RECENT CHANGES IN THE SIERRA SNOWPACK OF CALIFORNIA

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ABSTRACT

The mountain snowpack is an important element of California's water supply. Winter precipitation in the high mountains is held over in the form of snow as natural water storage for the spring and summer dry season when irrigation demands are high. Historically, snowmelt furnished about 30 percent of the water supply for irrigated and urban users. In a warmer climate, less snow is expected and accumulation would be more limited to the higher portion of mountain watersheds.

In a paper 5 years ago at the Western Snow Conference (Roos and Sahota, 2012), contrasting trends were described. For a northern Sierra group of snow courses, a decline in April 1 measured water content was noted; however, for another group of southern Sierra courses, a small increasing trend in water content was noted. In both north and south, there was a decreasing trend in the volume of April through July runoff (mostly snowmelt) compared to total water year nature runoff. Now, after the drought, a recheck and update of these charts show that the southern Sierra snowpack also shows a decreasing trend, although not as much as in the north. One possible reason for the original trend is that the extensive cloud seeding programs in the southern Sierra temporarily offset an overall decreasing trend caused by warmer temperatures in the past two or three decades. As warming in the 21st century has increased, the changes have more than offset the small incremental increase by the weather modification programs. (KEYWORDS: Sierra Nevada, snowpack, snow courses, climate change)

SNOW COURSES EXAMINED

Originally a group of 13 northern Sierra courses and 13 southern Sierra courses were chosen by Scripps researchers for use by the California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, for inclusion in a roughly 180-page 2009 report "Indicators of Climate Change in California" (CA EPA. 2009). The report has a large number of indicators for measured changes in economic factors, greenhouse gases, climate and temperature, physical systems, and biological systems with time. Over 30 indicators were discussed; the list included Sierra river runoff trends, the snowpack record, and two charts showing snow water content trends from 1950 through 2008 for a group of northern Sierra Nevada snow courses and a group of southern Sierra Nevada snow courses (Figure 1). In the Indicators report, the northern group showed a decline of about 15 percent since 1950 but the southern group showed about a 15 percent increase.

A primary consideration for the original snowpack groups was to select snow courses which had fairly complete records from 1950 and would give a good representation of the region. In Table 1, the northern and southern groups of 13 manually measured courses on April 1 were:

Paper presented Western Snow Conference 2017
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Department of Water Resource
California Cooperative Snow Surveys
Location of Major Snowmelt River Basins

