Retrospective Analysis of the 2010-2015 Drought in ERCOT

Prepared in Consultation with Black & Veatch

Executive Summary

From October 2010 through May 2015, drought conditions persisted throughout the state of Texas. This retrospective analysis report summarizes a range of issues experienced in the ERCOT Region during the drought, including short term impacts and longer term water supply concerns. The report also describes drought risk monitoring tools and procedures ERCOT has developed to help predict which generation units may face drought-related water supply problems in the future. Almost three quarters of the current installed capacity in the ERCOT Region utilize generation technologies that require water to generate electricity. Should their sources of water supply become impacted or otherwise unavailable due to drought, it could have implications for the reliability of the ERCOT grid on a local or broader level depending on the geographic scope of water shortages. The information in this report will help to provide a better understanding of the potential implications for grid reliability should drought conditions return to Texas in the future.

The period 2010-2015 was, on average, the second-worst multi-year drought experienced in the state of Texas, second only to the drought of the 1950s. During this period, conditions were most extreme in the summer of 2011, which ranks as the driest summer on record and set the record for the most days above 100 degrees Fahrenheit. The peak demand of 68,305 MW on August 3, 2011 remained the ERCOT record until it was broken in the summer of 2015 due to continued load growth since then. Given that high temperatures tend to correlate with peak load in the ERCOT region due to residential air conditioning demand, the occurrence of peak demand, low rainfall and high temperatures at the same time placed additional constraints on generation resources and the transmission system during the summer of 2011.

Drought conditions lingered for almost four more years after 2011, impacting water availability in Texas reservoirs – and, by extension, impacting generating resources which are reliant on that water for cooling and other processes. Though resource owners developed and implemented mitigation strategies as storage in reservoirs declined over this period, there were limited instances where units were placed on forced outage due to low lake levels. The drought finished before any widespread generation outages occurred, but ERCOT's predictions suggest that one more year of drought would have placed a much larger number of generating stations under significant stress.

The drought of 2010-2015 provided some important lessons on how drought conditions can affect generation resources. In response to these conditions, ERCOT has been working to improve its monitoring and assessment of drought-related risks. After the summer of 2011, ERCOT surveyed generation resources on their sources of water supply and contracted with Black & Veatch to develop a drought risk prediction tool. Since late 2014, ERCOT staff have been using this tool to predict which generators are at risk of experiencing operational impacts in the near-term (within 6 months) and medium-term (within 18 months) due to reduced storage in supply reservoirs.

With the end of the drought in May 2015, ERCOT formalized a multi-departmental drought risk monitoring process centered on use of the drought risk prediction tool. The associated procedures include continued periodic reporting on drought risk, internal coordination between the relevant departments at ERCOT, and proactive communication with owners of resources potentially at risk. Using these procedures, ERCOT will continue to monitor drought conditions to identify mitigation needs in advance of issues that could threaten the ability to maintain the reliability of the grid.

Table of Contents

Table of Figures

1. Introduction

The drought of 2010 to 2015 was, on average, the second-worst drought in Texas after the drought of the 1950s. The summer of 2011 in particular ranks as the driest summer on record for Texas. In response to these conditions, ERCOT has been working intensively to monitor drought conditions and potential operational impacts that may be driven by drought (e.g., reduced availability of generating units during certain periods of time). These efforts have led to development of a drought risk prediction tool (in consultation with contractor Black & Veatch (B&V)), periodic reporting to alert ERCOT staff of potential drought-related impacts to generation resources, and increased coordination with owners of impacted generating units.

The drought conditions of 2010 to 2015, and subsequent rains and flooding events in 2015, have provided further data with which to analyze how the drought and subsequent flooding has and could affect power generation within the ERCOT Region. During the drought, water levels in supply reservoirs generally did not become at risk except in a couple of cases (Palo Pinto reservoir, which supplies R.W. Miller, as an example). However, ERCOT's drought risk assessment tool indicated that an additional year or more of drought would have placed many additional generating stations under significant stress.

This report outlines the uses of water in the power sector, the nature of the 2010 to 2015 drought (and subsequent rains), and how this affected the ERCOT grid and prompted efforts to increase drought risk monitoring and planning activities. The report is organized as follows:

- **Section 1.1** summarizes conditions experienced in Texas during the drought;
- **Section 1.2** provides an overview of water use by the power sector in the ERCOT Region;
- **Section 1.3** discusses sources of drought risk for power generation;
- **Section 1.4** describes prior Department of Energy and Black and Veatch (B&V) analyses related to drought risk in Texas and the ERCOT Region;
- **Section 2** characterizes the climatological conditions conducive to the formation and ending of the drought and describes the prevailing conditions during the years of the drought;
- **Section 3** discusses the operational and planning impacts related to the drought experienced in ERCOT between 2010-2015;
- **Section 4** provides an overview of ERCOT's drought risk monitoring and coordination activities; and,
- **Section 5** provides a summary of the conclusions of this study.

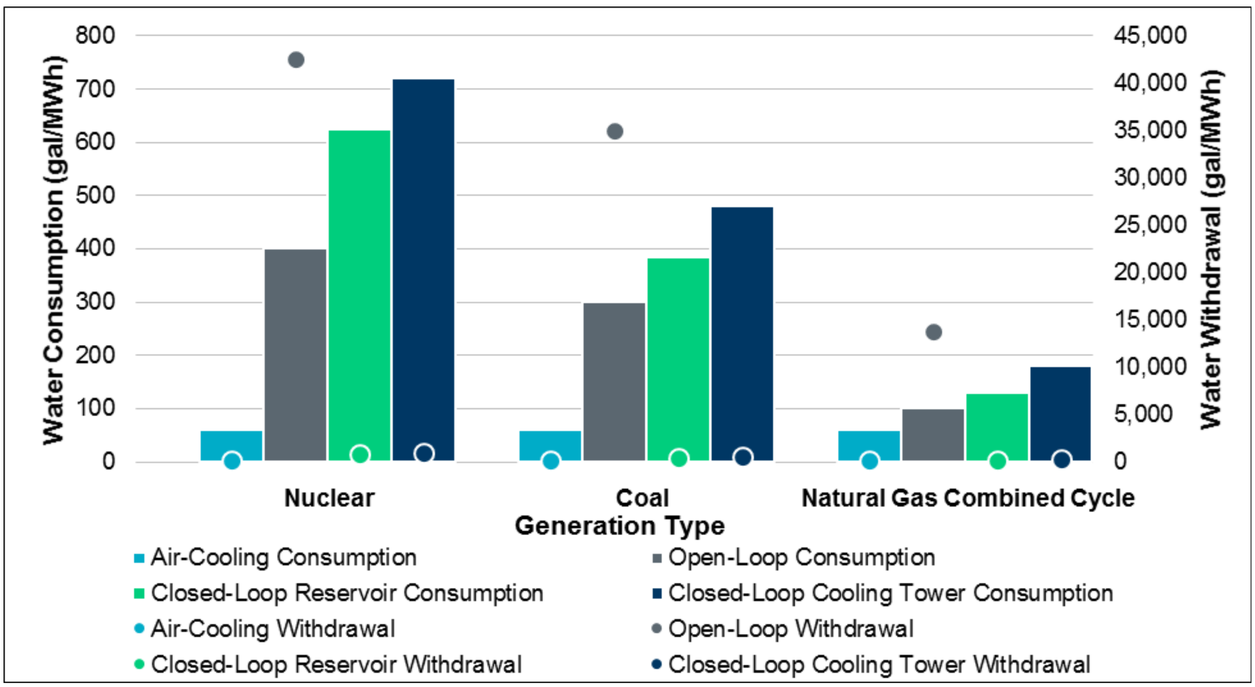
1.1. Background on the Drought of 2010-2015

The summer of 2011 was the driest summer on record in Texas, and 2011 overall was the second driest year on record for Texas, after 1917. Generally speaking, the period 2010-2015 is considered to be, on average, the second-worst drought in Texas, after the drought of the 1950s. From November 16, 2010 until May 12, 2015, at least 25% of the state experienced moderate or worse drought, and from December 7, 2010 to January 20, 2015, at least 40% of the state experienced moderate or worse drought. There were also several months, particularly in the 2011-2012 period, during which over 80% of the state was in moderate or worse drought. While a wetter pattern began to take hold in late-2014, the record setting floods of Memorial Day 2015 officially brought an end to the drought. [1]

1.2. Power Sector Water Use

Water is necessary to many forms of electric generation. Certain types of generation require very small amounts of water, for example wind and solar power or natural gas combustion turbines. However, other types of generation require significant amounts of water, including nuclear, coal, natural gas steam, and natural gas combined cycle generation. Hydropower is also dependent on water supply.

There are two considerations with respect to water use for power generation – withdrawal and consumption. Withdrawal refers to the total amount of water removed from a water source, some of which may be returned back to the source. Consumption, on the other hand refers to the total amount of water removed and used at the facility (i.e., not returned back to the source). The biggest driver of water withdrawal and consumption at power plants is for cooling. Often electric generators will have significantly higher withdrawals than consumption, for example due to the use of once-through cooling systems. Figure 1 shows typical consumption (left axis) and withdrawal (right axis) amounts for nuclear, coal, and natural gas combined cycle technologies by cooling technology type. As the figure shows, cooling towers *consume* the greatest quantities of water, but open-loop (i.e., once-through) cooling requires much greater water *withdrawals*, most of which is returned back to the source.



Source: Adapted from Stillwell et al., 2009. *Energy-Water Nexus in Texas*

Figure 1: Water Consumption and Withdrawal by Generation Type

[1] There are several metrics available for assessing drought conditions. The information provided here differs from the Texas Water Development Board (TWDB) assessment of the drought because it uses different metrics. The TWDB uses the Palmer Drought Severity Index (PDSI) in its determination of the drought timeframe and severity. As will be discussed in Section 2.2.3, the Palmer indices do not necessarily provide a good measure of the hydrological impacts resulting from long term drought, which can pose the greater risk to electric power generation. For this reason, this report characterizes drought conditions in Texas based on the timing of these hydrological impacts, rather than based on the PDSI.

Water requirements will vary depending on the generation technology type and cooling system technology type. In general, nuclear power requires the largest quantities of water on a gallon per MWh basis, followed by coal and natural gas steam generation, and finally natural gas combined cycle generation. A study prepared by B&V for ERCOT in 2013[2] provides more detailed information on water use and supply in ERCOT by the electric sector, and is summarized in Section 1.2. For additional information on power sector water use and supply, see Section 2.9 of the referenced report.

Figure 2 shows the installed capacity in ERCOT by fuel type at the end of 2015. Currently, 74% of installed capacity (MW) is provided by technologies like nuclear, coal, hydro, natural gas steam, and natural gas combined cycle generation which require significant amounts of water. Natural gas combustion turbines (7%), though requiring much smaller amounts of water compared to the other technologies, often also have a water requirement. Though less water-intensive technologies, like wind (18%) and solar (<1%), continue to grow within ERCOT, the vast majority of current generation is heavily dependent on water. As a result, these resources could become at risk during periods of drought if their sources of water supply are impacted.

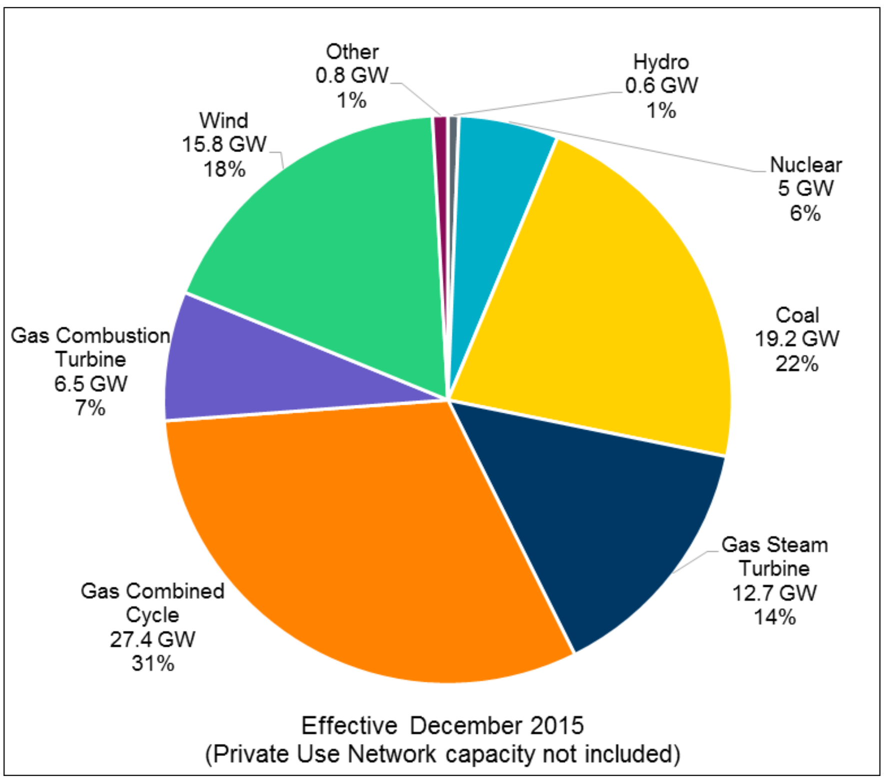


Figure 2: ERCOT Generation Capacity by Fuel

1.3. Drought Risk for Electric Generation

There are two major factors that create a risk for electric generation in times of drought: water availability and water temperature. During times of drought, the sources of water supply for generators may become unavailable due to low rainfall, evaporation, and other demands on the

[2] Black & Veatch. *Water Use and Availability in the ERCOT Region - Drought Analysis*, December 2013. Available at http://www.ercot.com/content/committees/other/lts/keydocs/2013/ERCOT_Water_Use_and_Availablility_-_DrtRpt_1DF.pdf.

source of supply. The transportation mechanism that conveys water to the generator (e.g., a pipeline) may present another source of risk should it be compromised. With reduced water supplies, generators may need to reduce their output or be taken offline completely. In addition, most power plants have temperature limits in their water discharge permits. Drought conditions, which typically correspond with high temperatures, may result in water discharge temperatures approaching these limits. This could also result in outages or deratings for impacted units. Both water availability and water temperature had impacts to generation in the ERCOT Region during the 2010-2015 drought.

