Using Geothermal Energy for Brackish Water Desalination in Texas

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Abstract

Texas is facing a severe drought and a population growth, making it imperative to find alternative methods of producing freshwater. One option is to use reverse osmosis to desalinate Texas' abundant supply of brackish groundwater. Reverse osmosis is an energy-consumptive process, making water desalination expensive. To mitigate the costs of desalination, water treatment plants may be able to use geothermal energy. This project uses borehole temperatures and brackish groundwater data in conjunction with ArcGIS to determine the feasibility of using geothermal energy for desalination. Based on preliminary results, utilizing geothermal energy may be a viable solution for alleviating the pressure on Texas to provide freshwater for its growing population.

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Introduction

Drought and Population Growth

Texas is in a severe drought, with groundwater supplies predicted to decline by 30% from 2010 to 2060, as shown in Figure 1 (1). At the same time, the population of Texas is predicted to grow by 21 million (2), which will further stress the demands for freshwater. With a dwindling supply of groundwater, it is necessary for Texas to examine alternative methods of providing freshwater. One option is to desalinate the abundant supply of brackish groundwater.

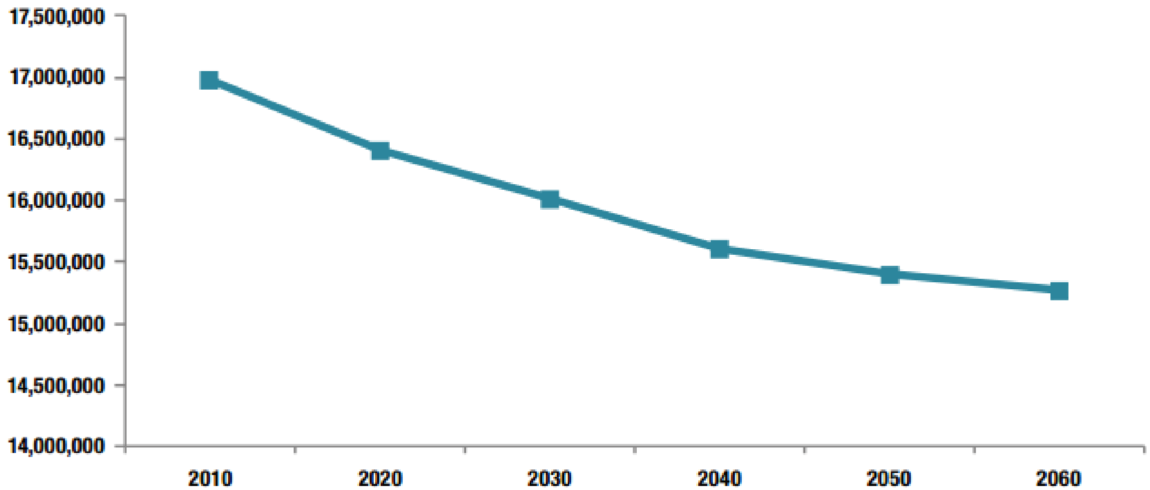

Figure 1: Projected existing water supplies in acre-feet per year, from 2010 to 2060 (1).

Brackish Water

Texas has more than 2.7 billion acre-feet of brackish groundwater (3). Brackish water has a Total Dissolved Solids (TDS) concentration ranging from 1,000 – 10,000 mg/L. For comparison, seawater has a TDS of 35,000 mg/L. The higher the TDS concentration, the greater the energy requirements required to work the pumps and therefore greater the cost. The most common method of desalination is reverse osmosis.

Reverse Osmosis Desalination

Reverse osmosis desalination is a process by which water is pumped through a hydrophilic membrane. This process purifies the water, as salt and other contaminants cannot pass through the membrane. Texas has 34 desalination plants in operation with a total design capacity of desalinating 73 MGD of brackish groundwater (4). A potential solution to meeting Texas' increasing demands on freshwater is to rely more on brackish groundwater desalination. This would require increasing the amount of water the operating plants desalinate, which is a more expensive process than purifying non-saline groundwater. Desalination of brackish groundwater costs approximately $1.50

per 1,000 gallons (4). This cost can be mitigated through the use of renewable energy sources, such as geothermal energy

Geothermal Energy

Geothermal energy is heat energy stored in the earth, which can be pumped to the surface via water and steam stored in the ground to generate electricity. There are several ways to utilize geothermal energy. One method is to locate and drill reservoirs with very hot water and steam (5). The steam can be pumped directly into turbines to generate electricity. After running through the turbines, the steam is released into the atmosphere or condensed and either disposed of or pumped back into the reservoir. This method is limiting as the water reservoirs must be greater than 150°C. A second method uses water less than 150°C, enabling access to much more geothermal energy than the first method (5). Instead of producing electricity with the water directly, the water is run through a heat exchanger, heating a second fluid with a lower boiling point, such as isobutane. The isobutene vaporizes and drives the turbine, generating electricity. A condenser liquefies the isobutene, which can then be run through the heat exchanger again. The groundwater can be pumped back into the ground to be reheated. This closed loop cycle is known as a binary cycle and is depicted in Figure 1.

