The Implications of Drought and Heat Wave on the Electricity Supply of Texas

Margaret Cook

CE 394K GIS in Water Resources

Fall 2012

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Introduction

The recent drought in Texas revealed the vulnerability of curtailment for some power plants due to the increased heat of cooling water supplies. Assessing the risk of reduced operations at thermoelectric power plants associated with thermal discharge limits and the potential for cooperation between power plants can increase the resiliency of the electricity grid in Texas and aid future planning without damaging the natural environment of the cooling reservoirs. This evaluation compares the observed and predicted effluent discharge water temperatures from thermoelectric power plants in the Electric Reliability Council of Texas (ERCOT) interconnection with Environmental Protection Agency (EPA) discharge temperature limits to determine the amount of electricity generation possible in the next twenty years.

Raster calculations done in ArcGIS helped characterize the vulnerability of certain areas of Texas to drought due to changes in temperature, dew point, and wind speed. Maps created in ArcGIS show the effects of drought on electricity generation levels.

This evaluation takes into account the large water users in the electric grid of Texas, as they will be most vulnerable to changes in water availability and temperature in the future. The largest water users utilize open-loop and recirculating cooling pond systems. These plants are known as OC (open-loop, cooling pond), OF (open-loop, fresh water), OS (open-loop, saline water), and RC (recirculating, cooling pond). Because of limited data availability, only 21 of the power plants using open-loop and recirculating cooling were evaluated in this study. The evaluation is also restricted to the Texas portion of HUC-2 Region 12, the Gulf Region, because of limited availability of data. The Texas Natural Resources Information System of the Texas Water Development Board provided boundaries for the state of Texas and the Gulf Region.

Background: EPA Temperature Limits

The EPA sets thermal limits on thermoelectric power plants to control the heated wastewater, or thermal pollution, discharged into cooling ponds, reservoirs, or rivers. Existing data show that at least two major power plants representing a significant quantity of generation capacity have operated at or near these temperature limits in the past. Predicted warming from heat waves, droughts, or climate change might increase ambient air temperature (one of the primary factors affecting effluent temperature) causing increased reductions in electricity generation in the future.

Data sources

To analyze the risk of power plant curtailment due to high effluent discharge temperatures, a linear regression model was created for each power plant in the ERCOT market that had reported discharge temperatures. The results of this model were then mapped using ArcGIS to add geographical relevance to the data. Many data sources helped in the development of the model and in mapping the results. The following section outlines the datasets used in this analysis. The section also gives the sources and format for each dataset.

Boundaries: State, County, and Hydraulic Units

The TWDB TNRIS website offers many useful shapefiles. One map includes the hydraulic units in Texas; another map includes the boundary of Texas and all of its counties. Since this assessment uses HUC-2 and HUC-8 polygons in Texas, these data served as the layers to which other data joined for mapping. County boundaries give reference to the location of power plants. Figure 1 shows the HUC-8s without any other data layers. The other maps use this layer or the counties of Texas as their background.

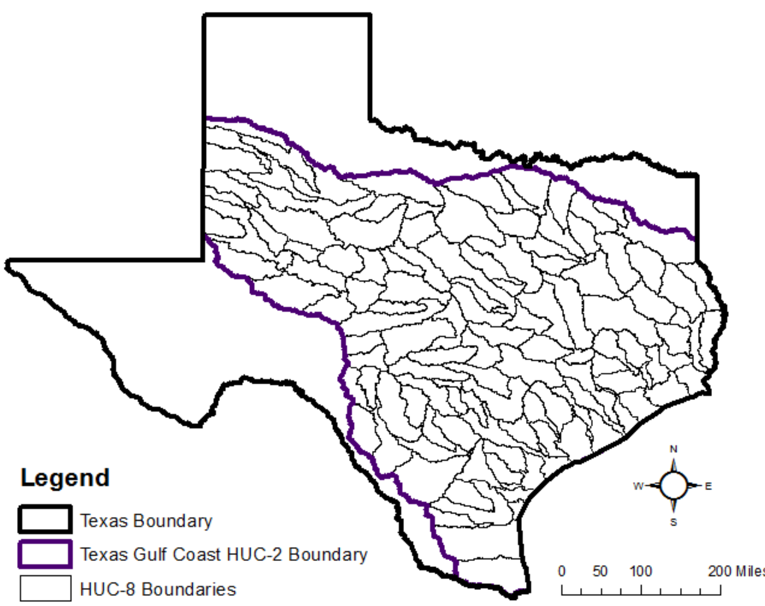

Figure 1 The plot indicates HUC-8s of the Gulf Region that reside within Texas. Since the HUC-8s have spacial references, any data given by HUC-8s can be joined to this map for display.

