Measuring Water Resources Unit 4 Student Assignment: A Water Balance Approach for Assessment of the California Drought

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Files associated with this module:

1. Summary file of data used
2. Sacramento-San Joaquin basin map
3. Precipitation: ssj-annual-precipitation-1895-2017.xlsx
4. Snow
   a. snow-data.xlsx (Reflection GPS and snow pillow examples)
   b. sierra-nevada-snow-data-2014-2015.kmz (Google Earth)
5. GRACE: ssj-grace-total-water-storage-anom.xlsx

4.1 Introduction

The 2012–2016 California Drought did not impact the entire state the same way. The drought was more intense in some regions than others; the societal impacts varied geographically due to complex relationships between climate, geology, spatial water transfers, agricultural production, and population centers. For this final unit, we will focus on the hydrologic budget of the Sacramento-San Joaquin Valley basin (see SSJV basin map provided). Note this basin does not encompass all natural water fluxes or human usage that played a role in the drought. However, it does include the largest fluxes and storage terms, including snow accumulation and melt from the Sierra Nevada Mountains and storage/pumping of water from the Central Valley aquifer.

Timing of the drought: The California drought began in 2012 and persisted through 2016 (Figure 1). By 2013 it was clear that this was a significant drought and by the end of 2014 more than half the state was experiencing an "exceptional" drought. The winter and spring of 2017 had well-above-normal precipitation and although groundwater aquifers were not recovered, at the surface level, the state was considered to no longer be in drought. The focus of this unit is on characterizing the exceptional period of the drought during water years 2014 and 2015 (Figure 2). As peak snow accumulation occurs in early spring, we compare drought intensity on April 1 of these years. Undoubtedly droughts of this severity will occur in the future and by studying this drought we can hope to minimize the human and environmental impact next time.

The final product for this unit will be an Report for California policy makers that summarizes the water monitoring methods available, their pros/cons/uncertainties, that will incorporate the results of a series of calculations, data assembly/integration, and data analysis that are described below. These activities will provide the basis for performing an analysis of the present state of affairs with regard to predicting and managing water resources within a complex framework of competing needs. An important role played by geoscientists is to communicate complex ideas and concepts in reports that advise policy developers. Your report will be written as if you are a science advisor to policy makers in the state of California. It is your responsibility to develop a scientific report detailing all you have learned in this module. As you work through the scientific section in this exercise (A–G), consider how best to use the resulting information within the report (e.g. examples of calculations, plots of data as time series). Make sure to consider how use of the water balance equation can help organize the report's introduction (including motivation for work), methods and data, discussion, and conclusion sections.