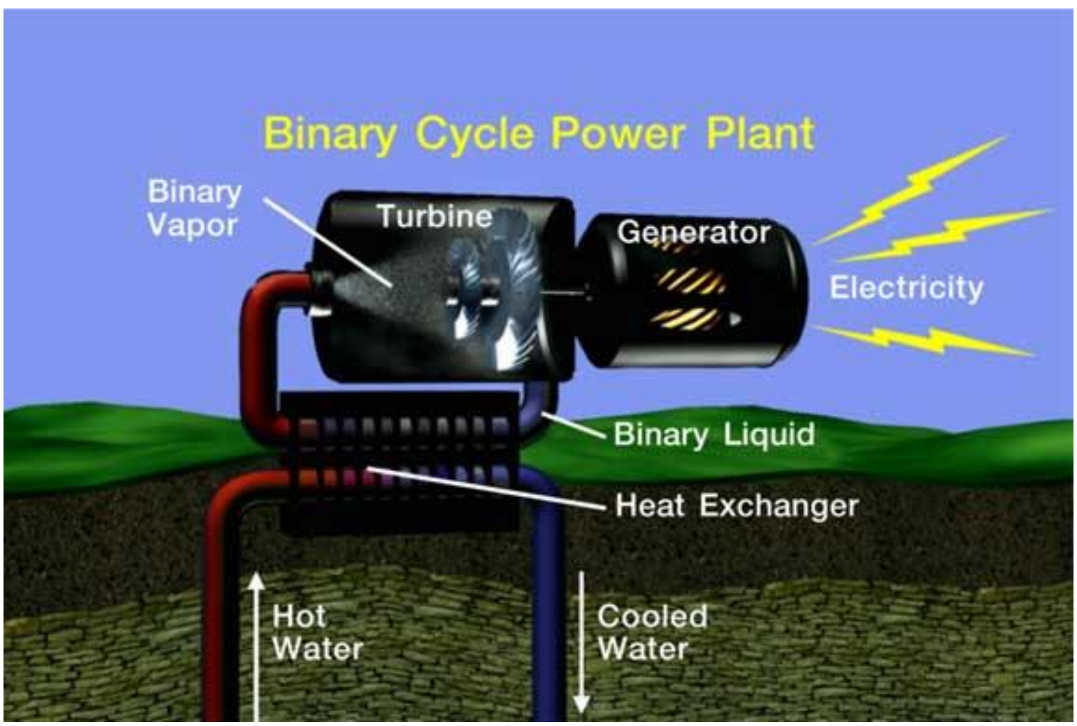

Figure 2: Binary Cycle method for collecting geothermal energy (6).

Objective

This project uses ArcGIS to analyze the geothermal energy potential in Texas for the purpose of desalinating brackish groundwater. Borehole temperature data and well data provide the necessary information for preliminary results.

Data

Data was collected from two sources:

1. Southern Methodist University's Geothermal Laboratory (7). This source provided the borehole location and temperature data, which is used to determine the underground temperature across Texas. This temperature is used to calculate the geothermal energy potential of the state.
2. Texas Water Development Board: Brackish Groundwater Database (8). The brackish groundwater database is used to determine the Total Dissolved Solids (TDS) concentration and the water level depth and the location of wells across Texas. The TDS concentration and water depth are used to calculate the energy requirements for reverse osmosis.

Methodology

Borehole Temperature

A borehole is a narrow shaft, which can be used for many purposes, such as extracting liquid or gas from deep below the ground. The temperature at the bottom of the borehole is often measured and it is this temperature that was used to calculate Texas' geothermal potential. Borehole temperature data from Southern Methodist University's (SMU) Geothermal Lab was mapped in ArcGIS and is shown in Figure 3 (7). The temperature has been corrected to take into account that the original measurements were taken shortly after drilling fluid stopped circulating. The data from SMU had borehole temperatures from all across the United States, so the borehole temperatures in Texas were extracted using a mask of Texas.

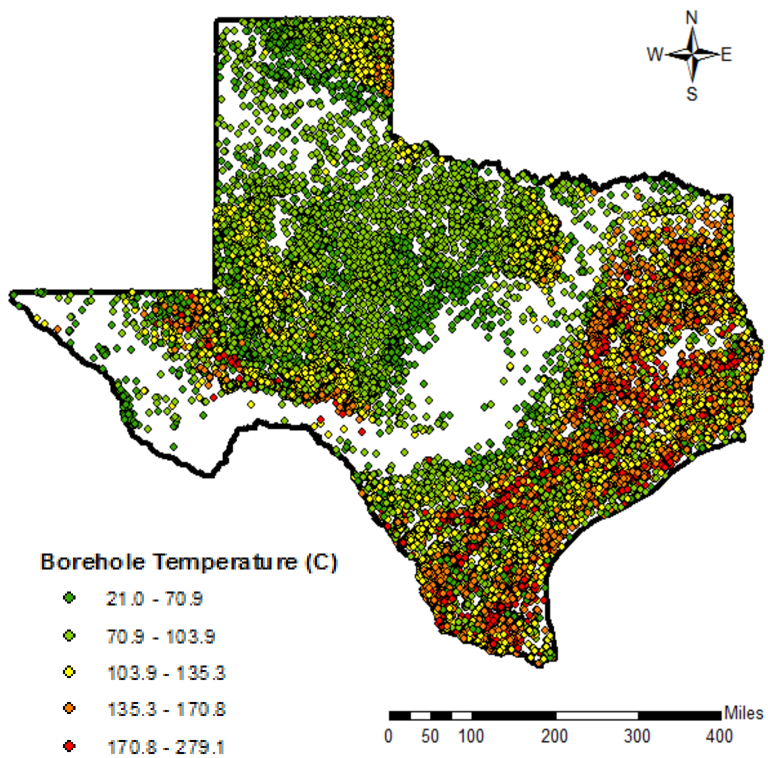

Figure 3: Borehole temperature across Texas

To determine if borehole temperatures are a fair representation of the underground temperature in Texas regardless of the depth of the holes, the temperature and depth relationship is plotted in Figure 4. The figure shows that by 3000 feet all five temperature ranges are represented and that there are low temperatures at high depths. As the range of temperatures are well represented regardless of the depths of the holes and because many boreholes were drilled to reach the groundwater in the area, all the data was used to interpolate the ground temperature across Texas.