Most power generators in ERCOT use surface water (i.e., reservoirs and lakes) for cooling, though some use groundwater or obtain their water from municipal suppliers who generally use the same types of sources. Figure 3 shows the ultimate source of water used by each thermal and hydro power generating site in the ERCOT Region.

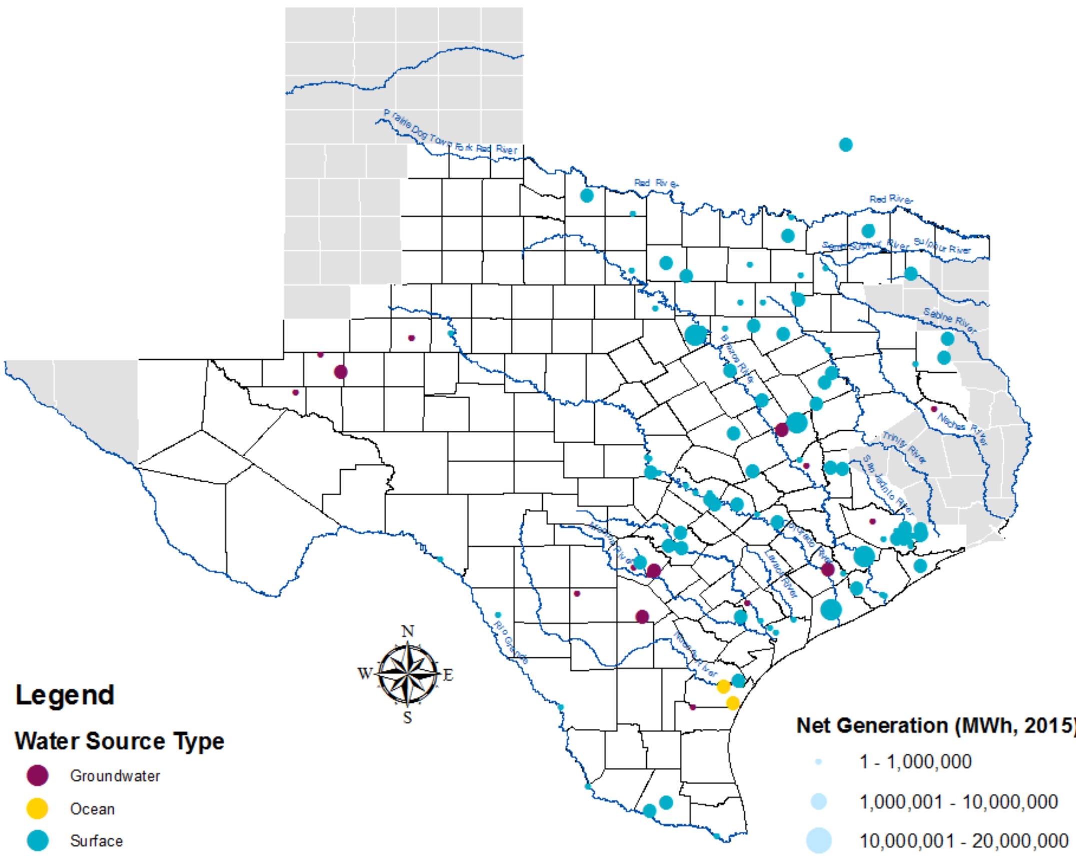
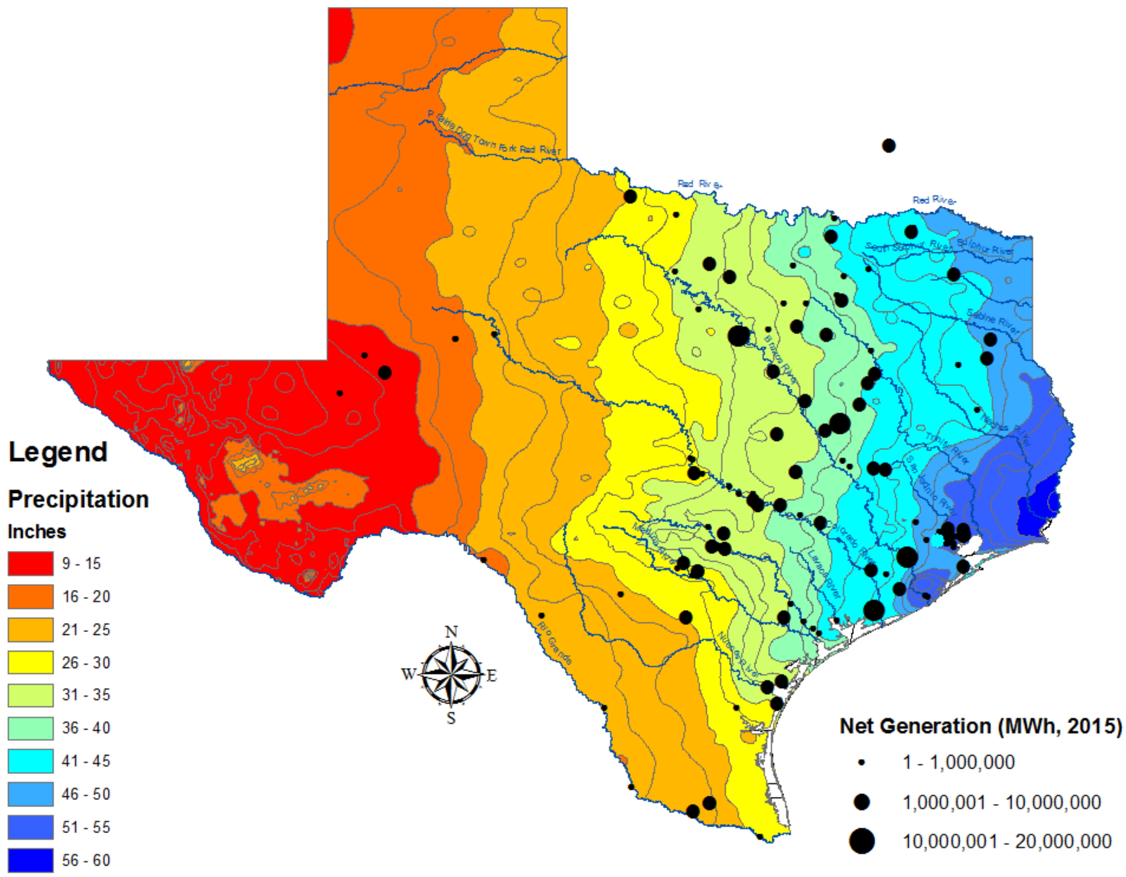


Figure 3: Water Sources for Power Generation in the ERCOT Region

The risk associated with different types of water supply during drought will depend on local rainfall, infiltration, runoff, recharge, and soil moisture content among other factors. Surface water has more of a direct connection to the current and recent conditions, whereas groundwater is affected over a longer term. High average temperatures, which range from less than 70 degrees Fahrenheit in the Panhandle to more than 82 degrees Fahrenheit in the Lower Rio Grande Valley, cause water evaporation to exceed precipitation in most of the state. In addition, Texas's climate varies widely, from an average of 8-inches (7.68-inches in Socorro) of rainfall in the arid west to 60-inches (59.76-

inches in the city of Orange) in the humid east. Figure 4 shows the average rainfall variations across the ERCOT Region. Just as rainfall varies geographically across Texas under normal conditions, the impacts of drought will also vary across the state.



Source: Developed from data sourced from the TWDB

Figure 4: Average Annual Rainfall in Texas Relative to ERCOT Power Plant Locations

With respect to drought risk, consumption of water through operational uses is the more important consideration for power plants which withdraw water from surface water supply reservoirs, as is the case for the majority of power plants in the ERCOT Region. Consumption of water by power plants reduces the amount of water in the associated supply reservoirs. Note, however, that for power plants that use run-of-river systems, withdrawals may be the more important consideration. Even for power plants that use supply reservoirs, withdrawal can be a contributing factor if there is not enough volume in a water body to allow the withdrawal to occur. Finally, units that withdraw water from groundwater sources are not as susceptible to drought over the short-term due to the nature by which groundwater aquifers are recharged. However, over the long-term drought can have an impact on groundwater availability, and thus requires separate analysis from surface water sources.

1.4. Previous Studies

There have been several studies since the start of the drought which looked at drought risk to power generation in the ERCOT Region. The first was conducted by the Argonne National Laboratory and published in December 2011.[3] That study looked at both ERCOT and the Western Interconnection, and sought to provide a high-level estimate of drought risk for the major water basins in those areas. The analysis found that Texas was vulnerable to drought due to the large amount of thermoelectric generation in the region and the area's propensity to experience severe droughts. The study recommended that more detailed studies be conducted specific to the region.

In January 2013, the Argonne and Sandia National Laboratories published a second study, *Impact of Future Climate Variability on ERCOT Thermoelectric Power Generation*.[4] The study used climatic models, hydrologic models, and power-plant specific assumptions to evaluate the potential impacts of single and multi-year droughts on electric supply in the ERCOT Region. The results indicated that reservoirs located near Dallas, Houston, Austin, San Antonio, Brownsville, and Lubbock may be vulnerable to reduced water availability during periods of drought. Drought conditions could result in summer power plant curtailments due to either water availability or water temperature limits in effluent permits. The study also considered water availability for future generation supplies, and found that little unappropriated surface water is available for new generation in Texas. Instead, water supply for future development will need to come from sources other than unappropriated surface water, at higher cost.

In addition to the two Department of Energy studies, in December 2013 B&V prepared a report for ERCOT on water availability and electric generation.[5] The report provides an overview of water use by the electric sector, water supplies available in Texas, and characterization of drought risk factors. The analysis also assessed the results of the 2011 Argonne study and evaluated other data sources, including a generator survey conducted by ERCOT, available to support drought risk analyses. As part of this and subsequent work, B&V developed drought risk analysis tools for ERCOT, which will be discussed in Section 4.1 of this report.

The B&V report also provided an overview of the impacts in the ERCOT Region of the drought during the single year of 2011. This retrospective analysis report builds on the 2013 B&V report to provide an assessment of the impacts of the drought during its full extent of 2010-2015. As both the B&V report and the 2013 Argonne and Sandia study concluded that multi-year droughts may pose greater risk to water supplies, it is important to examine the impacts of the 2010-2015 drought in its entirety.

[3] Harto, C.B. and Yan, Y.E. *Analysis of Drought Impacts on Electricity Production in the Western and Texas Interconnections of the United States*, 2011. ANL/EVS/R-11/14, Argonne National Laboratory, Argonne, IL. Available at http://energy.sandia.gov/wp-content/gallery/uploads/Drought-Analysis-Report-Final.pdf.

[4] Argonne National Laboratory. *Impact of Future Climate Variability on ERCOT Thermoelectric Power Generation*, January 2013. Available at http://www.ipd.anl.gov/anlpubs/2013/03/75723.pdf.

[5] Black & Veatch. *Water Use and Availability in the ERCOT Region - Drought Analysis*, December 2013. Available at http://www.ercot.com/content/committees/other/lts/keydocs/2013/ERCOT_Water_Use_and_Availablility_-_DrtRpt_1DF.pdf.