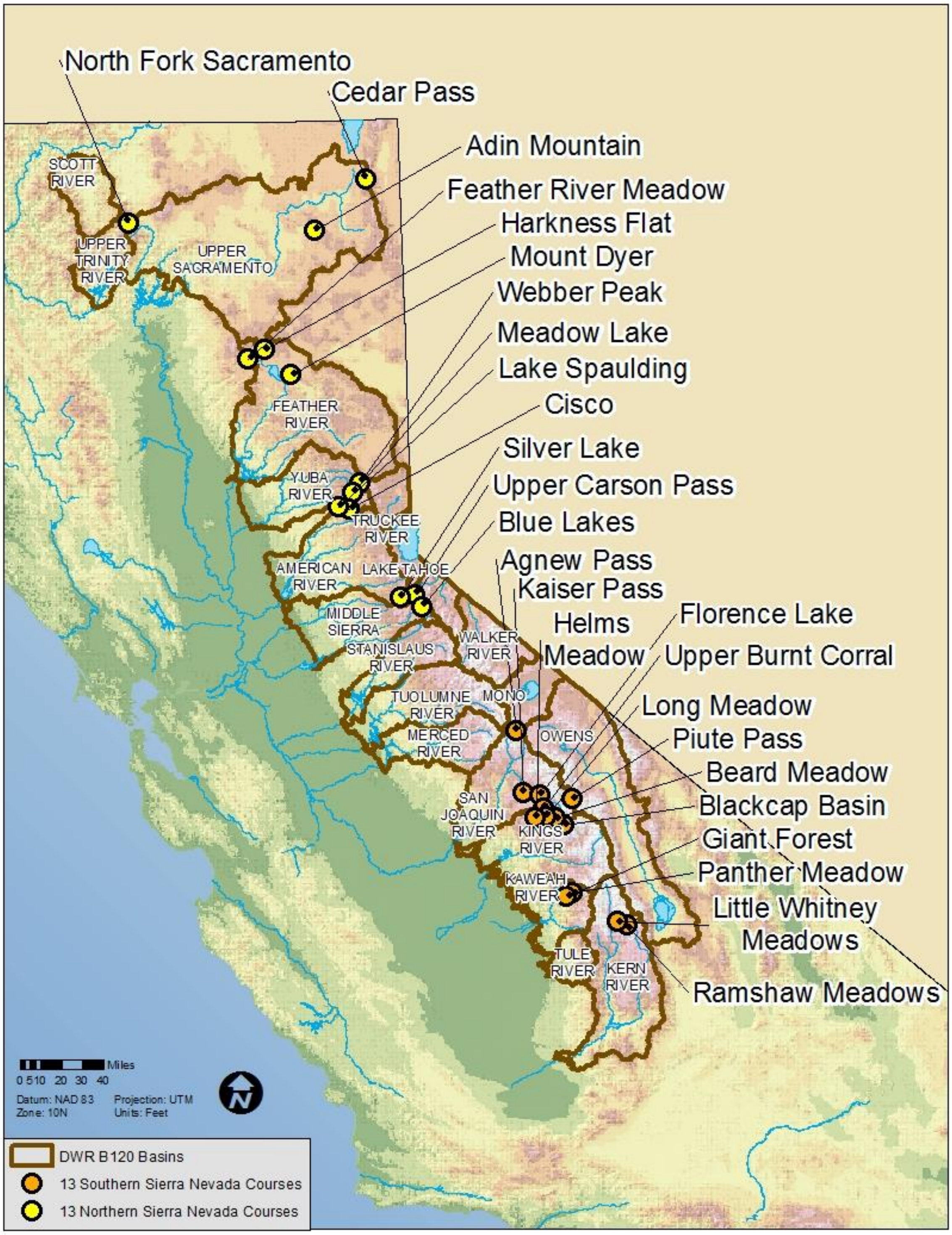


Figure 1. Location of Northern and Southern snow course groups

Table 1. Slopes and elevations for 13 snow courses

Course	River Basin	Elevation, in feet	60 year slope
Northern Group:			
North Fork Sacramento	Upper Sacramento	6900	+ .03
Cedar Pass	"(Pit)	7100	- .05
Adin Mountain	"(Pit)	6800	- .02
Mount Dyer	Feather	7100	+ .04
Harkness Flat	"	6600	.10
Feather River Meadow	Feather	5400	- .05
Webber Peak	Yuba	7800	- .10
Meadow Lake	"	7200	- .09
Cisco	"	5900	- .02
Lake Spaulding	"	5200	- .16
Upper Carson Pass	American	8500	- .04
Silver Lake	"	7100	- .10
Blue Lakes	Mokelumne	8000	- .02
Southern Group:			
Piute Pass	San Joaquin	11300	+ .04
Agnew Pass	"	10300	+ .05
Kaiser Pass	"	9100	+ .02
Florence Lake	"	7200	+ .00
Blackcap Basin	Kings	10300	+ .02
Beard Meadow	Kings	9800	+ .03
Upper Burnt Corral	"	9700	+.05
Long Meadow	"	8500	+ .06
Helms Meadow	"	8250	+ .12
Panther Meadow	Kaweah	8600	+ .13
Giant Forest	Kaweah	6400	+ .00
Ramshaw Meadows	Kern	8700	+ .06
Little Whitney Meadows	"	8500	+ .07

Note: The above table is in English units to match source data. To convert feet to meters, multiply by 0.305, and for the slope column, inches to centimeters, multiply by 2.54.

The last column in Table 1 above gives the 1950-2011 slope of each course in inches per year. The slope for the northern Sierra group average was minus .135 cm per year (-.053 inches) while that for the southern group was positive 0.137 cm per year (.054 inches) (Figure 2). Since the low elevation Lake Spaulding course was thought to overly influence the northern average, a run was made deleting that course (leaving 12). The Spaulding course is also likely to be affected by black carbon from Interstate 80 and the transcontinental railroad traffic just to the south. This changed the slope to minus .112 cm (.044 inches), nearly a 20 percent change. This still left us with a puzzle on why the south is positive and the north negative.