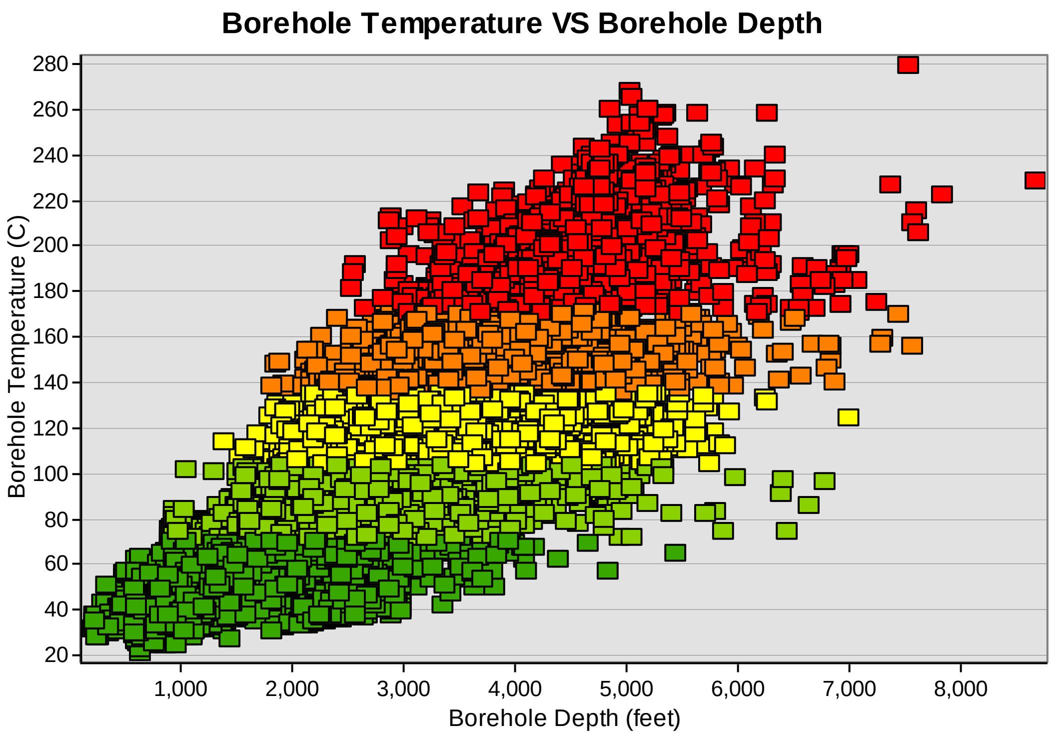

Figure 4: Borehole temperature plotted against borehole depth.

Several methods of interpolating the borehole temperature data were tested, with Kriging providing the best results. The results were fit to an outline of Texas using the extract by mask function, with the outline of Texas projected using NAD 1983 Texas Central FIPS 4203 (meters). The interpolated borehole temperatures are shown in Figure 5 and Figure 6.

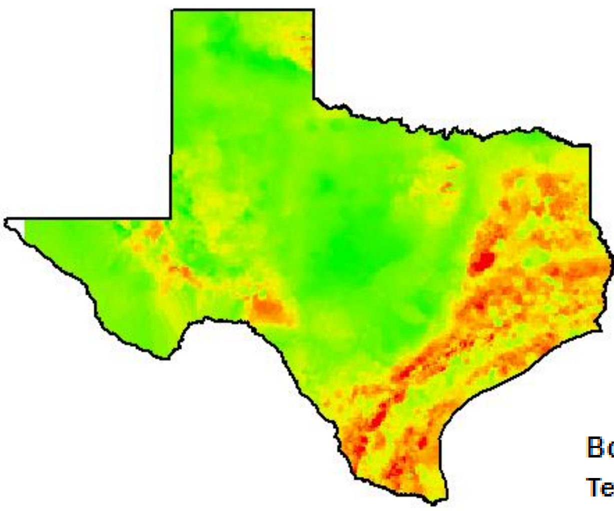

Figure 5: Kriging interpolation of the borehole temperature data in Texas.

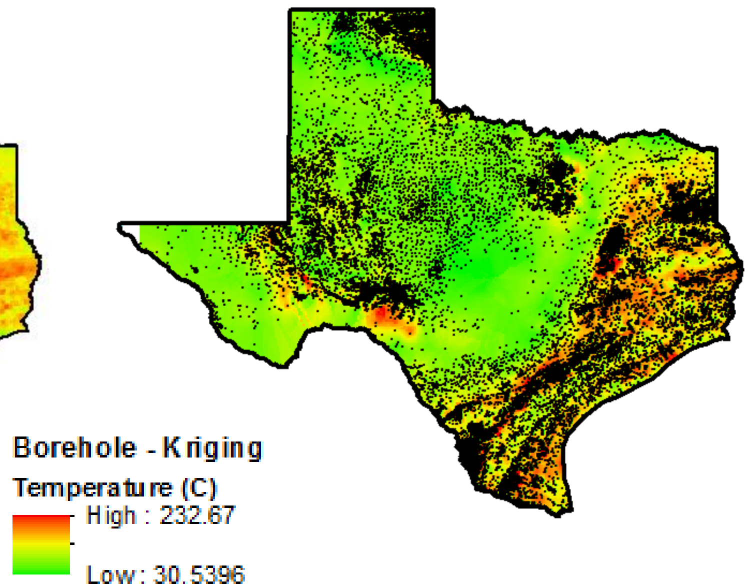

Figure 6: Kriging interpolation of the borehole temperature data in Texas and borehole locations.

