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The University of Texas at Austin

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[EFFECTS OF THE 2011 TEXAS DROUGHT ON WATER STABILITY AND SOIL MOISTURE CAPACITY IN THE LAKE SOMERVILLE WATERSHED]

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Introduction

In 2011, Central Texas experienced the hottest summer and most devastating drought on record. During this summer, water flow in many rivers and estuaries diminished, water storage in aquifers and lakes receded to critical levels, and soil throughout the region dried up. These drastic deteriorations in water and soil characteristics resulted in state-wide rationing and a severely decreased capacity for agriculture.

As part of this phenomenon, Lake Somerville dropped more than ten feet in water level (USACE 2011), a record low, and the soil in the Somerville Basin runs the risk of becoming incapable of supporting vegetation. This impact has been devastating to Somerville area communities that rely mostly on agriculture. What is not understood, however, are the long term impacts of the drought in this region or what will be required to restore the water resources and soil characteristics to pre-drought conditions.

The experience of this summer and the current situation for Central Texas communities is further complicated by the increasing awareness of the effects of global warming and predictions by meteorologists that significant rain is not expected this winter or in the upcoming years (DayMet 2011).

Area of Interest

The area examined in this study is the Lake Somerville Watershed. This watershed is located in the southeast portion of the Brazos Valley River Basin as shown in Figure 1.

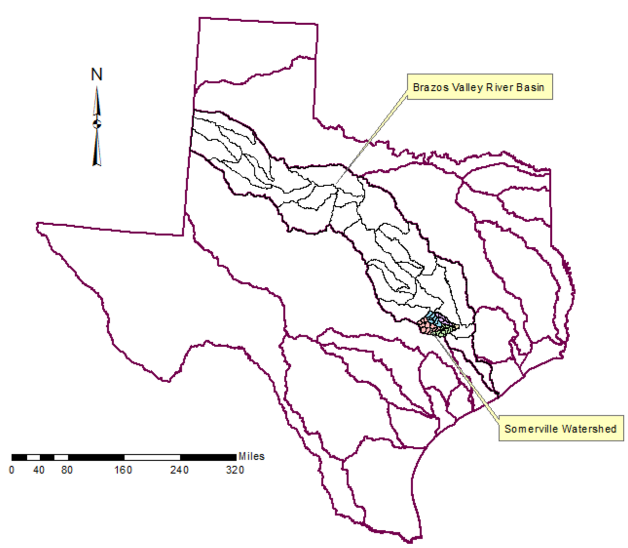

Figure 1. Map of the Somerville Watershed in the Brazos Valley River Basin. (TWDB 2006; TWDB undated)

As can be seen in Figure 2, four streams feed into Lake Somerville from the west and northwest. However, the small streams in the southern catchment surrounding the lake do not converge into a large flow stream like the rest. Instead, smaller streams flow directly into the lake. Although not shown in the figure, the basin overlays the Carrizo and Gulf Coast Aquifers (TWDB 2006; TWDB 2006). Additionally, though not shown, the watershed encompasses the Bastrop, Burleson, Lee, Milam, Washington, and Williamson counties.

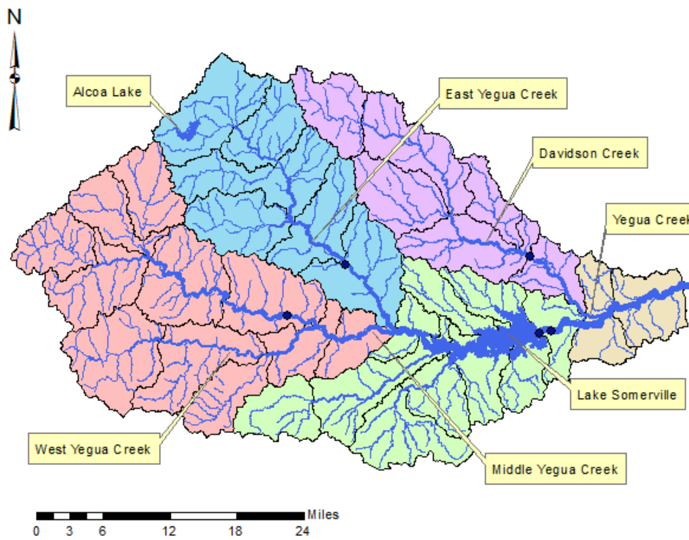

Figure 2. Map of the Somerville Watershed. (TWDB 2007; USGS 2010; TWDB undated)

The land in the Somerville watershed is primarily used for agriculture. Figure 3 shows the representative land cover of the watershed. It is apparent from the map and the corresponding statistics shown in Figure 3 and Figure 4 that there are a few small towns scattered throughout the watershed to connect the ranches that occupy the territory. The cattle ranches consist of many types of land; including barren land, deciduous and evergreen forests, shrubs, pastures, cultivated crops, and wetlands. Mostly, these ranches are used to raise cattle. Because of this, the land is not cultivated as it would be if it were used for agricultural crop production and approximately 25% of the land consists of forests (USGS 2001). The other implication of this is that open water exists on all ranches in the way of ponds and stock tanks that provide drinking water for the cattle and naturally occurring wildlife that include deer, hogs, and turkeys. Most of these ponds dried up in August of 2011, placing the ecological system in considerable stress.

