Mangrove Madness

Socorro High School Supercomputing Team

Final Report

April 3rd, 2019

Team Number: SHS 81

Socorro High School

Team Members:

Elias Zheng

Cody Johnston

Rio Sessions

Teacher Sponsor:

Jay Garcia

TABLE OF CONTENTS

TABLE OF FIGURES

EXECUTIVE SUMMARY

Drought and water shortages have become more and more common as the population is strangled by a shortage of available freshwater. To put this into perspective, if all the water in the world was represented by a gallon jug, only 3 ounces of the jug would be drinkable water, but of the 3 ounces, only 2 tablespoons are available to the population. The main goal of our project is to create and model a filter that mimics the Rhizophora Stylosa (The Spotted Mangrove). The spotted mangrove is able to intake saline water and output freshwater for usage in the plant.

Throughout this project, research was carried out with the purpose of graphing and modeling the impact of a mangrove-mimicking filter. The model supplies a general prediction to the efficiency, economic impact, and environmental footprint of the filter. The model includes five graphs in which each graph is a different output of the filter. The graphs also compare distillation to the proposed filter.

The filter was modeled using a series of programs which graphed the outputs and compared them to the current method of desalination. The first program is written in C and is used to output the data used in the second program. The second program is written in Python and uses the outputted data from the first program to graph the calculated values.

INTRODUCTION

Purpose

More than 844 million people are living without access to clean water, yet there has been no clear solution to this problem.[1] One fact remains, however. Almost all of these places have access to the ocean. The ocean has lots of potential for supplying humanity with fresh water. For one, the sea is large--covering 70% of our planet.[2] If this large resource can be efficiently tapped into, then water could be provided efficiently to many nations that have access to the sea.

Significance

While humanity makes leaps and strides in new technology, there are still millions in the world who don't have access to basic sanitation or drinkable water. Not only are current methods to desalinate water expensive (desalination for 300,000 people typically costs 100 million dollars[3]), they are also inefficient and have low durability. With an efficient, effective, and cheap filter that developing countries can easily afford, more people will have access to clean water and sanitation. In turn, public health improves, and the economy advances thanks to the betterment of living conditions. By improving basic services, the number of developing countries will slowly fade as countries advance their quality of life.

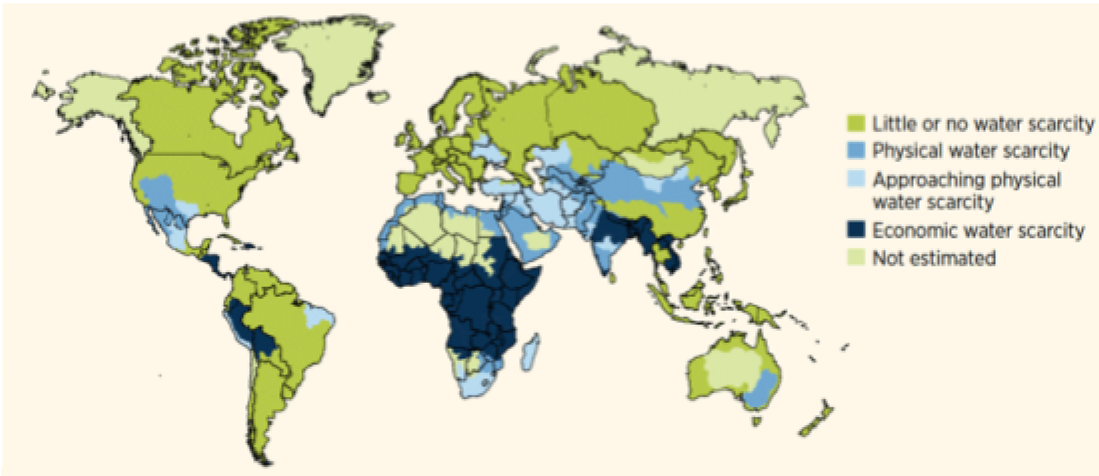

Figure 1: Global physical and economic water scarcity
Source: United Nations Department of Economic and Social Affairs

Background

The current, inefficient method of desalinating water is known as distillation. Distillation is a process in which water is evaporated, caught, and then cooled off, the final product being desalinated water. While it does work, it also removes important minerals, and then leaches those minerals out of the body when consumed.[4]

Scientists in South Korea conducted an experiment, examining the Rhizophora Stylosa's desalination capacity and comparing it to an experimental mimic filter based on polyethylene terephthalate. They found that the actual plant filtered 62% of the salt, while the mechanical filter filtered 95% of the salt in the fluid. Both desalination processes are based on zeta potential.

The root of a mangrove has an extremely negative zeta potential that repels chlorine ions. Positively charged salt ions are attracted to the surface of the root due to the attraction of opposite charges. They then collect on the surface of the root. Excess salt is then excreted through glands in leaves. Similarly, the filter uses zeta potentials to create an ion-depleted layer where ions are repelled.