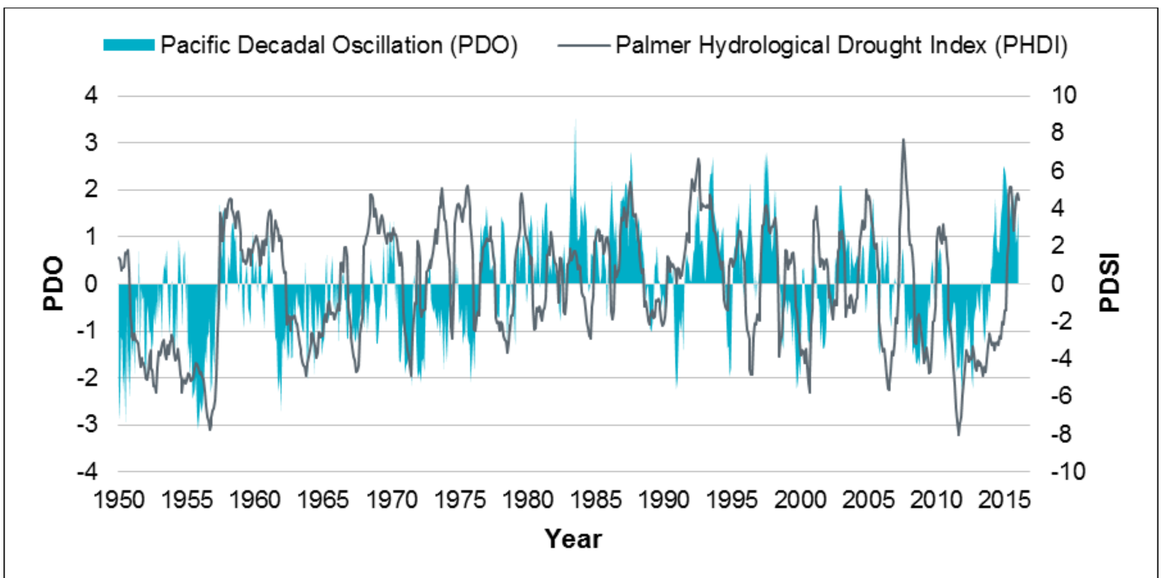
2. Nature of the Drought of 2010-2015

This chapter describes the climatological conditions that led to the formation of the drought of 2010-2015, the characteristics of the drought of 2010-2015, and the conditions resulting in the ending of the drought and flooding events in late 2014 and 2015. The chapter concludes with a comparison of the drought of 2010-2015 to other notable droughts in Texas.

2.1. Conditions Conducive to Drought Formation

The drought of 2010-2015 was highly complex in its development. There is a strong correlation between drought in Texas and Atlantic and Pacific Ocean temperatures. La Niña events also contribute to drought in Texas.

The long-term variations in Atlantic and Pacific Ocean temperatures are referred to as the Atlantic Multidecadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO), respectively. The most commonly mentioned cause of drought is when Pacific temperatures are cool and Atlantic temperatures are warm. However, cool temperatures in the Pacific are much more highly correlated to drought formation in Texas, whereas the correlation with Atlantic warm temperatures is not as strong. Figure 5 shows the correlation between PDO and drought conditions in Texas (as measured by the Palmer Hydrological Drought Index (PHDI)). As can be seen in the chart, cool phases in the Pacific (PDO less than zero, or PDO-) tend to correspond to drought conditions in Texas (PDSI less than zero). The 2010-2015 drought was characterized by cool Pacific Ocean temperatures, with PDO- conditions persisting until January 2014, even though the drought continued thereafter. Looking back at the drought of record, the 1950s were also characterized by largely PDO- conditions.



Source: National Climatic Data Center / NESDIS / NOAA

Figure 5: Pacific Decadal Oscillation and Drought

La Niña also played a role in the onset of the drought. Like El Niño, La Niña changes the global atmospheric circulation patterns. El Niño steers more storms across the southern tier of the U.S., including Texas. La Niña does the opposite, allowing high pressure ridges to form over Texas and reducing the prevalence of storms, thereby reducing rainfall in Texas. La Niña conditions arose in 2010 and 2011, contributing to the formation of the drought. La Niña conditions were moderately strong in 2010 and 2011, and continued in a weaker state through early 2014.

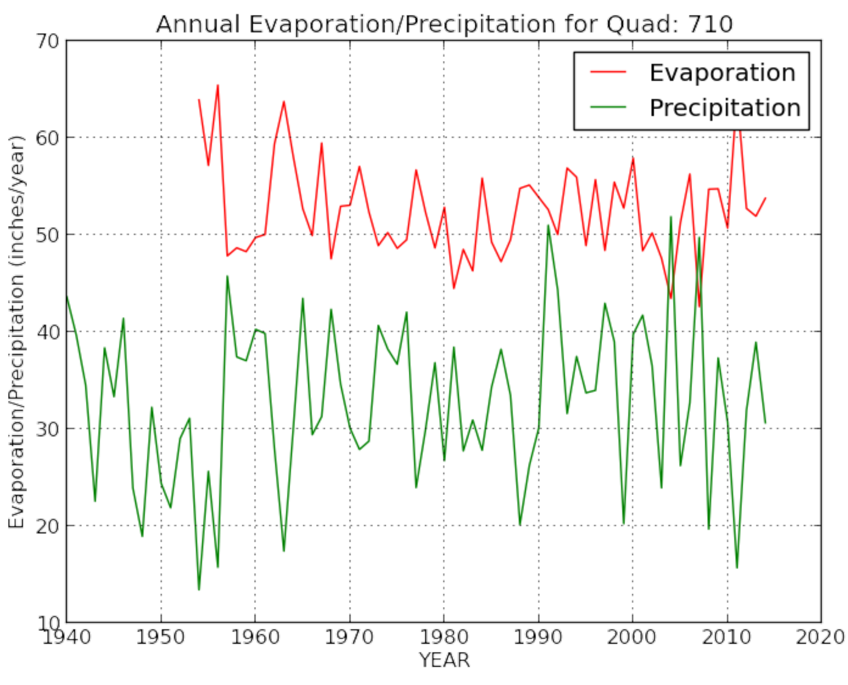
2.2. Characteristics of the Drought

The 2010 to 2015 drought developed relatively quickly with the exceptional single-year drought of 2011. This was the hottest summer on record across the state, and second hottest year on record. It was also the driest summer on record. These conditions were not preceded by prior years of below average rainfall, so managers of the reservoirs across the state had not actively been storing water to make up for an expected shortfall.

The subsequent period through late 2014 were classed as severe drought based on the Palmer Drought Index (PDI), but the overall rainfall was not significantly below average in many parts of the state for these later years. However, as the drought persisted, reservoir levels in certain parts of the state continued to decline, and in many cases reached their lowest points in late 2014.

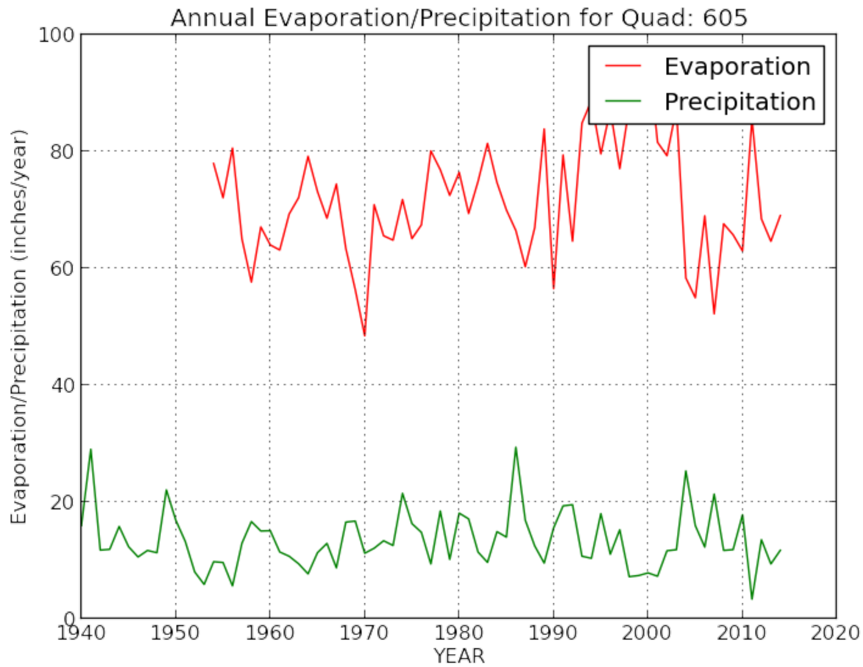
2.2.1. Rainfall

Figures 6 through 8 show variations in precipitation and evaporation at three representative locations within the ERCOT Region: Austin, Midland Odessa and Baytown. These three locations show the wide variation of rainfall across the state. There is little overall change in the western area (Midland Odessa), as this is consistently a low rainfall area. However, the other two locations saw significant reductions in rainfall from normal levels in 2011. Similar impacts were seen across the state in 2011. The following years (2012-2014) had slightly lower rainfall than average in both Austin and Baytown, but they were not as consistently low as the drought of the 1950's in these locations. The depth of the drought was not as severe over the extended period as compared to the 1950's. Therefore, the drought of 2010-2015 should not be considered as the worst conditions in the period of record, at least with respect to precipitation.



