

WATER STRESS IN THE CONTINENTAL UNITED STATES

ABSTRACT

A study over water stress in the continental United States and its effects on many aspects of human life, such as poverty and potential fire danger.

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Introduction

Water stress occurs when the human demand for water is greater than the natural supply. Unfortunately, human population keeps growing at an alarming rate and is putting stress onto many of our natural resources. According to Worldometers, the population in the United States grew about 0.71% from about 324.5 million to about 327 million people from 2017 to 2018. This increase in population is not something that is only happening in the United States, though. While I am writing this, Worldometer is showing the world population has increased by over 74 million this year alone. While clearly the population is increasing, the amount of water on the earth has not been. This has led to the issue known as water stress. The infographic below came from Nestle Waters and shows the major uses of water by sector within the United States. Those three main sectors are Agricultural, Industrial, and Domestic uses. Agricultural is by far the main use of this resource. If any changes need to be made to reduce water stress, reducing the amount of water used by that sector would be a good start.

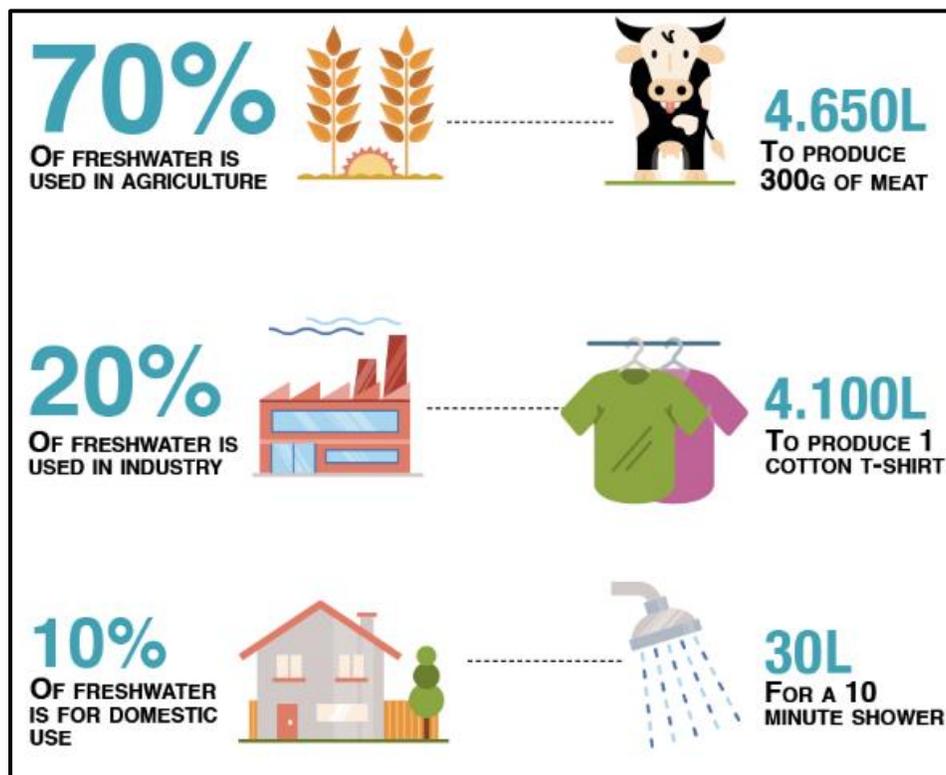


Figure 1: Water Use by Sector

Clearly water use affects many aspects of our lives. According to phila.gov, the average person uses about 101.5 gallons per day. When thinking about a daily routine, that involves brushing your teeth, drinking, going to the restroom, and many more activities. In order to protect these resources, something needs to change.

Data

This study used data from many different sources. The main data that spurred on the project came from the Living Atlas. This data set gave information on water stress per ecoregion over the entire world. An ecoregion is an area defined by environmental conditions. This means that land in one ecoregion will have similar climate, landforms, and soil. The picture below shows a map of the major ecoregions within Texas. As noted, an ecoregion does not have a defined shape, but rather follows the trends of the characteristics of the land.