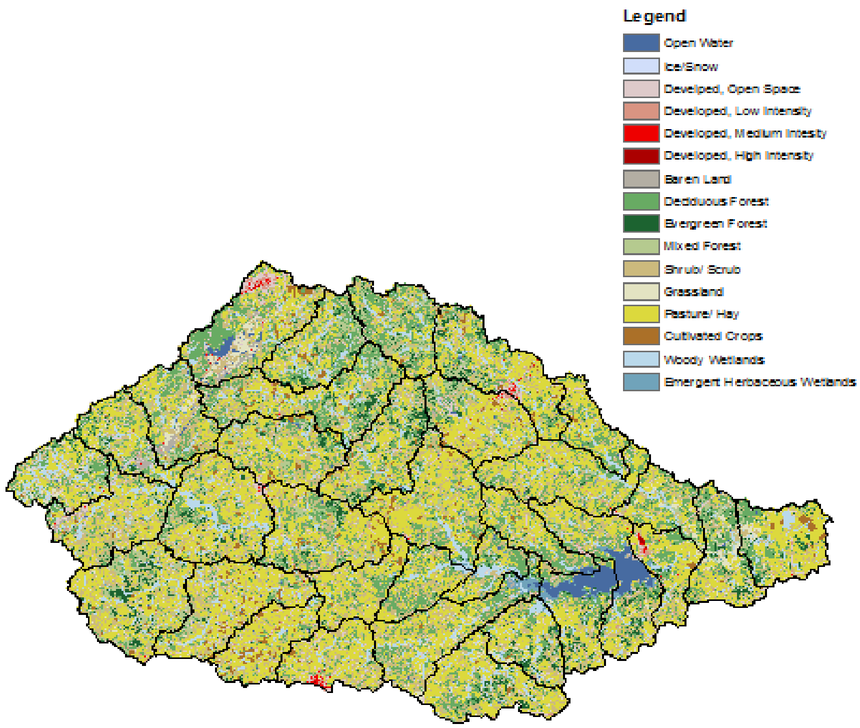

Figure 3. Land Cover in the Somerville Watershed.

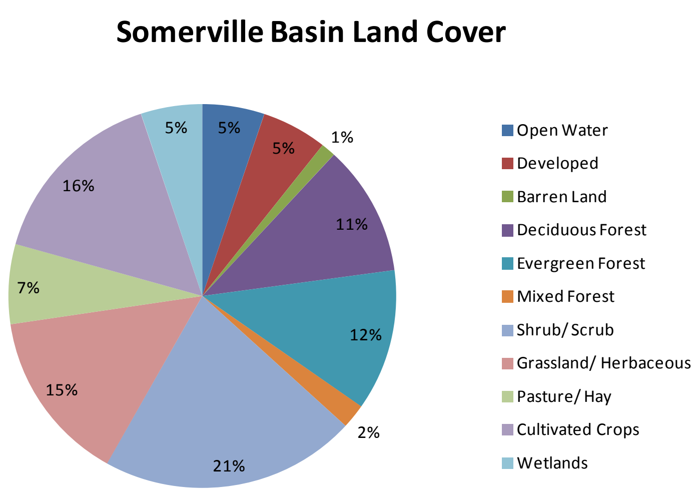

Figure 4. Land Cover Statistics in the Somerville Watershed.

Problem Definition

Sustained high temperatures and low precipitation have resulted in exceptionally low stream flows, the lowest recorded lake volume, and extremely dry soil throughout the watershed and has placed the system under considerable stress. As can be seen in Figure 5, 2011 yielded precipitation well below the mean every month starting in April (NRCS 2011; USGS 2011). The result of this was that ponds did not refill as evaporation, livestock and wildlife depletes them, stream flows decreased to critical levels or ceased to exist, and Lake Somerville continually decreased in volume. As of 19 November 2011, the lake only contained 38% of its capacity (USACE 2011; USGS 2011).

As can be seen in Figure 5, the trend of low precipitation is expected to continue throughout 2012 and potentially into 2013 as part of La Nina, which is a characterized by "unusually high temperatures in the equatorial Pacific Ocean" and yields unusually high temperatures and low precipitation inland (NOAA 2011).

