Future California Droughts in a Climate Change World

Michael Anderson, Ph.D., P.E.
State Climatologist
California Department of Water Resources
Division of Flood Management
Hydrology and Flood Operations Office
Hydrology Branch
3310 El Camino Ave., Rm. 200
Sacramento, CA 95821

Tel: (916) 574-2830
Fax: (916) 574-2767
Email: manderso@water.ca.gov
Web: http://www.water.ca.gov/floodmgmt/hafoo/csc/

BIOGRAPHICAL SKETCH

Michael Anderson began working in the Department of Water Resources Division of Flood Management (DWR-DFM) Forecasting Section in July 2005. He came to DWR after extensive graduate, post-graduate and consulting work with Prof. M. Levent Kavvas of U.C. Davis. Michael received his Ph.D. in 1998 in Civil and Environmental Engineering at UC Davis with a minor in Atmospheric Science. He received his M.S. in 1993 in Civil and Environmental Engineering from UC Davis. He received his Bachelor's degree in Civil Engineering from Colorado State University in 1991. His experiences include a variety of research and studies involving hydrologic and atmospheric models as well as field studies. He is also an experienced instructor having taught classes through UC Extension and at California State University Sacramento. He is currently serving as State Climatologist for California.

ABSTRACT

An often-cited impact of climate change is that floods and droughts will get worse in the coming century. Such an assertion leads to the question: What will future droughts in California look like over the next century. In an effort to explore this topic, characteristics of 20th century droughts in California are described followed by a quick look at paleodroughts. After reviewing climate change impacts relevant to California drought, the presentation explores how the aforementioned drought characteristics might change.


Future California Droughts
in a Climate Change World
Michael Anderson, Ph.D., PE
State Climatologist, California
California Extreme Precipitation Symposium
June 24, 2009

What will California drought look like in the next century as climate warms?

One of the often-heard impacts of climate change is the statement that there will be more floods and droughts in the future as the climate warms. For this talk, we'll explore some characteristics of 20th Century California droughts and discuss how these characteristics may change with climate change.

Talk Overview

- Defining Drought
- 20^{th} Century California Drought
- Paleodroughts
- Expected Impacts from Climate Change
- Future Drought Characteristics

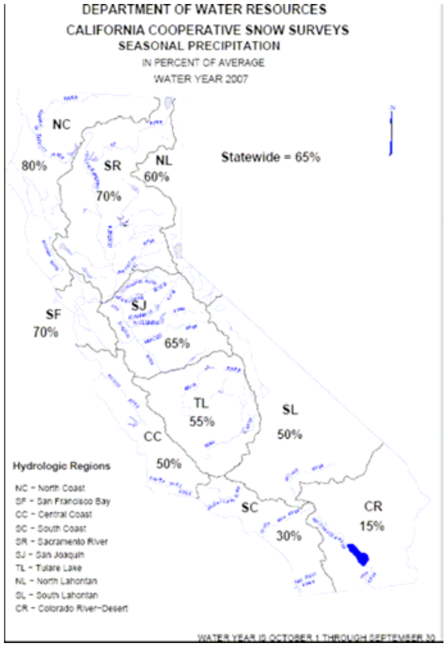
In order to frame this talk, I'll cover the following topics. First we'll set a definition of drought to set the stage for comparisons. Then we'll look at different characteristics of 20^{th} Century California droughts. For good measure we'll take a brief look at the paleorecord and discuss some of the mega-droughts of past centuries. Given that background we can then start to explore how climate change might influence drought characteristics.