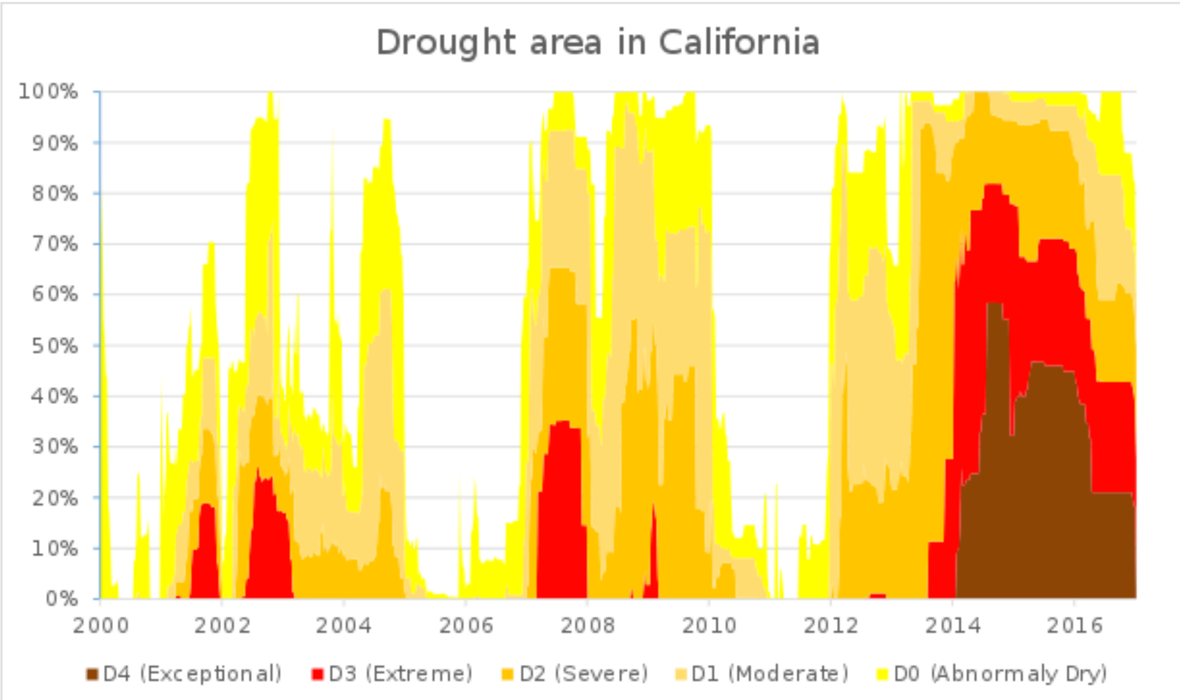
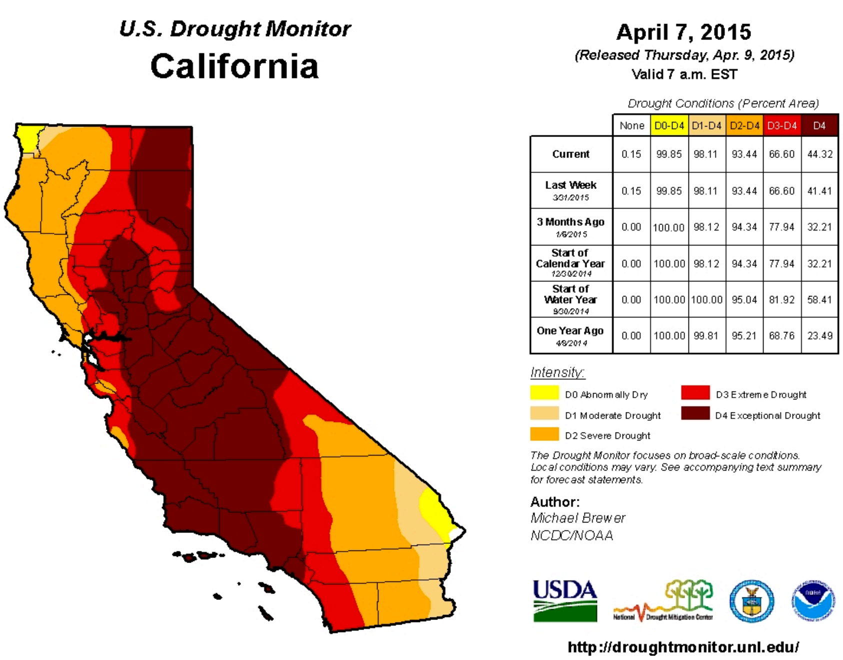


Figure 1. Time series of U.S. Drought Monitor intensity, from http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections/MAPPTaskForces/DroughtTaskForce/CaliforniaDrought.aspx



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.15	99.85	98.11	93.44	66.60	44.32
Last Week 3/31/2015	0.15	99.85	98.11	93.44	66.60	41.41
3 Months Ago 1/6/2015	0.00	100.00	98.12	94.34	77.94	32.21
Start of Calendar Year 12/30/2014	0.00	100.00	98.12	94.34	77.94	32.21
Start of Water Year 9/30/2014	0.00	100.00	100.00	95.04	81.92	58.41
One Year Ago 4/8/2014	0.00	100.00	99.81	95.21	68.76	23.49

Figure 2. US Drought Monitor map of California at the height of the drought in April 2015. http://droughtmonitor.unl.edu/data/jpg/20150407/20150407_ca_trd.jpg

4.2 Project Description

A. Motivation: Water usage in California and the 2014/2015 Drought

Visit: http://ca.water.usgs.gov/water_use/index.html

Our goal is to compare the 'natural" hydrologic water deficit during the drought to the water use in the basin.

If the drought deficit is large compared to water usage, then individuals, communities, and businesses will have to adjust how they use water in response to the drought. If the deficit is small, then the drought is not a societal problem (although there still could be ecological consequences). Deficits of about half than annual water use usually require societal adjustments.

The total population of California is ~40 million; we will only consider the ~20 million people using water directly from the Sacramento-San Joaquin basin, the focus of our study.