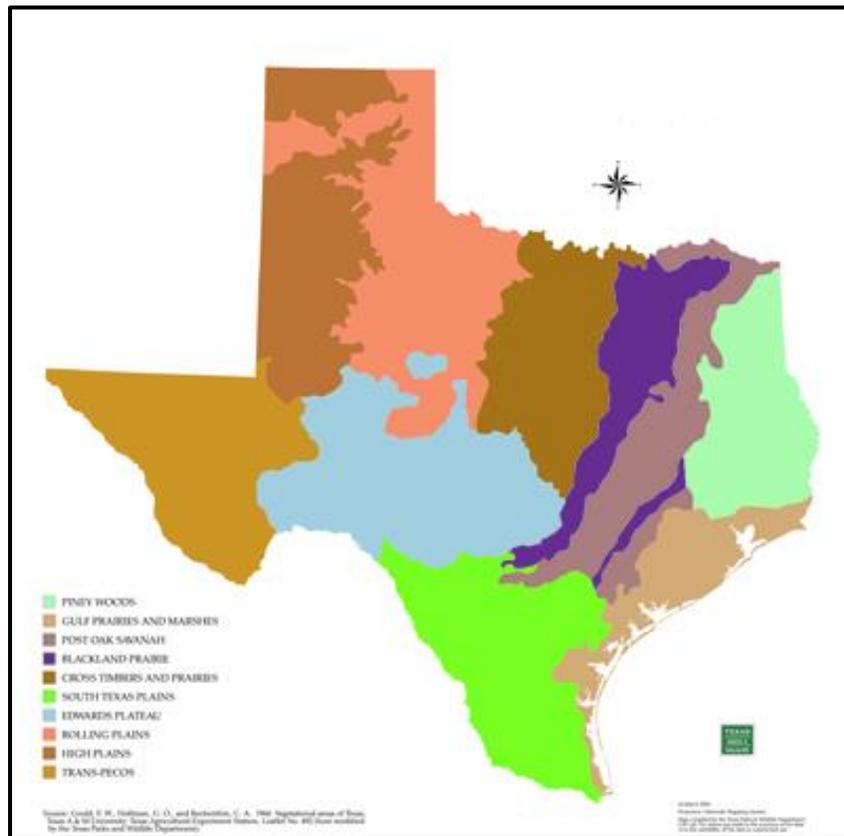


Figure 2: Ecoregions within Texas

The data actually used in this model was derived from the WaterGAP model developed by researchers at the University of Kassel in Germany in 2003. The WaterGAP model takes into account many of the same things that define ecoregions, such as climate, soil, etc., but it also takes into account the country in question, the sector using it, and the population. These water use statistics vary by location because different countries use water in different ways and in different amounts. This model then compares water use to water availability to determine the water stress in an area. One key thing to note for this model is that it does not take into account water that came from alternative sources such as groundwater and water reuse plants. On the flip side, the model also cannot take into account water that has been contaminated and can't be used again. These discrepancies and the fact that the model assumes that all water runoff is available for use by people, results in this model only representing surface water

stress. The map below is the basemap of the data discussed above. It covers almost every continent in the world. The vast size of this data made it difficult to manipulate. In order to make it more manageable, I decided to focus on just the continental United States for most of my analysis.

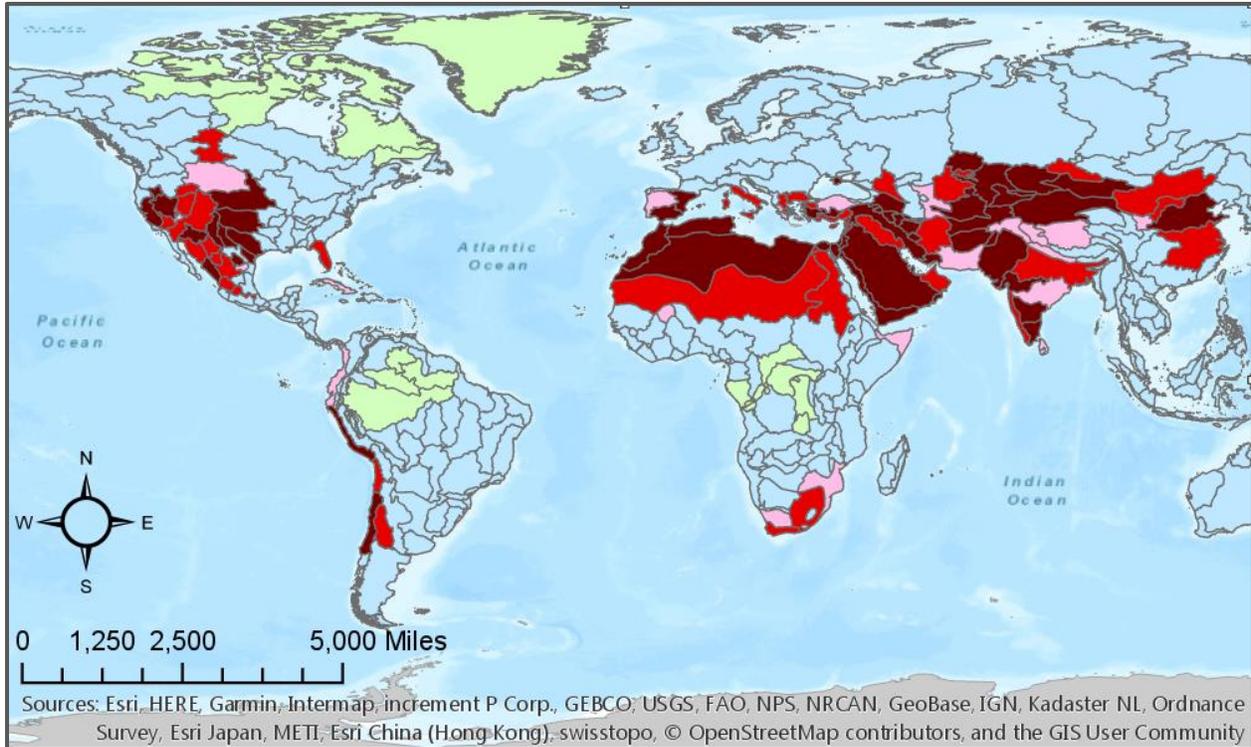
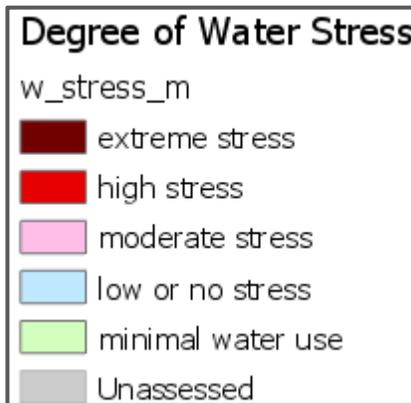