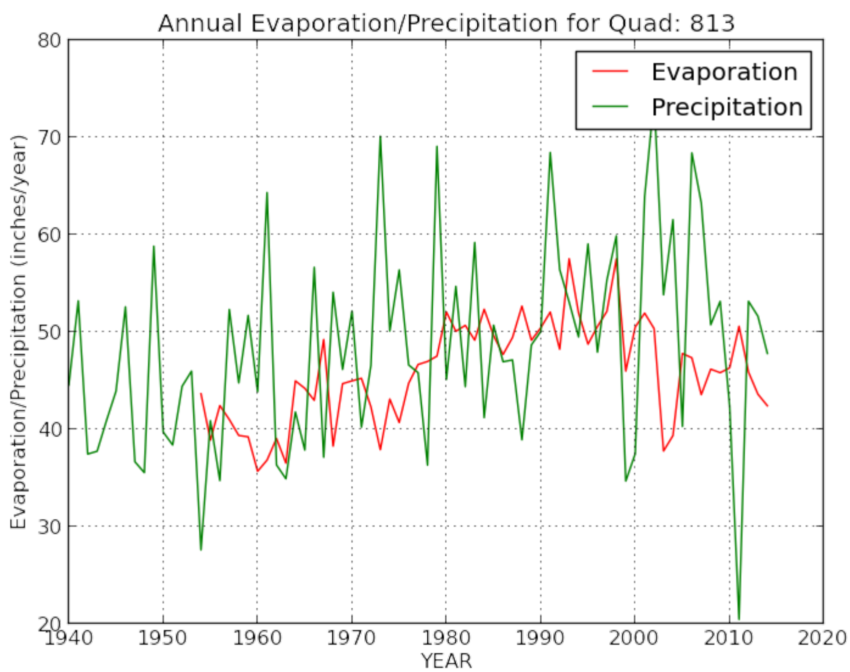
Source: TWDB

Figure 6: Rainfall Variations for Quadrangle 710 (Austin) 1940 to 2014



Source: TWDB

Figure 7: Rainfall Variations for Quadrangle 605 (Midland Odessa) 1940 to 2014

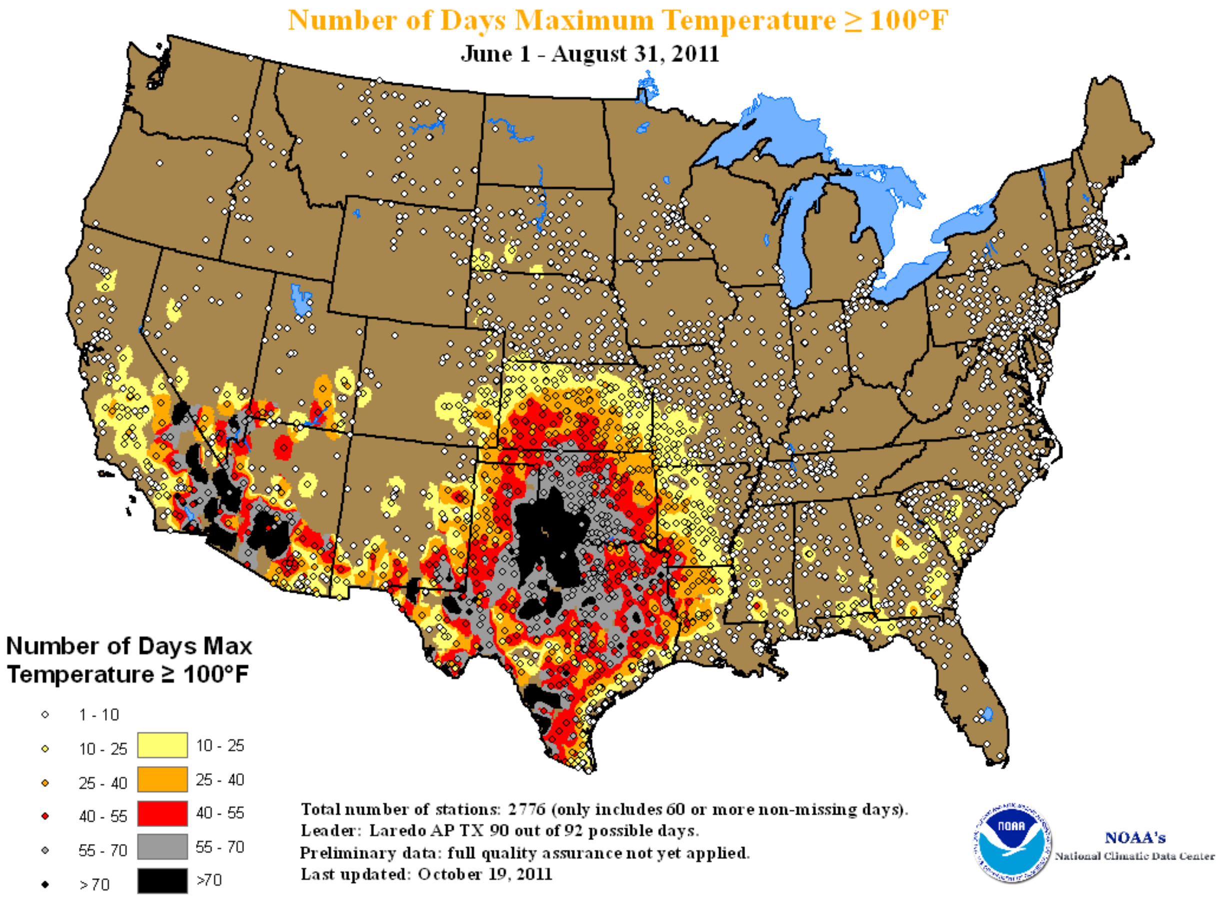


Source: TWDB

Figure 8: Rainfall Variations for Quadrangle 813 (Baytown area) 1940 to 2014

2.2.2. Air Temperature

When considering drought conditions, air temperature is an important indicator because of its impact on electricity use, evaporation, and cooling system efficiency. Average air temperatures across Texas were the second highest on record in 2011.[6] Figure 9 outlines how significant these high temperatures were when compared to the rest of the United States for the summer of 2011. The colors in the map indicate the number of days with maximum temperatures measured at 100 degrees Fahrenheit or greater, and each dot represents a day where temperatures met or exceeded 100 degrees Fahrenheit as measured at a weather station.



Source: NOAA

Figure 9: Maximum temperatures above 100°F in the Summer of 2011

In the ERCOT Region, peak demand for electricity typically occurs during the hottest time of the year due to residential air conditioning demand. The ERCOT peak demand record of 68,305 MW set on August 3, 2011 remained the ERCOT record until it was broken in the summer of 2015. Temperature also has an effect on lawn watering demand, and as a result peak water demand for municipal systems can also occur during the hottest time of the year. Lawn watering is not the largest water use in Texas, but the extra water use will further reduce water supplies in power generation reservoirs if they are connected in some way to a municipal supply reservoir.

[6] National Oceanic and Atmospheric Administration (NOAA). "Texas, Average Temperature, January-December." Available at http://www.ncdc.noaa.gov/cag/time-series/us/41/0/tavg/ytd/12/1895-2016?base_prd=true&firstbaseyear=1901&lastbaseyear=2000.

Despite the record temperatures, evaporation was not the highest on record in the three sites shown in Section 2.2.1. Though evaporation is often correlated to air temperature, there are some additional factors (e.g., wind, surface area) which could affect evaporation more significantly over the full calendar year beyond temperature alone.

The additional, and in many ways more important, factor with respect to temperature is the effect it can have on water temperatures in supply reservoirs. This is discussed in more detail in Section 3.2.

2.2.3. Severity and Extent

The Palmer Drought Index is the most often cited measure of drought severity. The PDI is also described as The Palmer Drought Severity Index (PDSI) and Palmer Hydrological Drought Index (PHDI). All of these are slight variations on the original meteorological drought index developed by Douglas Palmer in 1965, which responds to abnormally dry or abnormally wet conditions. It is relatively fast in its response to changes in these conditions, and is generally a good measure of short-term drought. The PDSI is one of the key indicators used by the U.S. Drought Monitor to classify drought conditions nationwide, along with soil moisture, streamflow, precipitation, and other drought indicators.[7]

While short-term drought conditions impact the operation of the ERCOT grid, as will be discussed in Section 3, water supply is more likely to become at risk during periods of long-term drought. Water storage in medium- to large-sized reservoirs (from which most power generating systems receive their water supply) is typically sufficient to withstand short-term periods of drought. However, multiple years of drought conditions may continue to drain reservoir storage, resulting in risks that may not be reflected by short-term indicators such as the PDI. While the PDI may reflect the development of abnormally dry conditions within three months, it does not take into account streamflow, lake and reservoir levels, and other longer-term hydrologic impacts. In contrast, it may take three years for a large reservoir to reach an at-risk point (from full). Therefore, while the PDI is a good measure of short-term drought, the reservoir levels in the relevant supply reservoirs are more appropriate to use as the primary metric to provide early warning of possible water supply issues.

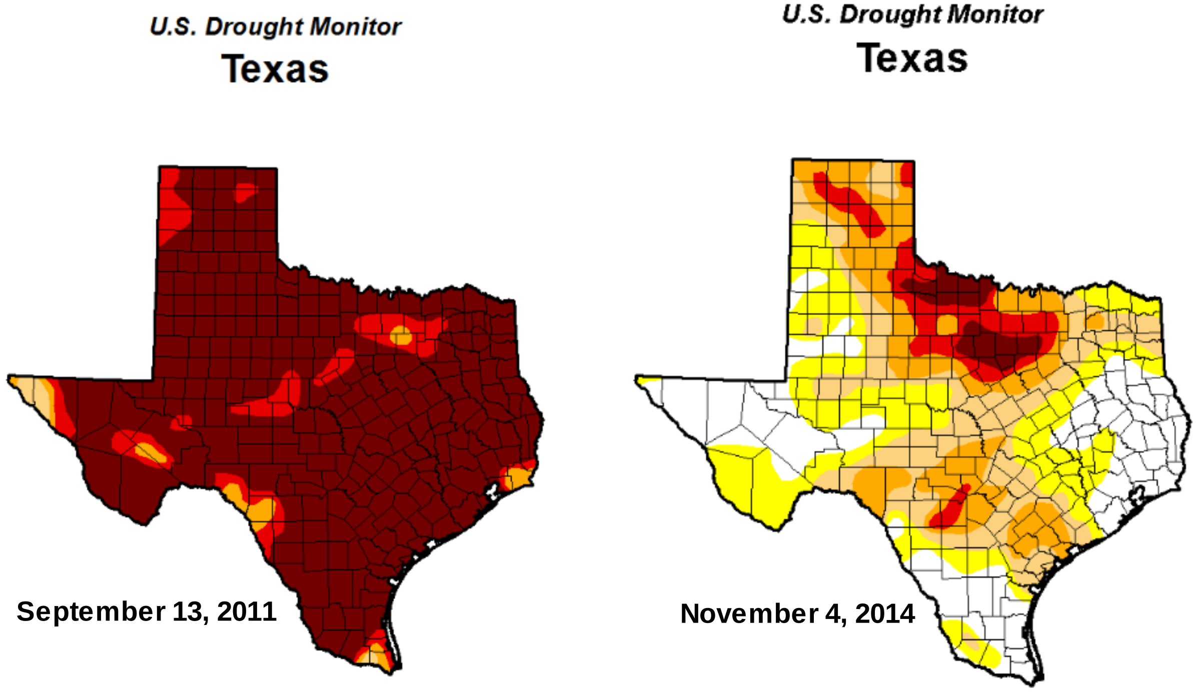
Conditions experienced during the summer of 2011 resulted in a serious reduction in reservoir stocks and reduced soil moisture to an extent that any rainfall did not generally find its way to reservoirs as run off in the subsequent years. As a result, the severity of the drought, as measured by reservoir levels, increased in the years after 2011. However, the severity does not appear as bad as it could have been with respect to overall temperature and evaporation due to cutbacks in consumption from all sectors (agriculture, municipal, etc.).

An additional important distinction is the geographical distribution of the impacts. While most reservoirs across the state lost storage during the summer of 2011, in subsequent years the severity of the drought varied geographically. The eastern part of the state, which typically has higher rainfall under normal conditions, received additional rainfall that largely replenished reservoirs after 2011. However, storage in reservoirs in the western and central parts of the state continued to decline as the drought wore on, reaching their lowest levels in November 2014, just before the heavy rainfall events began.

Figures 10 and 11 show the differences in drought severity as measured by the U.S. Drought Monitor versus reservoir storage levels. Figure 10 shows the U.S. Drought Monitor map for Texas for September 2011and November 2014. While the PDI, which is one of the measures used by the U.S. Drought Monitor, was at its worst levels in September 2011, reservoir storage, particularly for reservoirs located in the central part of the state, was lowest in November 2014. As an illustrative

[7] U.S. Drought Monitor maps and data are updated weekly and available at http://droughtmonitor.unl.edu/Home.aspx.

example, Figure 11 shows the declining reservoir levels from 2010 through early 2015 for Lake Ray Hubbard, which is located near Dallas and supplies water to the Lake Hubbard generating site.



Source: U.S. Drought Monitor

Figure 10: U.S. Drought Monitor for Texas, September 2011 and November 2014

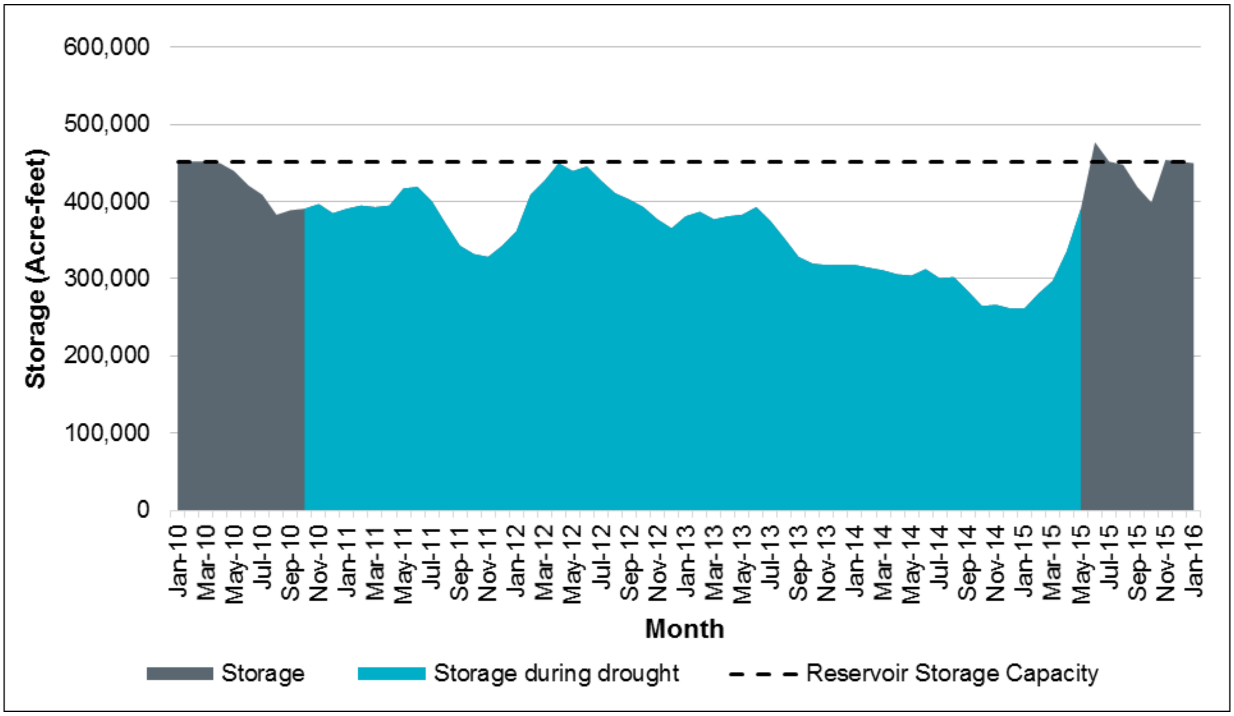


Figure 11: Reservoir Storage in Lake Ray Hubbard

Another example of interest is the case of the Highland Lakes, operated by the Lower Colorado River Authority (LCRA). The steep decline in storage in 2011 was water released for agricultural irrigation use. During the subsequent years, the reservoirs were unable to recoup the lost storage until the rainfall events of 2015. Figure 12 shows the reservoir storage in Lake Buchanan over the drought period, though it should be noted that the Highland Lakes are controlled as a system by the LCRA. The decline in storage over the summer of 2011 reflects releases for irrigation.

