CE394K – GIS IN WATER RESOURCES

TERM PROJECT REPORT

# Soil Water Balance in Southern California

Cheng-Wei Yu
Environmental and Water Resources Engineering Program

# Introduction

## Historical Drought Condition of California

Drought has become a serious problem for the United State, especially for California State and Texas State. The last severe drought for the state of California occurred from 1985 – 1991, and it is caused by extremely low precipitation. The drought caused low stream flow and loss of crops. The earliest historical drought for California can be traced back to 18$^{th}$ century. The 18$^{th}$ century is a relatively wet century in North America, however, there were still several droughts in 1721 and 1736.

In 1930 to 1936, there is a drought caused the dust storm and the storm hit California State and millions of acres of farmland became useless and thousands of people were forced to leave their home. Another drought happened in 1944 in the Southwestern United State and last to 1950s, it is the longest recorded drought observed in this area. This drought last until 1953 in California with most of the lakes was dried out, Southern California also suffer from the late 1950s drought in 1958 – 1959. In 1961, Southern California also experienced the worst drought recorded in 20th century. In 2000s, due to more and more extreme climate events happened, the drought became worse. Southern California experienced the driest rain season since records begin in 1877. There were only 3.21 inches rainfall in Los Angeles, compared to annual average of 15.14 inches. The drought in 2000s also contributed a badly wildfire in California in 2007. The latest drought in California is in 2008 – 2011, in this period, the snowpack reached the lowest recorded in the last century. Furthermore, California is now experienced a drought caused by low precipitation in 2013.

From the historical precipitation chart in Figure 1 and historical drought events, it shows that the precipitation is a critical water input for California because the historical drought events time is correspond to low precipitation period. So basically the drought will occur in California every one or two decades due to scarce rainfall. Therefore, this project will focus on the influence of precipitation on water balance problem.

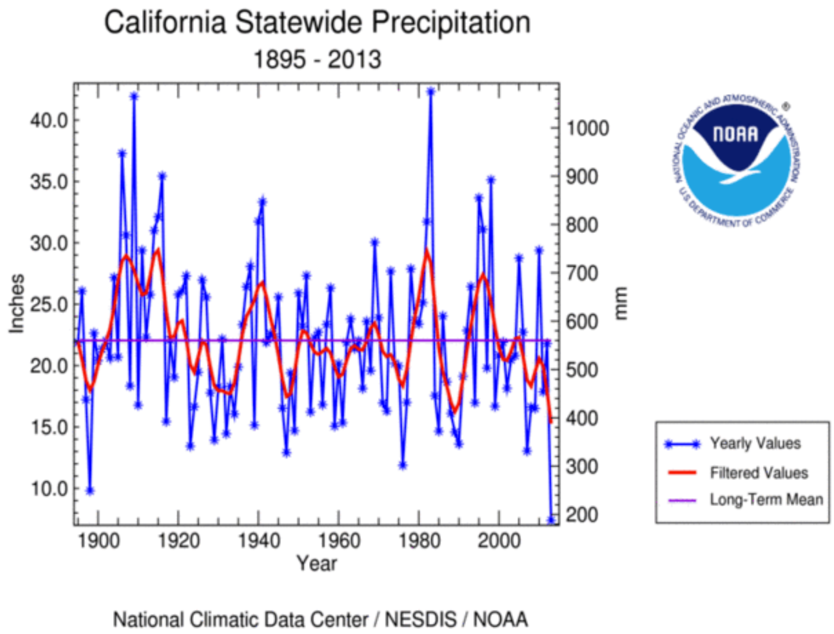


*Figure. 1 – California Historical Precipitation Data*

## Project Goals

This project aims to provide an irrigation strategy information map, which can be a clear and straightforward irrigation reference for agriculture industry. Besides, the water balance in the study area will also be analyzed. In order to accomplish this analysis, a water balance model will be developed in the following section. By using this model created, we can roughly estimate the soil water content and find out he drought region in our study area. Besides using the model that we created in this project, the GRACE satellite data will also be used to identify the drought area. Furthermore, the NLDAS model will also be used in this project to examine the soil moisture. At the end of the project, the model created by the author will be compared with NLDAS model and the difference will be discussed.

# Methods

## Study Area

The study area of this project is Southern California, consisted by 10 counties (Orange, Kern, Santa Barbara, San Luis Obispo, Riverside, San Bernardino, Los Angeles, San Diego, Imperial, and Ventura County). This area also includes Los Angeles City and San Diego City. With over 22 million people live in this area, Southern California contains roughly more than 60% of California's population. The climate type of the study area is Mediterranean climate type. The precipitation of Mediterranean climate normally concentrates in winter and spring season and has scarce rainfall in the summer.