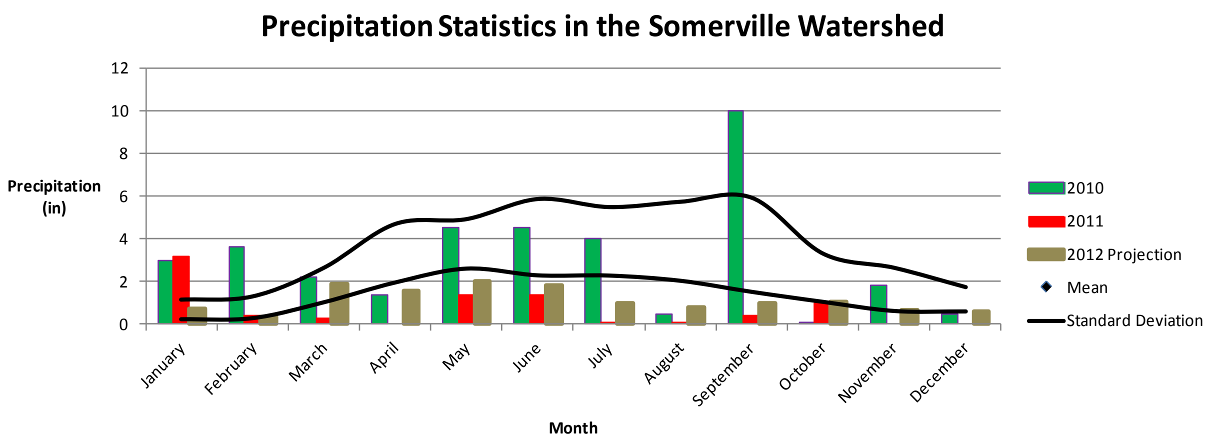

Figure 5. Summarized precipitation data for the Somerville Watershed.

As mentioned previously, Texas experienced record setting temperatures in 2011 with the most consecutive days over 100°F in history (NRCS 2011; USGS 2011). These high temperatures served to increase the demand for water to sustain livestock and wildlife while simultaneously decreasing the water supply through higher than normal evapotranspiration. Combined with low precipitation, these high temperatures also set the conditions for the fires that destroyed much of Bastrop County. As can be seen in Figure 6, this trend is expected to continue, much like the low precipitation condition, throughout 2012 and potentially through 2013.

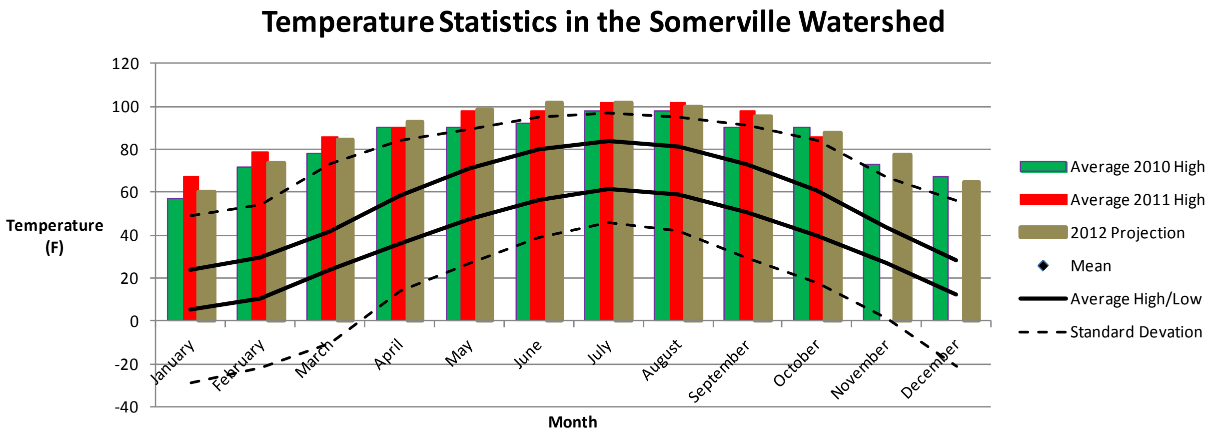

Figure 6. Summarized temperature data for the Somerville Watershed. (DayMet 2011; NOAA 2011; NRCS 2011)

These two factors pose a significant risk to the economy and environmental integrity of the Somerville Watershed over the next few years. Because precipitation and evapotranspiration conditions are not expected to ease over the next few years, the already stressed Lake Somerville may be unable to sustain the water demand and required environmental flows for the Yegua River. Additionally, the system may be unable to sustain available water supplies for livestock and wildlife, potentially forcing even more ranchers to sell their livestock, and thus, their livelihood before it is lost altogether.