Power Plant Specific Activity: Yearly Electricity Generation, Water Withdrawal, and Water Consumption

Due to the variance in electricity generation, water withdrawal, and water consumption across the electricity grid in Texas, the characteristics for each power plant needed evaluation. Researchers at the University of Texas at Austin created an excel database containing this information as well as other power plant specific characteristics, from which these data were obtained.

A map was created using the yearly electricity generation, water withdrawal, and water consumption data for the power plants in the Texas portion of the Gulf Region that utilize open-loop and recirculating cooling . This step required creating a shapefile from the power plant specific data. Characterizing the yearly electricity generation of each power plant using symbology shows each plants importance to the ERCOT electricity supply, as shown in Figure 2. Appendix B holds maps showing each power plant's dependence upon water for withdrawal or consumption, maps not used in this analysis, but relevant to any discussion on the implications of drought on power plants.

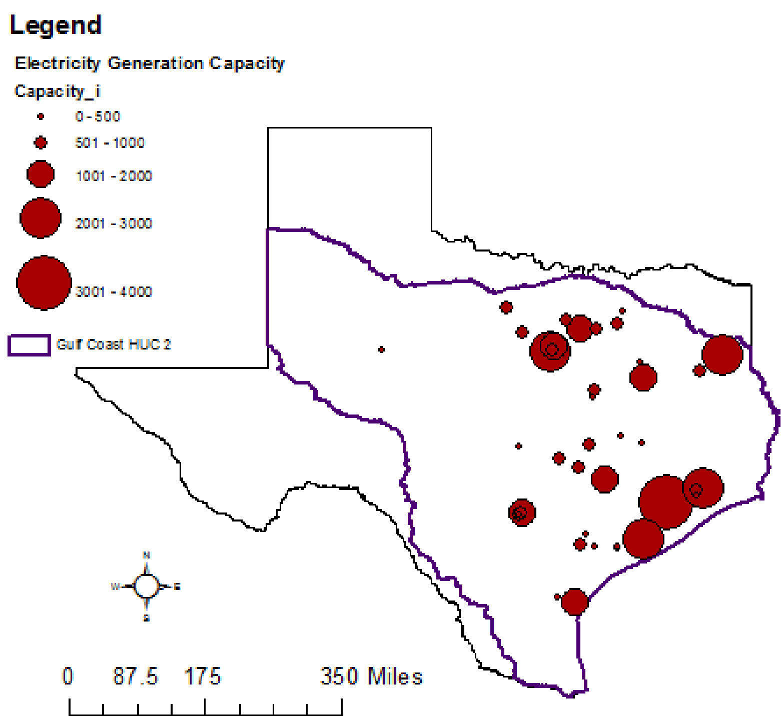

Figure 2 The plot indicates the yearly electricity generation capacity in 2011 of power plants in ERCOT that utilize open-loop or recirculating cooling technologies and reside within the Gulf Region. The symbolized data show that many plants generate small amounts of electricity while a few have very large generating capacities. The plants with largest generating capacities reside near Houston and Dallas-Fort Worth, the largest population centers of Texas.

Past and Future Climate Data

Pacific Northwest National Laboratory and Argonne National Laboratory provided climate information (air temperature, wind speed, wet bulb temperature) for each HUC-8 subbasin in the Gulf Coast Region in excel spreadsheets. The data were displayed through a join to the HUC-8, as shown in Figure 3. The graphs created in GIS showed that in the future, certain areas of Texas will have higher temperatures than other areas of the state. Through ArcGIS, these maps, displayed here as features were converted to rasters.