Well Data

Brackish water data was gathered from the Texas Water Development Board (TWDB) Groundwater Data (8). All of the documented water wells in Texas are shown in Figure 7. For the purpose of this project however, only wells ranging in depth from 100-12,000 feet with a total dissolved solids (TDS) concentration between 1,000-30,000 mg/L were needed. Water with these levels of concentration are considered to be brackish, with a TDS range of 1000-10,000 mg/L, and saline, with a TDS concentration greater than 10,000 mg/L. The project did not determine the feasability of desalinating seawater, which has a TDS concentration of 35,000 mg/L.

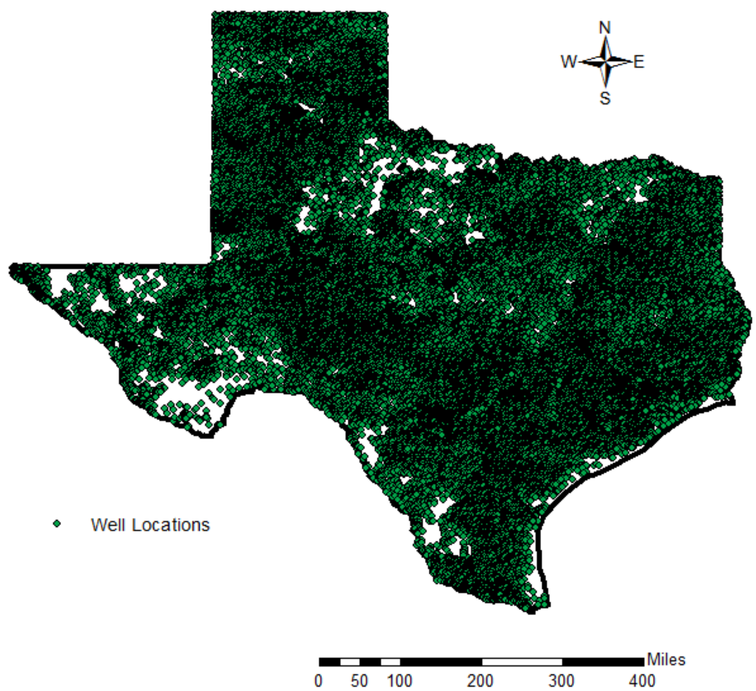

Figure 7: Well locations in Texas. The data is from the Texas Water Development Board: Groundwater Data.

Two files were downloaded from TWDB, one with well depth and the second with the well TDS concentrations. In GIS, the two lables were combined using the “join” function. Wells with the TDS concentration range of 1,000-30,000 and a depth of 100-12,000 feet were extracted from the table using the “select by attribute” function to select wells that meet these requirements. Using the new table, the TDS concentrations and well depths are plotted in Figure 8 and Figure 10. This data was interpolated across Texas using Kriging, as shown in Figure 9 and Figure 11. This data was also projected in NAD 1983 Texas Central FIPS 4203 (meters).

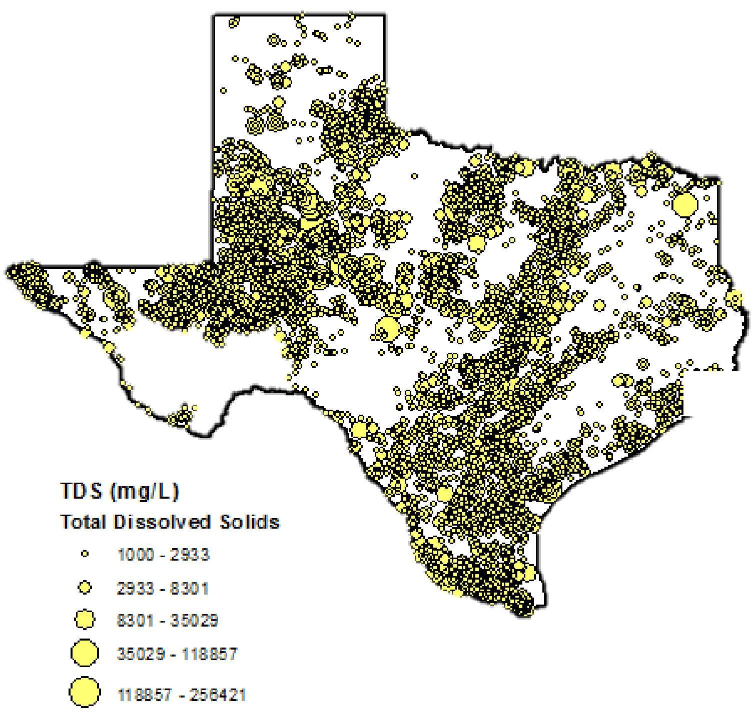

Figure 8: Total Dissolved Concentrations from 1,000 mg/L to 30,000 mg/L at well depths of 100 – 12,000 feet. Data from the Texas Water Development Board: Groundwater Data.