The combination of high temperature and low precipitation poses a significant risk within the watershed to the soil's capacity to sustain vegetation and recover when precipitation does increase. As evapotranspiration continues without precipitation, the soil's moisture content will continue to decrease. At some point, the moisture content will decrease below the wilting point, defined as the moisture content required to sustain vegetation (NASA 2011). As this happens, water flow in the soil will behave more like channel flow and less like seepage, resulting in increased erosion and decreased saturation.

Scope

The goal of this project is to assess the impacts of the 2011 drought on the Lake Somerville Watershed, including the Yegua Creek. Specifically, this amounts to a projected water balance of Lake Somerville and projected soil moisture content throughout the watershed. Included in this assessment will be an analysis of precipitation, evapotranspiration, and flow data in the watershed as well as soil moisture and capacity data in the surrounding area. However, complications with uploading and converting the spatial soil hydraulic parameters to raster prevented the realization of the latter goal. Subsequently, the scope is revised to include the relative impact of temperature, precipitation, and evapotranspiration on the soil moisture content without quantitatively defining the moisture content with respect to the soil's wilting point or field capacity across the spatial domain.

Methodology

This project was executed in two stages. First, statistical and spatial data were analyzed to project the water balance of Lake Somerville over a period of 36 months. Secondly, statistical and spatial data were used to analyze the relative impact of the drought on the system's soil moisture content. In reality, soil hydraulic parameters have an important impact on surface water flow. However, I was able to conduct these two separately because of the use of selected statistical data and the relative uncertainty of projecting three years into the future.

Lake Somerville Water Balance

The lake Somerville Water Balance was modeled using both statistical and spatial data incorporated into the standard model:

$$Storage\ Volume\ Change\ = Inflow - Outflow + Precipitation - Evapotranspiration$$

Because of the uncertainty associated with precipitation and temperature projections over a 36 month period, I modeled the water balance using two projection models based on information assimilated from DayMet to create an effective range of probable system response.

The first projection model served to establish a lower limit response, or worse case scenario. The parameters entered into the water balance were based on the assumption that La Nina conditions would persist through 2013 and that mean conditions would exist in 2014 before El Nino conditions dominate. As such, the 2012 projection values for precipitation and temperature shown in Figure 5 and Figure 6 were applied in both 2012 and 2013. Mean values were applied in 2014.

The second projection model established the upper limit response, or best case scenario. The parameters entered into the water balance were based on the assumption that La Nina conditions would persist through 2012 and mean conditions would exist in the years 2013 and 2014. The same 2012 projection values used in the lower limit response model were applied in 2012 since they are based on DayMet projections. The same mean values were then applied to the years 2013 and 2014.

Statistical Flow Data

Statistical flow data was derived from historical measurements at the USGS monitoring stations for the Yegua, Middle Yegua, East Yegua, and Davidson Creeks. Included with the 60 years worth of data were time, flow, stage, and channel datum. The relevant flow data is shown in Figure 7.