Elevation undoubtedly plays a role. The southern group is higher than the northern one. The average southern group elevation is about 2,700 m (8,900 feet) whereas the average for the north is about 2,100 m (6,900 feet). Historically the average April 1 snow line has been about 1,300 m (4,000 to 4,500 feet) in the north and around 1,750 m (5,500 to 6,000 feet) in the southern group. So elevation is a factor. But a major portion of the

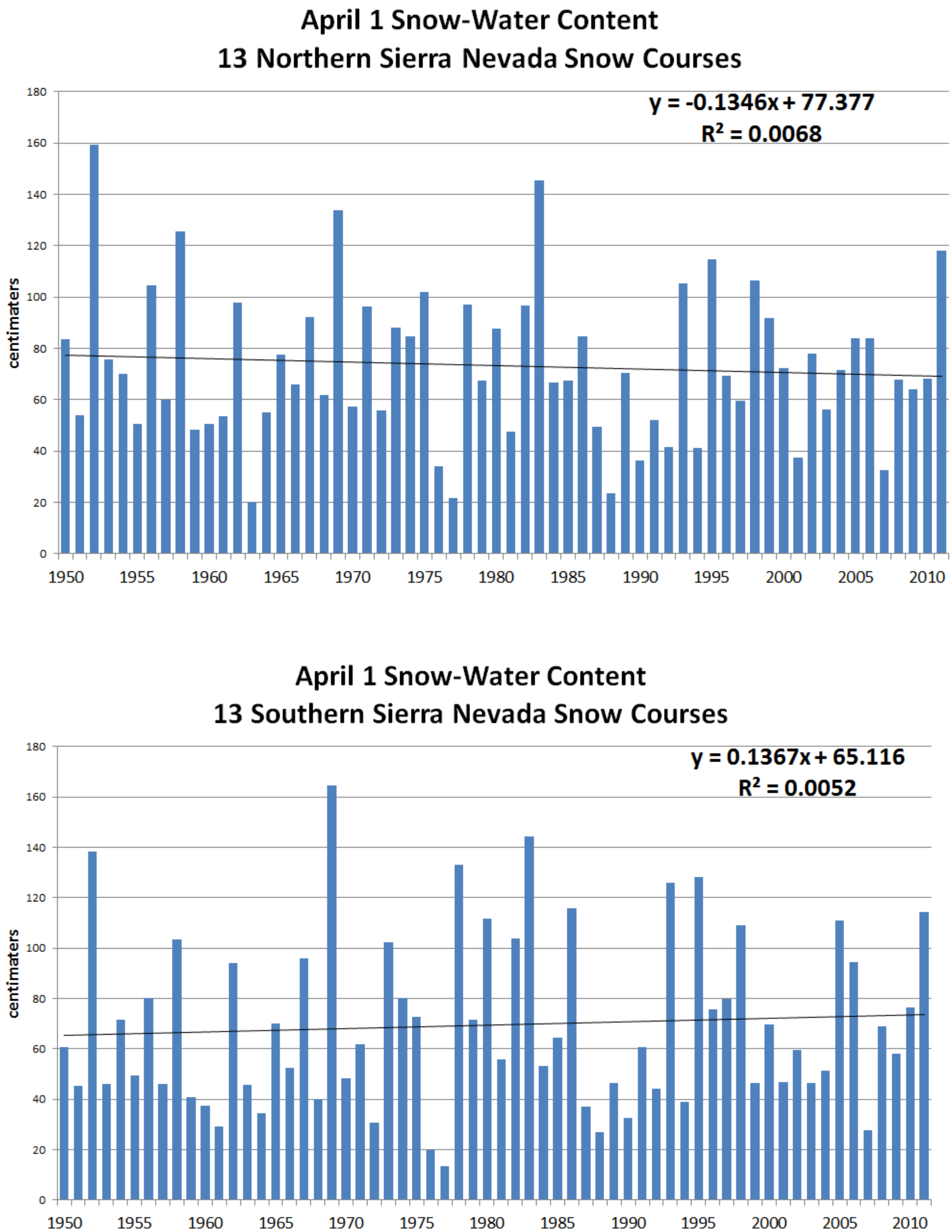


Figure 2. Northern and Southern Sierra snow course trends, 1950 – 2011.

difference remains when trying to match comparable elevation courses for the normal rise in snow levels as one moves south, i.e. 2100m (7,000 feet) in the north with 2400 m (8,000 feet) in the south. Also, another check was made using a lower elevation group in the southern Sierra, 10 courses equal or lower than the 13 in the original group. This lower group ranged from 1,950 to 2,100 m (6,400 to 7,000 feet). The slope was still upward at about 0.039 inches (0.10 cm) per year which is less that the 0.053 of the original 13 snow course group. Some other factor must be involved, which could be precipitation trends.