Figure 3: WaterGAP Model Basemap



The legend to the left describes the colors depicted on the basemap. It is clearly shown that the majority of the high or extreme water stress within the world is north of the Equator, with a lot of it being farther north than the Tropic of Cancer at 23.5 degrees north. According to Business Insider, ninety percent of people lived in the Northern Hemisphere in 2012. This statistic alone could explain why water stress seems to be so rampant within that region.

The second data set used was a cartographic boundary file developed by the United States Census Bureau. This set gave the boundaries for each state with a resolution level of twenty meters. This dataset was also projected into the WGS 1984 Web Mercator Auxiliary Sphere. This data set is shown overlaid on the Water Stress data set in Figure 4 below.

The last two data sets were taken for the purpose of finding the effects water stress has on our day to day lives. That led me to search for data sets involving poverty percentage by state and

fire potential. The data over the percentage of each states' population in poverty was taken from the United States Census Bureau. According to that bureau, poverty is when a family of four has a total income under about \$25,000.

The idea to look into how water stress affects fire potential was spurred on by the Camp Fire, which resulted in over eighty civilian deaths thus far. The U.S. Forest Service's Fire Modeling Institute provided data about fire potential across the United States along with the locations of all active fires in August 2018.

Analysis

My analysis started by refining my map to just the continental United States. To make the analysis go quicker, I clipped the data set to just the continental United States by using the select by polygon feature. I then used the data provided by the United States Census Bureau to superimpose the United States state boundaries upon the map. I had to make sure both of these layers were projected in the same coordinate system as the base map, which was WGS 1984 Web Mercator Auxiliary Sphere. Those changes to my map resulted in the new map below.

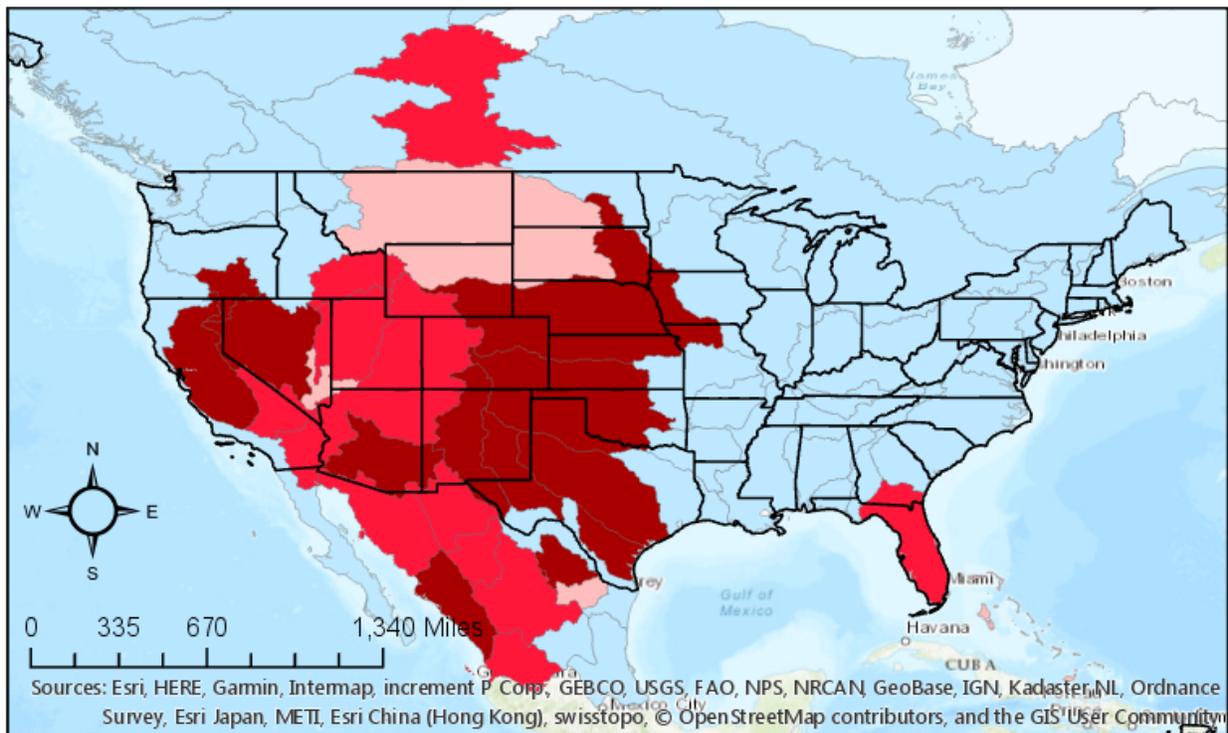


Figure 4: Water Stress by Ecoregion and State Visualization

The symbology of the map above is consistent with the basemap used previously. One important thing to note is that a large amount of the water stress in the area is in the south-west part of the country. The only exception to this is Florida. Further analysis about this outlier will be discussed later.

