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The Quantification of Rainfall Needed to Overcome Drought: A Study in North Texas

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1. Introduction: 2010–2015 drought over Texas

Texas is no stranger to dry, hot weather. The state has a reputation of being one large desert. That is not the case; but, in 2011, the perception of a desert seemed to become a reality. Texas had been through plenty of dry and wet spells and 2011 appeared to be just another dry spell, at first. When the heat did not let up and with a lack of rainfall, the state had entered a very serious drought.

With excessive heat and little rainfall, the year of 2011 became the driest year on record for the state of Texas (Richter 2012). The 2010–2015 drought was the second worst drought on record in the state. Days of heavy rainfall in May 2015 helped reverse the cumulative soil moisture deficit in the state. It was only in July 2015 that Texas was finally drought free (Fig. 1).

2. Study area and problem statement

The study focused on the drought that affected North-Central Texas, within the coordinates of 31.35°N-34.11°N and 95.41°W-98.56°W.

Starting in 2011, the drought caused lakes and rivers in North Texas to dry out. For example, a streamflow gauge on the East Fork Trinity River recorded a discharge of 0.0003 ft^3/s in September 2014. During the drought many lakes in North Texas fell to more than ten feet below full capacity (Fig. 2).

There was measurable rain over the study area in the winter of 2011/2012 and in the fall of 2013. However, the rainfall was not sufficient to raise water levels in lakes in the region. The research question this study seeks to address is: How much rainfall is needed to overcome a drought-induced soil moisture deficit so that runoff occurs?

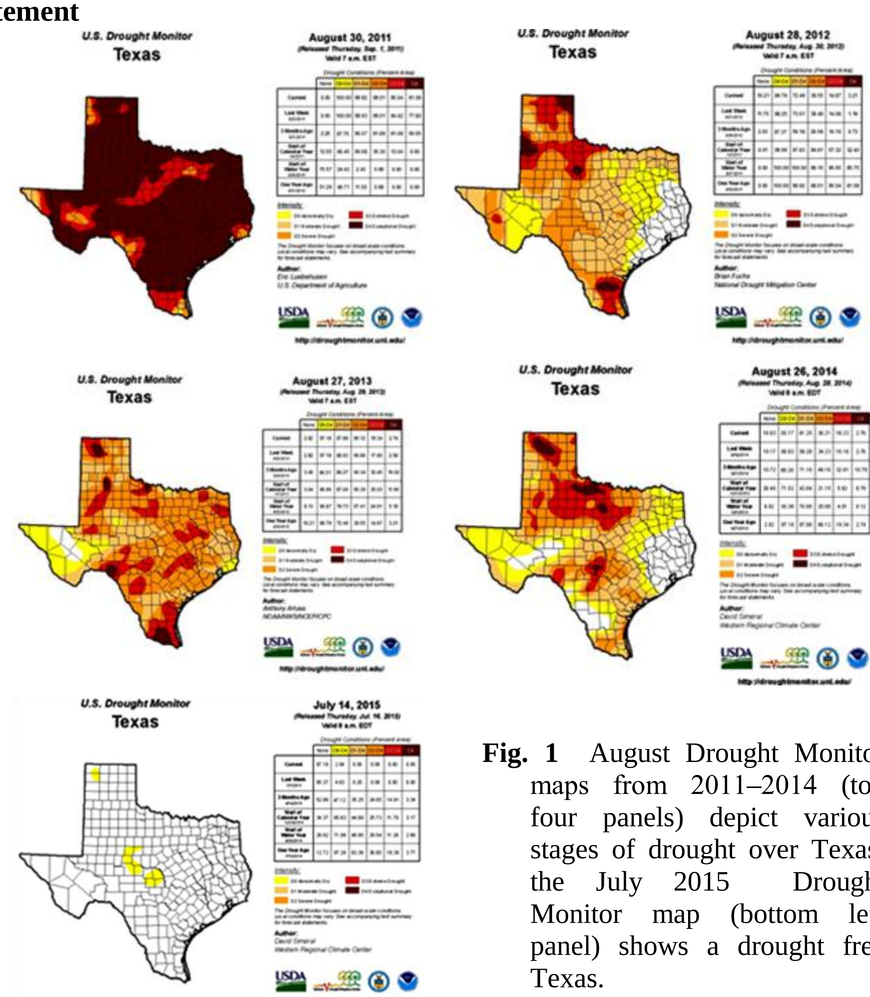

Fig. 1 August Drought Monitor maps from 2011–2014 (top four panels) depict various stages of drought over Texas; the July 2015 Drought Monitor map (bottom left panel) shows a drought free Texas.