## Water Balance Methodology - Simple Water Balance Equation

In this project, there are total two models will be used to examine the soil water content in the study area. The first model the basic water balance designed by without considering snowmelt water. The equation of this model is shown in the following equation:

$$Change\ of\ Water\ =\ Input\ Water - Output\ Water \qquad (1)$$

According to this water balance equation, it is obvious that the soil water content is decided by two factors, water input and water output. If the variables were introduced into the equation, the equation will become:

$$\Delta = P + D + I - ET - RO - C \qquad (2)$$

$P\ =\ Precipitation$

$ET\ =\ Evapotranspiration\ (Evaporation\ +\ Transpiration)$

$RO = Runoff\ Water$

$D\ =\ Groundwater\ Recharge$

$C\ =\ Groundwater\ Infiltration$

$I\ =\ Irrigation\ Water$

In this question, an assumption was made here. It assumes the groundwater recharge and infiltration is under a balance condition, which means that the groundwater will not affect the soil water balance. So basically the D term and C term in the Equation (2) can be eliminated.

According to this assumption, the water balance equation can be reformed as:

$$\Delta = P + I - ET - RO \quad (3)$$

If we move the P, ET and RO to the other side of the equation and keep the irrigation on the one side, we can get the irrigation is a function of P, ET and RO. Once we can apply the historical data of these three terms, we can roughly estimate the total amount water that we should irrigate to keep the soil water balance. The irrigation relationship will be shown in Equation (4).

$$I = ET + RO - P \quad (4)$$

## Water Balance Methodology - NLDAS Model

NLDAS is a water balance model developed by Prof. Maidment and Gonzalo Espinoza at University of Texas at Austin. It is a tool can automatically download the monthly hydrologic flux and hourly hydrologic storage data for both drainage areas on a 1/8 arcsecond grid resolution. The download process was automated using a Python script developed by Dr. David Tarboton of Utah State University, with modifications to analyze the drainage areas of interest. The model will average the grid data by the area once the download process is finished. It will calculate monthly changes in precipitation, evapotranspiration, canopy water storage, runoff (including surface runoff and baseflow), snowfall and other variables. NLDAS model will use these variables as input variables in the formula shown below:

$$(SM+C_{stor}+SWE)_{T1} - (SM+C_{stor}+SWE)_{T2} = RF+SF-ET-Q_{base} - Q_{surface} \qquad (5)$$

Where:

$SM = Soil\ Moisture\ Storage$

$Cstor = Plant\ Canopy\ Storage$

$SWE = Snow - Water\ Equivalent\ Storage$

$RF = Rainfall$

$SF = Snowfall$

$ET = Evapotranspiration$

$Qbase = Baseflow$

$Qsurface = Surface\ Runoff$

$T2 = beginning\ of\ month\ 2$

$T1 = beginning\ of\ month\ 1$

## Historical Data

In this project, the data from January 1st , 2010 to December 31st ,2013 were used for the analysis. The data used in Simple Water Balance Model are downloaded from GATEWAY website, which is a free and public climate database on the Internet. The NLDAS data is automatically downloaded from NASA's database. All the data used are monthly recorded.

# Results

## Simple Water Balance Model

By using the data from 2010 to 2013, the result of simple water balance model is shown in Figure 2, which can be regarded as a water deficit map. The water deficit can also be regarded as total amount of water that need to be irrigated. From Figure 2, we can find out the water deficit condition in Southern California is quite consistent. It is because the precipitation and evapotranspiration in Southern California are uniformly low. However, there are still some place has inferior soil water condition than others. For instance, there is a dry band at the north part of Kern County, which is exactly the south part of the central valley. There are some other dry areas can be found at the edge of San Bernardino County and Riverside County. This result provides us a way to estimate the dry area in Southern California, which can be a reference for irrigation strategy.

