Moving Water

New Mexico Supercomputing Challenge
Final Report
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Table of Contents

Executive Summary

Our project presents the feasibility of using a pipeline system to transport water across the country to regions that suffer from intense drought. We created a computer model to simulate a pipeline from Lake Livingston Reservoir in Houston, Texas to Elephant Butte Reservoir in Truth or Consequences, New Mexico. This pipeline is similar to pipelines that transfer oil and natural gas, but will be environmentally beneficial. We used Java to calculate the total pressure needed to pull the water out of Lake Livingston and then across Texas and New Mexico to Elephant Butte Reservoir. We had to figure out how to change the pumping pressure across the landscape as the elevation changed in order to decide where to put pumping stations. Ultimately, we created a program that can be easily changed for a multitude of different pipeline ideas. We were able to show that our proposed pipeline is possible to use for water transportation. However, we would require a more extensive knowledge about pipeline engineering in order to take this project to the next step.

Problem Statement

As the global population increases, global access to clean water resources continues to decline. In 2015, 844 million people lacked a basic water service and among them almost 159 million people had to collect drinking water directly from rivers, lakes, and other surface water sources (Drinking Water). This lack of water occurs even in the United States. Many of the Southwestern and Western states specifically are suffering through a historical drought period. As of mid-June 2001, 45 percent of New Mexico was in a “exceptional drought,” the worst drought category possible, and a 25 to 50 year recurring event (Exceptional Drought Conditions…). While water sources are lower than ever, demand continues to increase as the global population grows.

However, the Northeastern region of the United States does not suffer from drought on a regular basis. While many Northeastern states have regulatory issues concerning water distribution, water remains a plentiful resource (Gellis). In fact, many Americans do not have to think about conserving water in their everyday life the same way that others do. Finding a way to better distribute water sources across the United States would help to lessen the detrimental impact of drought in many Western states. In addition, this redistribution could greatly increase agricultural production, as many products are currently grown in areas where there is little water available. Historically, the western half of the United States withdraws more water per day for irrigation than the eastern half, with the most irrigation-intensive counties withdrawing more than one billion gallons of water per day (Harris). It is not sustainable to continue withdrawing this much water for irrigation in these areas. If nothing is done, agricultural production will decline and citizens of the United States will not have enough food.

To solve this issue, we propose building a pipeline to transport water across the United States. Already, the United States has the largest network of energy pipelines in the world, with more than 2.4 million miles of pipe. The network of crude oil pipelines in the U.S. is extensive. There are approximately 72,000 miles of crude oil lines (PIPELINE 101), and a total of 192,396 miles of liquid pipeline operating across the United States (About Pipelines). In addition, there are already many water transportation pipelines in the works. As shown in Figure 1, there are fifteen existing pipeline projects in the western United States (Forte). Our proposed pipeline would move water from Lake Livingston Reservoir in Houston, TX to Elephant Butte Reservoir in Truth or Consequences, NM. This would increase the water levels in the reservoir, and provide water for agricultural water rights holders in El Paso County (Rio Grande and Elephant Butte).