One might wonder about the gap between the northern and southern groups. A last-minute check was made for a group of 11 snow courses from the Mokelumne through Merced River basins. The average elevation of this middle group was about 2400 m (7,800 feet). This group (not shown) also had a small upward trend of .036 inches (.09 cm) per year, a bit less than the lower elevation southern group. Thus, it would appear that the fulcrum of change is near Lake Tahoe, the normal division between the northern and southern Sierra. These results are not that different from those observed by Jeff Dozier in a spring 2003 power point paper on trends (Dozier, 2003), although he felt there was a stronger elevation influence.

In comparing the snowpack trends in the two regions five years later after 2016 in Figure 3, the northern Sierra group decline was steepened by adding the recent drought, from -0.14 cm to -0.34 cm per year. The southern group switched from a gain of 0.14 cm to a decline of -0.13 cm per year. That shows how sensitive regression lines are to events near the end of the record. It is also true that the drought was relatively more severe in the southern Sierra, with the 4-year average San Joaquin 4 river runoff considerably below the worst similar length period of record. Adding one year, 2017, a very wet year, in Figure 4 reduced the\slope for the northern group to -0.28 cm per year and for the southern group to a much smaller -0.04 cm. This latter chart is probably more representative of current trends. It is possible that the reason for the apparent previous gain in southern Sierra snowpack in the first char**t** could be partly the result of weather modification (cloud seeding) operations (Stone, 2016). There are long running cloud seeding programs on all the major southern Sierra river watersheds except the Merced River. The estimated average percentage increase is probably around 5 percent or so, around 0.3 million acre-feet. That, along with the higher elevations (with proportionately less area in the transition zone than the northern Sierra), may have helped offset the decline in snowpack noted in most other western states. During the 5 years of recent drought, there was a notable lack of the usual colder storms which normally help build up the spring snowpack. Water year 2015 set a new record low pack with only 5 percent measured on April 1, far below the previous drought record of 25 percent (see Figure 5).

RUNOFF CHANGES

A decreasing percentage of water year runoff during the April-July snowmelt season was first noticed in the late 1980s. The decline is stronger in the Sacramento River basin 4-river group which would be expected because of generally lower mountain basin elevations than the higher southern Sierra watersheds. The trend over the 100 plus years of runoff record is shown by the final double chart, Figure 6, the top being the Sacramento River and the bottom the San Joaquin River system.