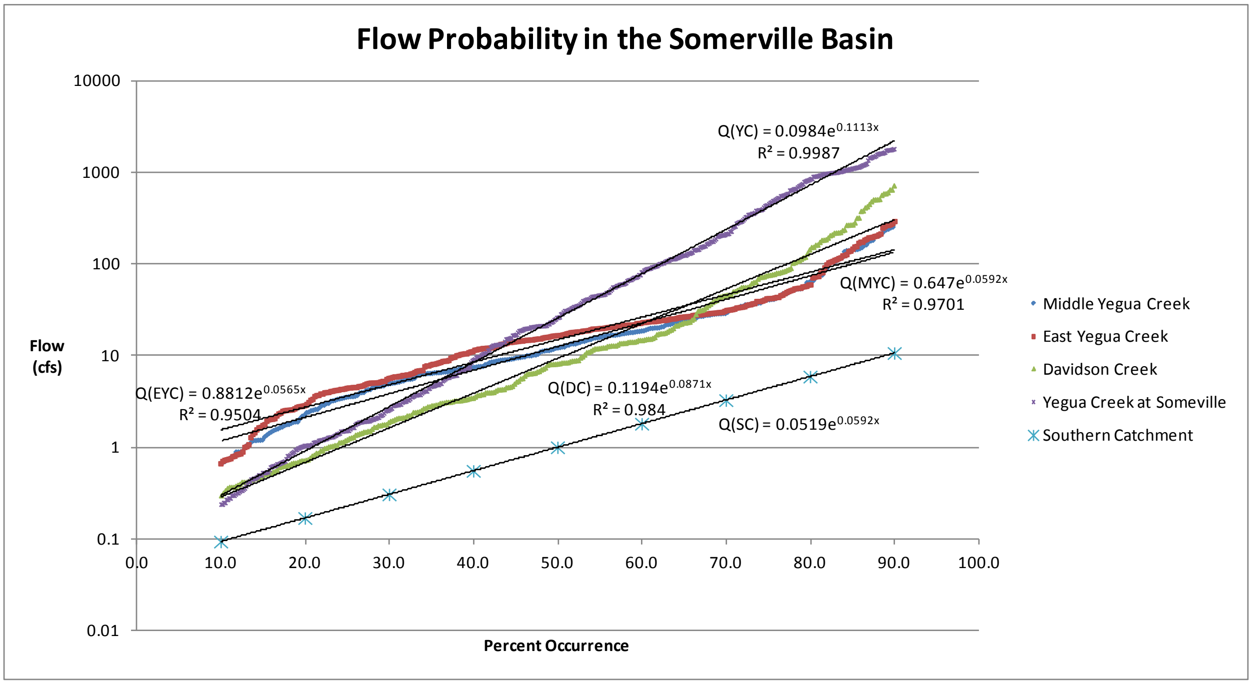

Figure 7. Flow Probability in four Streams in the Somerville Watershed. (NRCS 2011)

Because the streams in the southern catchment do not converge to create a large stream or river, no monitoring gauge is in place to provide the same type of data. However, the effects of precipitation over this catchment play a significant role in the inflow, or lack thereof, into the lake. To fill this gap, I compared the attributes of the southern catchment streams to those of the Middle Yegua and East Yegua Creeks and was able to use that relative flow data to extrapolate a model flow parameter that conforms to the USGS data for the other streams. Those statistics are shown in Figure 7 as well.

Precipitation and Evapotranspiration

Both precipitation and temperature were observed to be spatially uniform across the Somerville Watershed. This made evaluation easy by eliminating the spatial variable and enabling direct application in accordance with the statistical data presented in Figure 5 and Figure 6. For the lake water balance, the projected precipitation was applied in two ways. First, it was used to extrapolate flows on a statistical basis. Second, it was applied directly as a separate input over the surface area of Lake Somerville as described in the water balance.

Evapotranspiration is a function of temperature and soil hydraulic parameters. Unlike precipitation and temperature, it varies across both the temporal and spatial domains. I used the MODIS toolbox to develop multiple raster files with average monthly evapotranspiration values and clipped them to the watershed and then again to Lake Somerville. This tool imports MOD 16 global evapotranspiration data, MOD 11 surface temperature data, and MOD43 albedo data from the NASA Terra satellite for the selected zone. The statistical data from each of the lake evapotranspiration raster files were then collected and analyzed to determine mean quarterly values that could be applied over the surface area of the lake.

Soil Moisture Content

The soil moisture content projection was modeled using the same temperature and precipitation values applied to the lake water balance to provide upper and lower limit responses. The mass balance used for the model is:

$$Change\ in\ Water\ Volume\ in\ the\ Soil = Precipitation - Evapotranspiration - Runoff$$

This model is much more difficult when you consider both spatial and temporal variance, which was not necessary for the Lake Somerville Water Balance. As discussed previously, precipitation only varies with time. However, the relevant soil hydraulic parameters (porosity, field capacity, wilting point) vary spatially and evapotranspiration varies with both time and space. I simplified the model by assuming runoff was negligible based on the low precipitation levels relative to the rate of evapotranspiration resulting from high temperatures.

Soil Hydraulic Parameters

The NASA Land Data Assimilation System (LDAS) provides the relevant baseline soil hydraulic parameters and can be accessed to provide spatial and temporal data, including soil moisture content. This data was to be used as the base layer for the model to show the spatial variation in changes to the soil moisture content with respect to porosity and the wilting point. Once converted to an ArcGIS compatible file, it could be projected and clipped with respect to the Somerville Watershed. However, I was unable to convert the data to a format usable by ArcGIS.

Despite the technical difficulties associated with file conversion, I was able to manually extract average soil properties to enable the completion of the temporal aspect of the model. The values applied to the model are: porosity – 46.5%, field capacity – 35%, wilting point – 21.4% (NASA 2011).

Precipitation and Evapotranspiration

Precipitation was applied as the water input for soil moisture modeling using the same values in the same manner that they were applied to the Lake Somerville Water Balance. The total area of the watershed minus the surface area of Lake Somerville was calculated to be 834,260 acres.

Evapotranspiration data was downloaded using the MODIS toolbox as described previously. Several files were downloaded for every month over a ten year period between 2000 and 2009.