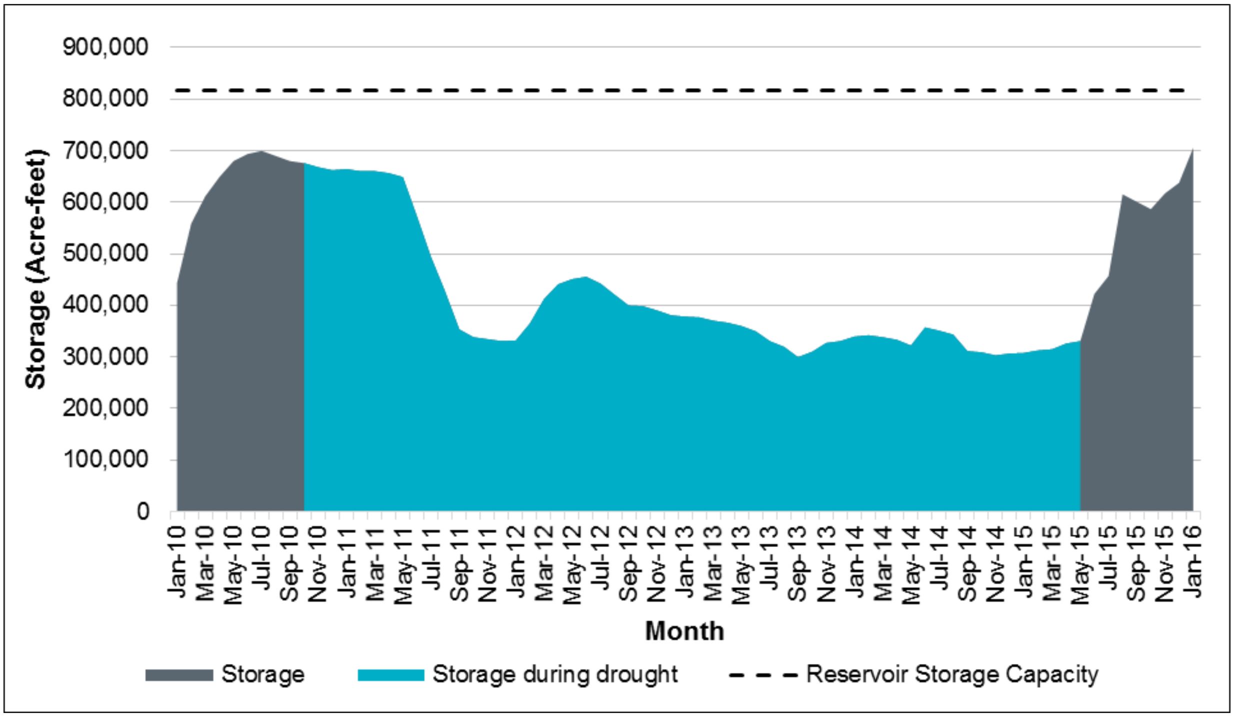


Figure 12: Reservoir Storage in Lake Buchanan

Largely in response to the drought during this period, the LCRA has made several changes to its water management plans and the way it supplies water to agricultural customers. In its 2015 Water Management Plan for the Highland Lakes, the LCRA added additional decision points, placed limits on the amount of water available to agricultural customers, and set three types of water supply conditions ("Normal," "Less Severe Drought," and "Severe Drought").[8] These changes were intended to improve the LCRA's ability to respond to drought conditions.

2.3. Conditions Prevalent to Ending of the Drought

As described in Section 2.1, drought formation in Texas is highly correlated to cool temperatures in the Pacific Ocean (PDO-). Similarly, droughts typically end with the Pacific being in a warm cycle (PDO+). A PDO+ alone may or may not be enough to immediately end a drought. However, PDO+ combined with an El Niño, particularly a strong event, has historically resulted in rapid ends to droughts.

The PDO changed to positive in January 2014. While 2014 is considered a part of the drought of 2010-2015, drought conditions in 2014 were largely a carryover of conditions during 2011-2013 rather than a result of conditions during 2014 itself. In addition to the shift to PDO+, an El Niño developed in October 2014, becoming a strong event beginning in July 2015.

Between May 24-26 2015, a slow-moving storm system moved across much of Texas and Oklahoma. This occurred immediately after light rainfall events which increased the soil moisture (and ability for runoff to occur), and included significant precipitation which triggered record-breaking floods. The National Weather Service issued a number of flash flood warnings during this period and a flood emergency for southwest Harris County (which includes the city of Houston) and northeast Fort Bend County. These rainfall events in May 2015 officially ended the drought.

[8] Lower Colorado River Authority (LCRA). "Water Management Plan for the Highland Lakes," 2015. Available at http://www.lcra.org/water/water-supply/water-management-plan-for-lower-colorado-river-basin/Pages/default.aspx.

Although a “flash drought” developed over the summer of 2015, this was also removed by record rainfall amounts, which occurred in October 2015. In some cases the October 2015 flooding events surpassed those from May. October 2015 was Austin's wettest month on record, with 22.08 inches of rain recorded at Austin-Bergstrom International Airport and parts of Austin receiving up to 14.54 inches in one single 24-hour period. The old monthly record was 15.59 inches in June 1981.Overall, the year 2015 ranks as the wettest year on record for Texas, ahead of the previous wettest year (1941).

2.4. Comparison to Previous Droughts in Texas

The period 1950 to 1957 was always considered the drought of record in Texas until 2011, and this period is still considered the drought of record for planning purposes. The 2010-2015 drought has a number of similarities compared with that of the 1950’s. Both were multi-year droughts and both had large prolonged rainfall events to bring them to an end. The drought of the 1950’s lasted longer overall, but there was a slightly wetter period in 1954 (comparatively) which broke this up into two three-year cycles. The drought of 2010-2015 was more severe over the short term because the demands on the water resources have significantly increased. However, if the 1950’s drought were repeated today, it would likely have a slightly greater effect on the reservoir volumes as compared with the most recent drought.

3. Generation Issues and Risks throughout the Drought

There were several different types of impacts experienced in the ERCOT Region from the drought conditions that persisted from 2010 to 2015 in Texas. As noted in Section 1.3, the major risks to generation resources from drought come from water availability and water temperature. In addition, the high temperatures coupled with high electricity demand during the summer of 2011 strained the operation of the transmission system. While the conditions of 2011 stressed the system on a short-term basis, the ongoing drought in 2012-2014 put water supplies at risk up until the May 2015 rains ended the drought. This section describes the short-term impacts experienced during 2011, the longer-term impacts on water supplies, and the implications on planning for future droughts.

3.1. Grid Operations During the Summer of 2011

During the drought, conditions were most extreme in the summer of 2011, which ranks as the driest summer on record, and set the record for the most days above 100 degrees Fahrenheit. As previously noted, high temperatures tend to coincide with drought conditions, as was the case during the record-setting summer of 2011. In the ERCOT Region, peak demand for electricity typically occurs during the hottest time of the year, due to residential air conditioning. Thus, the temperatures during the summer of 2011 resulted in high demand for electricity. The peak demand of 68,305 MW on August 3, 2011 remained the ERCOT record until it was broken in the summer of 2015.

At the same time, the high temperatures also had an impact on the transmission system. The dynamic ratings of transmission lines were reduced due to the high temperatures. In addition, transmission lines, primarily along the coast, became contaminated with salt and dirt due to the lack of rainfall, and had more frequent forced outages during the summer of 2011. Thus, at the same time that demand for electricity was at its highest, the transmission system was also being strained to meet that demand.

With regards to generation, there was a single case (24 MW) of a generator forced outage during 2011 due to water supply (an additional case would occur towards the end of the drought, in the 2014-2015 period). In addition, the high temperatures of the summer of 2011 affected the temperatures in generator cooling reservoirs, as will be discussed in Section 3.2. In general, water supply risks increased over the 2011-2014 period as the drought progressed and reservoir levels declined (see Section 3.3).

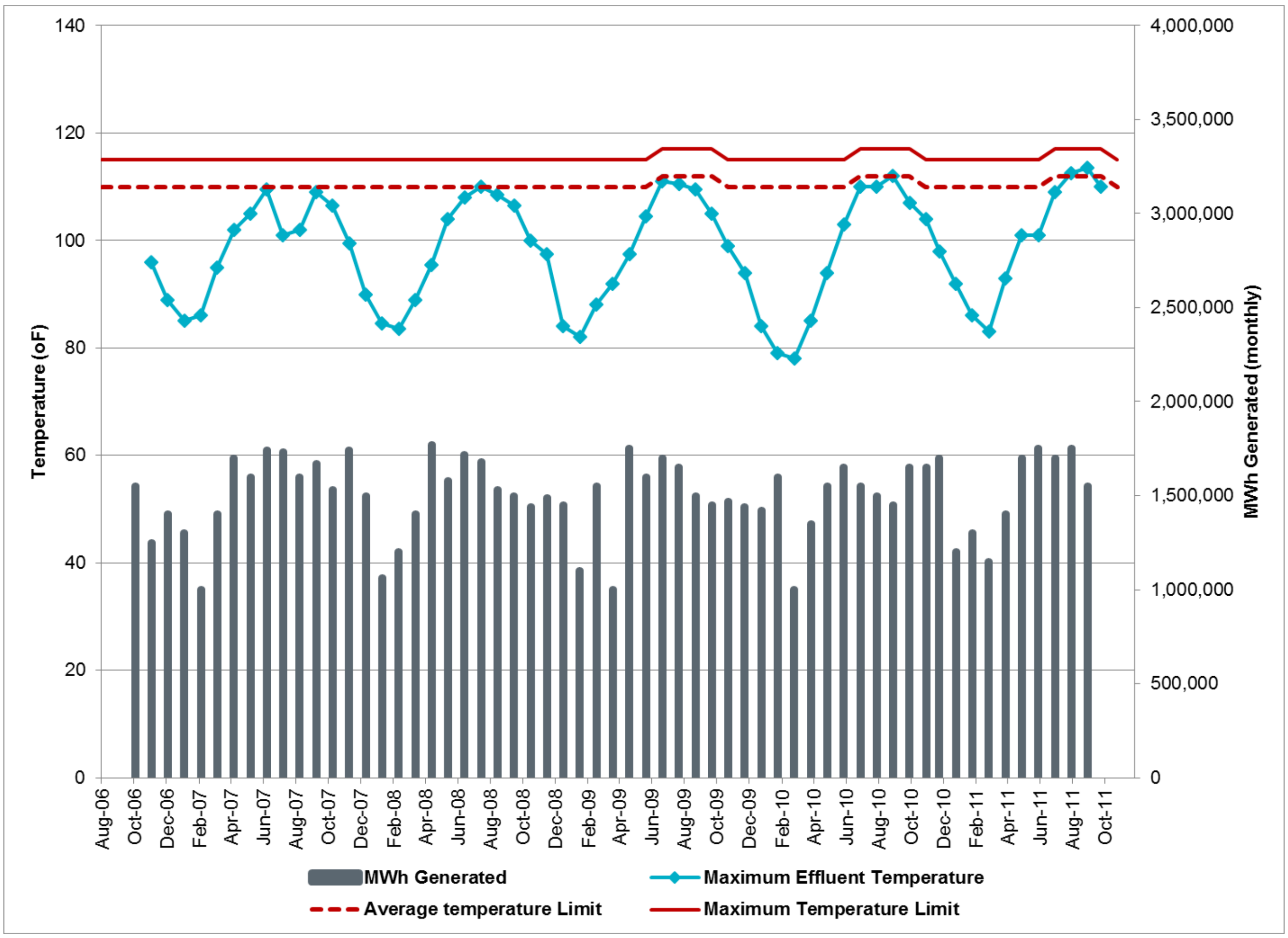
3.2. Lake Temperature Issues

The high temperatures of the summer of 2011 also resulted in increased water temperatures in supply reservoirs. Increased water temperatures have implications for the efficiency of generator cooling systems as well as for compliance with temperature limits in water discharge permits.