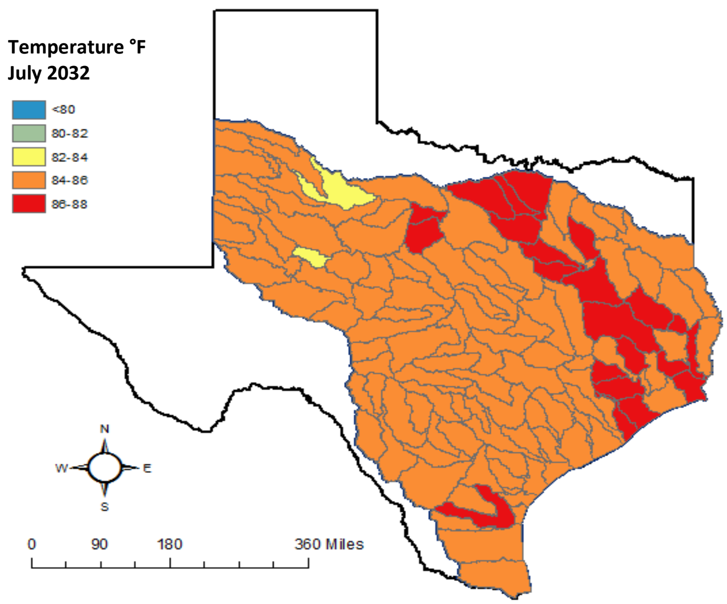

Figure 3 The plot indicates the predicted average monthly temperature for each HUC-8 in July 2032. The map shows a strip of higher temperatures in the northeastern part of Texas, forming a trail between the Houston and Dallas where many power plants reside.

Data from Historical Regression Analysis

To analyze the risk of power plant curtailment due to high effluent discharge temperatures, linear multiple regression models were created for each power plant in the ERCOT market that had reported discharge temperatures and utilized open loop and recirculating cooling pond systems. The linear regressions estimated the temperature of cooling water effluent discharge temperatures using historical monthly climate data and calculations of monthly heat dissipated in generating electricity. The model utilized the climate information provided by PNNL and Argonne and information about monthly power generation and heat dissipation from each power plant obtained from Form 923 and Form 860 created by the Energy Information Administration (EIA). The models were calibrated via comparison to the measured monthly effluent temperatures made publicly available through the Enforcement and Compliance History Online (ECHO) database of the

Environmental Protection Agency (EPA). The regressions focus on estimating summer effluent discharge temperatures since the summer heat creates the highest potential for thermal pollution levels to reach the permitted limits.

Data Analysis

Future Climate Risk in the Gulf Coast Region

Because power plants need a significant amount of water for cooling, one of the primary vulnerabilities for a power plant in drought is the temperature of the water. Because data on historical lake temperature were unavailable, this analysis on the risk of drought uses climate parameters as a proxy for the temperature of the water. The temperature of the air surrounding water, the moisture in the air, and the amount of wind around the water available to evaporate hot water all affect the temperature in the water. Thus, the model combines air temperature, dew point, and wind speed to determine risk to drought.

The climate data for each HUC-8 in the Gulf Coast Region of Texas for 2027-2032 were joined to existing HUC-8 maps as features and then converted to rasters using the feature to raster tool in ArcGIS. Using the raster calculator tool in ArcGIS, each of the three sets of rasters now containing temperature, dew point, and wind speed information were then combined. The calculations employed the average regression coefficients determined in the historical regression analysis for power plants.

$$Raster\ Calculation = 0.12 \times (R_{DP}) + 0.62 \times (R_T) - 1.48 \times (R_W) + 24$$

Where,

R_{DP} = Raster created from Dew Point profile

R_T = Raster created from the Temperature profile

R_W = Raster created from the Wind Speed profile

The resulting raster captures the effects climate parameters have on effluent temperature. It also shows a profile of future risk to electricity generation for power plants due to drought in the Gulf Coast Region. Due to the vulnerability to drought, as shown in Figure 4, many power plants currently contributing a significant amount of electricity to the grid could be at risk to suffer curtailments. A regression analysis was then conducted to quantify the effects to electricity generation.