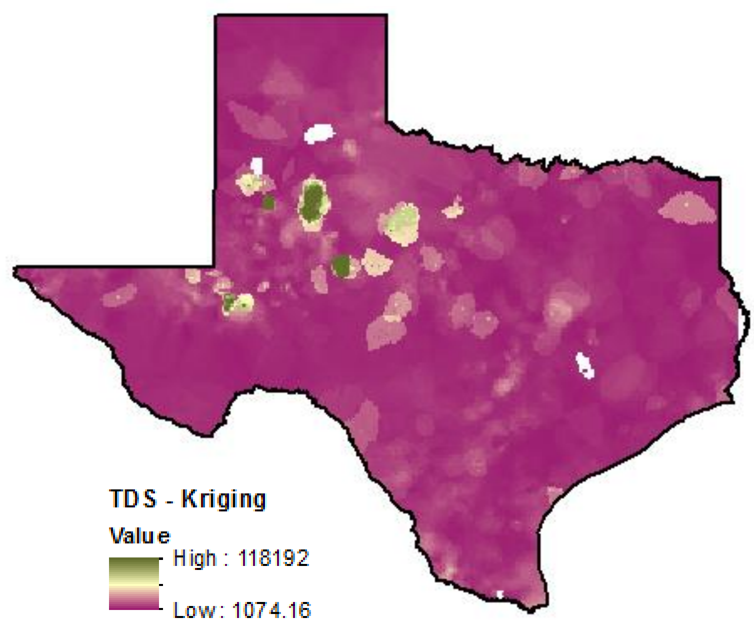

Figure 9: Kriging interpolation of the Total Dissolved Concentrations from 1,000 mg/L to 30,000 mg/L at well depths of 100 – 12,000 feet. Data from the Texas Water Development Board: Groundwater Data.

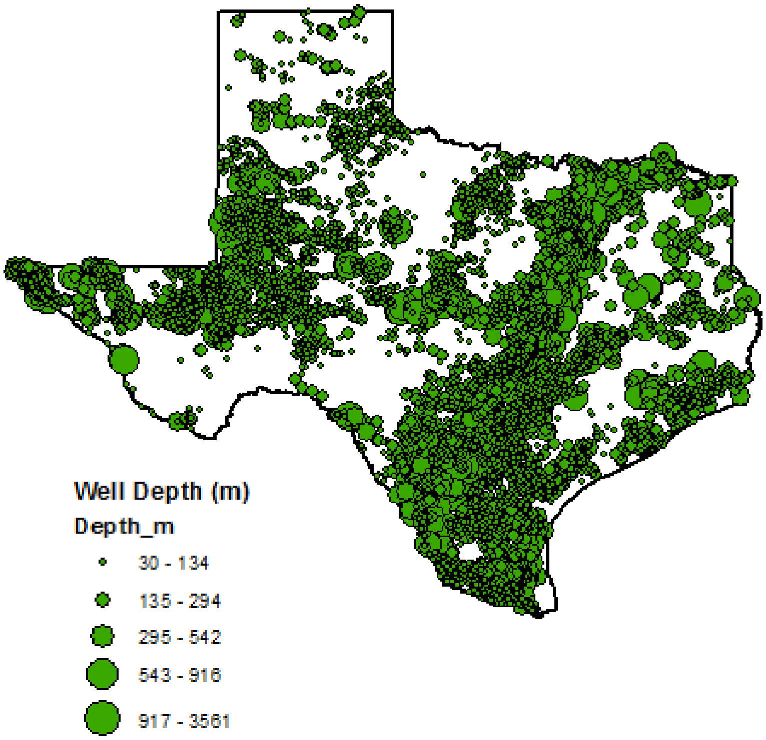

Figure 10: Well Depths of 100-12,00 feet with TDS concentrations from 1,000 mg/L to 30,000 mg/L. Data from the Texas Water Development Board: Groundwater Data.

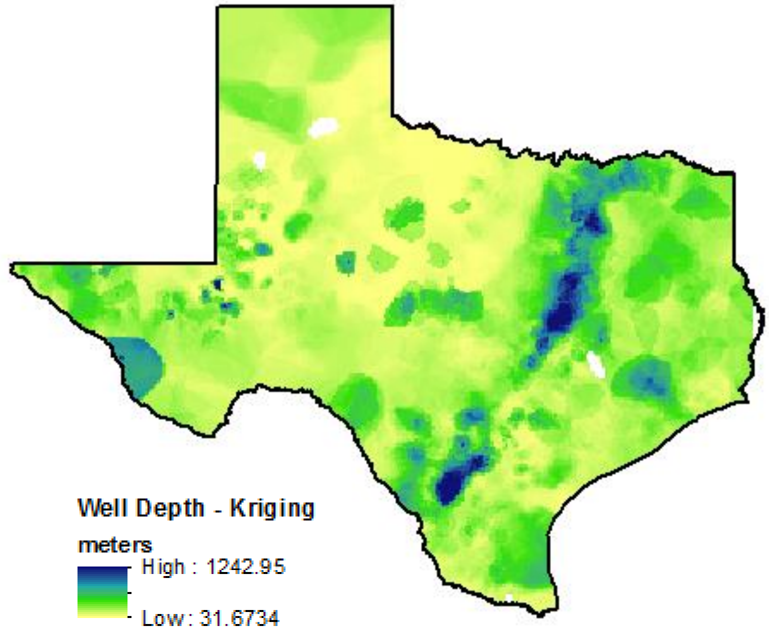

Figure 11: Well Depths of 100-12,00 feet with TDS concentrations from 1,000 mg/L to 30,000 mg/L. Data from the Texas Water Development Board: Groundwater Data.