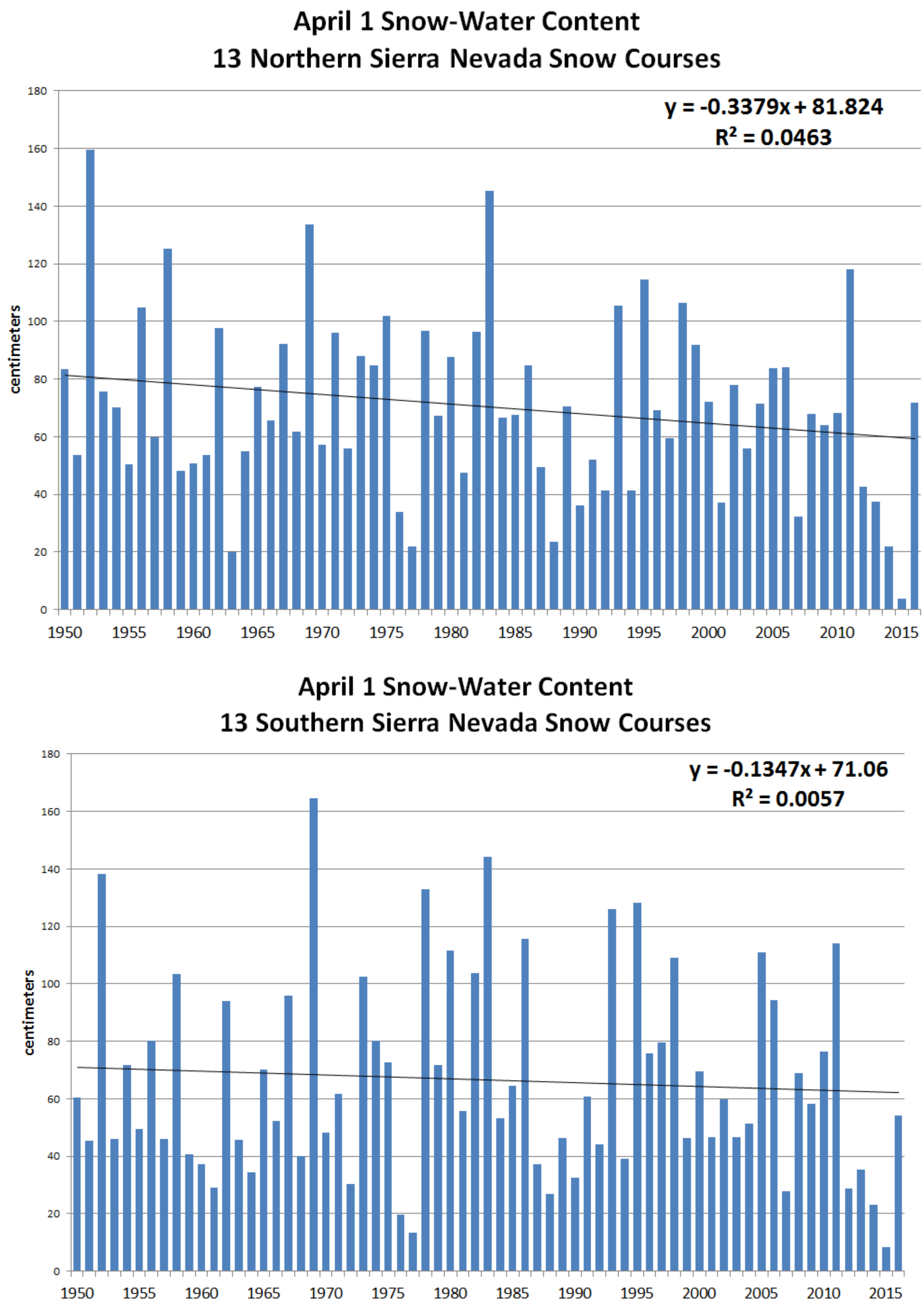
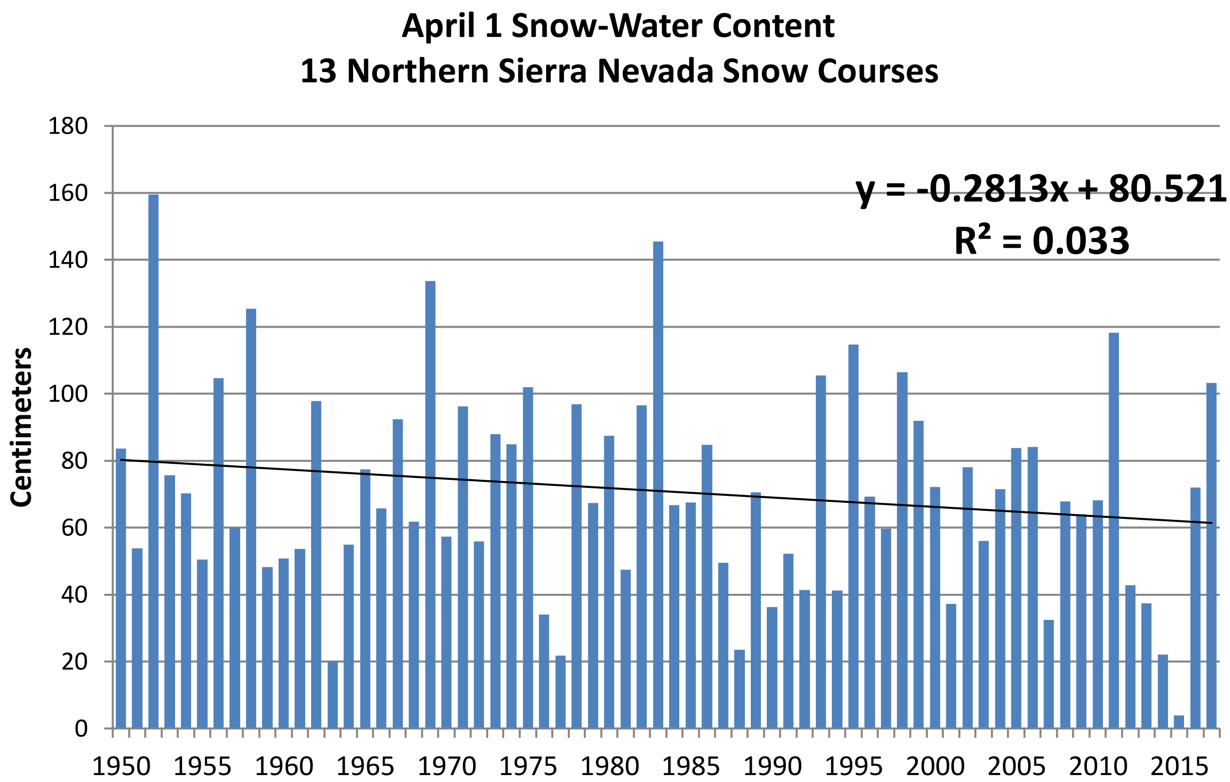


Figure 3. Northern and Southern Sierra snow course trends, 1950 – 2016.