Defining Drought

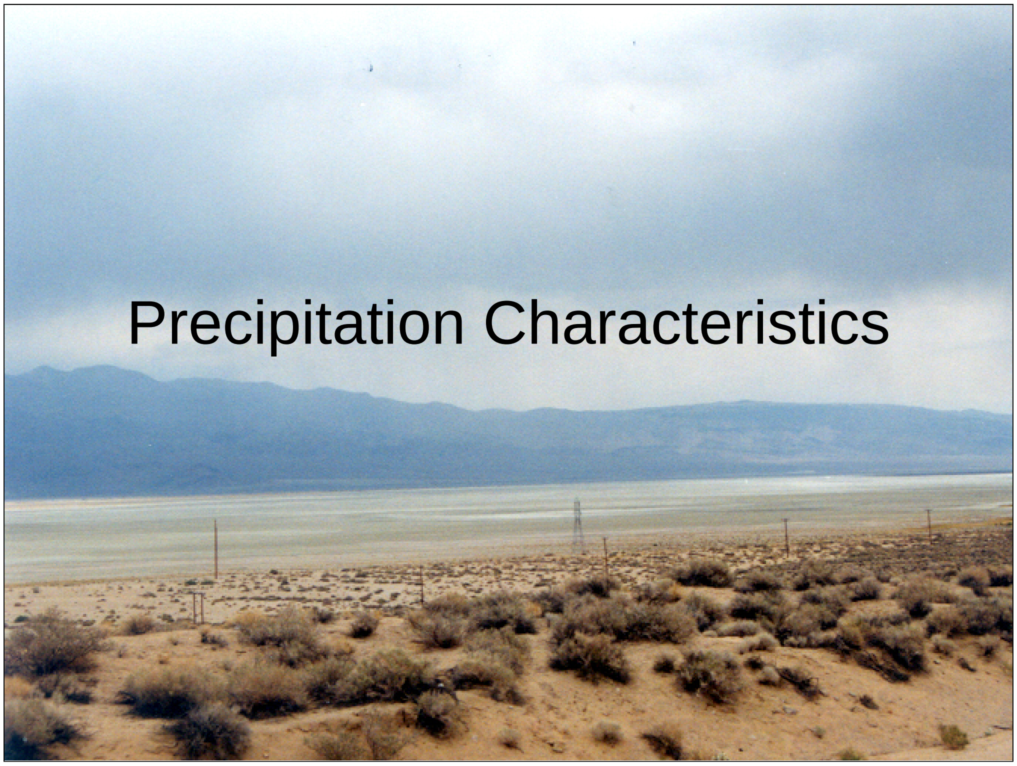
- Short-Term Climatic Anomaly
- Below Average Precipitation
- Below Average Snowpack
- Below Average Runoff
- Duration Greater than One Year

Drought is a versatile word that has a variety of definitions and connotations depending on perspective or field of study. For this talk, we will define drought as a short-term climatic anomaly that yields below average precipitation. This oftentimes corresponds to below average snowpack and below average runoff. However, we want to consider multi-year periods of these conditions as the observed record has quite a few instances of single dry years.

Location Matters

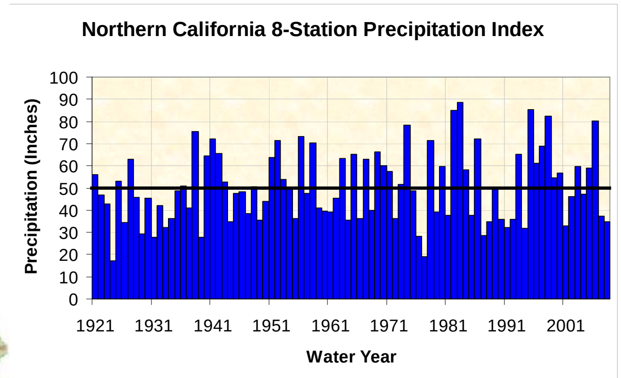


Because California's climate is amazingly diverse, it is also important to identify a location to discuss drought. It is quite possible to have drought conditions in one part of the state and not in others. For this talk, we'll focus our attentions on the Sacramento Basin due to its importance in the state's water supply portfolio.



First up, we'll look at precipitation characteristics.

