17.52	13.72	-5.06	-1.14	3,108.4
	9000-10,000'	158.79	149.67	16.49	18.13	19.61	18.06	-3.13	0.06	2,237.1
	10,000-11,000'	145.80	134.82	22.08	26.57	22.60	25.85	-0.53	0.72	2,300.9
	11,000-12,000'	135.74	139.39	34.40	22.95	30.99	22.43	3.40	0.53	1,150.5
	12,000-13,000'	132.65	**N/A**	45.35	**N/A**	38.92	**N/A**	6.43	**N/A**	346.3
	13,000+	130.14	**N/A**	46.52	**N/A**	38.44	**N/A**	8.08	**N/A**	25.1
Upper Green	6000-7000'	7.38	**N/A**	0.09	**N/A**	0.43	**N/A**	-0.34	**N/A**	11,164.6
	7000-8000'	142.95	138.72	6.42	14.60	10.37	14.20	-3.95	0.40	10,008.7
	8000-9000'	170.08	153.56	20.31	23.22	20.96	22.19	-0.65	1.03	2,482.9
	9000-10,000'	156.07	142.47	26.68	18.95	24.57	18.72	2.11	0.23	1,230.6
	10,000-11,000'	144.59	125.31	38.46	17.10	33.41	16.25	5.06	0.85	926.1
	11,000-12,000'	143.08	**N/A**	58.50	**N/A**	48.17	**N/A**	10.33	**N/A**	300.6
	12,000-13,000'	141.38	**N/A**	66.25	**N/A**	53.30	**N/A**	12.95	**N/A**	50.9
	13,000+	132.84	**N/A**	80.91	**N/A**	63.99	**N/A**	16.91	**N/A**	1.7
Weber	6000-7000'	233.88	188.22	15.04	16.25	18.18	18.35	-3.14	-2.10	1,155.3
	7000-8000'	207.29	156.95	23.34	35.37	23.73	34.17	-0.40	1.20	1,039.4
	8000-9000'	172.67	154.00	29.63	21.17	27.37	20.00	2.26	1.17	363.5
	9000-10,000'	165.93	148.02	33.28	35.55	28.88	33.15	4.40	2.40	124.6
	10,000-11,000'	152.84	**N/A**	39.44	**N/A**	33.34	**N/A**	6.11	**N/A**	70.1
	11,000+	143.33	**N/A**	49.04	**N/A**	40.91	**N/A**	8.13	**N/A**	0.9

Figure 6. Graph that corresponds to Table 2 above.



References

Guan, B., N. P. Molotch, D. E. Waliser, S. M. Jepsen, T. H. Painter, and J. Dozier. Snow water equivalent in the Sierra Nevada: Blending snow sensor observations with snowmelt model simulations. Submitted to *Water Resour. Res.*

Molotch, N.P., 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, 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, 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, 2006.

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

Molotch, N.P., T.H. Painter, R.C. Bales, and J. Dozier, 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, Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. *Remote Sensing of the Environment*, 113: 868-879, 2009.

Schneider D. and N.P. Molotch, Combining remotely-sensed snow water equivalent with in-situ measurements to produce a real-time SWE product. Poster. American Geophysical Union Fall Meeting, San Francisco, CA, 2013.