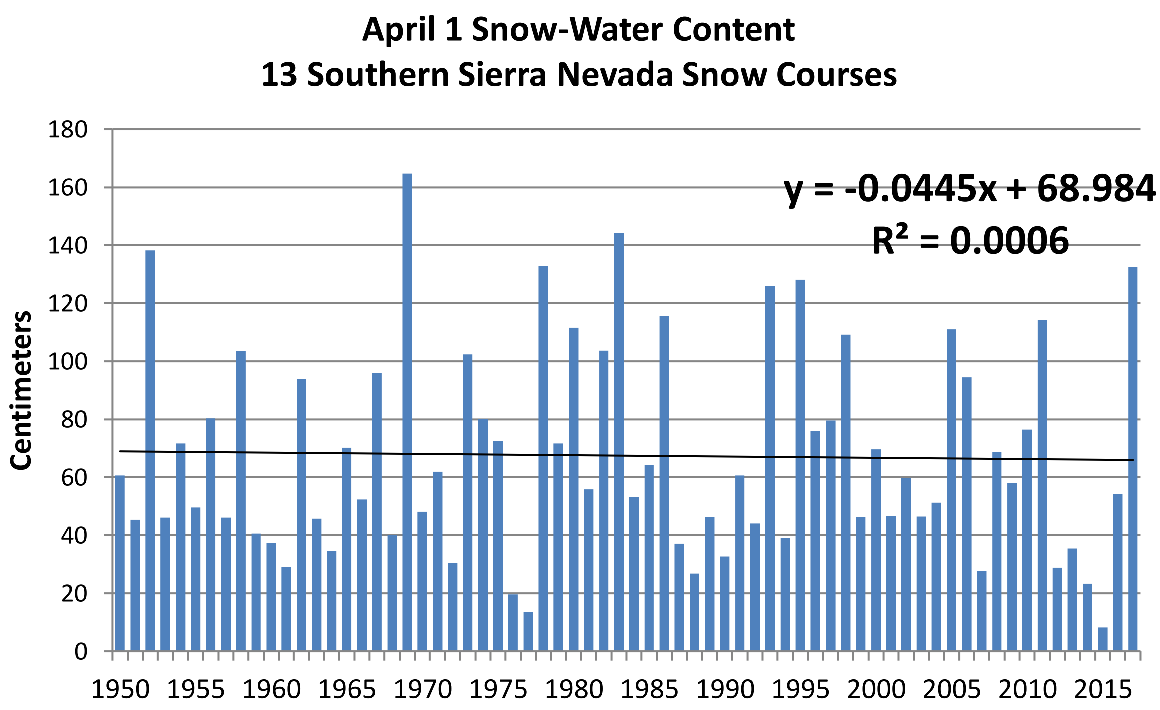


Figure 4. Northern and Southern Sierra Snow Course Trends 1950-2017