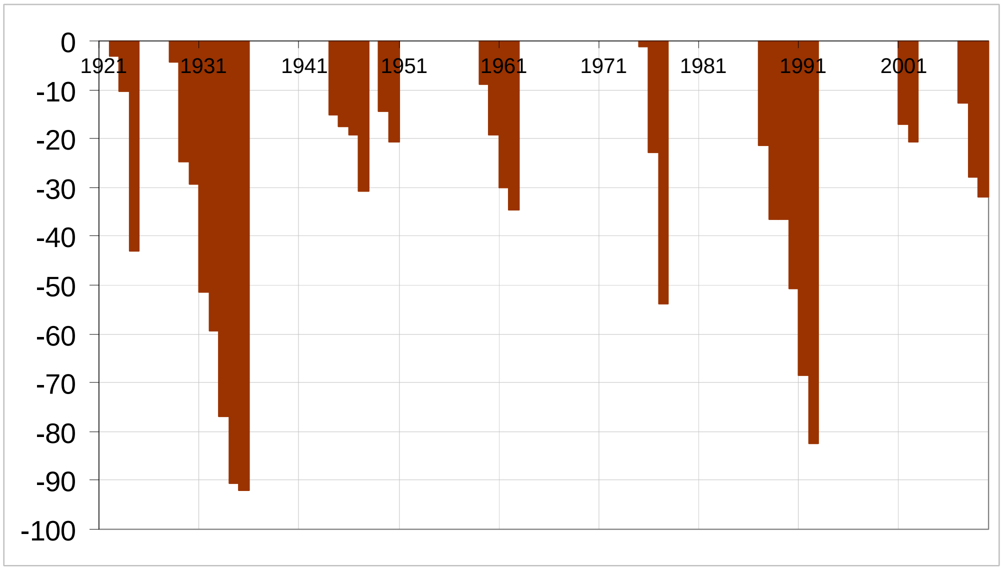
The Northern CA 8-Station Index



Eight Stations: Mt. Shasta City, Shasta Dam, Mineral, Quincy, Brush Creek, Sierraville, Blue Canyon, and Pacific House

We'll focus our analysis on the 8 station index. The 8 station index is an average of 8 stations that span the Sierra Nevada portion of the Sacramento Basin. The 8 stations are listed here ranging from Mount Shasta City in the north down to Pacific House and Blue Canyon in the American River watershed. Average annual precipitation for the 8 station index is 50 inches. Our period of record extends back to 1921 as can be seen in the chart on the right. The heavy black line represents average conditions to help highlight wet and dry periods. As can be seen from the chart there are single dry years as well as multi-year drought periods to explore.

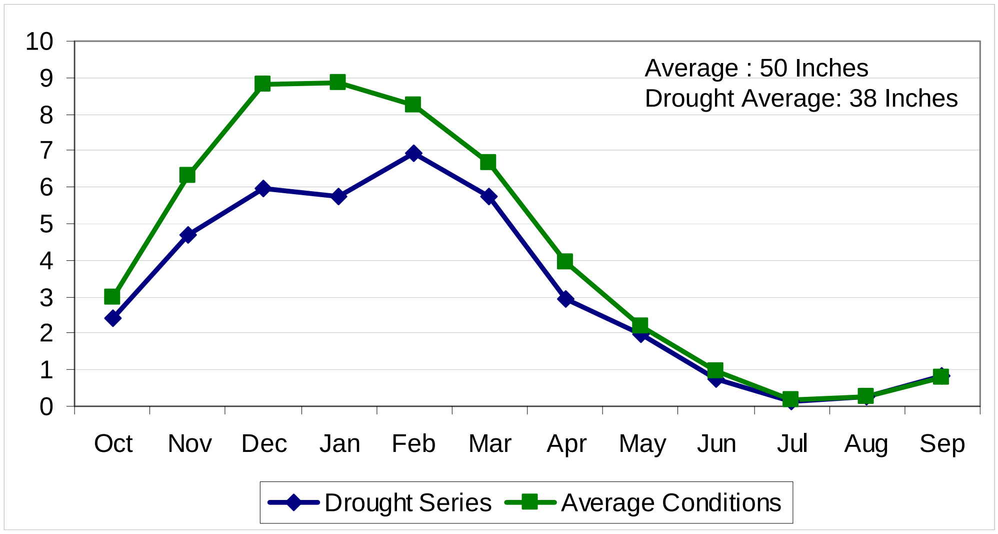
20th Century CA Droughts – 8 Station Index



This chart focuses in on the multi-year drought periods in the 8-station index. The bars represent the cumulative deficit of the drought period. You can see the extreme dry years of 1924 and 1977 with the big drops in a single year. You can also see the impact of multiple dry years like the dustbowl drought of the 1930s and the last big drought from 1987 to 1992.

You can see that there are 2, 3, and 6 year droughts in the 8-station record with varying degrees of severity. One last note is that the current drought is depicted as of June 10, 2009. Any precipitation that increases the 8-station index value will decrease the cumulative deficit shown in the last bar.