The next step of the project was to determine the percent of each state that was in each category of Extreme, High, Moderate, or Low or No stress. As discussed before, ecoregions don't follow state boundaries or other governmental boundary. Ecoregions, such as the temperate coastal rivers and xeric freshwater regions in this data, only care about the environment. This meant that some ecoregions could go between multiple states. To fix this issue, the ecoregions were clipped to each state boundary so that each state was made up of small polygons that filled their area.

The next part of the analysis was to determine the percent of each state that was covered by each water stress category. The first thing that I did was find the percent that was in each category alone. The map below shows a heat map of Extreme Stress across the United States.

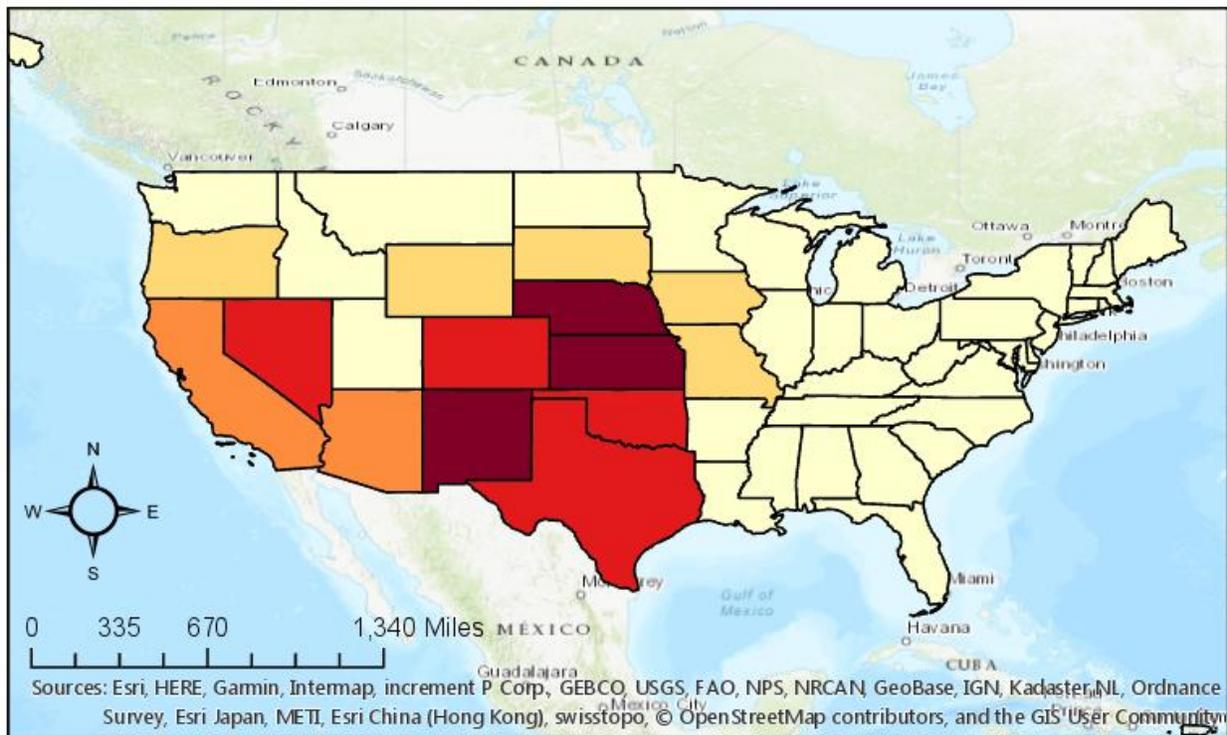
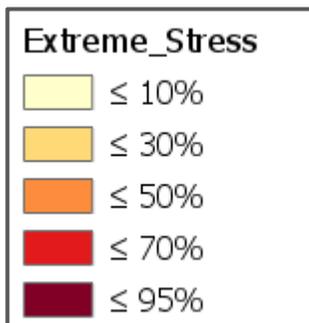


Figure 5: Extreme Water Stress Heat Map



The legend to the left gives the percent of each state that is covered in extreme stress. For example, the darkest red color means that 70% to 95% of the state is in extreme water stress. Upon first glance, it is clear that something is off with this map. Yes, this map gives areas that are in extreme water stress, but it makes it appear as if states that are mostly in high stress have low or no stress. An example of this is Utah. Utah is almost entirely in high water stress, but the map makes it appear as if it not under any stress. While this may be true, it makes the plot very visually misleading since that state is experiencing a large amount of stress.