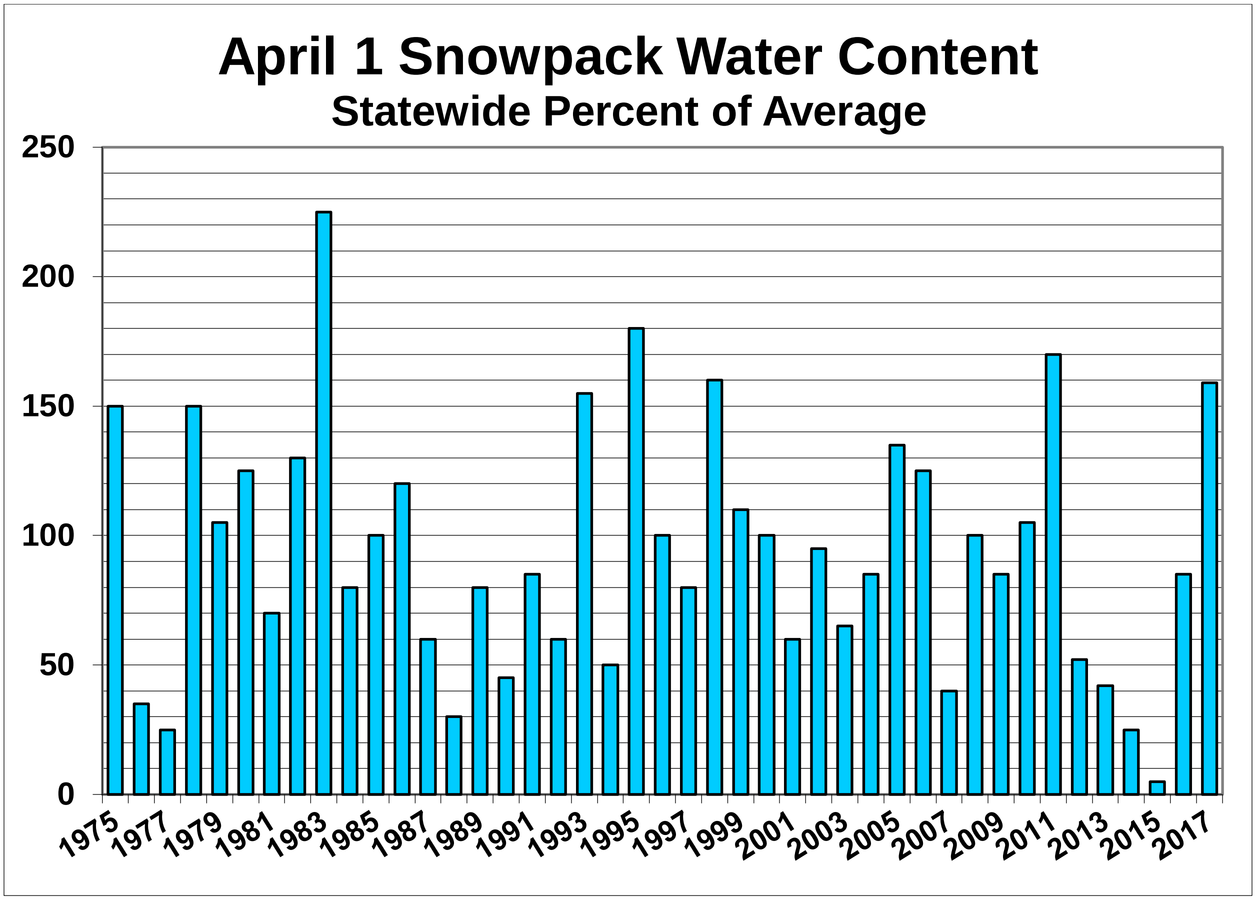
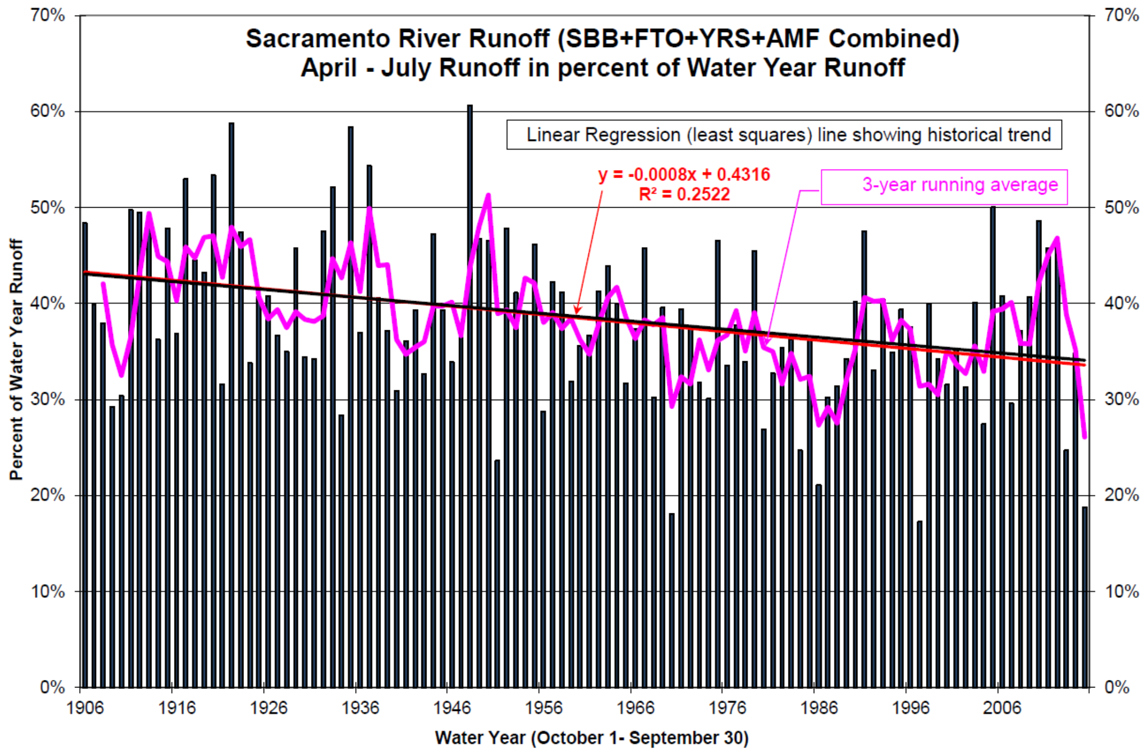