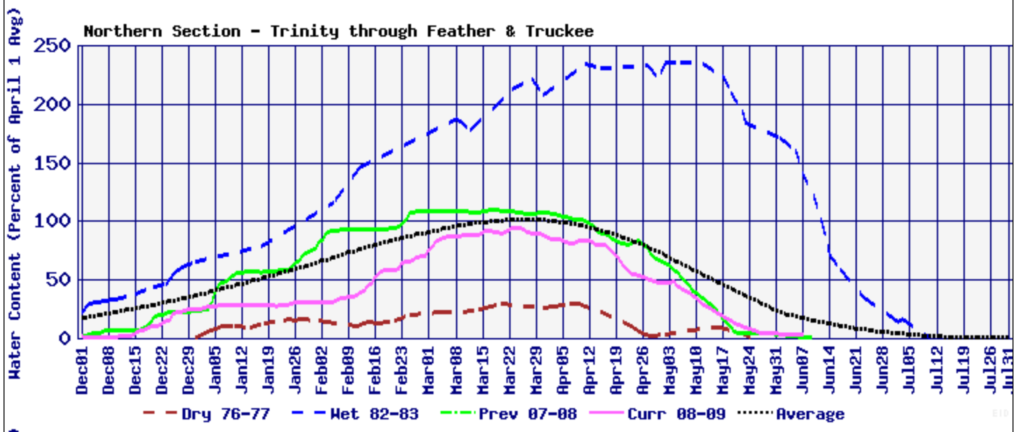
Monthly 8 Station Distribution



This plot compares the average monthly accumulations of 8 station precipitation for period of record for normal conditions and drought conditions. An average of the drought conditions yields an annual total of 38 inches for the index. The plot shows the big deficits coming in December and January on average. This would imply that on average an anomalous atmospheric condition blocking precipitation from the region during the winter months sets the stage for drought conditions.

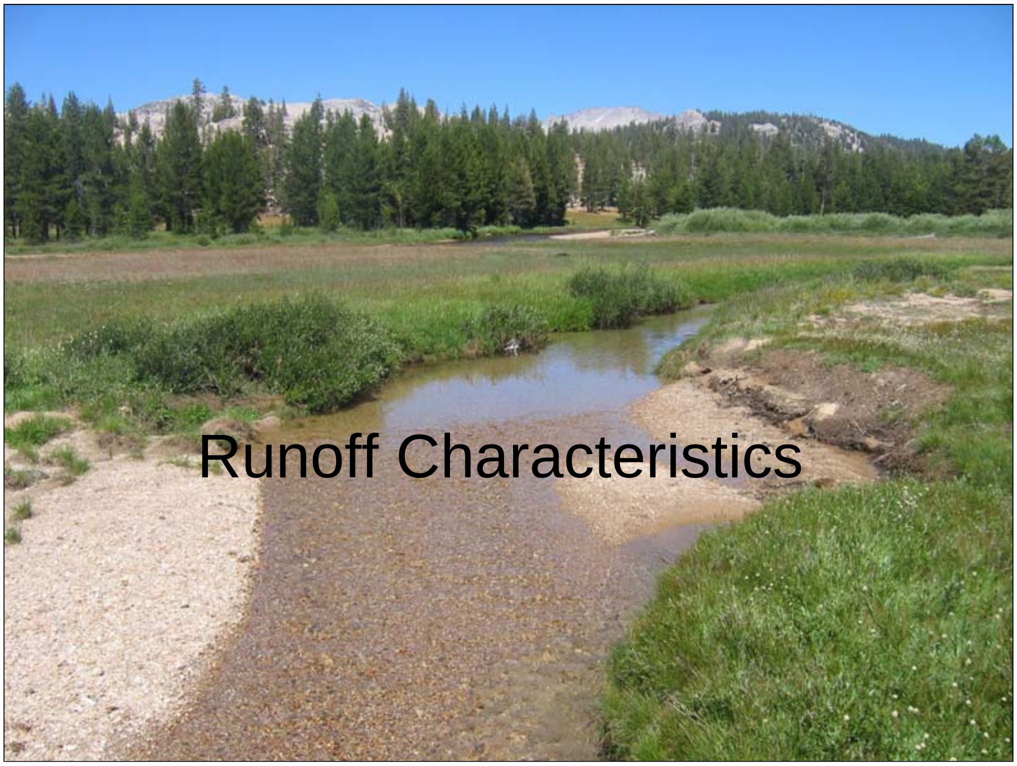
Next, we'll look at snowpack Traditionally April 1st is considered the peak accumulation date for snowpack in California. Climate change is expected to change this characteristic, but we'll get to that later in the talk.