To account for this, in further analysis, the heat maps were made by lumping multiple

categories together. The new lumped categories are extreme and high stress together and moderate and low or no stress lumped together. This change resulted in the new map below, which makes more intuitive sense.

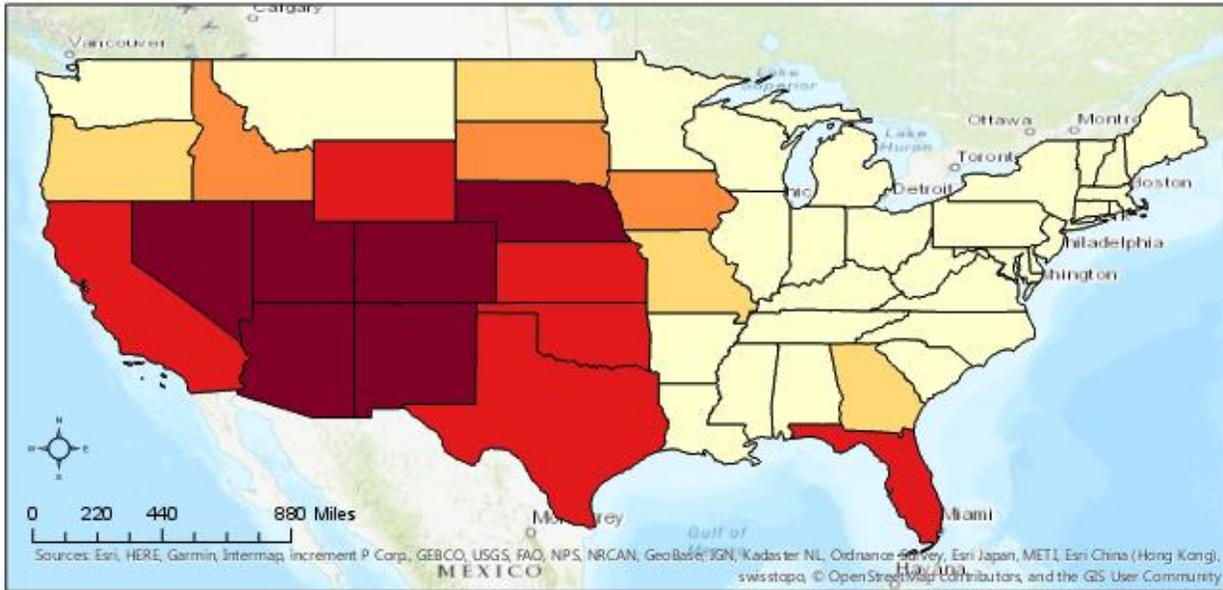


Figure 6: Extreme and High Water Stress Heat Map

Extreme_High_Stress	
	≤ 5%
	≤ 20%
	≤ 50%
	≤ 85%
	≤ 100%

This map has a similar legend as the map above. The darkest red now means that 85% to 100% of the state is in extreme or high water stress. States like Colorado, New Mexico, Arizona, Nebraska, and Utah all have 97% or higher of the state in extreme or high stress. This is another visualization of what was stated before. Most of the East Coast states, with Florida being an exception, have relatively low or no water stress. The next step was to look at the

opposite view of this map, which is the heat map that takes into account the lumped moderate and low or no stress data. This map is below.