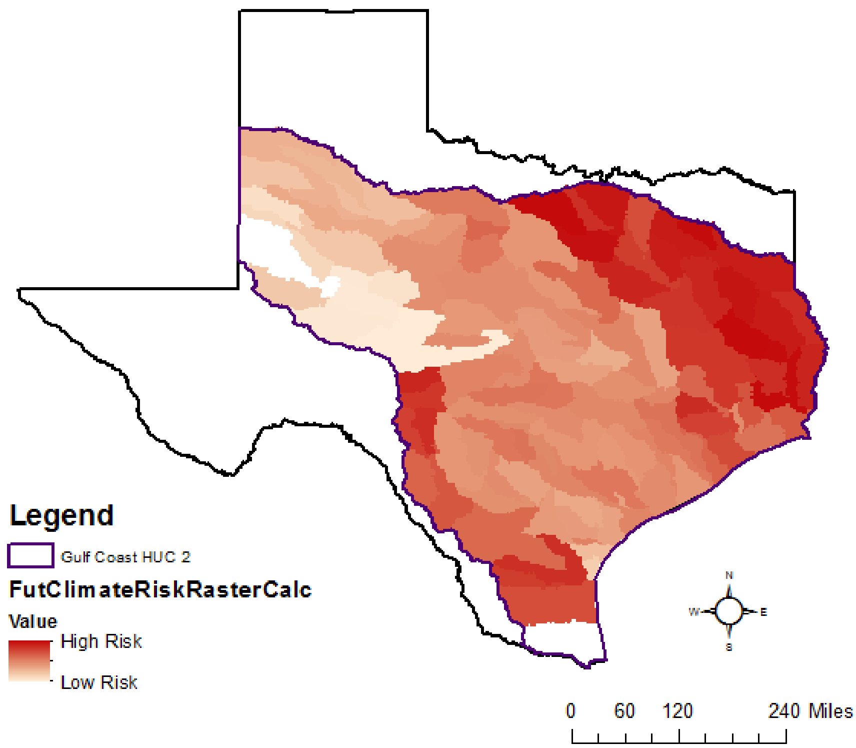

Figure 4 The plot indicates the risk to power plant operations via the effect on effluent temperature cause by air temperature, wind speed, and dew point.

Regression Analysis

Future effluent temperatures were modeled using the regression equation for each power plant and the climate simulations for 2027-2032. The predicted effluent temperatures as compared to the thermal limits determined whether a power plant might need to curtail its electricity generation in summer months given an assumed amount of future monthly electricity generation. Figure 5 shows examples of the various scenarios modeled: (i) 2011 generation levels, (ii) the maximum amount of electricity generation allowable without breaching the EPA thermal discharge limit, and (iii) full electricity generation capacity of the plant. Figure 5 (a) shows an example of the effluent temperatures that would result from increasing the power plant generation to 100% capacity factor during the summer. In some years, the effluent temperature breaches the maximum effluent temperature limit. Figure 5 (b) shows an example of the effluent temperatures that result from increasing electricity generation to meet the limit on effluent temperature. The estimated increases in electricity associated with the increases in effluent temperature slows for characterization of the electricity generating capacities for each of the 21 power plants evaluated under the three different scenarios: (i) 2011 generation levels, (ii) the maximum amount of electricity generation allowable without breaching the EPA thermal discharge limit, and (iii) full electricity generation capacity of the plant.