Snowpack Characteristics



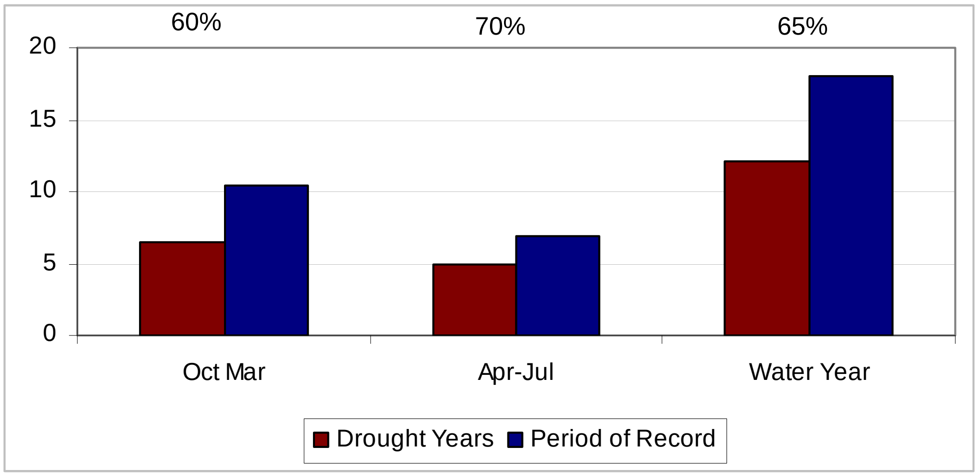
Drought Average April 1st: 60%

Here we have a chart of Northern section snowpack conditions. This year, last year, 1983, 1977, and average conditions are shown. Note that in the dry years, accumulation is delayed and contains stretches of flat lines indicating no precipitation falling. Note that in the dry years the melt occurs early as well. Looking at the last 50 years of April 1st percentages, the average dry year April 1st percentage is 60% of normal for the traditional peak accumulation date.



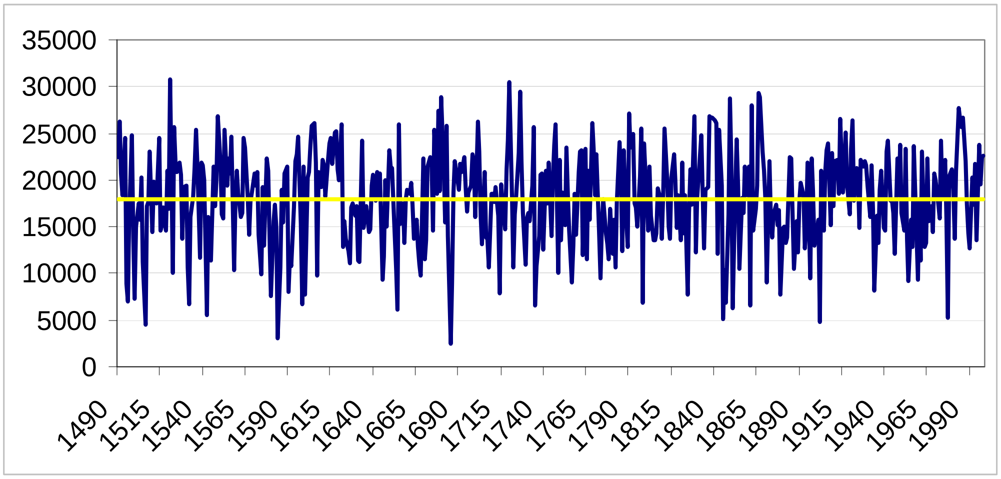
Finally, we'll look at runoff characteristics of the Sacramento Basin. We'll focus on the Sacramento 4 rivers runoff data that can be found on CDEC on the water supply page.

Drought Runoff Characteristics – Sacramento Basin



From the runoff data on the water supply page, we have information for fall/winter flows, spring flows and total water year amounts. Period of record averages are depicted with the blue bars while drought years are depicted with the red bars. For the drought years, the October through March runoff is on average 60% of normal while the April through July runoff is 70% of normal. For the total water year, the average drought condition is 65% of normal.

Paleodroughts



Woodhouse et al., 2006: Upper Colorado River Basin Streamflow Reconstruction

Now let's take a quick look at paleorecords. Paleo reconstructions use proxy data like tree rings or lake sediments to generate a picture of runoff or precipitation that extends far beyond the observed record. Shown here is the Lee's Ferry flow reconstruction for the Colorado River developed from tree ring data by Connie Woodhouse and others. The yellow line depicts the period of record average. From this chart, you can see that the paleorecord gives the impression of greater variability and extended periods of below average runoff. As these are expected characteristics of climate change, the paleorecord can be used to guide planning efforts for the future.