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3. Methodology and datasets used

The study focused on understanding the evolution of soil moisture anomalies and associated rainfall accumulations and reservoir levels. Area-averaged monthly soil moisture anomalies within the study domain were compared with area-averaged monthly rainfall accumulations, as well as with reservoir levels and streamflow to determine when the soil moisture deficit eased and runoff occurred.

Datasets used include:

- Precipitation Reconstruction over Land (PREC/L) rainfall dataset from the Climate Prediction Center (Chen *et al.*, 2002)
- Simulated soil moisture from the MOSAIC model output of the North American Land Data Assimilation System (NLDAS, Xia *et al.*, 2012)
- Reservoir levels for lakes in North Texas from http://waterdatafortexas.org/reservoirs/statewide
- Streamflow data for gauges upstream of the reservoirs from the U.S. Geological Survey (http://waterwatch.usgs.gov)

4. Results

During the 2010–2015 drought, the soil moisture anomalies in North Texas were negative for most of the time. That would be expected of a drought, but there were moments that the anomalies became positive. If the soil moisture anomalies are positive (Fig. 3), that may show relief in the region; but it does not always mean the drought is ending. The soil moisture anomalies during the 2010–2015 drought ranged from [negative] 0.03807 to [positive] 0.027442. From the worst of the drought to the end of the drought, there is a difference of 0.065. The lowest anomaly, - 0.03807, occurred in December 2012; but the lowest soil moisture value occurred in August 2011 with a value of 0.048 m^3/m^3. A reason as to why the dates do not match up is because August is the driest month of the year. So, a low value for soil moisture is not too far away from the norm; of which, the anomaly for August 2011 was - 0.022. When the lowest anomaly occurred by December 2012, North Texas had been in an intense drought for over a year. When the heavy rains came to North Texas in 2015, the moisture content rose and the anomalies became positive. December and May of 2015, respectively, had the highest and second highest amounts of soil moisture.