1. Based on the USGS report (USGS Circular 1405; https://pubs.usgs.gov/circ/1405/), the amount of water used *by each person* in the Sacramento-San Joaquin basin (SSJ) basin in 2010 was 1200 gallons per day (assuming the primary uses are the "domestic" and "irrigation" categories). Using the USGS per capita water usage in the SSJV, what is the total volume of water used in a year (in km^3)?
[1 gallon = 3.79×10^{-12} km^3]

2. To help yourself visualize this amount, convert this number to a depth of water used (in mm) over the entire SSJ basin. The area of the basin is 1.56×10^5 km^2.

3. Based on your answer from Question 1, how large would the natural water deficit need to be (in km^3) in any year for there to be a *bona fide* problem that requires attention by businesses, regulators, and water managers?

4. How do you think you could measure the natural hydrologic water deficit resulting from drought? What would different tools tell you about different terrestrial water storage terms? For now, just provide a list that describes what different data sets tell you about water storage. At the end of this exercise, you will write a report comparing the strengths/weaknesses of traditional and geodetic techniques for monitoring water storage.

B. Precipitation analysis

Annual total precipitation (mm) for Water Years (WY) 1895 to 2017 in the Sacramento-San Joaquin basin is provided in the data file ssj-annual-precipitation-1895-2017.xlsx *(source: National Climatic Data Center, Climate Division Monthly Data, ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv)*. The area of the basin is 1.56×10^5 km^2. The annual amount represents the average across the basin: precipitation tends to be greater at high elevations and lower in the Central Valley. The Water Year calculation includes data from October 1 of one year through September 30 of the next. For example, Water Year 2014 includes data from October 1, 2013, through September 30, 2014. We will first analyze several aspects of this record to understand the intensity of the 2014 drought.

For each of the following, provide an answer and a description of how the calculation was made.

5. Calculate the annual average precipitation over the period of record.

6. What is the wettest year on record and what was the precipitation total that year? What are three the driest years on record?

7. For the two-year period of the drought (WY 2014 and 2015), what is the difference between the water year precipitation and the long-term annual average?

8. Convert this deficit to a volume of precipitation for the entire basin.

9. Now consider this deficit in terms of how it might affect society. From a human water use perspective, predict if the change in terrestrial water storage during the drought years is larger or smaller than you calculated based on precipitation. You must consider the different terms of the water balance equation ($dS/dt = P - ET - R - use$, from Unit 2) and feedbacks between them.

C. Snow analysis from GPS reflection and snow pillow stations

Year-to-year variations in seasonal snow accumulation in the Sierra Nevada affect California in many ways: too little snow and there is limited water for agriculture and power generation during the spring and summer; too much snow can lead to flooding. Observations of snow depth and Snow Water Equivalent (SWE) throughout the drainage basin are critical to guide management decisions (e.g., reservoir operations).

10. First, look at the record of snow depth from a PBOH2O Reflection GPS station P346. Use the data provided in snow-data.xlsx (or go to http://xenon.colorado.edu/portal/index.php, choose the "Snow" product, and then find the

station page for P346). How does the snow depth in the winters of 2014 and 2015 compare to the previous years?

11. Now, use data from a standard snow pillow from station (Pilot Peak, CA) close to P346 (also in snow-data.xlsx). How does the SWE in the winters of 2014 and 2015 compare to the previous years? Calculate difference from normal, both in terms of mm of water and as a percentage of the long-term average. For this comparison, use observations from April 1 of 2014 and 2015 (compared to that date from the multiyear average for April 1). The peak snowpack is typically around April 1.

12. Compare and contrast the advantages and disadvantages of the standard snow sensor and Reflection GPS records for quantifying the anomalies during drought?

13. Map evaluation: Look at spatial variations of snowpack in 2014 (April 1) as recorded by the snow-sensing network in California (kmz file). Identify the maximum and minimum deviation of SWE (as a percentage) compared to normal values. Describe the pattern in the magnitude of anomalies—are the deviations similar throughout the basin?

14. Use the map of 2014 SWE anomalies to estimate the average deviation over the portion of the basin where there is a seasonal snowpack. Now, distribute this anomaly over the entire basin. You will need to estimate the portion of the basin that has a seasonal snowpack. What volume of water is missing from the basin in 2014 due the anomalously low snow accumulation?