100+yr. Droughts in California?

"Here I present a study of relict tree stumps rooted in present-day lakes, marshes and streams, which suggests that California's Sierra Nevada experienced extremely severe drought conditions for more than 2 centuries before AD~1112 and for more than 140 years before AD~1350."

"Future natural or anthropogenically induced warming may cause a recurrence of the extreme drought conditions"

"California's mediaeval precipitation regime, if it recurred with today's burgeoning human population, would be highly disruptive environmentally and economically."

(ref. Scott Stine, *Nature*, June 1994)

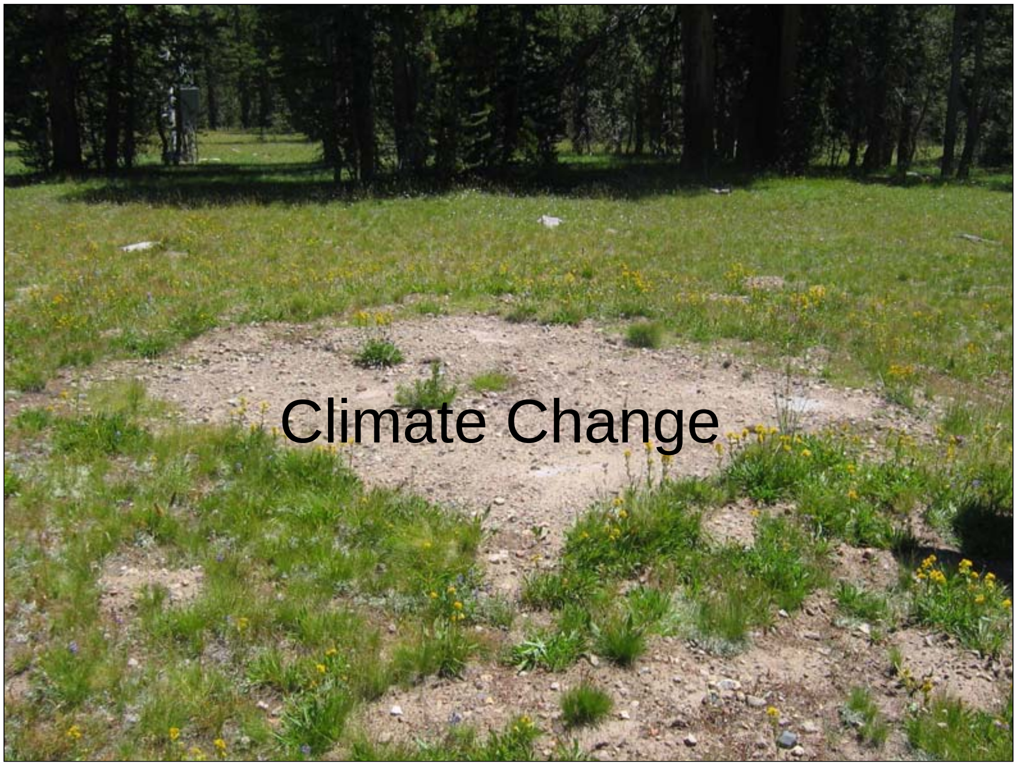
Slide Acknowledgement: Jay Lund, UC Davis

One of the often cited events in the paleo record are the medieval droughts around 1100 AD and 1300 AD. These multi-decadal to century long droughts are thought to have played a significant role in the evolution of native civilizations in the American Southwest. This slide, borrowed from Jay Lund (UC Davis) quotes Scott Stine's *Nature* article noting that if these droughts were to re-occur in modern times, similar civilization changing results are likely to occur.