As water temperatures increase, cooling systems become less efficient and water loss through evaporation increases. Most thermal generators operate at lower capacity levels during summer months due to this loss of efficiency. ERCOT's Capacity, Demand, and Reserves (CDR) report reflects this through the separate summer and winter ratings – where summer ratings often reflect a derate as reported to ERCOT by the resource owners. This effect may be magnified as storage in reservoirs declines, since temperatures may rise more quickly at smaller volumes. Had there been a summer similar to 2011 later in the drought period, when reservoir levels had declined further, it could have resulted in additional constraints on the availability of thermal generation capacity.

In addition, the temperature of the discharges to the supply lakes are regulated by the Texas Commission on Environmental Quality (TCEQ). As water temperatures increase, particularly in smaller lakes, and effluent from cooling systems further increases the water body heating, it is possible that temperature limits in TCEQ permits may be exceeded. A prolonged period of high temperatures such as that experienced in 2011 may result in cooling reservoirs approaching their permitted temperature limits. To avoid exceeding those limits, units may be forced to reduce output or take outages.

No generator was curtailed due to reservoir temperature in 2011, but a few did reach their maximum temperature limits. Analysis was conducted as part of the Sandia study on most of the generating sites in the ERCOT Region that have a pond or reservoir utilized for cooling purposes. At least one site (Martin Lake) exceeded its temperature limits (see Figure 13). The resource owner asked TCEQ to use its enforcement discretion to raise the temperature limit temporarily to allow continued power generation during the summer of 2011. After 2011, there were no known exceedances in the 2012-2014 period, but it is possible that if a second summer similar to 2011 had occurred later in this period, when water levels in reservoirs had declined further, the temperature limits could have been exceeded in a number of locations.



Source: Sandia National Labs (graphic re-configured). The grey bars show the electricity generation, w hereas the blue line show s the w ater effluent temperatures. The red lines indicate the average and maximum temperature limits for effluent from the cooling process. This unit exceeded its average temperature limit during the summer of 2011, and received a permit w aiver from the TCEQ.

Figure 13. Reservoir Temperature Variations and Limits for Martin Lake

3.3. Water Supply Driven Outages

The loss of water supply also poses a risk to the availability of generators. After 2011, storage in reservoirs continued to decline over consecutive years of below-average rainfall. Though resource owners developed and implemented mitigation strategies to address water quality and quantity issues as storage declined, there were limited instances where units were placed on forced outage due to low lake levels.

ERCOT prepares monthly maps showing the current reservoir storage available in the primary reservoirs from which generating resources withdraw water.[9] Each dot on the map corresponds to a generating site, sized according to the amount of power (MWh) provided to the grid annually, and colored according to the amount of storage currently available in the reservoir. Figure 14 shows the reservoir map from November 2014. At that time, there were a number of generating resources whose water supplies were less than half full. The water supplies at risk were generally located in the central and central-western part of the state, whereas reservoirs in east Texas were close to full at the time.

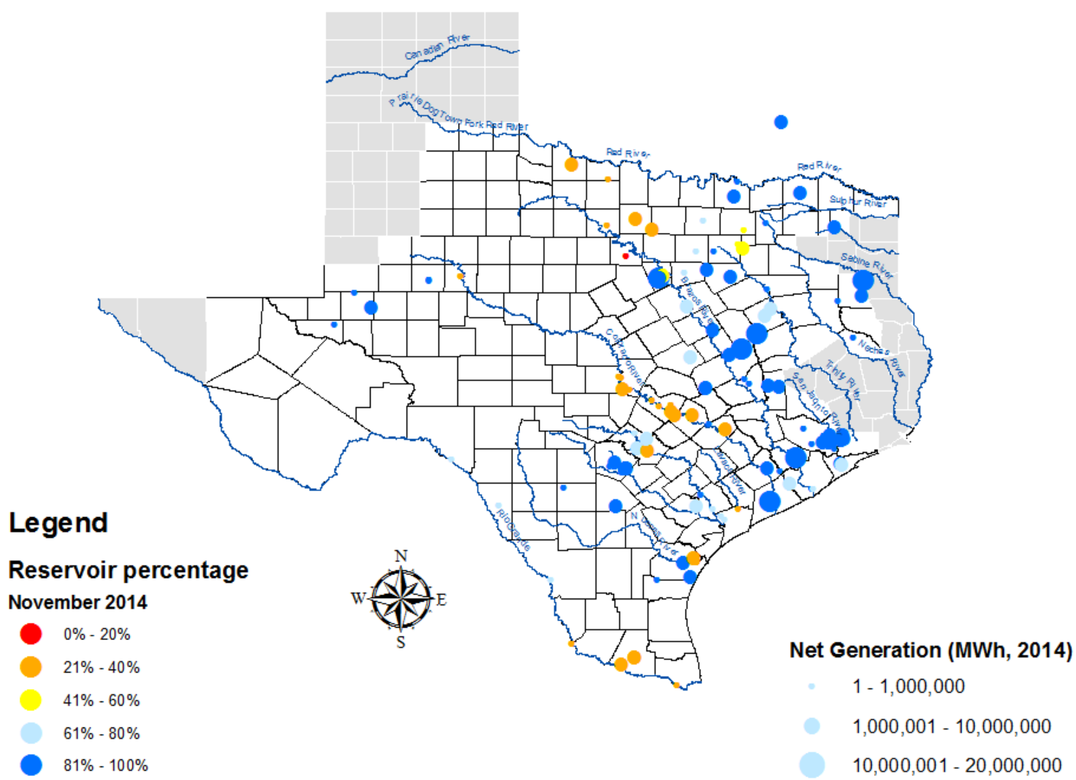


Figure 14: Reservoir Storage in November 2014

In Figure 14, the red dot in North Texas along the Brazos River corresponds to the R.W. Miller generating site. R.W. Miller withdraws its cooling water from Lake Palo Pinto, which in November

[9] Groundwater and ocean water sources are assumed to be at 100% of available storage. ERCOT is considering refining the estimates of groundwater availability in future projects.

2014 was at about 12% of storage capacity. As a result of the low lake levels in Palo Pinto, three gas-fired steam units at R.W. Miller (units G1, G2, and G3, which comprise 403 MW) were put on forced outage in late summer 2014 when storage in Lake Palo Pinto fell below the level of their intake. The units came back online in June 2015, after the rainfall in May 2015 replenished the reservoir.

Though the May and subsequent rains replenished reservoirs and effectively ended the drought, ERCOT predictions suggested that if there had one more year of drought there would have been a much larger number of generating stations under significant stress. These predictions are discussed in greater detail in Section 4.1.

3.4. Other Impacts

In some cases, other issues arose as a byproduct of low lake levels. For example, in Lake Kemp, which provides water supply to Oklaunion, the water quality worsened as lake levels fell, requiring additional treatment before it could be used for cooling by the power plant. Lake Kemp was built for flood control and water supply and is operated with Lake Diversion as a system. The water for Oklaunion is transferred from Kemp to Lake Diversion before being pumped to the generating facility and to agricultural concerns in the region. Lake Kemp has always been too saline to use as a potable water supply without desalination except after large precipitation events. As the water levels declined during the drought, the lake system became more saline and required treatment before use in the power generation facility cooling systems.

In addition, the drought also had implications for the operations of hydro units. By 2014, most hydro units were operating only under emergency conditions, and in some cases derated. This effect can clearly be seen when comparing the total energy provided by hydro units in 2014 to prior years, as shown in Figure 15.

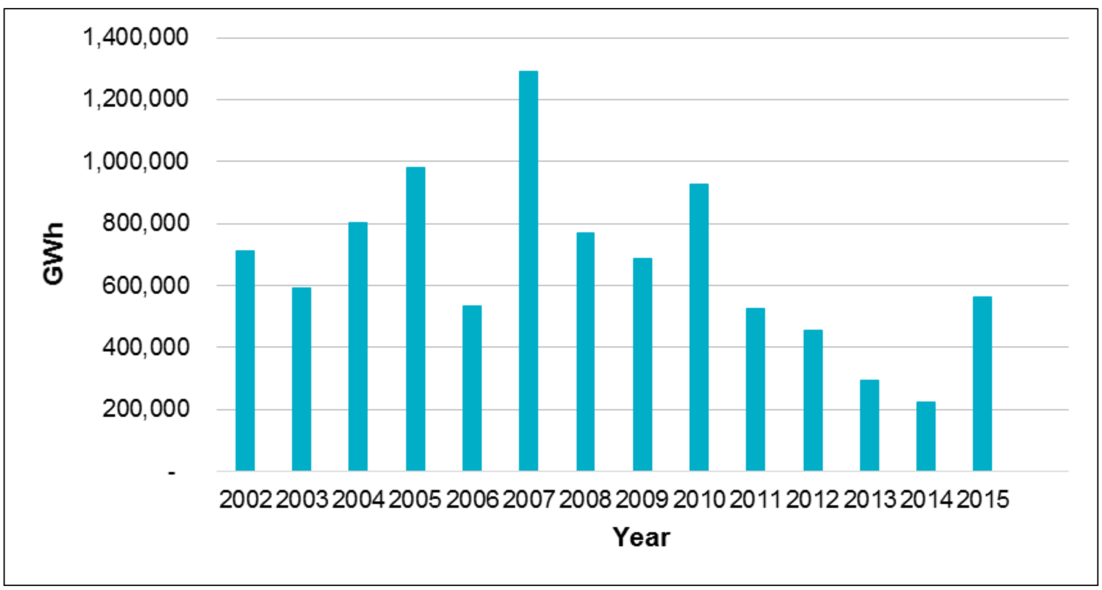


Figure 15: Annual Energy from Hydro Units

Finally, the flooding events of 2015 also impacted the operation of the grid. There were some forced outages on the transmission system due to flooding, and in some cases the heavy rainfall placed reservoirs at risk. One example occurred at the Lewis Creek reservoir in Montgomery County in May of 2015. The heavy rainfall, combined with soil saturation, raised a risk of dam failure. In addition to the potential flooding impacts, the Lewis Creek reservoir provides cooling water to the Lewis Creek power plant operated by Entergy (outside of the ERCOT Region). Had the dam failed, the power plant would no longer have been able to operate. Though this case did not occur in ERCOT, it represents one of the risks to grid reliability associated with heavy rains.

3.5. Planning Impacts

Beyond the immediate operational impacts, the drought also resulted in changes to the planning of operation of existing resources as well as development of new resources. While the storage available in reservoirs generally provides protection against short-term (i.e., single year) droughts, multi-year droughts may affect reservoir storage and require additional mitigation. In response to the drought, owners of existing resources undertook various actions to mitigate against potential impacts of longer-term drought. These included obtaining secondary water sources and developing mitigation plans should water levels decline below at-risk levels in the future. For example, Luminant added a pipeline to deliver additional water from the Sabine River into the Martin Lake reservoir, which provides cooling water for the Martin Lake generating site. As another example, the LCRA in 2012 authorized a project to construct the Lane City Reservoir downstream of the Highland Lakes in Wharton County. The new reservoir will provide an additional 100,000 acre-feet of water and is projected to be completed in 2018.[10]

The drought also impacted how ERCOT assesses proposed generation projects for planning purposes. In 2014, ERCOT implemented a requirement that developers of new resources submit a water attestation form indicating adequate water rights for planned units have been obtained in order for the resources to be included in transmission planning models and resource adequacy assessments. This requirement helps raise the visibility of sufficient water supplies as an important grid reliability planning consideration. Resource developers have also considered water-related issues in the planning of new units with water requirements. For example, a second natural gas combined cycle unit planned at Wolf Hollow Generation Station will use an air cooling system to lower water requirements. In addition, as less water-intensive technologies (e.g., wind and solar) continue to grow in the ERCOT Region, the associated level of grid reliability risks from drought may be mitigated.

Even with the continuing changes to the ERCOT resource mix, it is likely that a significant portion of the ERCOT fleet will continue to rely on water supply sources in the years to come, and the lessons of 2010-2015 can be instructive in how to plan for future drought conditions. The next section will describe some of the tools and protocols ERCOT has adopted to provide early warning and mitigation of these issues.

[10] Lower Colorado River Authority (LCRA). "LCRA pursuing new water supply." Available at http://www.lcra.org/water/water-supply/pages/new-water.aspx.

4. Future Drought Risk Monitoring and Mitigation

During and after the drought of 2010-2015, ERCOT has taken steps to improve its monitoring of drought-related risk to electric supply. Following the summer of 2011, ERCOT surveyed resource owners on their source of water supplies, and, through work completed by Black & Veatch (B&V), used this information to develop a tool to forecast future water availability for electric generation. ERCOT used this tool during the last year of the drought to identify resources nearing at-risk water levels, coordinate with the owners of those resources, and communicate those risks internally. Since the drought ended in mid-2015, ERCOT has developed protocols to ensure monitoring continues and information in the drought risk assessment tool remains up to date, so that ERCOT is able to mitigate potential impacts of future droughts. This section describes ERCOT's drought risk monitoring activities and the protocols ERCOT staff have developed to continue these efforts.