Water Conflict

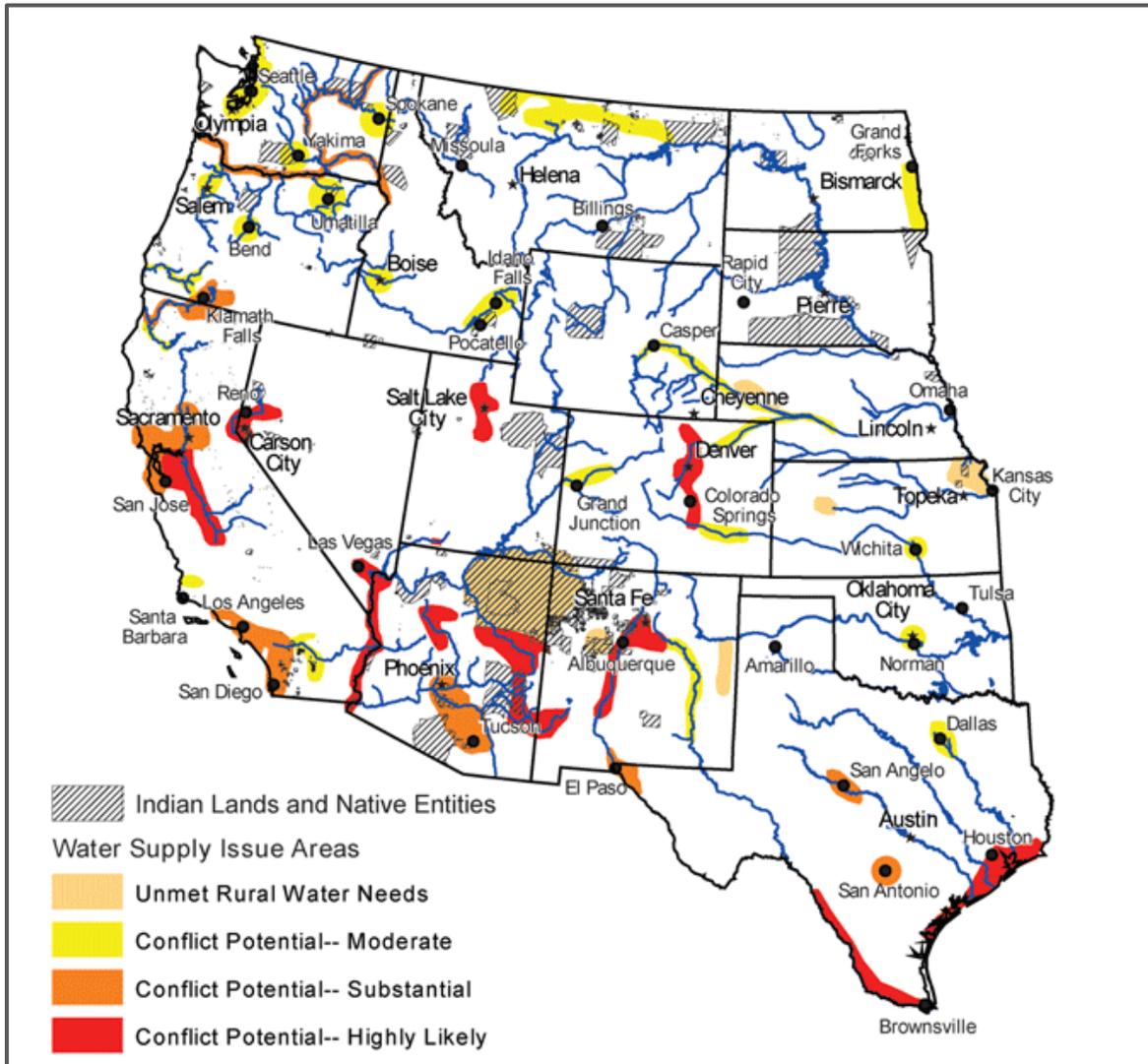


Figure 8: Potential Water Supply Conflicts by 2025

This plot shows another way to visualize the many impacts of water stress. The heat maps shown previously show a lot of the states that are experiencing the most water stress also have the highest potential for water conflicts. For example, a state like California that seems to constantly be in drought and dealing with fires, has a large portion of the state that has a high potential for water conflict. These conflicts have been ongoing for years, and may not be resolved quickly. This could be due to the increasing stress over time because of the rise in water demand. As global temperatures continue to rise, more evaporation will happen which could leave areas even drier. As shown earlier in this paper, the agricultural industry is one of the main users of water by a substantial amount. As the surface of the earth gets drier due to more evaporation, that industry's need for irrigation will start to increase. The section below goes into a very specific example of a water conflict caused by water stress within Florida.

Florida

Florida, seemingly the anomaly of the East Coast, is under high water stress. A reason for this could be a continuation of the discussion of water conflicts stated earlier. Currently, Georgia, Alabama, and Florida are in a conflict called the Tri-State Water Dispute, over their water distribution between their states. Their water sources, the Apalachicola–Chattahoochee–Flint River system, is used for almost every aspect of life, from farming to drinking to energy. This river system helps to make up the ACF River Basin. Florida happens to be on the downstream end of this river basin and in result will have a depleted water source if the upstream users take more than their share. The water that arrives in Florida through this river basin is used to strengthen the economy with industries such as shrimping. Unfortunately, if the water from this basin does not reach Florida, there will be a massive negative effect on its economy. This is what has been happening and is the cause of this conflict.



Figure 9: Tri-State Water Stress Basins

This conflict was so large that it ended up becoming a case that was tried in front of the Supreme Court. In June of 2018, the Supreme Court ruled 5-4 in favor of Florida to help increase water flow within the Apalachicola River.

Poverty

Now that there is a good understanding of how water stress changes across the state, it was time to see how this correlated to other variables. Since water impacts almost everything we do, it would make sense that there would be some sort of a link between the stress a state is under and the poverty a state has. Without water, it would seem that a community would have a hard time developing. The map below shows the poverty percentage by state.