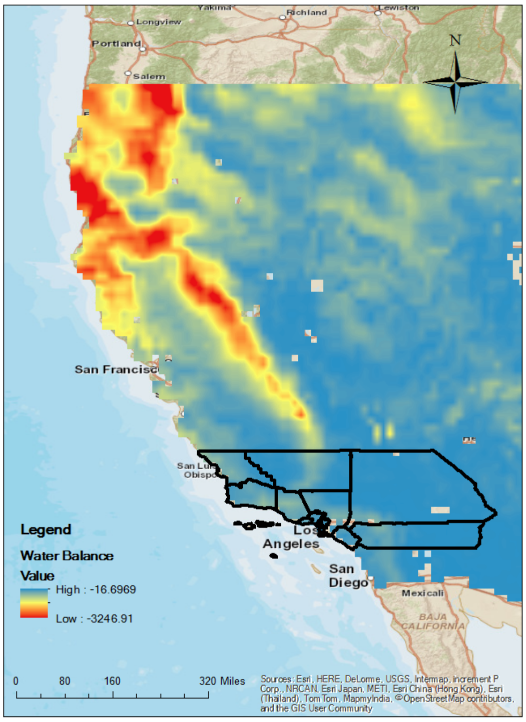


*Figure. 2 – Soil Water Content by Using Simple Water Balance Equation*

### NLDAS Model

The monthly precipitation data for Southern California are retrieved from NLDAS tool and shown in Figure 3. In this Figure, we can find that the rainfall concentrates in winter and spring seasons, which matches the characteristic of Mediterranean climate type. However, we can see that the rainfall apparently decreases in the winter of 2012 and there is nearly no rainfall in 2013 winter. The scarce rainfall may be the main reason responsible for the drought in 2013.

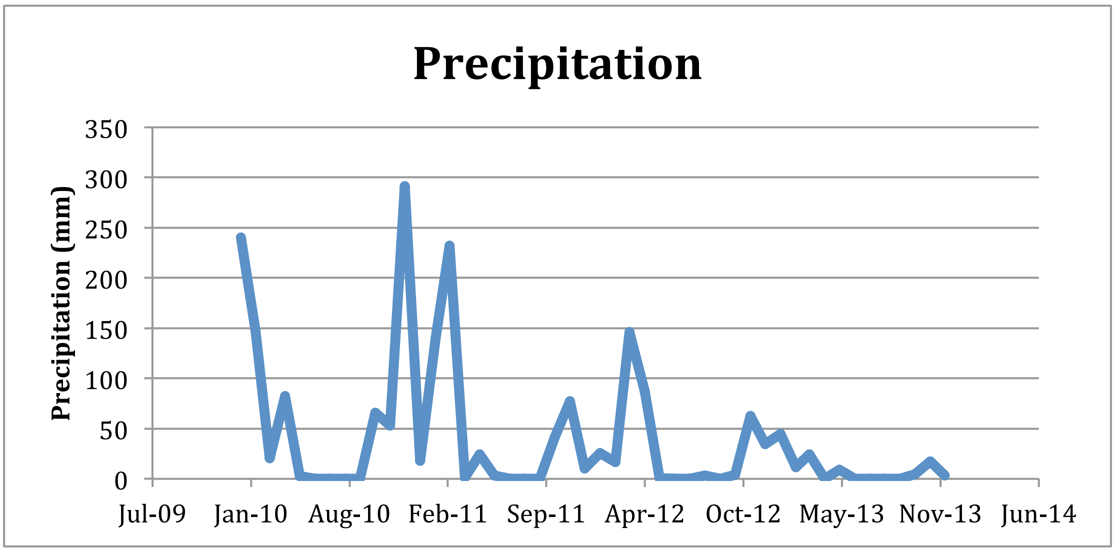


*Figure. 3 – Monthly Precipitation From 2010-2013*

The NLDAS water balance variables map were also shown in Figure 4. The upper left corner is the evapotranspiration map; it shows that there are no large change in the study area except a high-evapotranspiration band in Riverside County and Imperial County. The vegetation cover in this area may cause this high-evapotranspiration band. For the upper right corner map is the snow melt water map, which is quite correspond to the evapotranspiration map. This phenomenon will explain the vegetation coverage in this area is fed by snow water. For the two maps on the bottom, the runoff map on the right hand side does not show huge difference in the study area. Although there are several areas in San Bernardino County and Riverside County have relatively high runoff, but overall the whole study area has pretty consistent runoff.