They were then averaged over three-month periods using a raster calculator to develop four time-averaged raster files spanning one quarter each. Those quarters are defined as 1st Quarter (January to March), 2nd Quarter (April to June), 3rd Quarter (July to September), and 4th Quarter (October to December). Figure 8 shows the mean evapotranspiration values across the watershed for each quarter.

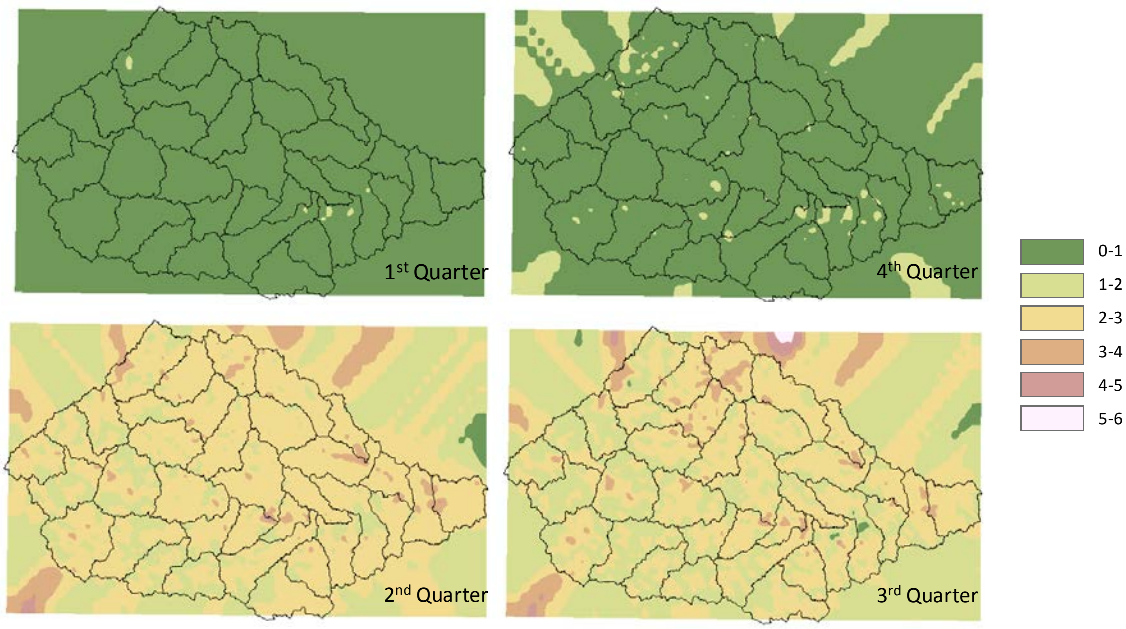

Figure 8. Mean evapotranspiration (inches/month) across the Somerville Watershed by quarter.

It is evident from Figure 8 that the spatial and temporal variation across the Somerville Watershed is relatively insignificant. To verify this and convert the data to that ore suitable for a strictly temporal analysis, I analyzed the statistical data from the rasters as shown in Figure 9. Not only did this analysis confirm the spatial and temporal consistency of the data, it revealed the truth behind the saying that Texas has only two seasons.

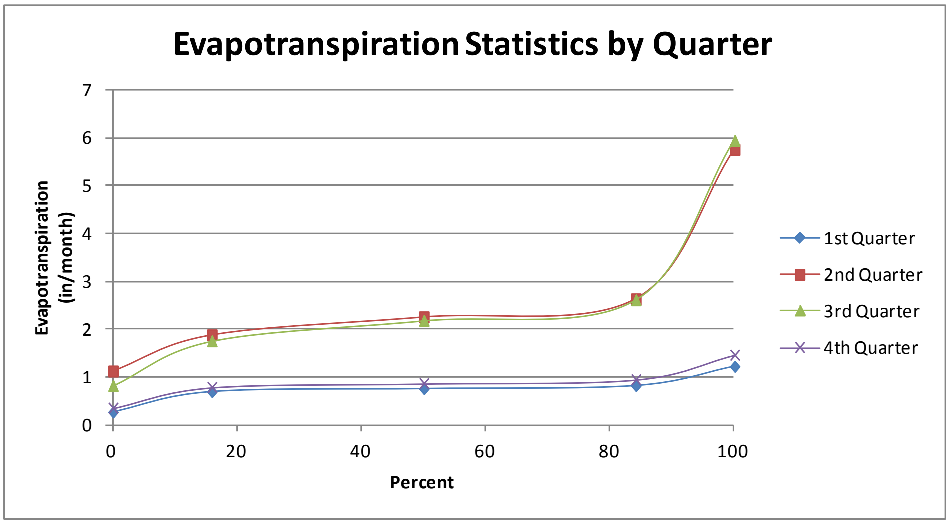

Figure 9. Summarized quarterly evapotranspiration data for the Somerville Watershed.