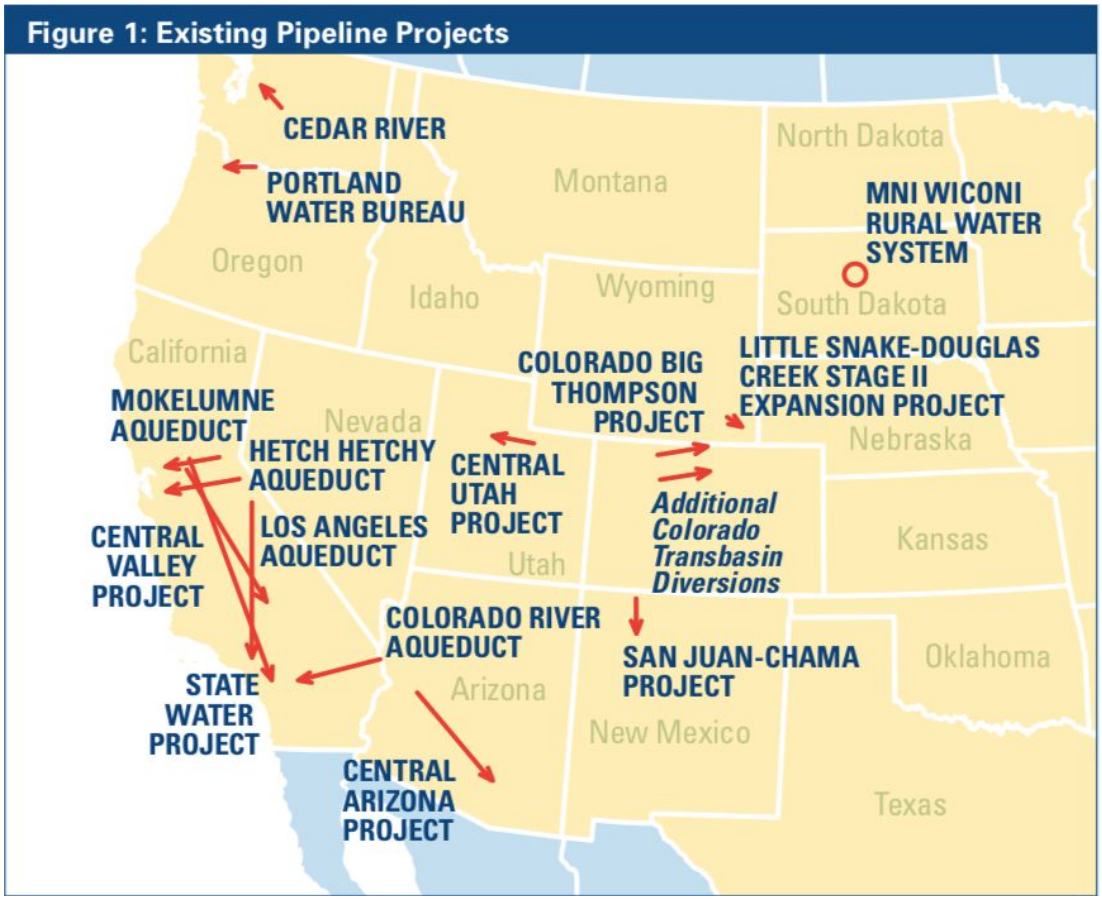

Figure 1 - Natural Resources Defense Council, 2012

The problem that we are addressing with our code is the location of pumping stations and power of pumping pressure across the landscape. In order to know the pressure needed, we must calculate the dynamic head needed to pull water out of Lake Livingston, which will tell us the type and power of the first pumping station. Then, we must calculate the pressure needed to transport water as the elevation changes across the landscape, which will tell us the locations, number of, and power of the rest of the pumping stations.

Methods

We used Java to calculate the operating pressure required to pump water from the lake to the receiving tank on the shore. To make this calculation we needed to find the Static head and Dynamic head of this part of the system. The change in elevation between the surface of the reservoir and the discharge point is the static head of the system. This calculation leaves us with two values: a maximum and a minimum. The maximum static head comes from the difference between the bottom water level of the reservoir to the discharge point in the receiving tank. The minimum static head comes from the difference between the bottom water level of the reservoir to the discharge point in the receiving tank. To calculate the dynamic head we must first calculate the velocity in the pipe as well as the loss coefficient. The velocity in the pipe is calculated by the flow rate through the pipe divided by the pipe cross sectional area. To find the cross sectional area you take pi times the diameter squared divided by four. Going back to the dynamic head equation, the loss coefficient is found by adding the K_fittings to the K_pipe. The value for the fitting was found on a standard table for different fittings. The value of the pipe came from calculating the friction coefficient times the pipe length divided by the diameter of the pipe. To find the friction coefficient we used a modified version of the Colebrook White equation (fig. 2).