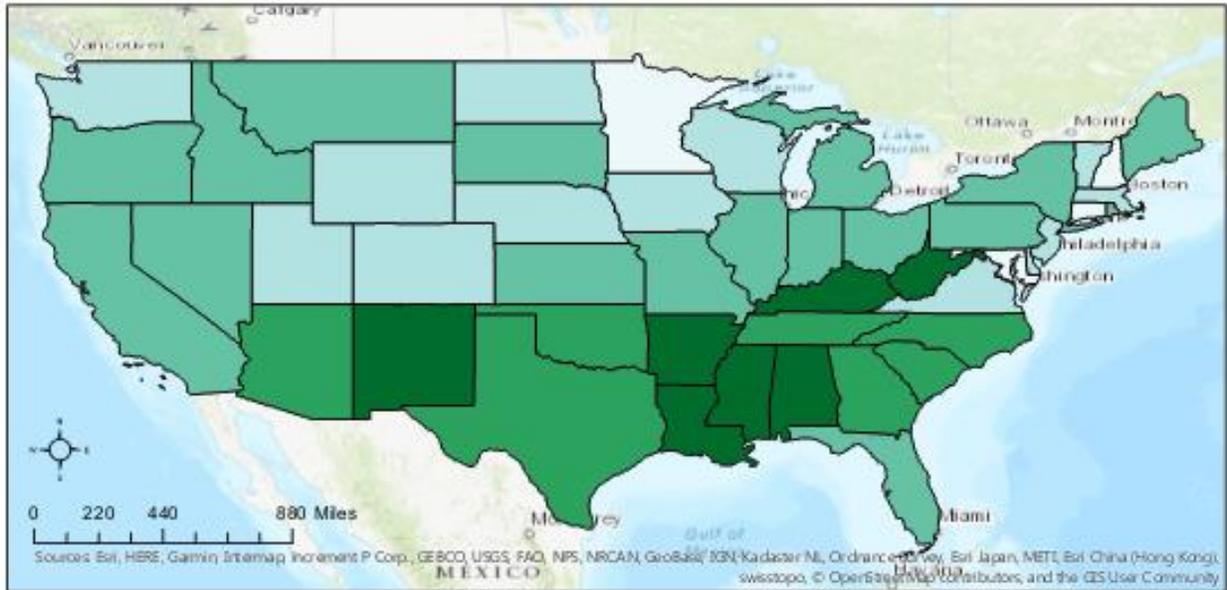
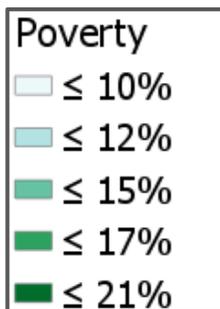


Figure 10: Percentage of Population in Poverty Heat Map



When comparing this map with the maps developed previously, it is very clear that there doesn't seem to be any correlation. There seems to be other variables at play that have a much larger impact on poverty. The two tables below show the five states with the highest percentage of poverty and highest percentage of the state in high or extreme stress. Of the two tables, it is clear that only New Mexico is on both of those lists.

State	Poverty %
Mississippi	21
Louisiana	20.1
New Mexico	19.1
District of Columbia	18.5
Kentucky	18.2

Table 1: Maximum State Poverty Percentages

State	Extreme and High Stress %
Colorado	100
New Mexico	100
Arizona	99.5
Nebraska	97
Utah	97

Table 2: Maximum State Extreme and High Water Stress Percentages

Fire Potential

This poverty determination was interesting, but was not the ultimate direction of the project. Currently, wildfires are a major issue in the United States. Water also has a large impact on that aspect of life, so the project direction pivoted. The new data set used in this project was provided by the U.S. Forest Service's Modeling Institute. This new data was once again projected into the WGS 1984 Web Mercator Auxiliary Sphere coordinate system.

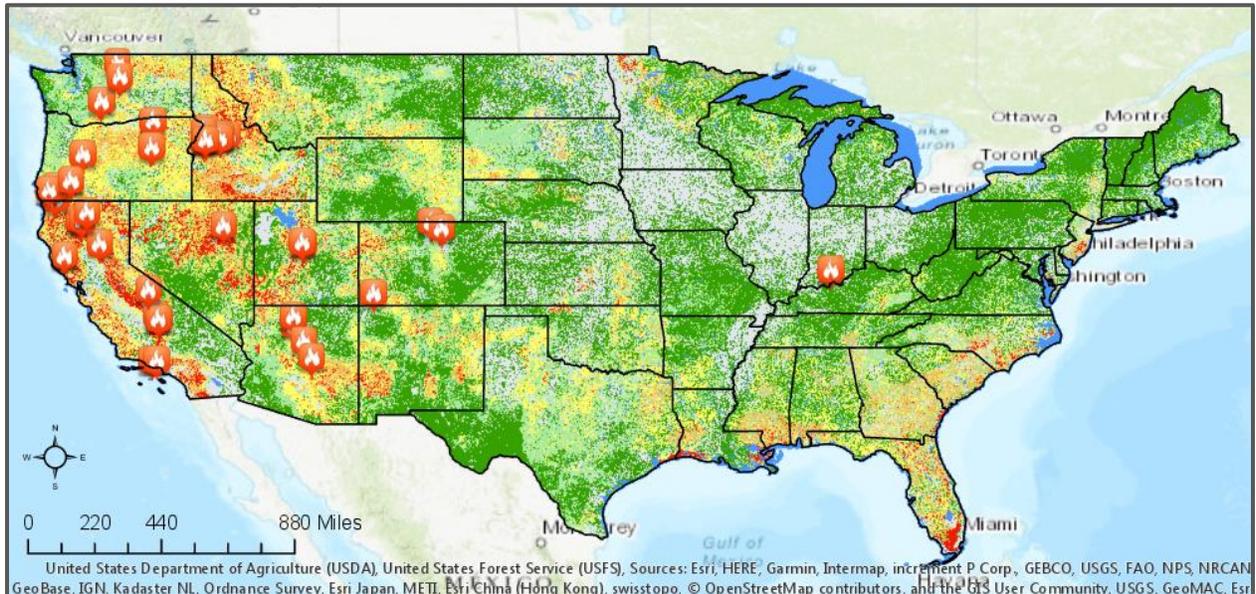
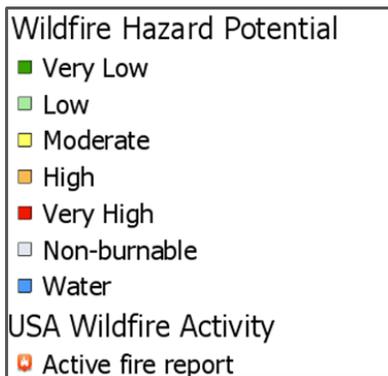