1921-1940 Sacramento Basin

- Only 6 years with above average rainfall in 8 Station Index (1921, 1925, 1927, 1936, 1938, 1940)
- Average annual precipitation 44 inches during this time
- Water year runoff average 14.9 MAF
- Water Supply Index Class Distribution: 2W, 4AN, 4BN, 5D, 5C

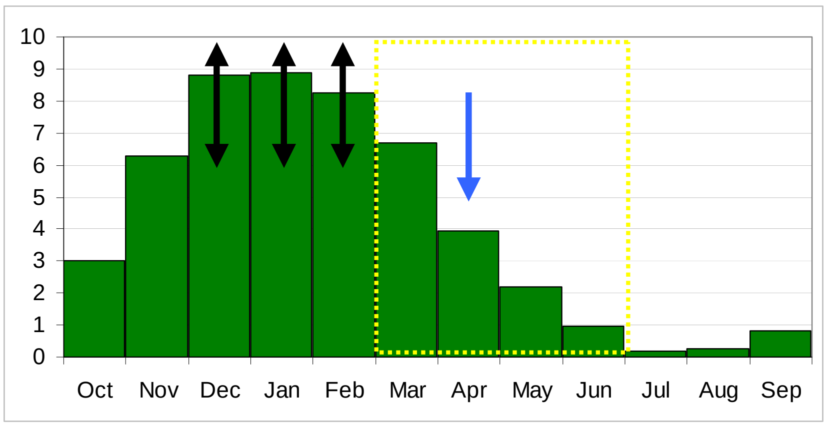
While I consider these megadroughts to be climate shifts rather than droughts, it is worth noting that a smaller duration shift is present in the observed record for the Sacramento Basin. The twenty year period from 1921 to 1940 had only six years with above average rainfall. The average rainfall during this period was six inches less than the period of record average of 50 inches that we use today. Runoff during this period averaged 14.9 million acre-feet which is over 3 million acre-feet less than our current average of 18 million acre-feet. I also show the water supply index water year classification distribution for this period which shows a distinctly dry bias (W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, and C = Critical).



Now that we have an idea of what historical drought looks like, let's explore how climate change might influence things. Hopefully our winters won't leave our snow pillows this bare.

Climate Change Impacts

- Less Precipitation Falling as Snow
- Drier Springs
- Increased Variability

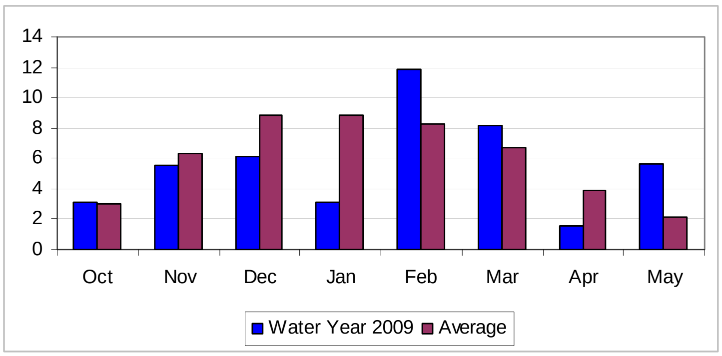


Climate change is expected to increase temperatures which will cause the percentage of precipitation falling as rain to increase which will decrease the size of the snowpack. Warmer, drier springs will initiate snowmelt earlier and decrease the volume of runoff traditionally used to refill reservoirs for the summer's water supply. In addition to these changes, the variability is expected to increase meaning greater fluctuations in what is observed relative to average conditions.

The graph shown here is of the monthly 8 station index precipitation distribution. The black arrows indicate the increasing varaibiltiy while the yellow box with the blue arrow is used to illustrate the expectation that this portion of the distribution will decrease. All of these features can have profound impacts on the drought characteristics we have discussed so far.

Signs of Change?

- Driest Precipitation Year Southern CA 2007
- Driest Spring Northern Sierra 2008
- Water Year 2009 Precipitation Distribution



Some of our expectations for the future have made an appearance in this latest drought. Two years ago, several locations in southern California experienced their driest precipitation year which is July 1st through June 30. This comes two years after one of the wettest years on record and five years after the previous low record was set. Last year, many sites in northern California, including the 8 station index, experienced their driest spring ever. An average snowpack for April 1 produced only 58% of the expected April through July runoff.

Finally, this water year has seen some big shifts in conditions from month to month. In January and the beginning of February, dry conditions were setting the stage for record low runoff values. Conditions then changed abruptly in the latter half of February and beginning of March with a series of storms with subtropical taps that greatly improved the situation. The latter half of March and April returned to very dry conditions which changed again in the beginning of May with a series of storms that hit northern California. Is this a preview of what is to come?