$$f = \frac{0.25}{\left[\log\left\{\frac{k}{3.7 \times D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right\}\right]^2} \quad \dots (7)$$

where

k = Roughness factor (m)

Re = Reynolds number

Figure 2 - Colebrook White equation

The roughness factor comes from the type of pipe used (Pipe Roughness). We decided to use a commercial or welded steel pipe because corrosion occurs at a lesser degree with steel piping, and it is safe for outdoor use (Standards for Materials Used in Plumbing Systems). The Reynolds number is found by multiplying the velocity in the pipe times the diameter of the pipe all divided by the kinematic viscosity of water which is $1.31 * 10^{-6}\ m^2/sec$ 1. By finding this we can then calculate the maximum and the minimum total head values for the system.

We then needed to create a pumping system pressure curve. To do that we changed the value of the flow rate through the pipe by ten every iteration. We then exported the data to excel to create this graph (fig. 3).

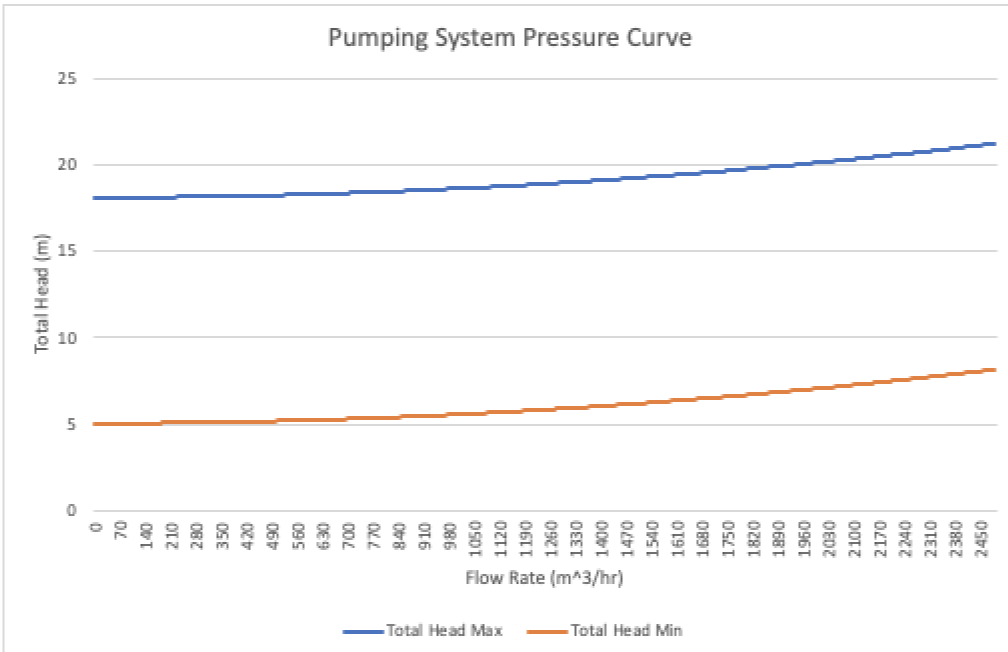

Figure 3 - Pumping System Pressure Curve

Next, we had to choose a pump to use in order to find the operating point on the curve. To do this, we researched commonly used pumps for a water pipeline. We found a pump with a desirable flow rate (240 m^3/h), head max (120 m), and pressure capacity (220 psi) (Pipeline Transportation Pumps). This pump is the “MEN End Suction” model, which we then found an informational pamphlet for, which included the flow range graph (MEN End Suction Water Pump). From this catalogue, we were able to transfer the flow range onto the Pumping System Pressure Curve graph that we generated from the Java program. This is shown in Figure 4 below.