Production of desalinated water using geothermal energy

Geothermal energy production can be found using Equation [1] (9):

$$P_{geo} = C_p * Q_g * \Delta T * \eta_g - P \qquad \text{(Equation 1)}$$

Where:

P_{geo} = Power produced by geothermal energy [Watts]

C_p = Specific heat of working fluid [J/kg °C]

Q_g = Flow rate of working fluid [kg/s]

ΔT = Temperature of fluid in resevoir – heat lost [C]

η_g = Efficiency

P = Parasitic loses

Assumptions:

1. C_p is water
2. η_g = 10%, based on literature (9)
3. P = 0

The power requirements for reverse osmosis water desalination can be found using Equation [2] (10):

$$P_{desal} = P_{RO} + P_{Pumping} \qquad \text{(Equation 2)}$$

$$P_{desal} = \frac{Q * \gamma * WD}{\eta_d} + [Q * 0.08 * (TDS_{in} - TDS_{out})]$$

Where

$P_{desal} =$ The power requirements to desalinate water. This consists of the reverse osmosis and pumping power. [Watts]

Q = Flow rate of product water [m^3/s]

γ = Specific weight of water [N/m^3]

WD = Well depth [m]

η_d = efficiency of pump and motor

TDS_{in} = TDS concentration from well [kg/m^3]

TDS_{out} = TDS concentration of product water [kg/m^3]

Assumptions:

1. No power requirement to transport water from a well to the desalination plant. The plant is assumed to be located at the well.
2. Specific gravity = 9.81 x 10^3 N/m^2
3. $\eta_d = 65\%$ (10)
4. TDS_{out} = 500 mg/L

To determine the overall freshwater capacity, equations (1) and (2) were set equal to eachother and solved for the product water (Q), Equation [3].

$$Q = \frac{C_p * Q_g * \Delta T * \eta_g}{\frac{\gamma * WD}{\eta_d} + 0.08(TDS_{in} - TDS_{out})} \qquad \text{(Equation 3)}$$

Equation [3] was solved in GIS using the raster calculator tool and the Kriging interpolations of the borehole temperatures, the TDS concentrations, and the well depths.

Results

To determine the geothermal energy capacity of producing fresh water, four scenarios were tested in GIS. The first scenario, shown in Figure 12, has a high geothermal flowrate (Qg = 1111 gpm) with the assumption that the temperature of the geothermal water remained constant. The second scenario, shown in Figure 13, has a high geothermal flowrate (Qg = 1111 gpm) and a temperature drop of 15°C. The third scenario, shown in Figure 14, has a low geothermal flowrate (Qg = 1.5 gpm) with a constant temperature. The fourth scenario, Figure 15, has a low geothermal flowrate (Qg = 1.5 gpm) and a temperature drop of 15°C. As the GIS graphics are difficult to compare, the results from the tests are also presented in Table 1.

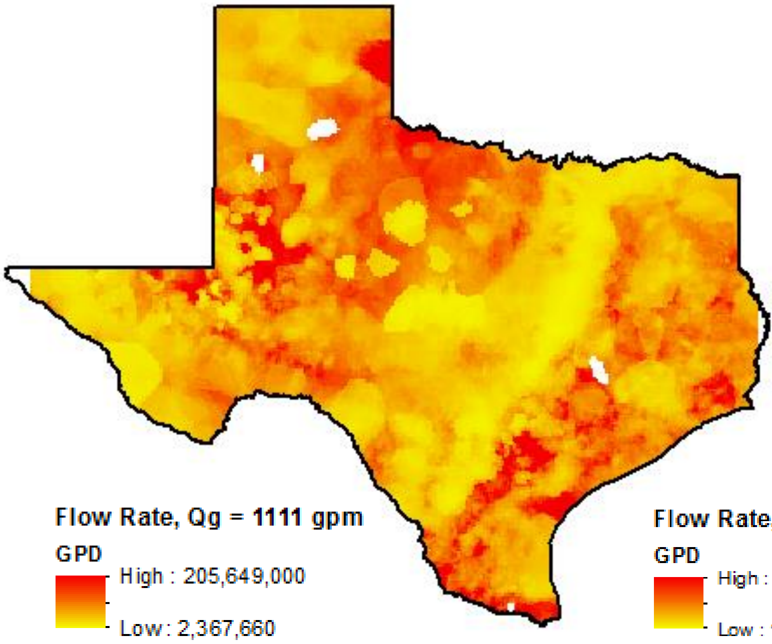

Figure 12:Flow Rate (Q) with a Geothermal Flow Rate (Qg) = 1111 gpm and no temperature loss.

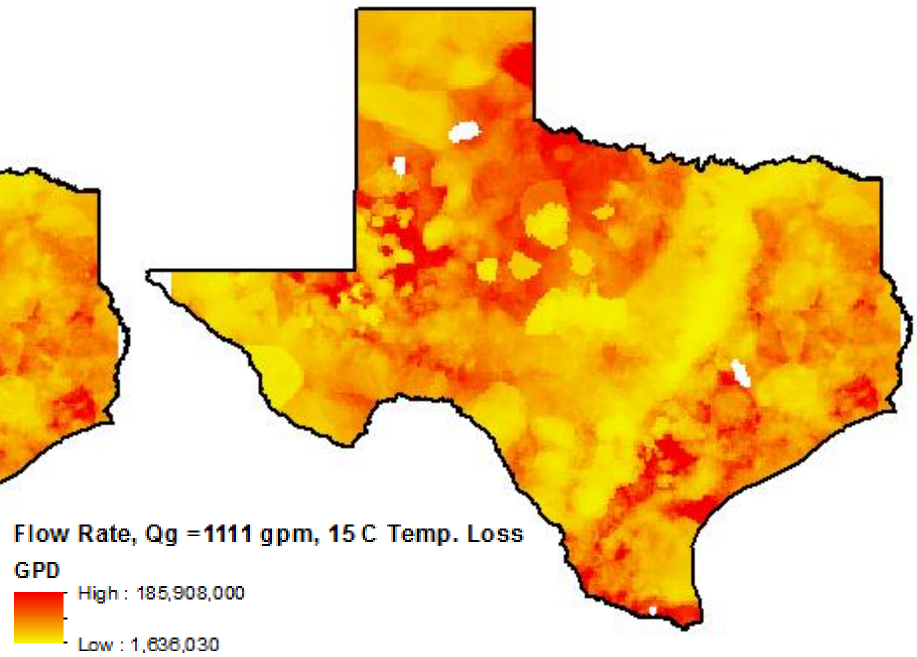

Figure 13: Flow Rate (Q) with a Geothermal Flow Rate (Qg) = 1111 gpm and a temperature loss of 15°C.