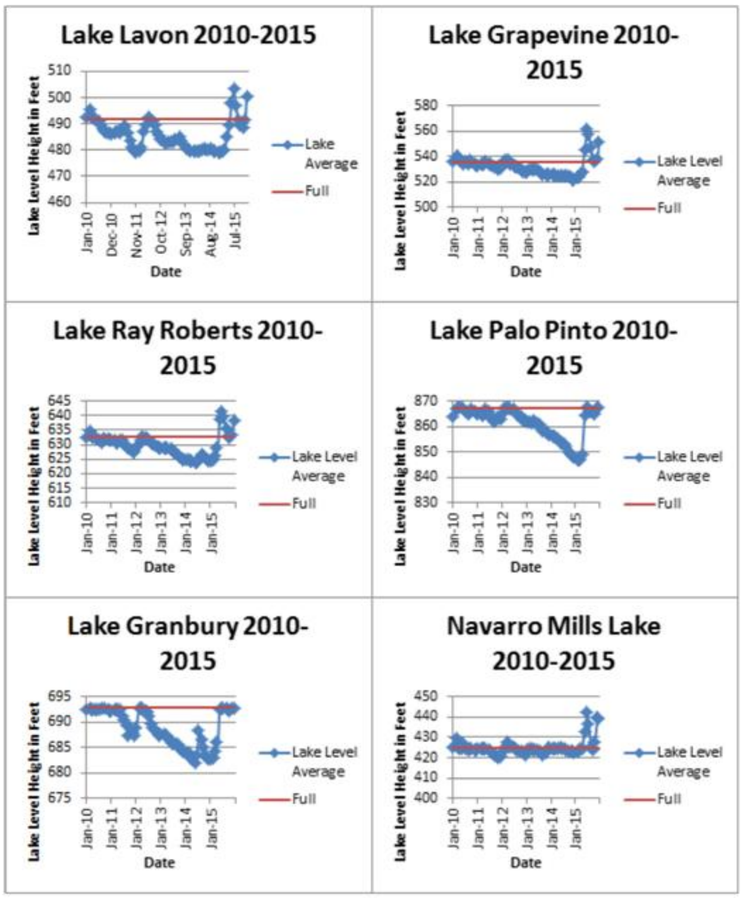

Fig. 2 Lake levels for six reservoirs in North Texas from 2010 to 2015. The blue line shows the lake level and the red line shows conservation storage capacity (data source: http://waterdatafortexas.org/reservoirs/statewide).

The calculated monthly rainfall average was about 3.15 inches from the PREC/L 1979-2015 dataset. This allows an answer to be reached for the original question of how much rainfall is needed to overcome a drought. The rainfall and soil moisture datasets were compared graphically (Fig. 4) to assess how much rainfall it took to end a drought, specifically the 2010–2015 drought. We assumed that three consecutive months of positive soil moisture anomalies could be a possible indicator of the

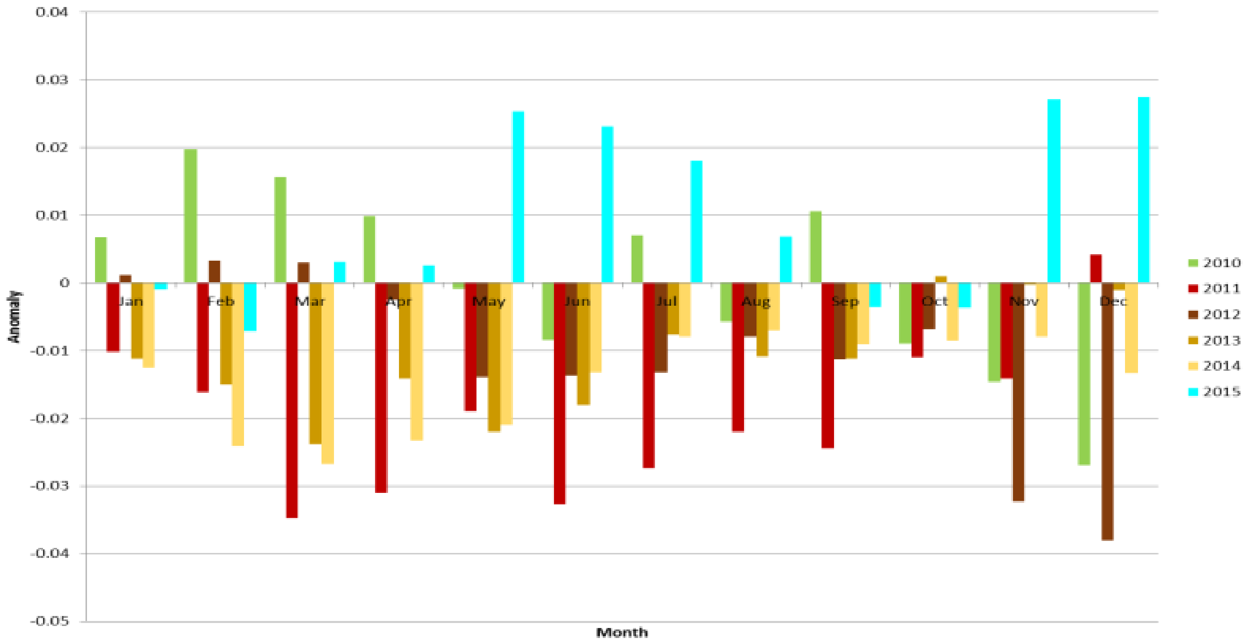

Fig. 3 Monthly soil moisture anomalies from 2010–2015.