4.1. Drought Risk Monitoring

After the summer of 2011, ERCOT contracted with Black & Veatch (B&V) to develop a tool to help identify generation resources whose water supplies are potentially at risk due to drought conditions. B&V developed a drought risk analysis tool which monitors and forecasts water availability to hydro and thermal generation resources in the ERCOT Region. The tool provides a snapshot of current water supplies, and identifies units at risk of losing water supply within the near- and mid-term planning horizons. ERCOT uses the results of these analyses to identify potential operational impacts and coordinate with affected resource owners.

The drought risk analysis tool provides an early warning of possible drought risks by identifying generation resources potentially at risk of losing their primary source of water supply. To do so, each hydro and thermal generating unit in ERCOT was linked to its primary source of water supply based on responses to a generator survey on water supply. For each implicated water supply, the tool tracks current water availability and forecasts future water availability. For most surface water sources used by generating resources, monitoring data is available from the Texas Water Development Board.[11] To forecast future water availability, historical profiles of water withdrawals (i.e., change in water storage by month) were developed for each relevant reservoir.[12] From the historical information, a prediction of future water storage changes under drought conditions is estimated. This "drought scenario" is then compared to current storage in the reservoir to estimate the number of months before the water supply is likely to become unavailable. Figure 16 provides an example of this calculation. A more detailed explanation of the methodology used in the drought tools is provided in Appendix 3.

[11] For more information, visit http://www.waterdatafortexas.org/reservoirs/statewide.

[12] A different methodology is used for off-channel reservoirs, described in Appendix 3.

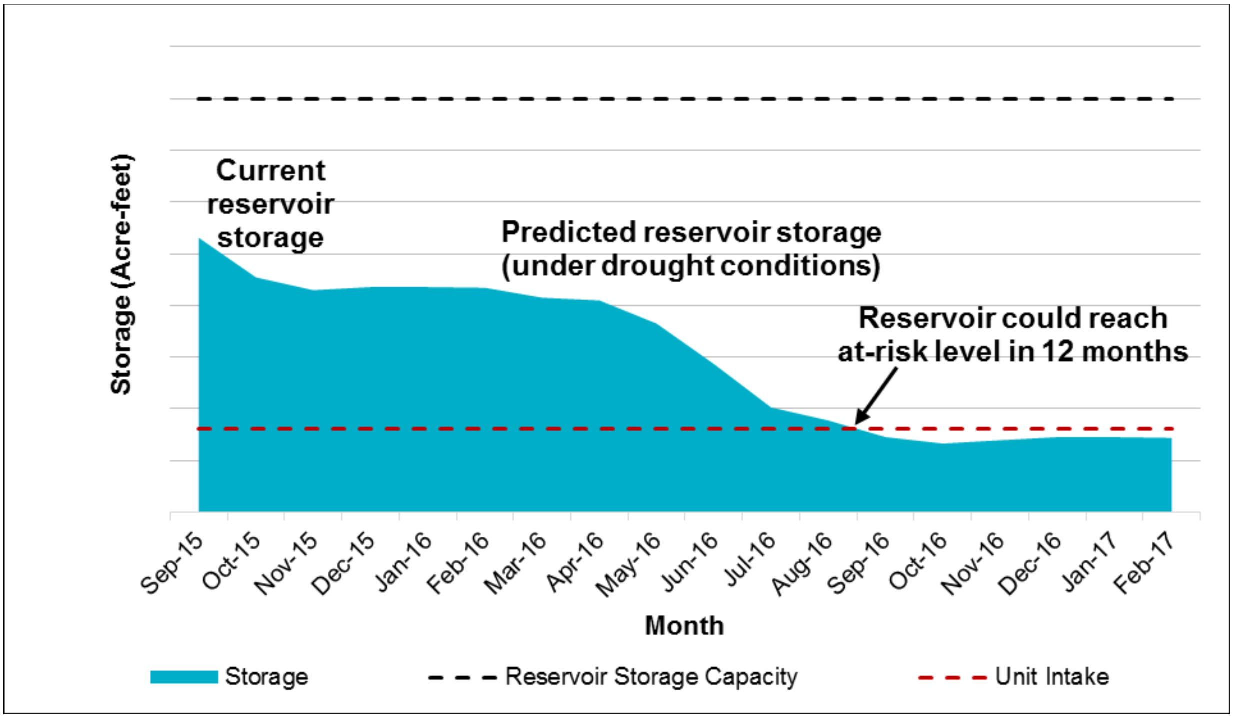


Figure 16. Reservoir Storage Prediction Example

The results of this analysis indicate the number of months before reservoir storage likely becomes insufficient for generating unit operations. The tool reports out both the amount of capacity (MW) and energy (annual MWh) predicted to become at risk within the next 18 months as part of the monthly drought risk analysis. As can be seen in Figure 17 in November 2014, over 11,000 MW of capacity were potentially at risk within the next 18 months, corresponding to over 30 TWh of annual (2014) generation (Figure 18).

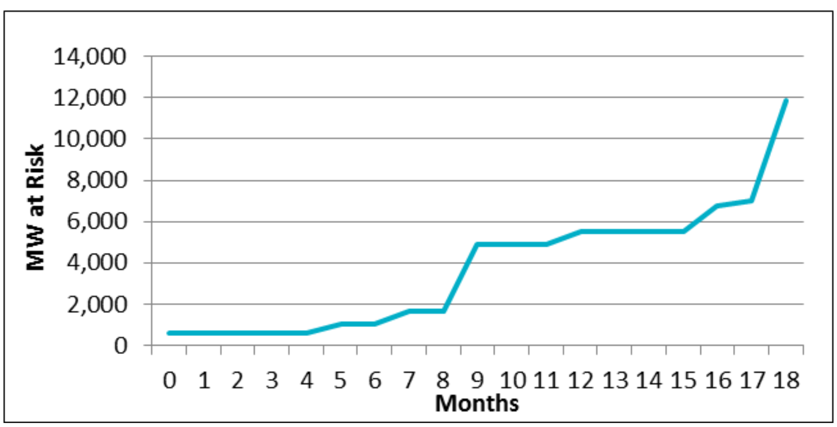


Figure 17. Cumulative Risk for MW Outages over next 18 months (November 2014)

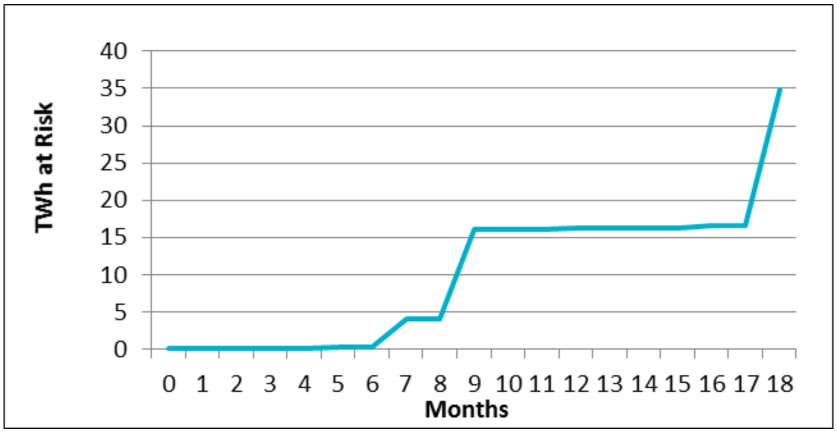


Figure 18. Cumulative Risk for TWh Outages over next 18 months (November 2014)

The MW and MWh hour metrics convey different types of risks associated with generation de-rating and outages due to drought-related issues. The MW at risk metric provides an indication of potential loss of capacity, which is most relevant to implications for resource adequacy, i.e., the ability to serve demand during the peak hours of the year. However, different generation technologies operate at different capacity factors based on their operating characteristics and variable costs, and the loss of the energy (MWh) provided by a nuclear unit, for example, would have much larger implications to the operations of the system compared to a gas steam or combustion turbine unit, which may only operate for a few days of the year – though both would be significant during peak hours of the summer when demand for electricity is typically the highest.

The tool also reports information by generation technology type and by congestion management zone. The geographic location of impacted units provides an initial indication of potential local issues that may arise from the loss of these units. Finally, ERCOT uses this tool to enhance situational awareness regarding resource owners' drought risk mitigation plans.

4.2. Ongoing Drought Monitoring and Mitigation

With the end of the drought in May 2015, ERCOT developed procedures to enhance the monitoring of drought risk and associated risk mitigation activities. ERCOT continues to update its drought risk analysis results monthly, and reports on the results periodically. To ensure information in the drought tool remains up to date, ERCOT developed procedures to routinely survey resource owners on relevant information, including changes to intake levels, water sources, water use, and mitigation plans. Finally, ERCOT staff across several departments will continue to coordinate on these issues through annual drought risk reviews and additional discussions as needed. In addition to the periodic drought risk analysis, staff in ERCOT's Outage Coordination group also monitor the outage scheduler for known drought-related issues and follow up as necessary according to the ERCOT protocols. These procedures help ERCOT to get ahead of any mitigation needs and initiate coordination with higher risk generators at the beginning of elevated overall risk. More information about these procedures is available in Appendix 4.

5. Summary and Lessons Learned

The 2010-2015 drought had impacts on the operation and planning of the electric grid in the ERCOT Region. In addition to short-term impacts experienced due to the record high temperatures and low rainfall in the summer of 2011, generators faced increased risk of outages due to loss of water supply as the drought continued in 2012-2014. The drought ended in May 2015 with record flooding events, which also resulted in some short-term flood-related transmission outages.

Most medium- to large-sized reservoirs have sufficient storage to withstand short-term periods of drought – i.e., one or even two very dry years in a multi-year period. However, multiple years of drought conditions may gradually drain reservoir storage, resulting in risk that may not be reflected by short-term indicators such as the PDI. While the PDI is the most often cited measure of drought severity, and is one of the measures used in the U.S. Drought Monitor designations, it is most appropriate as an indicator of short-term drought risk. The drought of 2011-2014 confirmed that most reservoirs do have sufficient storage to withstand one and even two very dry years in a multi-year period, but that after three or more years reservoirs may begin to reach at-risk storage conditions. Therefore, reservoir levels in the relevant supply reservoirs are the more important metric for identifying long-term drought risk to generation.

As a result of the impacts experienced during this period, ERCOT developed tools and procedures to track drought risk more closely. One of these tools was a drought risk analysis tool, which is described in Section 4.1 and Appendix 3. Development of the tool was very useful during the summer and fall of 2014. The predictions of water supply failures did match the problem locations, so the tool enabled ERCOT to predict outages and therefore focus operational planning attention where needed. The drought finished before any significant generation outages happened, but the predictions suggested that if there had been one more year of drought there would have been a much larger number of generating stations under significant stress.

Almost three quarters of the current installed capacity in the ERCOT Region utilize generation technologies that require significant amounts of water. Should their sources of water supply become impacted or otherwise unavailable due to drought, it could have implications for the reliability of the ERCOT grid. The drought of 2010-2015 provided some important lessons on how drought conditions can affect generation resources, including the regional and local variations in impacts, different risks associated with short and long term drought, and need for monitoring of reservoir supplies so that potential issues can be managed proactively. ERCOT will continue to monitor drought conditions to identify mitigation needs in advance of issues that could threaten the ability to maintain the reliability of the grid.

Appendices

Appendix 1. ERCOT Drought Risk Analysis Report

See attachment.

Appendix 2. Reservoir Prediction Example Spreadsheet

See attachment.

Appendix 3. Description of Water Supply Prediction Methodology

This appendix describes in greater detail the methodology used to predict future reservoir storage in ERCOT's drought risk prediction tool, which was developed as an Excel workbook. As part of this report, ERCOT has also developed a sample spreadsheet that demonstrates the prediction methodology for a generic reservoir, available in Appendix 2 of this report. The tool was developed for ERCOT by B&V during 2013-2014. The purpose of the tool is to provide both six- and 18-month advanced notice of those generation resources that are at risk of reaching low reservoir supply levels.

Background

In developing the tool, B&V initially considered several factors contributing to drought risk for power generation: generation type and cooling method, generation size, rainfall and runoff, reservoir storage volume, additional supply sources, water temperature, historical water usage, and level of intake or at-risk water level. However, after initial review B&V determined that the greatest risk of failure due to drought is directly related to the water storage in each of the relevant cooling water storage systems. Therefore, the tool uses information about total reservoir storage, at-risk levels (i.e., level of intake), and a prediction of future storage changes to estimate the time to failure for a given reservoir. ERCOT is considering future work to add additional prediction capabilities to the tool and consider additional risk factors, such as temperature and precipitation forecasts.