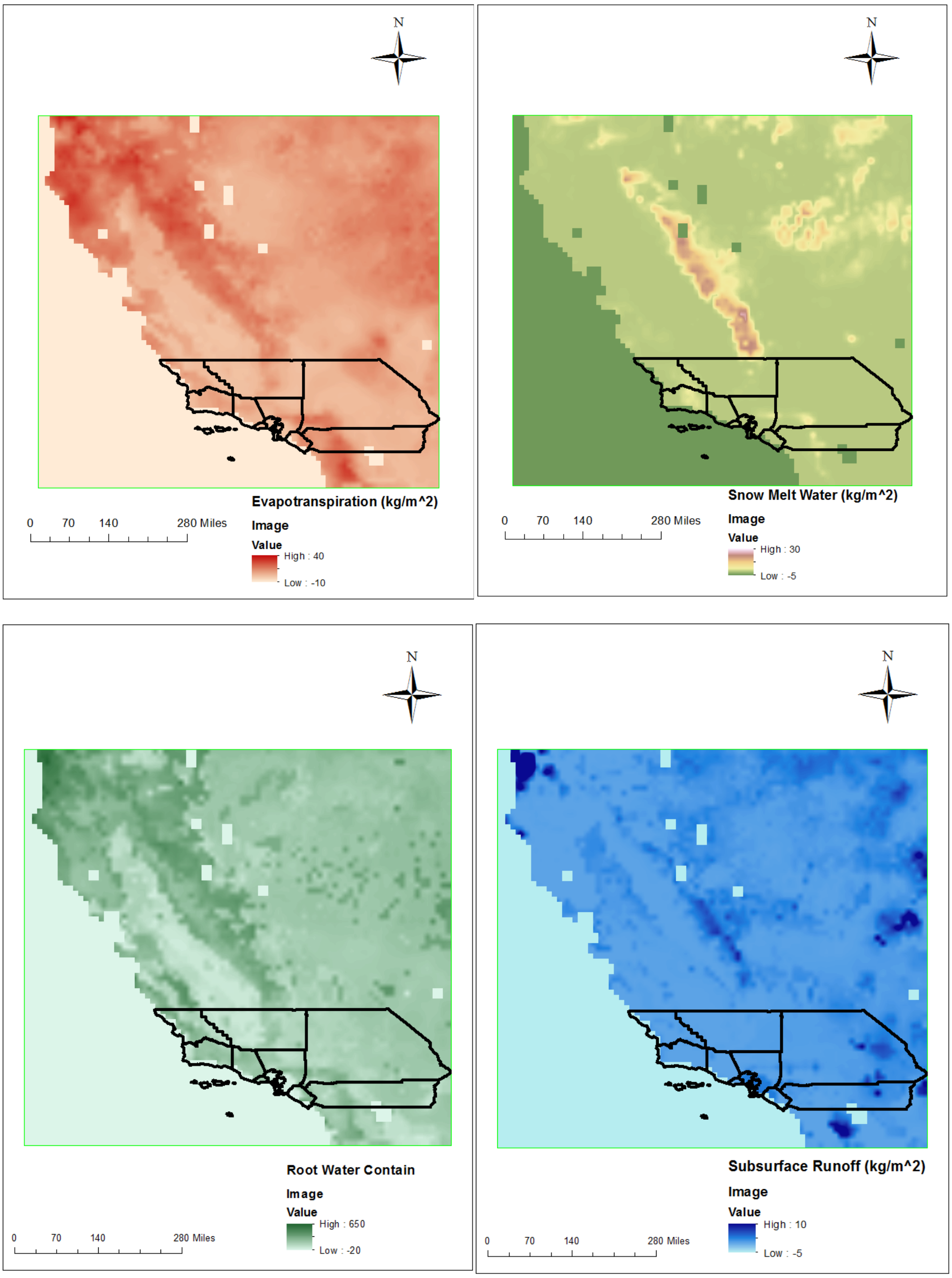


*Figure. 4 – NLDAS Model Result*

## GRACE Satellite Data

GRACE satellite data is shown in Figure 5. The color in this figure means the amount of soil water content, red color represents less water in soil and blue means more water. The black frame in the figure is our study area. From this figure, it is clear that the soil water content in February is relatively higher than other two months due to the rainfall in the winter season. This figure also shows that the peak period of soil water content is in winter and spring, and it will gradually decrease in summer and fall. However, the soil water condition in June 2013 is worse than other two years, which can be regarded as a sign of the drought in 2013- 2014.