Future Drought Characteristics

- Fall runoff decreases due to drier antecedent conditions in watershed
- Decrease in Spring precipitation decreases odds of “March Miracles”
- Smaller snowpacks and drier springs decrease April-July runoff

Looking at climate change and drought characteristics, we can start to make some qualitative assessments. First, we might expect fall flows to decrease due to drier antecedent conditions in the watershed. Second, a drier spring might lead to the expectation that the probability of a so-called March Miracle or Awesome April will decrease. Another component leading to lower spring flows is the expectation of a smaller snowpack on average. The net effect of these changes is a greater reliance on winter precipitation to make up the bulk of the seasonal total. A dry winter month in the future would then be expected to cause more of a drought impact.

What If Drought Year – 8 Station Index

- Blend elements of past drought years to represent climate change drought year
- Low 10 Monthly Average: 6.91 inches
- Low 10 Seasonal Total Average: 17.10 inches
- 1977/1991/1924 Seasonal Mix: 11.07 inches

Given this picture of future conditions, we can start to imagine what-if scenarios for a dry year. One way of doing this is to combine elements of the historical record that mimic our expectation of future conditions. As a starting point, for the 8 station index, I averaged the lowest 10 monthly values and summed these low months together to get an annual value. The total only amounted to 6.91 inches. This is likely an extreme situation as it assumes the worst conditions will be present for all months. Backing off a step, I looked at the seasonal totals and averaged the lowest 10 values for each season. The annual sum for this event came out to be 17.10 inches which is in the ball park of the 1924 and 1977 water years. While extreme, it has already been demonstrated that such outcomes are plausible.

Another alternative I explored was to look at the lowest 10 winters and combine the lowest winter (1991) with the lowest fall from this subset (1977) and the lowest spring (1924). This generated an annual total of 11.07 inches. Note that 1977 is not the driest fall, but the driest fall associated with the 10 driest winters and 1924 is the driest spring associated with the 10 driest winters. This would also be an extreme case, but may be plausible given our expectations for climate change.

What If Drought Year - Runoff

- No snowpack for spring runoff
- Fall runoff decrease due to drier antecedent conditions
- Winter flows maintained only with continued precipitation
- Average of 10 Lowest Drought Flows:
  Oct-Mar: 3.8 MAF (10.4 MAF)
  Apr-Jul: 2.6 MAF (6.8 MAF)
  Water Year: 7.5 MAF (18 MAF)

In terms of runoff, the extreme condition would be no snowpack and a fall that requires more precipitation to see an increase in river flows. In this scenario, winter flows would likely rise with an event, but fall back to lower values than they would under current conditions. In terms of quantifying low runoff, the average of the 10 lowest Oct-March flows for the Sacramento Basin yielded only 3.8 million acre feet compared to the current average of 10.4 MAF. The spring runoff would only be 2.6 MAF instead of the current expectation of 6.8 MAF. The average of the 10 lowest water year totals yields only 7.5 MAF compared to the current average of 18 MAF. Note that these numbers assume that the future drought will look like the average of today's most extreme conditions. This may not be the case due to the expectation that variability will increase and month to month fluctuations may become the norm.

Multi-Year Sequencing

- 20th Century shows 2, 3, 4, and 6 Yr droughts
- 20-year dry period 1921-1940 in observed record for 8 Station Index & Sacramento Basin Runoff
- Paleorecord shows multiple 10+ year droughts as well as 2 century-long dry periods (climate shifts)

As for multi-year sequencing, it is very hard to say what the future will bring. Historically in the observational record we have seen 2, 3, 4, and 6 year droughts. The paleorecord shows multiple 10+ year droughts as well as our medieval monster droughts. A more recent 20-year shift to drier conditions is also present. All of these conditions can be considered possible for the future.

Conclusions

- Climate change is expected to have fewer wet springs potentially increasing risk of drought occurrence and severity.

- The expectation of increased variability means future conditions can change quickly. This year serves as an example of this possibility.

To wrap this up, I want to focus on two points. First, in the past century we have seen some wintertime precipitation/runoff deficits offset or mitigated by wetter than average spring conditions. The expectation of drier springs can be interpreted to mean a decrease in the probability of this happening in future droughts. This means that the risk of drought occurrence and severity increases as seasonal precipitation values become more dependent on winter conditions. Note that a decreased snowpack only aggravates conditions.

The second point is that our expectation of increased variability can cause conditions to change rapidly. The current water year serves as an example. In January, precipitation was 1/3 of average, reservoir inflows fell to record low levels and storage was nearing historic lows in some watersheds. Things changed drastically in February turning a desperate year into a bearable year.