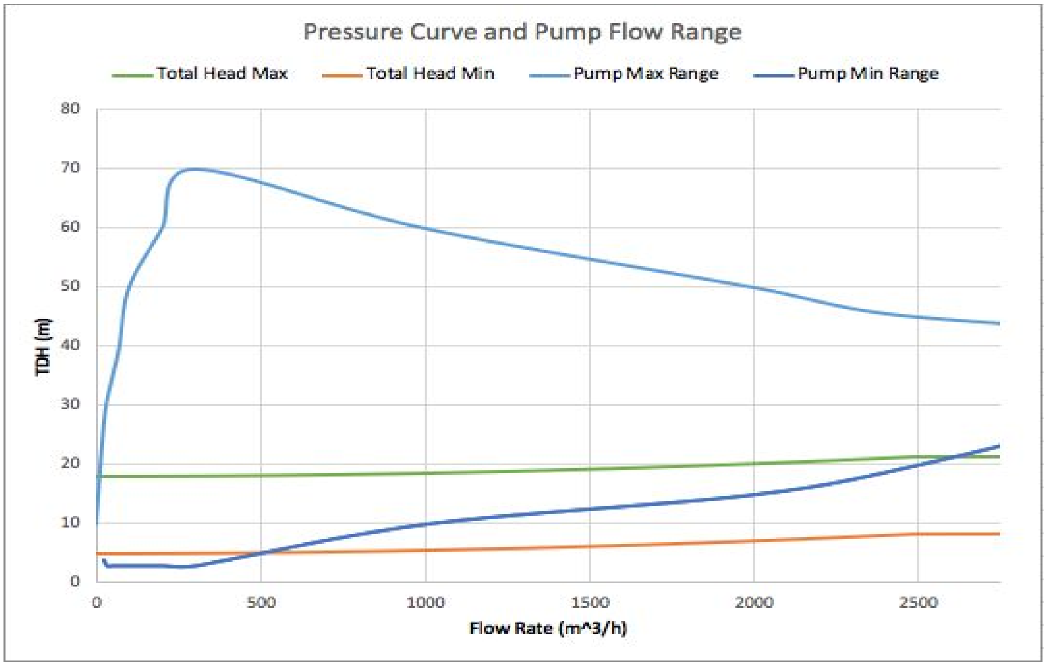

Figure 4 - Pressure Curve and Pump Flow Range

The points where the Minimum Pump Range function intersects with the Total Head MInimum and Total Head Maximum functions are the possible operating pints for the pumping system. This tells us what flow rate and dynamic head are required to pump water out of Lake Livingston.

Next, we had to figure out the locations for the rest of the pumping stations along the 1,161.3 kilometers of pipeline. To do this, we simply had to calculate the total pressure needed to move the water forward as the elevation increased across the land. This was a simple equation, $H_f + H_e + P_d = Total\ Pressure\ Needed$ (Menon; Menon 2004). Where H_f = head loss, H_e = elevation head, and P_d = minimum delivery pressure (Menon; Menon 2004). We had to use a seperate equation, $H_f = f(\frac{L}{D}) \times (\frac{v^2}{2g})$ to calculate the head loss (Pipe Flow Software). In this equation, f = friction factor, L = length of pipe work (m), D = inner diameter of pipe (m), v = velocity of fluid (m/s), and g = acceleration due to gravity (m/s^2) (Pipe Flow Software). Using these equations, we were able to figure out how far the water could travel before the pressure in the pipe exceeds its limit and another pumping station is required.

To figure out the elevation change across the landscape we are proposing for this pipeline, we used the USGS National Map. Using this resource, we mapped the elevation profile across the landscape that we wanted the pipeline to travel across, which is shown in Figure 5 (The National Map).