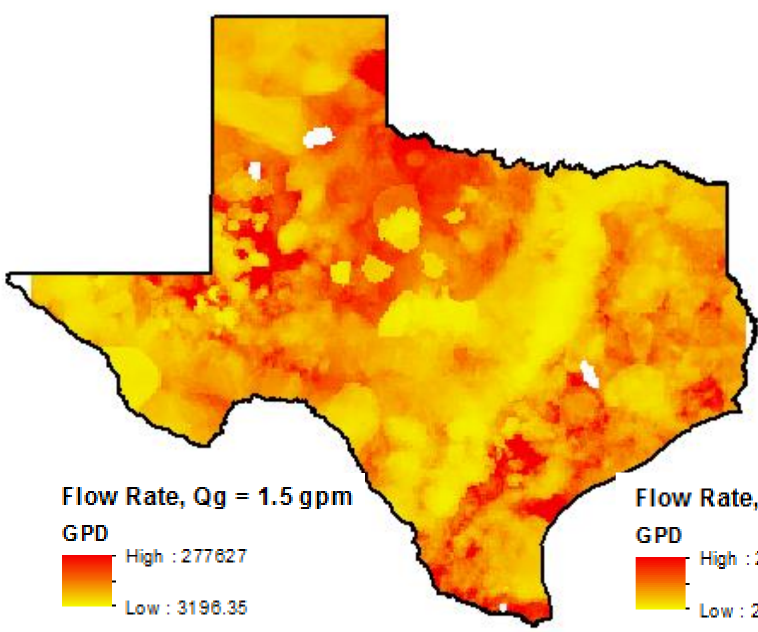

Figure 14: Flow Rate (Q) with a Geothermal Flow Rate (Qg) = 1.5 gpm and no temperature loss.

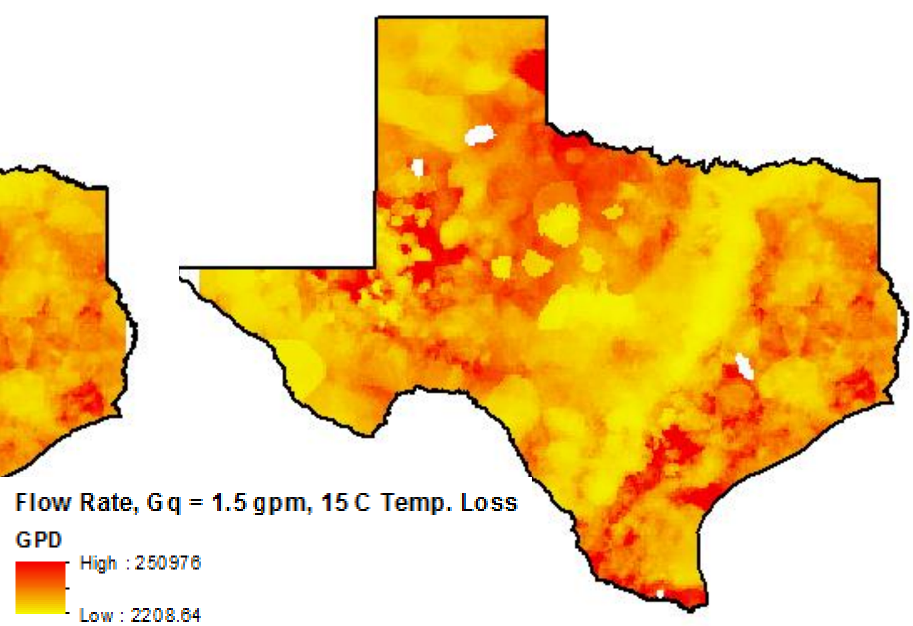

Figure 15: Flow Rate (Q) with a Geothermal Flow Rate (Qg) = 1.5 gpm and a temperature loss of 15°C.

Table 1: Flowrate of desalination plants using geothermal energy as determined by Equation (3), for four scenarios.

	Low Product Flow Rate (Q) (MGD)	**High Product Flow Rate (Q) (MGD)**
Qg = 1.5 gpd (No temperature change)	0.003	0.278
Qg = 1.5 gpd (Temperature loss of 15°C)	0.002	0.251
Qg = 1111 gpd (No temperature change)	2.36	205
Qg = 1111 gpd (Temperature loss of 15°C)	1.64	186

Table 1 show the results from the four scenarios, with the low product flow rate (Q) representing the lowest expected production from a desalination facility in each senario and the high product flow rate (Q) representing the highest expected production. The low geothermic flow rate scenarios produced much less product water than the high geothermic flow rates. The temperature decrease of 15°C resulted in a more significant decrease in product flow rate for the high geothermic flow rate than for the low geothermic flow rate.

Discussion and Conclusion

Based on these preliminary results, utilizing geothermal energy for brackish water desalination is a possibility. The average design capacity for a desalination plant in Texas is 1.6 MGD. The low geothermic flow rates do not come close to meeting this average, with the product flow rate reaching a maximum of 0.278 MGD when the temperature is constant and a maximum of 0.251 MGD with a temperature drop of 15°C. Many plants in Texas however, are operating much under the average, in which case even the low geothermic flow rates could provide enough energy for desalination.