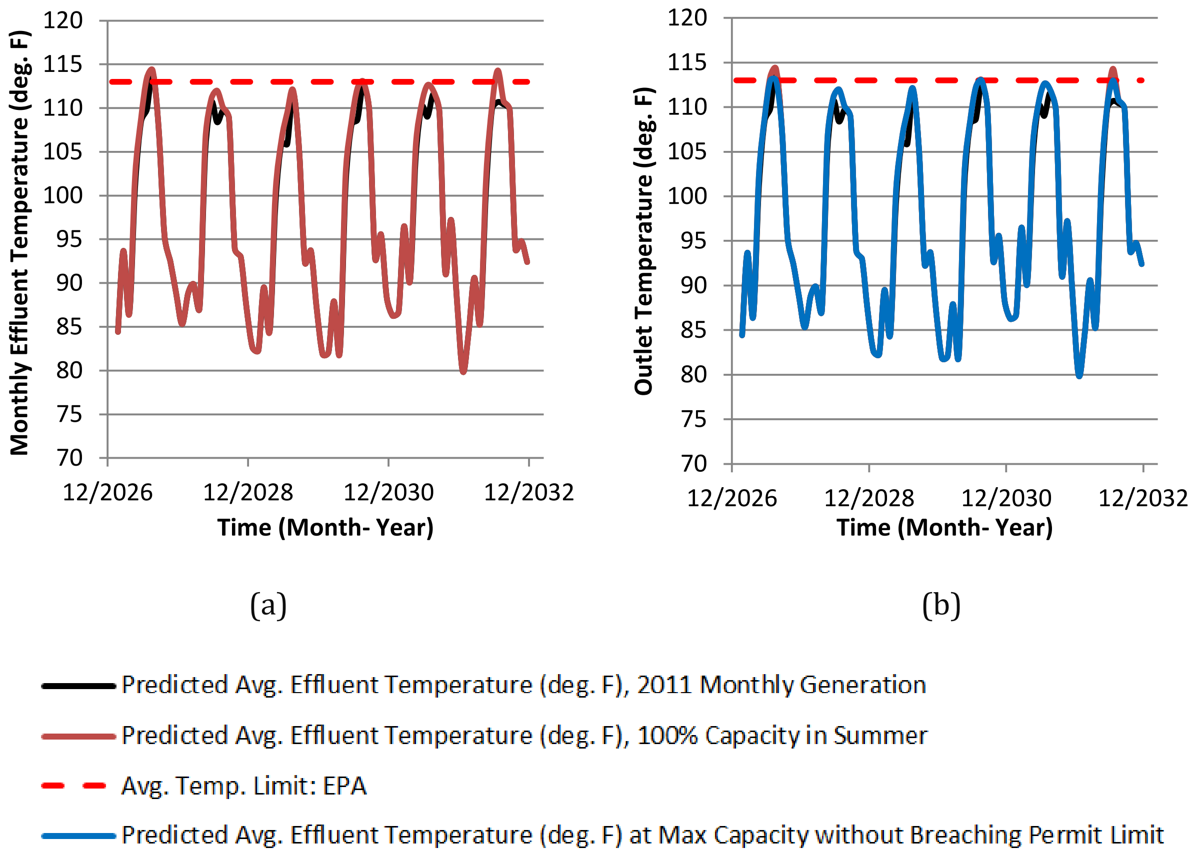

Figure 5 The plots indicate the three modeled scenarios: (i) 2011 generation levels, (ii) the maximum amount of electricity generation allowable without breaching the EPA thermal discharge limit, and (iii) full electricity generation capacity of the plant.

Results and Discussion

The modeled effluent temperatures were then used to determine the amount of electricity generation possible in the future, including whether a plant would be able to generate more or less electricity than it did in 2011. If each power plant attempted to operate at scenario (i) levels, the monthly generation levels seen in 2011, while experiencing the future climate of 2027-2032, an estimated 6 power plants would experience some degree of reduction in electricity generation due to thermal discharge limits or conversely would be discharging thermal pollution. The power plants might need to curtail 25,000-210,000 MWh/month in the summer months (May – August) of 2027-2032 if they attempted to operate at 2011 monthly generation. Figure 6 shows a direct comparison between two electricity generation scenarios in the past and in the future. The map also shows that less electricity generation is possible at certain power plants in 2031 because of curtailments in generation due to temperature limits.

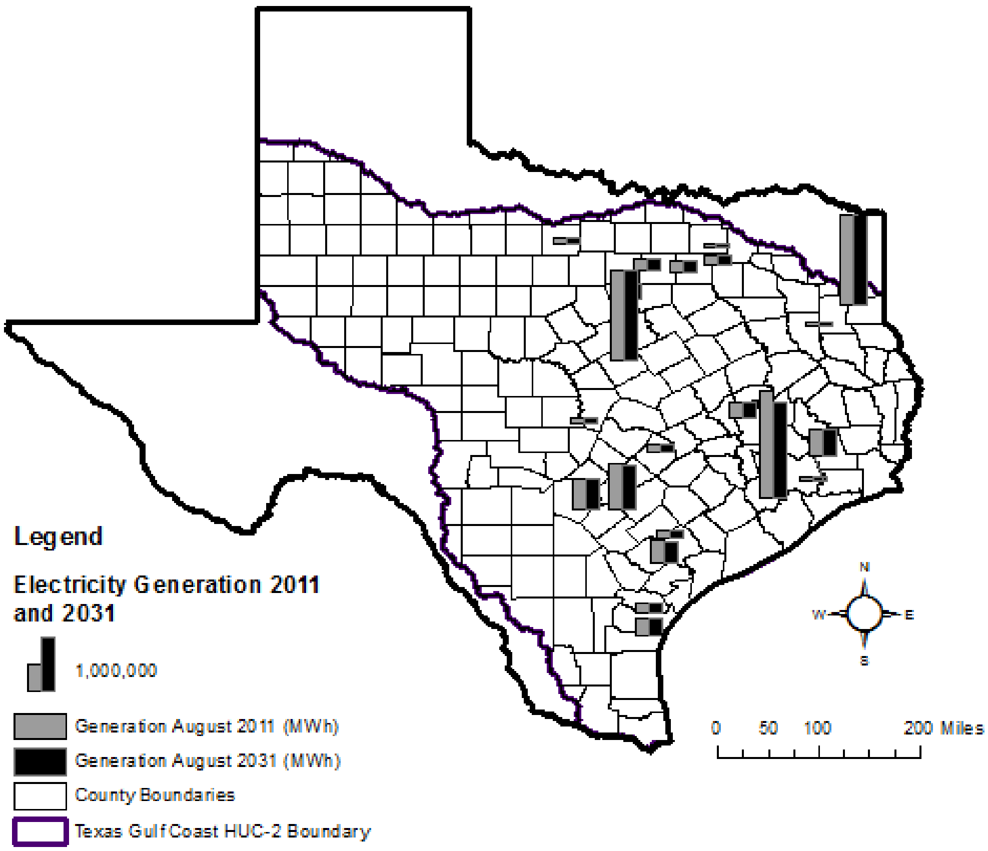

Figure 6 The plot indicates the electricity generation that occurred at select OC, OF, OS, or RC plants in August of 2011 (in gray) and the electricity generation that could occur at each plant assuming 2011 electricity generation levels in August of 2031 (in black). One major power plant will not be able to generate as much electricity in 2031 as it did in 2011.