Results

Water Balance

In response to climactic projections based upon the current La Nina cycle, Lake Somerville will continue to decrease in volume over the course of 2012, with the vast majority of the water loss occurring during the summer months when temperatures and evapotranspiration are high and precipitation is exceptionally low. In 2013, it is likely that the water volume will continue to fall, but at a slightly lower rate than the loss in 2012. This assumption is based on the assumption that La Nina conditions will continue to exist, but precipitation levels will be greater than those experienced in 2011 and 2012, which were and are expected to be exceptionally low. As can be seen in both Figure 10 and Figure 11, however, the potential is there for the lake to recede by another 30% of its current volume before it begins to recover. This equates to volume equal to 25% of the lake's total capacity.

The lake will recover as precipitation and the corresponding stream flows increase. However, this is not expected to happen until at least 2013. Even so, it is evident in Figure 11 that the rate of recovery will be slow. If the right conditions exist in 2013, then Lake Somerville could reach its initial volume after 18 months. Otherwise, it could take up to 36 months. Even so, the initial model volume is still only 38% of the total capacity and much lower than the critical water level established by the Corps of Engineers. As El Nino conditions become predominant, lake levels will continue to rise, but it will be at least another 12 months before the system recovers to self-sustaining level and could take as long as 6 or even 10 years to reach maximum capacity

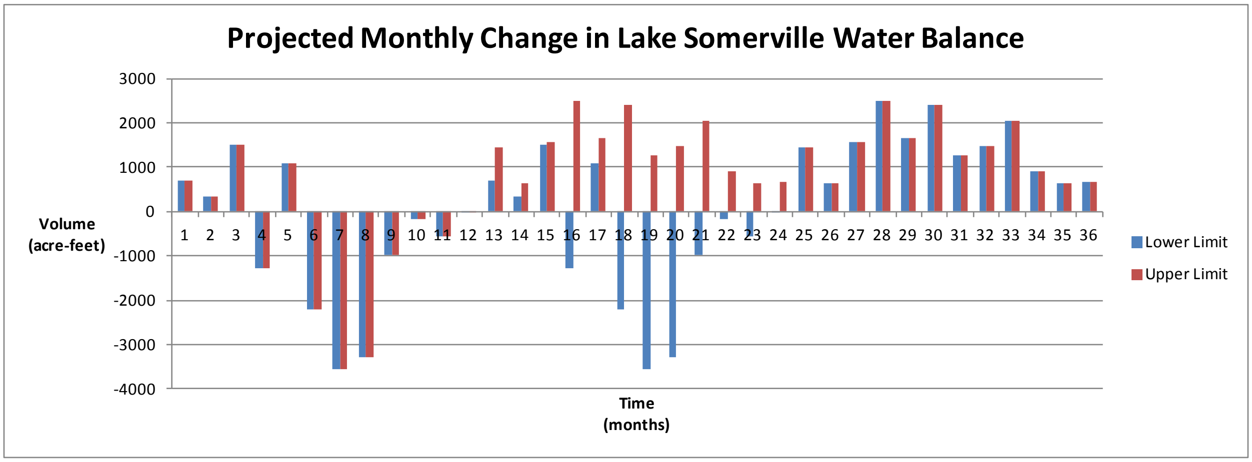

Figure 10. Project monthly change in the Lake Somerville water volume from January 2012 to December 2014.