The tool considers each reservoir that has a connection to an operating generation facility that uses water in any part of its operation.[13] As noted in Section 4.1, ERCOT linked each hydro and thermal generating unit to its primary source of water supply based on responses to a generator survey on water supply, as well as additional research where necessary.

The reservoirs providing water supply to power generation generally fall into two categories: reservoirs fed by drainage basins (drainage-fed reservoirs) and reservoirs fed from rivers or other reservoirs (off-channel reservoirs). For drainage-fed reservoirs, the tool predicts future storage based on an analysis of historical changes in reservoir storage. For off-channel reservoirs, the tool predicts future storage based on evaporation and generator water usage calculations. The reason for the two different methodologies is due to the different design of the two types of reservoirs, as will be described below.

Drainage-fed Reservoirs

These types of reservoirs are fed from runoff from drainage basins. Current and historical reservoir water levels are available for most of these reservoirs from the Texas Water Development Board (TWDB) website[14] or other sources (e.g., U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE)). The available information is stored (in terms of elevation (ft)) in the spreadsheet in the box entitled "Historical Data" (Column Y). The current reservoir level is updated on a monthly basis, to enable up-to-date predictions.

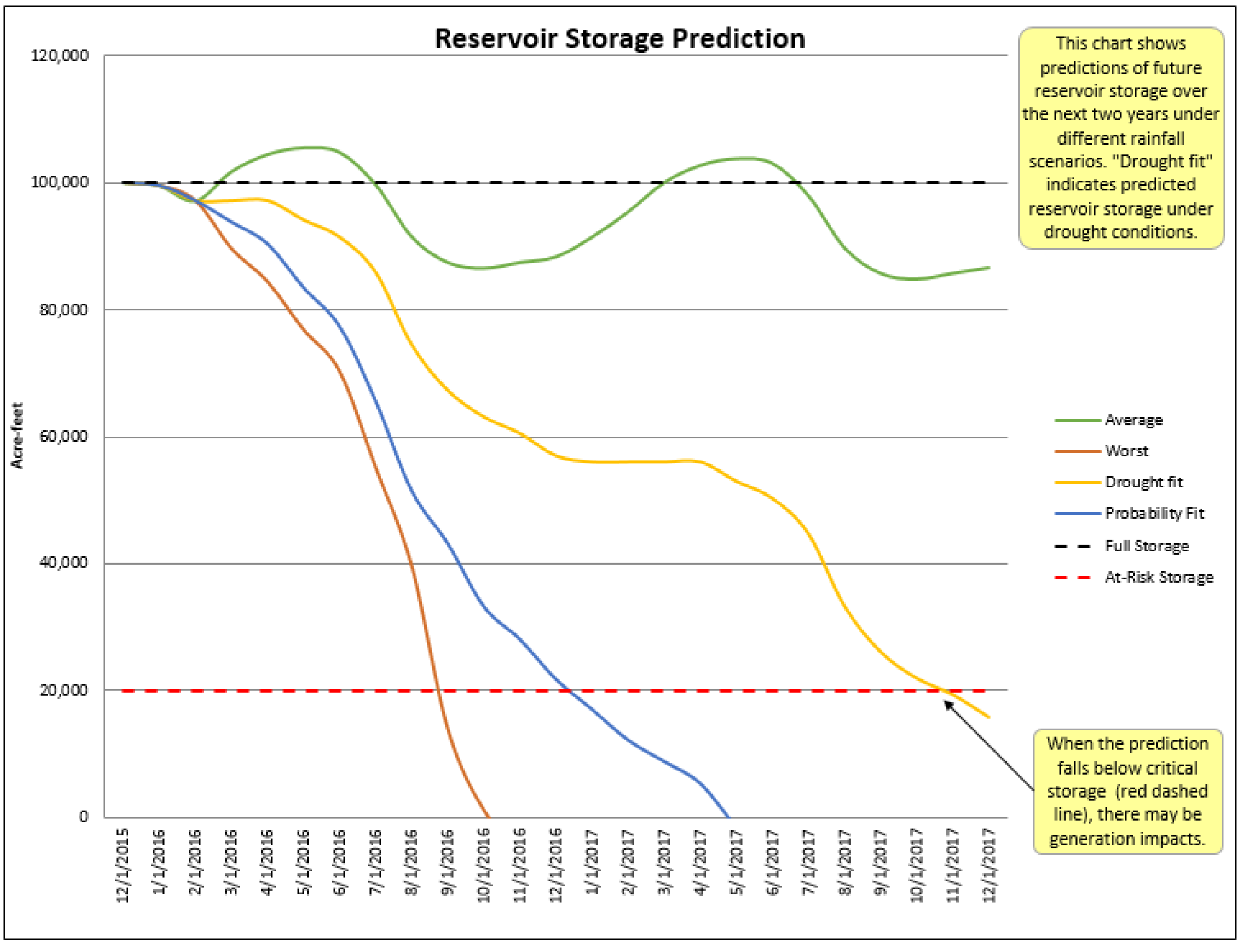
Elevation-volume curves are available for most reservoirs from the TWDB or USGS. These curves link water levels (feet) to storage volume (acre-feet). The elevation-volume curve is stored in columns BS and BT. The tool uses this information to compute the storage volume associated with the historical elevation data (column Z, and the chart entitled "Historical Storage"), and the month to month change in storage volume (column AA). The table entitled "Historical Monthly Changes in

[13] At this time the drought risk prediction tool is limited to surface water sources. ERCOT is considering refining the estimates of groundwater availability in future projects.
[14] For more information, visit http://www.waterdatafortexas.org/.

Storage" (Columns BA to BP) shows the monthly changes in storage. All the data is then analyzed to enable percentiles of the data to be developed (Columns AR to AX).

A "Drought Fit" prediction is used to simulate the storage changes in times of drought, and is developed in the table entitled "Monthly Changes in Storage – Statistics" (cells AR18 to AY31). For most of the reservoirs that are fed by natural drainage, the level of the 30th percentile is used as the guide for developing the monthly usage. In some cases, modifications to the 30th percentile are necessary. For example, some systems that have large releases for agricultural or flood control reasons that would be very unlikely under drought conditions. If these were included in the calculations they would skew many of the results. Any deviations from the use of the 30% percentile are described in the table below entitled "Explanation of Drought Fit."

Once the drought fit is calculated, the associated storage change is then removed from the current reservoir level, in the table entitled "Reservoir Storage Predictions" (Columns AC to AL). These predictions are shown in the "Reservoir Storage Prediction" chart (Columns B to P and shown in Figure 19). The worst case (minimum value), drought fit (30th percentile or other value) and average (50th percentile) are shown on the reservoir prediction graph to enable an understanding of risk levels across different scenarios.



Note: The "Probability Fit" is a user-selected value that allows users to view predictions based on different percentiles of the historical data. The percentile shown in the chart is based on the 50th percentile of data.

Figure 19: Reservoir Storage Prediction Example

Off-Channel Reservoirs

Off-channel reservoirs are generally kept at close to full storage and fed by a secondary water source.[15] Since reservoir level data for these reservoirs is driven by the man-made inputs (of which volume data are generally not available) a different risk model is necessary. Instead of basing predictions on historical data, water losses from evaporation and usage by the generation resource are calculated under the assumption that there is no inflow to the reservoir and no transfers from other sites are available, representing a worst-case scenario.

Current and historical reservoir levels are available for a few off-channel reservoirs, but most do not have this information available publicly. Therefore, the “Estimated Storage” table (Columns W to AA) estimates storage under the assumption that the reservoir is generally kept at or close to full levels. ERCOT surveys the owners of generation resources that use off-channel reservoirs, as per the procedures outlined in Appendix 4, to validate this assumption.

Similarly, elevation-volume curves are generally unavailable for these types of reservoirs. Instead, a storage profile is created based on known information about the depth, elevation, and total storage of the reservoir (Columns BB to BE).

Instead of percentiles based on historical information, the “Drought Fit” (Columns AI to AR) is calculated based estimated storage losses from evaporation from the lake and consumption by the generation resource. The reservoir evaporation was calculated using a pan evaporation average for the area where the reservoir is situated (there were three locations used – West Texas, East Texas and I-35 Corridor).[16] The area chosen provided a monthly evaporation constant in inches which was used to calculate a reduction in the reservoir level. The amount of water consumed by the generation resource was added to this calculation and is estimated by multiplying the unit’s annual generation (apportioned on a monthly basis) by an assumed water consumption amount (gal/MWh). The water consumption per MWh assumption varies depending on the generation type and cooling system type.

As with drainage-fed reservoirs, these storage changes are subtracted from the assumed full condition in columns AC through AG, and the results are shown in the chart entitled “Reservoir Prediction” in columns B to P.

At-Risk Reservoir Levels

The level at which a reservoir becomes at risk can vary between reservoirs and generation units. An intake structure may be near the top level of the lake, or it may be very close to the base. By default, the tool assumes at-risk levels at 20% of total storage for drainage-fed reservoirs and 50% of total storage for off-channel reservoirs (see table entitled “Reservoir Details” in columns Q to T). The values are set at different default levels due to the different modes of operation for the two types of reservoirs. In addition, information reported to ERCOT on the generator surveys was used as a way to check these assumptions, and in some cases they were modified to reflect generator-specific conditions.

Prediction of Months Until At Risk

For both drainage-fed and off-channel reservoirs, predictions of the number of months to at risk (the number of months before the water levels become at risk in that specific reservoir) are made. This is

[15] ERCOT is considering refining the linkages between off-channel reservoirs and their secondary water sources in future work.

[16] Evaporation estimates were adapted from the U.S. Geological Survey report: Harwell, G.R. *Estimation of Evaporation from Open Water – A Review of Selected Studies, Summary of U.S. Army Corps of Engineers Data Collection and Methods, and Evaluation of Two Methods for Estimation of Evaporation from Five Reservoirs in Texas, 2012*. Available at http://pubs.usgs.gov/sir/2012/5202/pdf/sir2012-5202.pdf.

done in the table entitled “Risk” (Columns Q to T and Figure 20). Each reservoir is included in the monthly drought risk report (see Appendix 1), and the total amount of capacity and annual energy associated with reservoirs potentially at risk within 6 and 18 months is reported (see Figure 17, Figure 18, and Appendix 1).

Risk	Average	Worst	Drought Fit
Months to Empty	45	8	29
Months to At Risk	45	6	20

Figure 20: Risk Table Example

Appendix 4. ERCOT Drought Risk Reporting Protocols

ERCOT has developed the following protocols to correlate the frequency of drought reporting activities to the level of risk. The protocols will ensure that measures are in place to resume more frequent reporting and implement mitigation should drought conditions return to Texas. The protocols will tie the frequency of drought reporting activities to the level of drought risk, ensure the drought risk prediction tool is kept up to date through periodic surveys, and institute annual reviews to anticipate risks.

1. Frequency of Drought Reporting

ERCOT staff will continue to update the drought risk analysis results monthly, but will issue reports based on current drought conditions and water supply projections, according to the following criteria:

- **Monthly reporting**, to be conducted when at least one unit is potentially at risk within 6 months.
- **Quarterly reporting**, to be conducted when at least one unit is potentially at risk within 18 months, or when meteorological forecasts indicate the likely development of drought conditions.
- **Biannual reporting (spring and fall)**, to be conducted during long-term wet periods – i.e., Texas is drought free and no generators are identified to be at risk within 18 months.

2. Generator Surveys

Even during periods of long-term low risk, it is necessary to keep the information in the drought risk prediction tool up to date so that it can be used when drought conditions arise. To this end, ERCOT will survey resource owners every three years in normal to wet conditions and every year within a drought cycle. The survey questions will include: changes to intake levels, water sources, water use, and mitigation plans (mitigation plans during drought cycle only).

3. Annual Reviews

To ensure the level of drought reporting is appropriate to current conditions, ERCOT will institute discussion points to evaluate the current level of risk and ensure that mitigation can be initiated in advance of actual issues. Resource Adequacy staff will organize annual reviews**,** in collaboration with ERCOT's meteorologist and the ERCOT Operations Planning group, to forecast drought conditions for the year ahead and estimate the risk of problems in the coming year. This information will be used to determine the frequency of reporting (see #1 above) required for the upcoming year. ERCOT staff will also hold discussions at the relevant reporting points with Operations Planning to get ahead of any mitigation needs in advance of actual issues and initiate coordination with higher risk generators at the beginning of elevated overall risk. The outcome of these annual risk reviews will also be communicated in a summary fashion to the North American Electric Reliability Corporation for use in its short and long term reliability assessment reports.