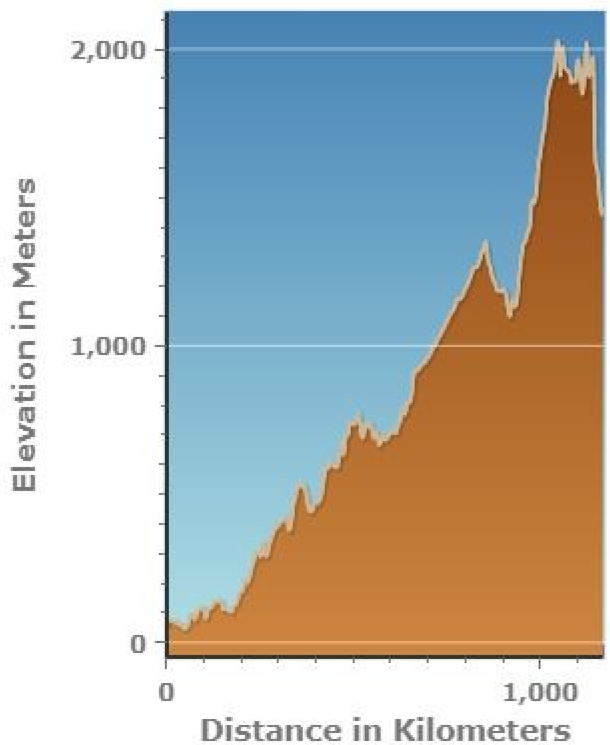

Figure 5 - USGS Elevation Profile for the Proposed Pipeline

Using the different elevation changes for different sections of pipe we performed an iteration for the different flow rates to calculate the total pressure. Using this total pressure we would be able to find out where to put the pumping stations. However, we are unable to do this without knowing what pumping station or the pressure the pipe can hold.

Results

Using the Eclipse Java IDE we were able to create a program that displays the minimum and maximum total head needed to pump water out of the lake. We found the the total head needed is a range from 4.92 - 17.17 meters. The program also gave us the total pressure for the pressure in different sections of the pipe. We found that the pressure depended heavily on the elevation change. With a better understanding of pipeline engineering we would have been able to create an actual beginning of a pipeline. This program proves that it is possible to create a pipeline that could move water from Houston Texas to the Rio Grande in New Mexico. We learned about the basics of pipeline engineering as well as how much is necessary to create a pipeline.

Discussion

This project turned out to be more difficult than we thought, because there are a plethora of factors that go into engineering a pipeline. From this project, we discovered how important computer science is when building pipelines. We had to factor in many variables, such as the velocity and density of water, the roughness factor of the pipeline, the pipeline material, and the elevation and pressure change across the pipe. If we attempted to design this pipeline without using Java, it would have taken a very long time. We believe that further developing this model would streamline the design process for future pipelines. Hopefully our model would be used primarily for water transportation pipelines, but could be used for natural gas or oil as well.

What held us back from completing the project when we intended was the research process. Specifically, there are many different pump models that we could have used. Since we did not have an expert to help us choose the best pump model, we spent a significant amount of our time simply researching pump models. We were finally able to find one that fit within our desired parameters, which then enabled us to finish the project.

Conclusions

From the iteration in Java, a pipeline engineer would be able to determine where the place pumping stations along the pipeline. To do this, they would have to figure out the pressure capacity in the pipe that they design. We were unable to acomplish this part, because we would have had to figure out the desired flow rate, which depends on the water demand from Elephant Butte and the capacity of the reservoirs. We do not know the specific water demand from Elephant Butte. However, we were able to determine preliminary distances using an assumed pressure capacity. Through extensive research and computer programming, we created a rough design for a water transportation pipeline. We were able to determine the dynamic head, choose a pump model, and roughly map out locations for pumping stations. If we were to develop this project further, we would have spoken to experts about pipe design and pump models. We could have also taken it further and calculated the price of this pipeline project. However, we reached the most comprehensive results possible within the timeline and our skill level.

Acknowledgements

We would like to thank Andy Leonard, a science teacher at Taos High School who helped us to develop our model. He helped us conduct research and find examples of other proposed and existing water transportation pipelines in the United States. Mr. Leonard showed us the Natural Resources Defense Council's report "Pipe Dreams: Water Supply Pipeline Projects in the West." Mr. Leonard has been a mentor and teacher for every member of our team throughout high school.

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