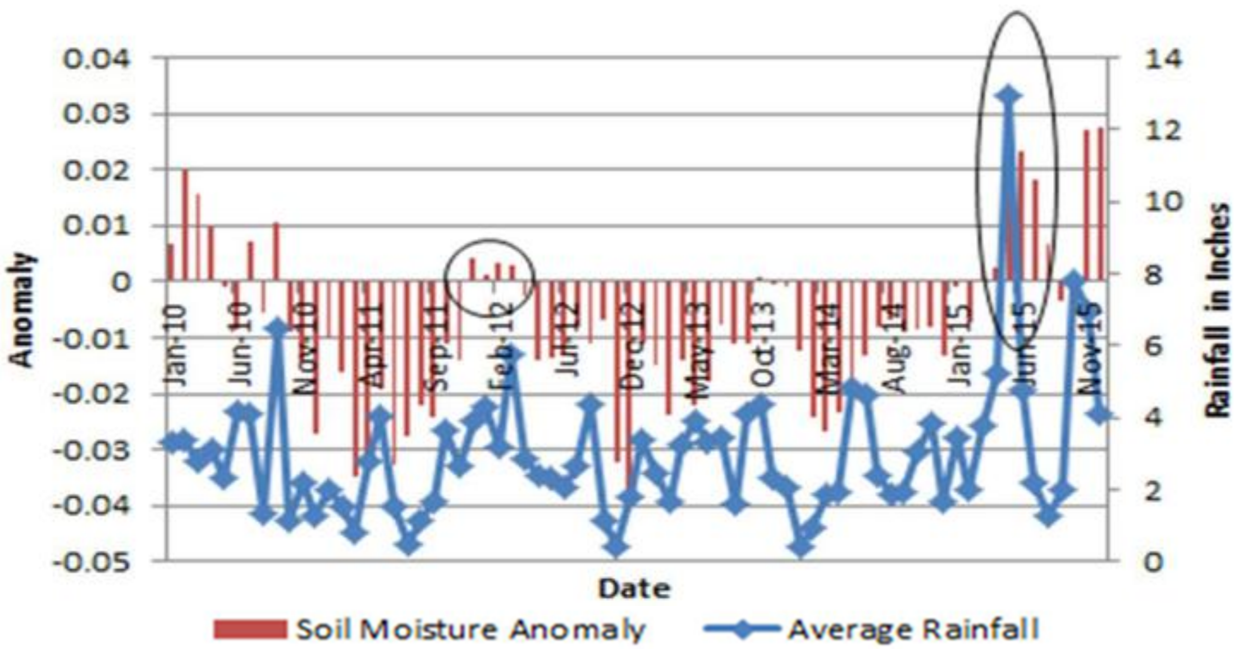

Fig. 4 Soil moisture anomalies and the average monthly rainfall from 2010–2015.

drought ending. The occurrence of three months of positive anomalies happened twice during the period of 2010–2015.

December 2011 through March 2012 is four months of positive anomalies, but the anomaly for these months was less than 0.01. The second continuous spell of positive monthly soil moisture anomalies commenced in March 2015 and remained positive through August. There were positive anomalies in rainfall during the first and second occurrences of consecutive months with positive soil moisture anomalies. The last positive rainfall anomaly before October 2013 was in March 2012 with 5.78 inches of rainfall. The rain that fell in May 2015 made that month the wettest month on record (Chuck 2015) with an average of 12.97 inches falling over the area of study.

5. Conclusions

The 2010–2015 drought was incredibly harsh on the state of Texas. As the drought lengthened, the amount of rainfall required to overcome it increased. A comparison of rainfall and soil moisture anomalies indicated that three consecutive months of positive soil moisture anomalies could be a possible indicator of drought termination. We found that it takes about 10–15 inches of rainfall within a thirty day period is needed to overcome a soil moisture deficit of the same severity as the 2010–2015 drought in North Texas. The methods applied in this study could be applied to different drought scenarios (*e.g*. short-term or multi-year under varied geographical settings) to quantify the rainfall needed to overcome prevailing soil moisture deficits.

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