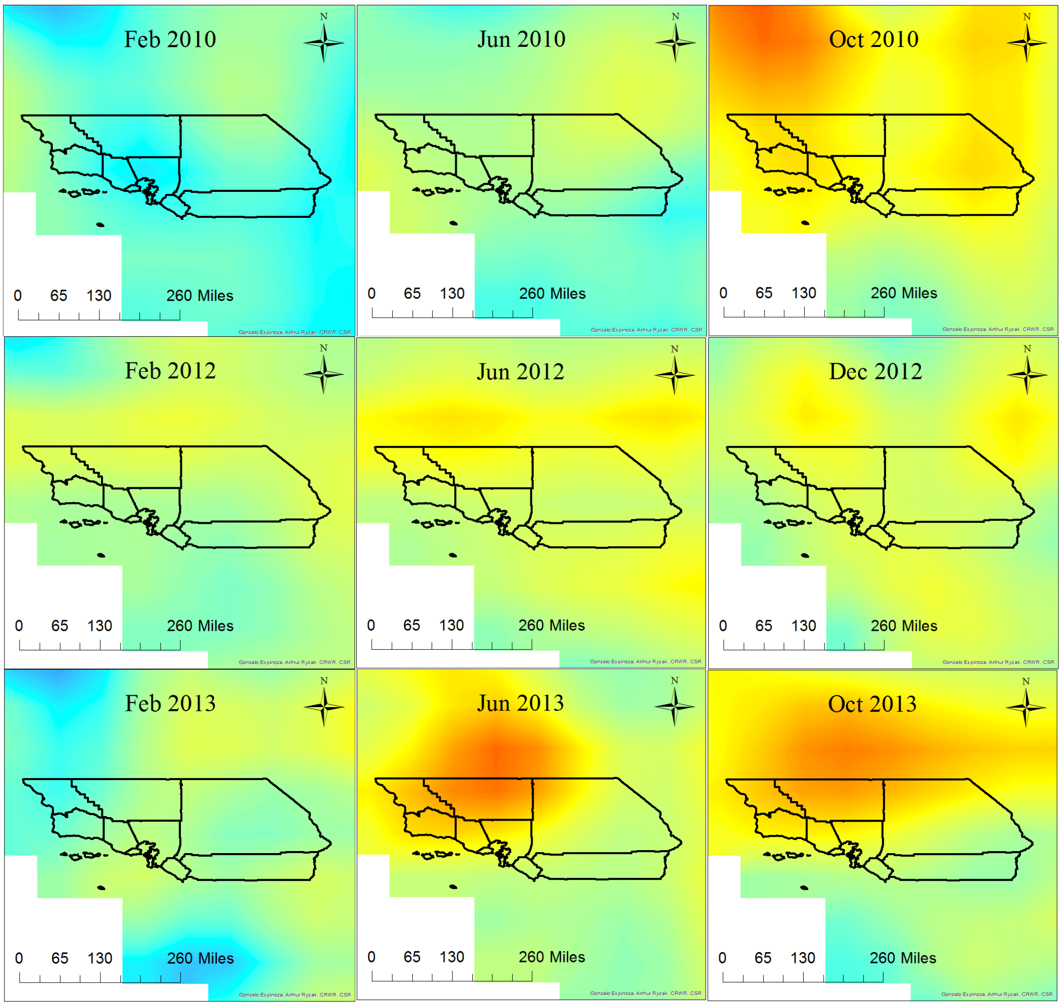


*Figure. 5 – Grace Satellite Data*

## Discussion and Future Work

From the difference between NLDAS result and simple soil water balance model result, it is pretty clear that snow water in the study area plays an important factor. It is because the precipitation in Southern California is relatively low and concentrate, so the snowmelt water become an important water source in this area especially for streams and rivers. However, the simple soil water balance in this project did not consider the effect caused by the snowmelt water impact. The result from NLDAS model is much more comprehensive and convincible, due to the variables it contains are more detail and more fit the real world.

Overall, there are still spaces for improvement for this project and needed to be done in the future. For example, it will be more convincible if the real county water usage data can be applied on the water balance model, the result we get from this project will be more meaningful and useful. By applying the real-world water usage data, we believe this project can be helpful on enhancing the efficiency of water usage and irrigation.

# Reference

Chen, F., K. Mitchell, J. Schaake, Y. Xue, H.-L. Pan, V. Ko- ren, Q. Y. Duan, M. Ek, and A. Betts (1996), Modeling of land surface evaporation by four schemes and comparison with FIFE observations, J. Geophys. Res., 101(D3), 7251V7268, doi:10.1029/95JD02165.

Koren, V., J. Schaake, K. Mitchell, Q.-Y. Duan, F. Chen, and J. M. Baker (1999), A parameterization of snowpack and frozen ground intended for NCEP weather and climate models, J. Geo- phys. Res., 104(D16), 19569V19585, doi:10.1029/1999JD900232.

Xia, Y., et al. (2012), Continental-scale water and energy flux analysis and validation for the North American Land Data As- similation System project phase 2 (NLDAS-2): 1. Intercompar- ison and application of model products, J. Geophys. Res., 117, D03109, doi:10.1029/2011JD016048.

Howitt R, Medellin-Azuara J, MacEwan D, Lund J, Sumner D (2014), Economic Analysis of the 2014 Drought for California Agriculture, UC Davis