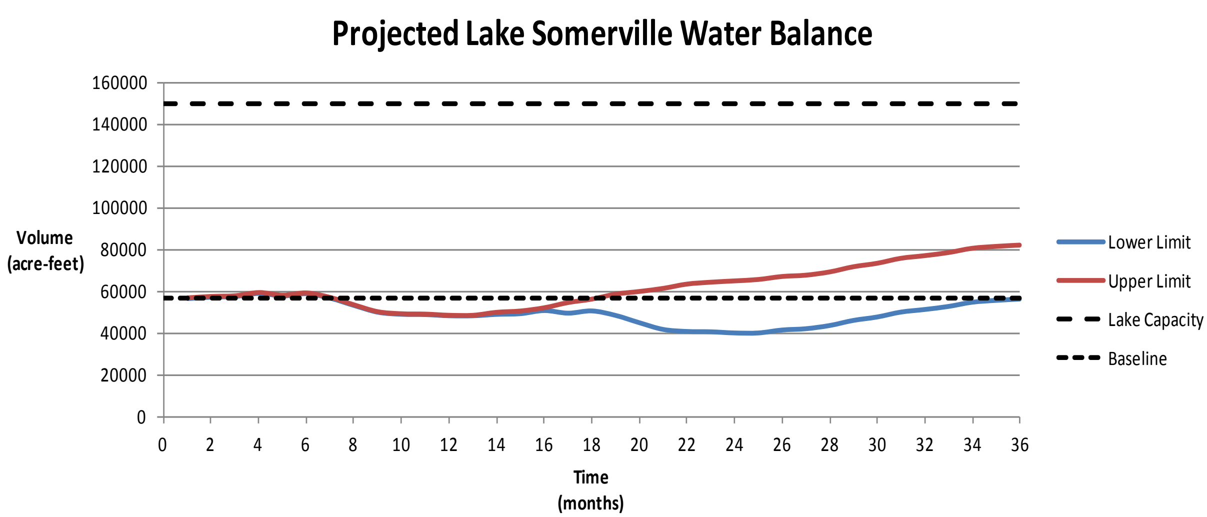

Figure 11. Projected water balance for Lake Somerville from January 2012 to December 2014.

Soil Moisture

The Somerville Watershed soil will respond in a similar manner as Lake Somerville. As temperatures increase, evapotranspiration rates will far exceed resaturation rates from low precipitation, causing the soil to quickly lose moisture and lose its capacity to sustain vegetation. As shown in Figure 12, the potential exists for the soil to make a full recovery with sustained steady rains that often exist with El Nino conditions. However, it is unlikely that those conditions will exist until late in 2013. If that is the case, it is apparent that the soil could become effectively barren for as long as three years.

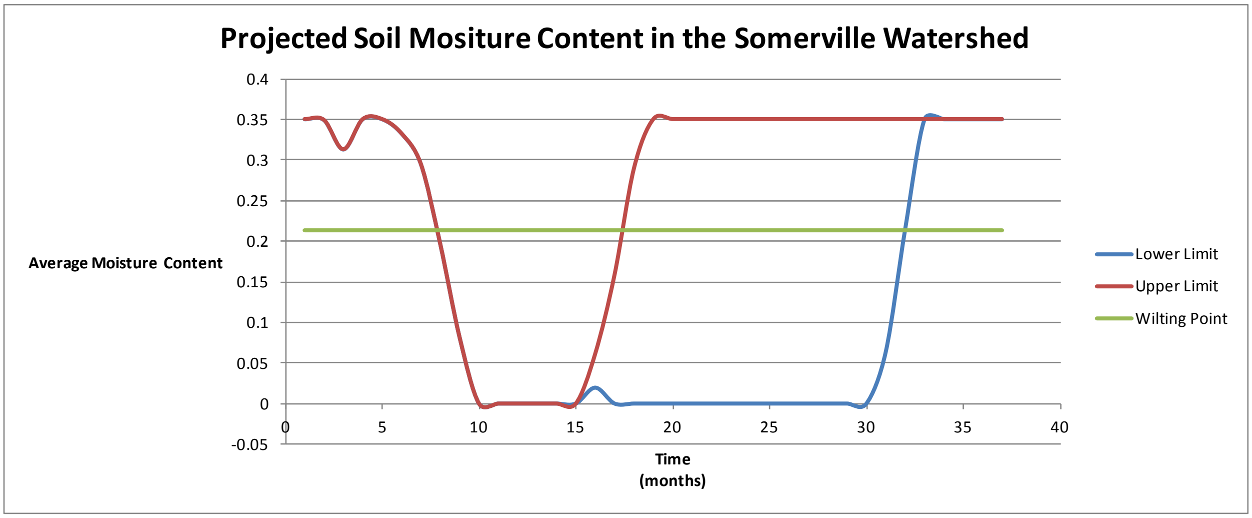

Figure 12. Projected soil hydraulic response from January 2012 to December 2014.

It should be noted here that this model assumes saturation to the average field capacity and only models one foot of soil. Obviously, the initial soil condition was not complete saturation. Additionally, because I was not able to manipulate the LDAS soil moisture data, I was not able to analyze the impact of soil memory as moisture content recedes below the wilting point. Certainly, this will reduce the slope of soil recovery up to the wilting point.

The other major factor that will affect the actual soil moisture response over the next few years is irrigation. Since many ranchers in the Somerville area have active wells, they are likely to pump water from the aquifers for irrigation and stock tanks. Even with these additional factors, though, the predicted response zone shown in Figure 12 provides a good indication of conditions over the next few years.

Conclusion

The Texas drought of 2011 has had a very significant negative impact on the Somerville watershed, yielding an all-time low in the reservoir volume and significant stress to the watershed's soil environment. Based on climactic predictions for the years 2012 and 2013 and the average El Nino cycle, it is likely that very similar drought conditions will exist for another 12 to 24 months before significantly higher precipitation levels enable the system to recover. Even after environmental conditions change and the system begins its recovery, it will likely be at least another six years before the lake reaches maximum capacity again.

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