Figure 11: Fire Potential August 2018



Depending on the type of fire, water can be a very useful tool to help in the fight to contain a fire. Water, along with chemical retardants, can be used to help suppress a fire and prevent it from rapidly spreading to other areas. The map above shows the fire potential across the continental United States in August of this past year. According to National Geographic, over 100,000 fires happen per year and burn on average of four to five million acres of land. It would make sense that areas that are dealing with water availability issues would be more

susceptible to fires, but clearly that is not the case. The West Coast is a great example of that. When comparing the heat maps from previous sections to the fire potential map, it is easy to see the clear discrepancy. Those maps show that states such as Oregon and Washington have relatively low or no water stress. That does not seem to be making a difference when looking at the active fires and fire potential on the map. Those states have large sections that have moderate or high potential for fires and had at least eight fires between the two states in one month. California, in contrast, had a large portion of the state in high or extreme water stress but also had a large number of fires this year. Clearly there does not seem to be a correlation in the potential of wildfires in a state and its water stress, but maybe there is a correlation

between the state's ability to fight a fire and the amount of water stress in an area. Unfortunately, wildfires are so unpredictable and have many different influencers. This means it is very hard to pinpoint one exact reason that a fire is hard to fight. Factors such as rainfall in an area, the amount of dead brush, and wind can all greatly increase or decrease a wildfire's ability to spread. A future analysis could be done of the relationship between wildfire fighting and water stress to determine if there is an overall correlation.

One thing is for certain, though. Four out of five fires are started by people and not by nature. Billions of dollars each year is spent to fight these man caused fires that ultimately shouldn't have started to begin with. Especially as climate continues to change, humans need to be more cognizant of their effects on the environment.

Conclusion

This project showed how water stress varies across the continental United States. Interestingly, the west coast seems to have a larger problem with the water stress than the east coast. Rising temperatures due to climate change could have a drastic effect on water stress and will cause this problem to be exasperated. Water stress happens when the demand for water is higher than the amount of water available. This issue is compounded by two main things. One is increasing population, which is clearly happening all around the world. The other is climate change and rising temperatures. As temperatures increase, more water is evaporated and less water is available for use. The fact that both of these situations are happening at the same time means our water supply will continue to be under stress until something changes. Water use sectors such as the agricultural business need to figure out a more efficient way to use water in order to not deplete the supply.

The average human uses over one hundred gallons of water per day. If water is not readily available, it could impact the average person's ability to go about their day. This led to the thought that maybe there is some sort of correlation between water stress or availability and poverty. Analysis of these two data sets showed that no, there does not seem to be any sort of correlation. The majority of the water stress in the United States was west of Louisiana, while the states that dealt with the most poverty were generally east of Texas. The only state that had both high water stress and high percentage of the state in poverty was New Mexico. This showed that while water does play a big part in a person's day to day life, it is not one of the main causes of poverty.

This led to the final look into what water impacts, and that is wildfires. A majority of wildfires in the United States are caused by humans. Fires need three things to form, and those are a fuel source (debris), oxygen, and a heat source. It would seem that the more stress the water supply is under, the more likely an area is to have a fire. That hypothesis was shown to not be the case. California, Oregon, and Washington are all perfect examples of this. California is dealing with a lot of water stress and a large number of fires. Oregon and Washington are dealing with considerably less water stress, but are also dealing with fires. The impact that water stress may

have on wildfires deals more with the ability to fight them. As the water supply is depleted, less water is available to fight the fires, thus making the issue worse. The rising temperatures could be causing more evaporation in the area and thus leaving the debris and ground dryer. This increases the amount of one of the main things needed for a wildfire, a fuel source. Ultimately, it seems as if the fires and water stress in the continental United States could be distantly caused by the same thing, rising temperatures.

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