While increased heat waves and drought could expose some power plants to thermal effluent-related curtailment, an estimated six times as much electricity generation is potentially available from other existing generators. These generators can meet electricity demand without any power plants reaching thermal effluent temperature limits, thereby maintaining grid electricity by offsetting the curtailment of other power plants. Figure 9 shows the areas of estimated electricity generation curtailment under the future climate scenarios and the areas of potential increases in electricity generation. Considering additional electricity generation potential *up to effluent temperature limits*, as evaluated in scenario (iii), existing power plants could generate an estimated 6,400,000-6,800,000 MWh/month more electricity in the summer of 2027-2032 than they could generate in the summer of 2011 without breaching temperature limits.

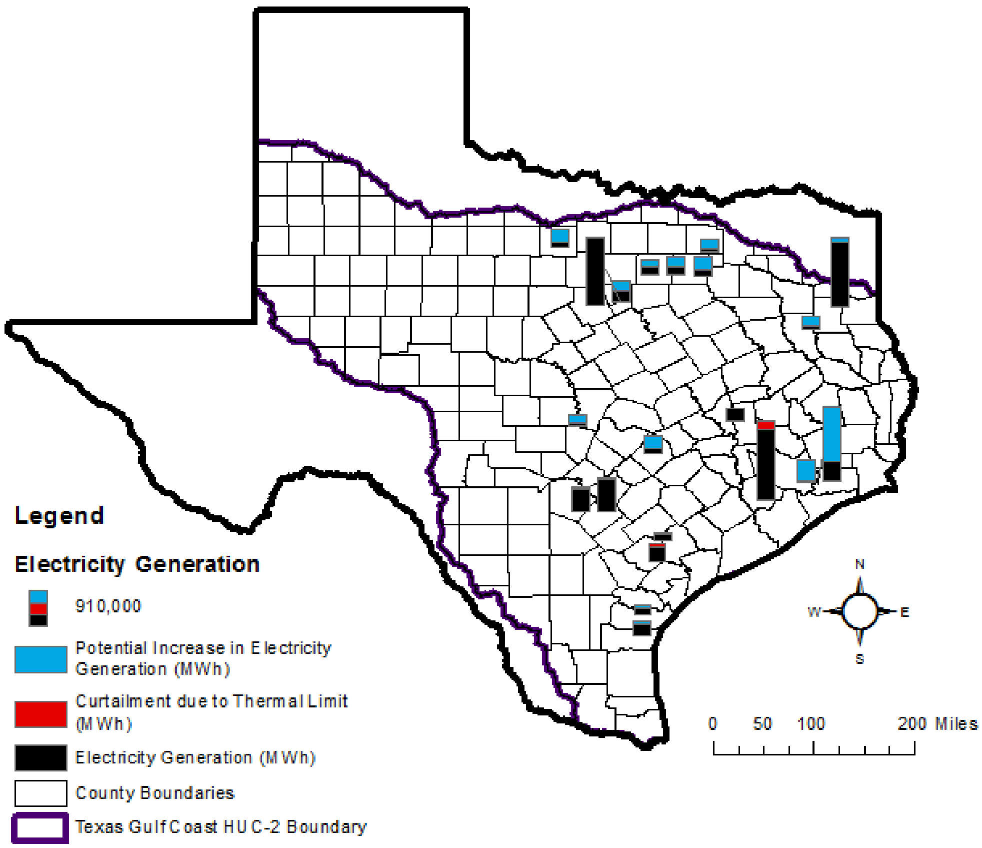

Figure 7 The plot indicates the electricity generation possible at select OC, OF, OS, or RC plants assuming 2011 electricity generation levels, the electricity generation curtailed due to thermal limits, and the potential increase in electricity generation without breaching thermal limits.