15. Based on variability you see on map, develop a simple method to estimate uncertainty in the 2014 SWE anomaly. Scale this to the basin as in the previous question (answer in km^3). (Note: this measure of uncertainty will be included in your final report.)

D. GRACE analysis

16. Use the data provided (ssj-grace-total-water-storage-anom.xlsx). Plot Total Water Storage (TWS) anomaly through time.

17. The uncertainty in estimates of water storage from GRACE are approximately 20 mm. Scale this to the SSJ basin and report in units of km^3, for comparison to uncertainty in snow anomalies and other terms.

18. What is the amplitude of the seasonal cycle of TWS? What months are TWS highest and lowest? Explain the timing of seasonal TWS maxima and minima in terms of the annual cycle of the different components of the water balance equation.

19. What is the TWS anomaly during the 2014 drought (answer in mm)? First compare the 2014 TWS anomaly to the long-term value *at the time of year when TWS is typically highest*. You will need to estimate the "long-term" average at that time of year.

20. Convert the TWS anomaly during the 2014 drought to a volume of water over the entire SSJ basin.

21. Discuss the advantages and disadvantages of the GRACE data for quantifying changes in water storage during the California drought.

E. Comparing components of the water balance

We will now compare the various calculations: total precipitation, snow in the mountains, and TWS based on GRACE. The comparison will be in terms of km^3 of water throughout the Sac-SJ basin.

22. Compare the precipitation deficit summed for Water Year 2014 to the TWS anomaly from GRACE on April 1, 2014.

23. Explain this difference in terms of the water balance equation for a basin, being specific about feedbacks or interactions between different components of the hydrologic cycle.

24. You calculated the snow deficit on April 1, 2014 (relative to the average value for this date), and scaled this to the entire basin. How does this compare to the TWS anomaly from GRACE. Can you explain the entire TWS anomaly due to the snow deficit alone?

Given the estimates of uncertainty established above, explain how confident you are about this answer?

25. Is it reasonable for a significant part of the TWS anomaly to be caused by a decrease in groundwater storage? The Central Valley covers ~1/3 of the basin. Using your estimate of the snow deficit, what would be the loss of groundwater in terms of volume (km^3) and equivalent water thickness (in mm)?

26. How much would the water table decrease given this loss of water (in mm)? (Assume the Central Valley aquifer sediments have a specific yield of 0.15.) Is this a reasonable decrease of the water table (given the historic record of groundwater and subsidence)?

F. Water usage and drought revisited

Now, we will return to comparing the water deficit during the drought with expected water use in the basin.

27. Above, you calculated the volume of water used in the SSJ basin in a typical year (in km^3). How does this compare to the precipitation deficit in WY 2014 and the GRACE-based TWS anomaly in April 2014?

28. Estimate uncertainty associated with calculated annual water use (answer in km^3). Hypothesize the major sources of uncertainty in the water use data and calculation.

29. Evaluate the severity of the drought, comparing the estimated annual water usage to the observed change in precipitation and storage (snow and total TWS). This evaluation must include a discussion of uncertainty in each component.

G. Evaluate current monitoring network: traditional and geodetic

30. Critique the existing monitoring system. Design or propose a plan for improved monitoring of water resources using traditional and geodetic tools.

A. What are the strengths and limitations of each data type (e.g., GRACE, snow data) for quantifying storage and flux? This can be done in table format. Although this unit did not explicitly include groundwater data, include this in your comparison. Consult the following document for information specific to groundwater observations in California: http://waterinthewest.stanford.edu/groundwater/overview/index.html.

B. Which components of the water budget are measured most reliably and least reliably by the various monitoring options that currently exist? Rate them in terms of accuracy (in km^3 at the basin scale) and how useful / how representative their spatial coverage is (1–10 scale, 10 being best)? This can be done in table format.

C. Identify which geographic areas need more observations. Be specific about what types of observations are needed in different parts of the basin.

D. Choose the two highest priorities to improve networks for quantifying changes in water storage during drought, specifically as it pertains to society's need for water.

H. Reflections

31. Over the course of completing this unit, you have been asked to consider terrestrial water storage using both traditional and nontraditional geodetic data sets. Please reflect on the following:

A. How familiar were you with regards to the basic concepts of reservoirs and fluxes that address terrestrial water storage?
B. Were you surprised to learn about new geodetic-based methods of determining the same parameters used in documenting terrestrial water storage?
C. What value do you see in the incorporation of geodetic based data sets?