Figure 5. April 1 California snowpack water content for the entire state as percent of average.



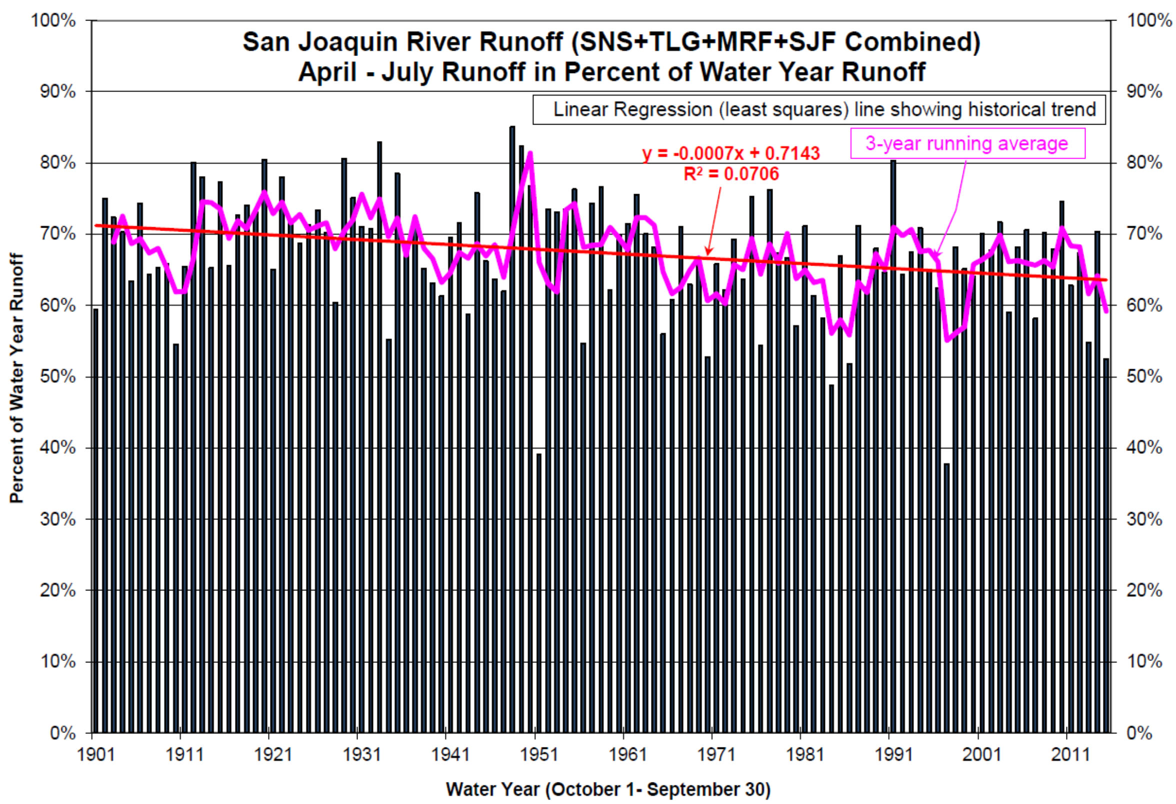


Figure 6. Trends in Sacramento (top) and San Joaquin (bottom) River portions for water year runoff during April – July snowmelt period.

REFERENCES

CA EPA. 2009. Indicators of Climate Change in California. (Updated in August 2013).

Dozier, Jeff. 2003. Do California's Snow Course Data Show an Historical Trend? A power point presentation.

Roos, M. and S. Sahota. 2012. Contrasting Snowpack Trends in the Sierra Nevada of California, Proceedings of Western Snow Conference, April 2012, Anchorage, AK.

Stone, Rick. 2016 (unpublished). RHS Consulting, a cloud seeding firm. Verbal presentation at Western Snow Conference in Seattle, April 2016.