At high geothermic flow rates, the minimum product flow rate is 2.36 for a constant temperature and 1.64 MGD when the temperature decreases by 15°C. Both the minimum production capacities are higher than the average desalination design capacity. This means achieving a high flow rate can potentially meet all the energy requirements for reverse osmosis brackish water desalination.

The current desalination plant locations in Texas are shown in Figure 16 and are overlapping scenario 1's flow rate capacity map in Figure 17 (11). Figure 17 shows that many of the existing desalination facilites are located in the high product flow rate areas. Depending on the economic viability of installing a geothermal energy system, it may be worth installing geothermal systems at the existing desalination facilities.

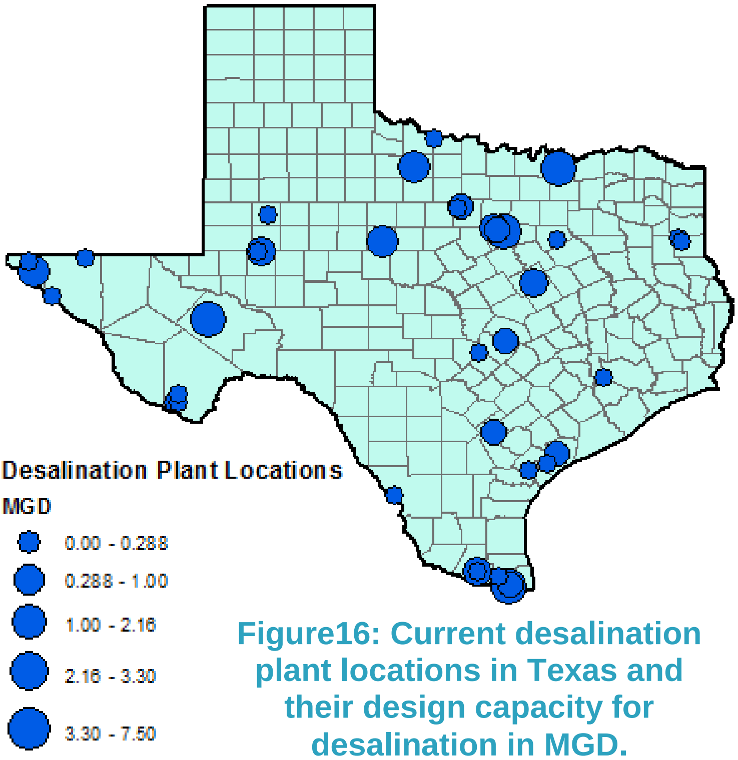

Figure16: Current desalination plant locations in Texas and their design capacity for desalination in MGD.

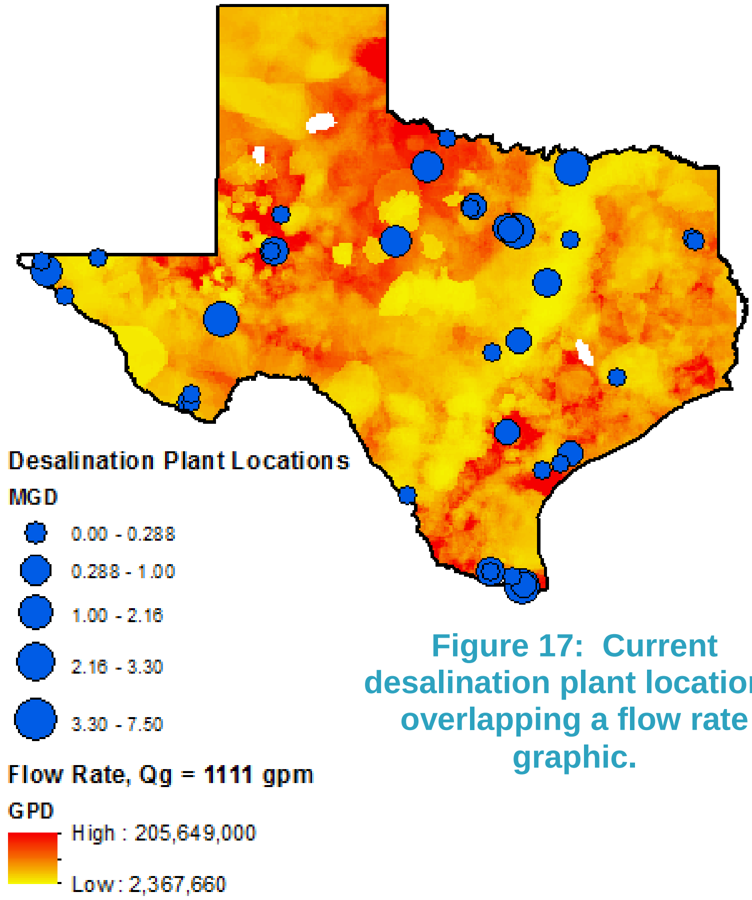

Figure 17: Current desalination plant locations overlapping a flow rate graphic.

Future Work

Based on the results, geothermal energy may be a viable means of mitigating the costs associated with reverse osmosis desalination. The next step is to improve upon the assumptions made for Equation [2], thereby improving the product flow rate capacity predictions. An economic analysis should be conducted on the cost of installing geothermal systems in current desalination plants and in planned desalination plants. If the cost of install and upkeep of a geothermal system is too high compared to the amount of freshwater produced, it would not be worth turning to geothermal energy for desalination.

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