If, due to increases in demand for electricity, power plants wanted to operate at scenario (iii) levels, full capacity in the summer (May – August) of 2027-2032, up to 13 power plants could experience reductions in electricity generation due to thermal discharge limits. The 13 power plants would experience a combined loss of 1,000,000-1,400,000 MWh/month from their full capacity between 2027 and 2032. One MW can power 200 homes in peak demand periods. Figure 10 shows the potential electricity generation possible if power plants generate at 100% capacity in the summer of 2027-2032 and the amount of electricity generation that might be curtailed due to effluent temperature limits.

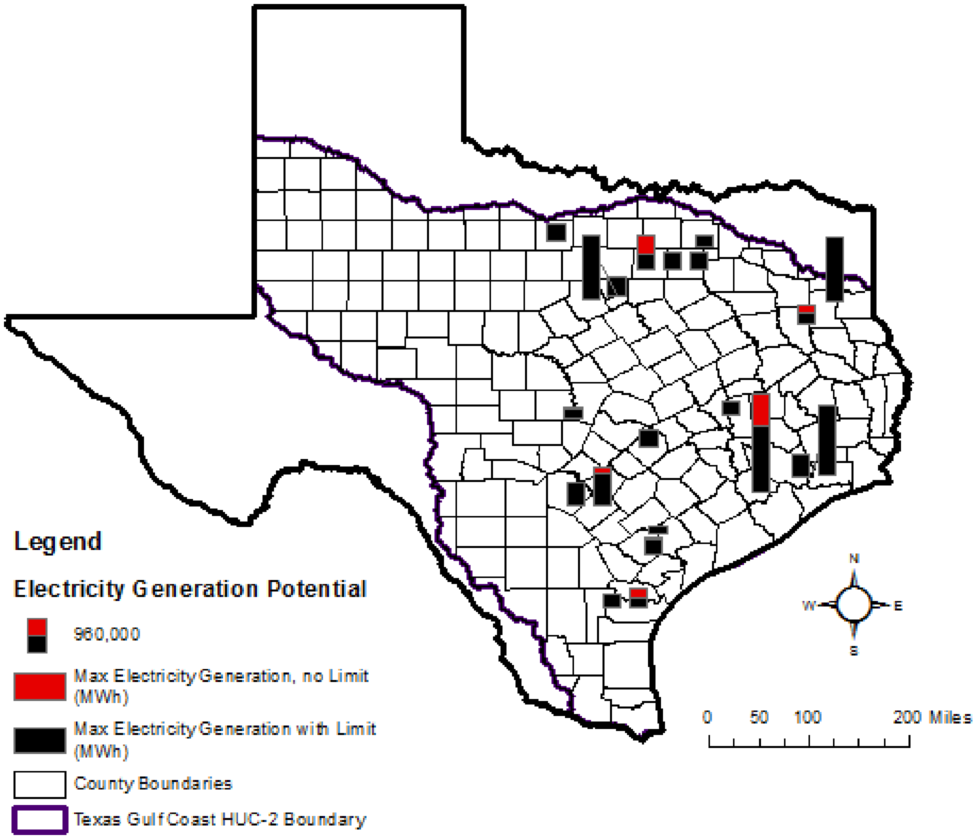

Figure 8 The plot indicates the maximum allowable electricity generation at select OC, OF, OS, or RC plants without breaching the EPA temperature limits and the electricity generation curtailed due to thermal limits at 100% capacity of the plant.

Conclusions

In mapping the modeled data, one can easily see the locations of electricity generation curtailments and potential increases. Similarly, one can find the locations of curtailments in the event that all plants much generate at capacity. The situations could help in planning by showing the areas of the state most vulnerable to electricity supply issues. Assuming the electricity demand in the future remains at 2011 levels, other plants with large potential to increase their electricity generation can help supply the vacancies created by shortages at other plants, as shown in Figure 9. Assuming that electricity demand will increase in the future due to projected population and industrial increases, other power plants might not be able to meet the excess demand created by supply shortages. ERCOT will need to improve the water availability for its existing electricity generators or develop new sources of electricity.

To prevent thermal pollution while also preserving the resiliency of the electricity grid in Texas, implications of drought and heat waves should be reconciled. Estimating the future effluent temperature and the maximum allowable electricity generation could help resolve future issues with pollution and improve planning for future electricity supply.

Future Work

The future work for this assessment will include evaluating various planning objectives. The first step will involve characterizing the electricity supply with regard to the projected increase in demand ERCOT has estimated for the next ten years. If the curtailment in certain generators would mean the generator will not meet the projected supply ERCOT has assumed in the future scenario, ERCOT might not meet its target supply. Since in the next ten years ERCOT's reserve margin will decrease to below zero, any decreases in service due to drought will intensify the problems with reserve margin.

The second step will include an in-depth analysis of heat transfer in a lake to characterize the lake temperature more accurately and in turn the effects of drought and heat wave on the power plants in ERCOT. The analysis will first take into account one lake used in open-loop cooling and one lake used in recirculated cooling. The analysis will then increase in scope to include the cooling ponds at all other open-loop and recirculated cooling plants in ERCOT.

The third step will include determining the amount of water needed to generate more electricity at plants that will undergo electricity curtailment in the future. This determination could improve water planning for power plants and allow for an increase in the amount of generation possible at each plant in question.

Appendix A: References

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Acknowledgements

Ashley Evans
Dr. Carey King
Barbara Moreland and Vince Tidwell at Sandia National Laboratory
Eugene Yan at Argonne National Laboratory
Dr. Michael Webber

And

Gonzalo Espinoza and Dr. David Maidment

Appendix B: Supplementary Figures

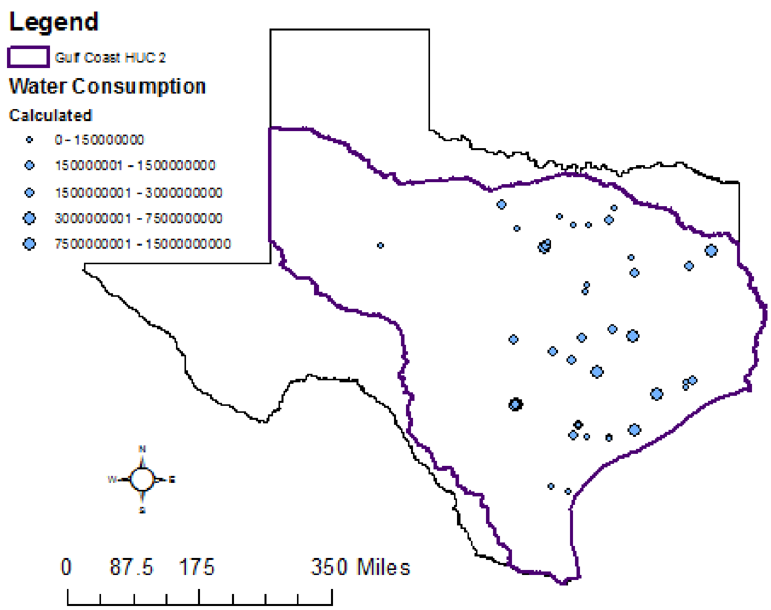

Figure B- 1 The plot indicates the yearly water consumption for 2011 for power plants in ERCOT that utilize open-loop or recirculating cooling technologies and reside within the Gulf Region. Most of these plants consume little water compared to the amount withdrawn (shown in Figure 5). Water consumption refers to the water pulled but not discharged again.

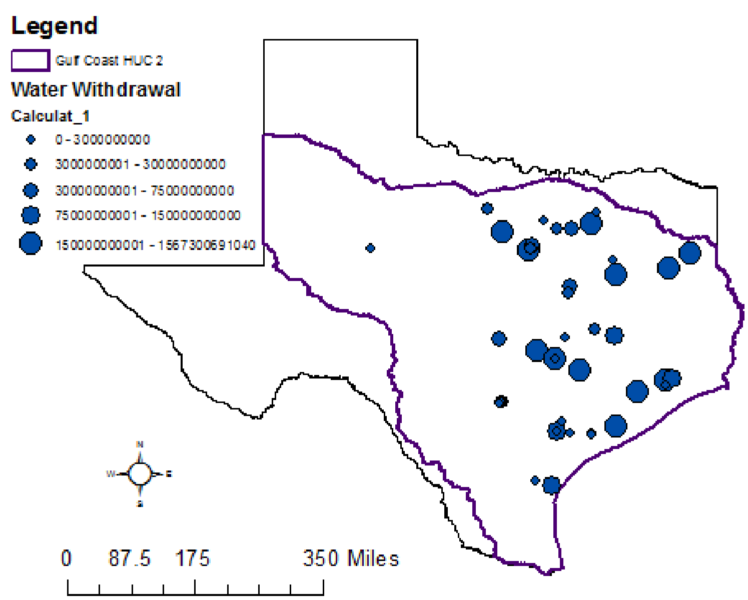

Figure B- 2 The plot indicates the yearly water withdrawals for 2011 for power plants in ERCOT that utilize open-loop or recirculating cooling technologies and reside within the Gulf Region. These power plants withdraw much more water than they consume. Even though they release most of the water they use, this high dependence on water creates potential for vulnerability in drought.