METHODS

Filter

With the knowledge that mangrove-mimicking membranes (Figure 3) have been developed, we plan to utilize them in a water desalination plant model. The filter would contain three parts: the sediment filter first, then the mechanical filter, followed by the mangrove-mimicking filter. The sediment filter, would take out the large particles, such as dirt, sand, small pieces of garbage, etc. The mechanical filter (Figure 2) would take out things as large as plankton, algae, and microplastics, and as small as viruses and large ions. The mangrove filter (Figure 3) is made up of the membrane discussed in the Background section. It would remove

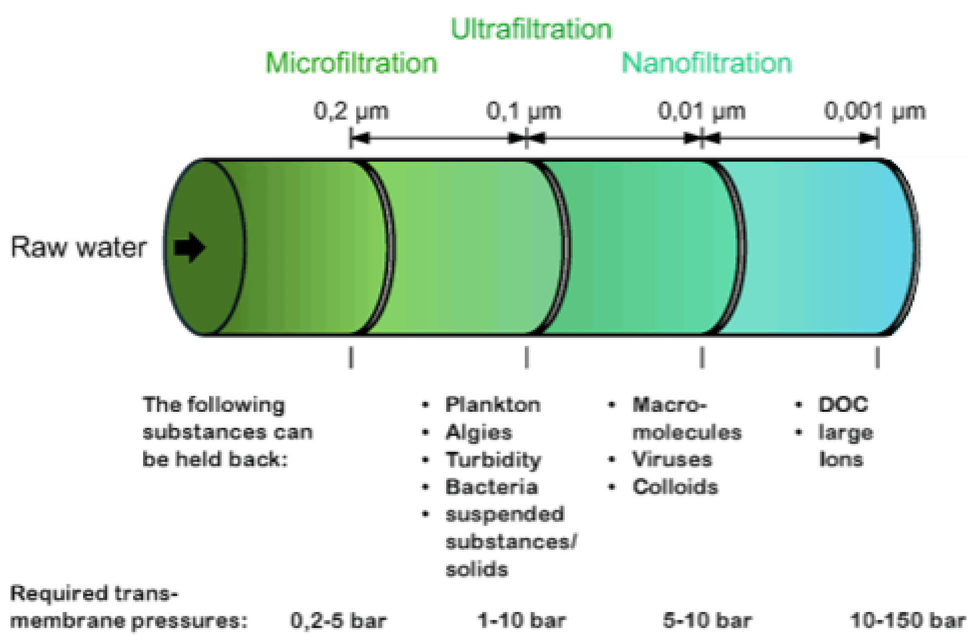

Figure 2: A model of the layers of a water filter.
Source: HydroGroup

salt ions from saline water. This filtration system would also allow the device to operate in freshwater, where it could potentially remove contaminants.

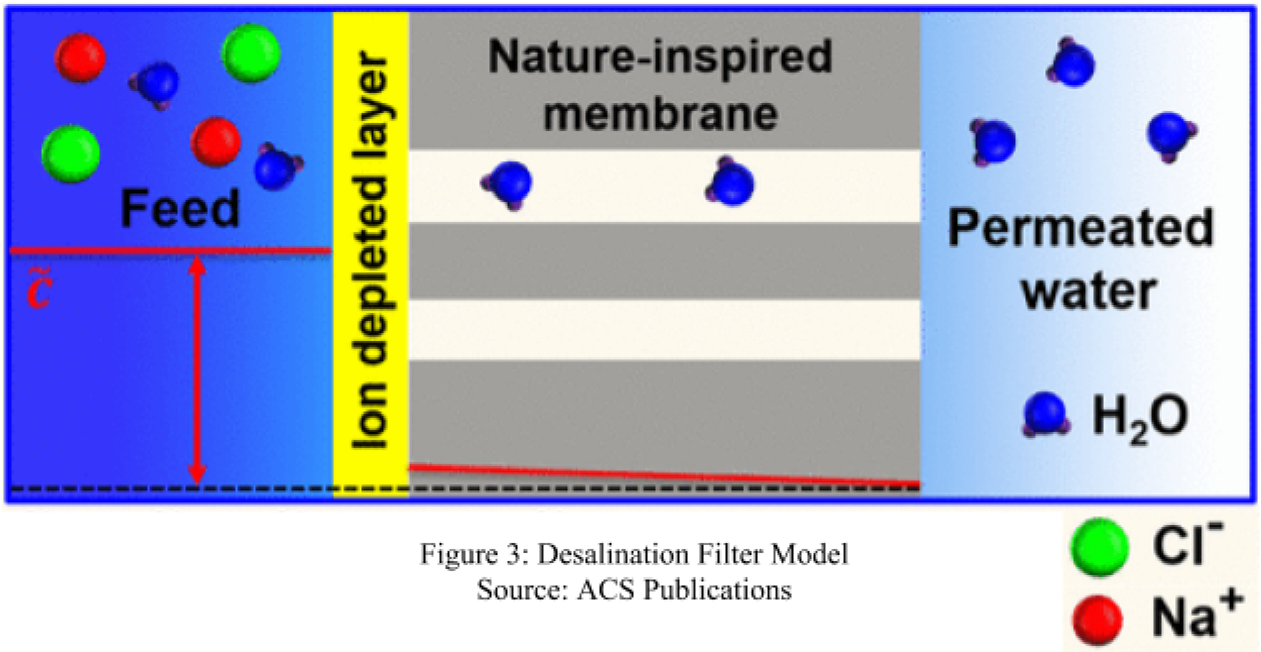

Figure 3: Desalination Filter Model
Source: ACS Publications

The water would be pumped through the filters with centrifugal pumps (Figure 4), which work by rotating a set of vanes in the center of a sealed chamber filled with water. When these vanes rotate, the water is caused to rotate, and centrifugal force pushes it outward, where it is caught in the volute chamber. More water is then siphoned into the system, pushing the initial water out. The process repeats, and water is moved.

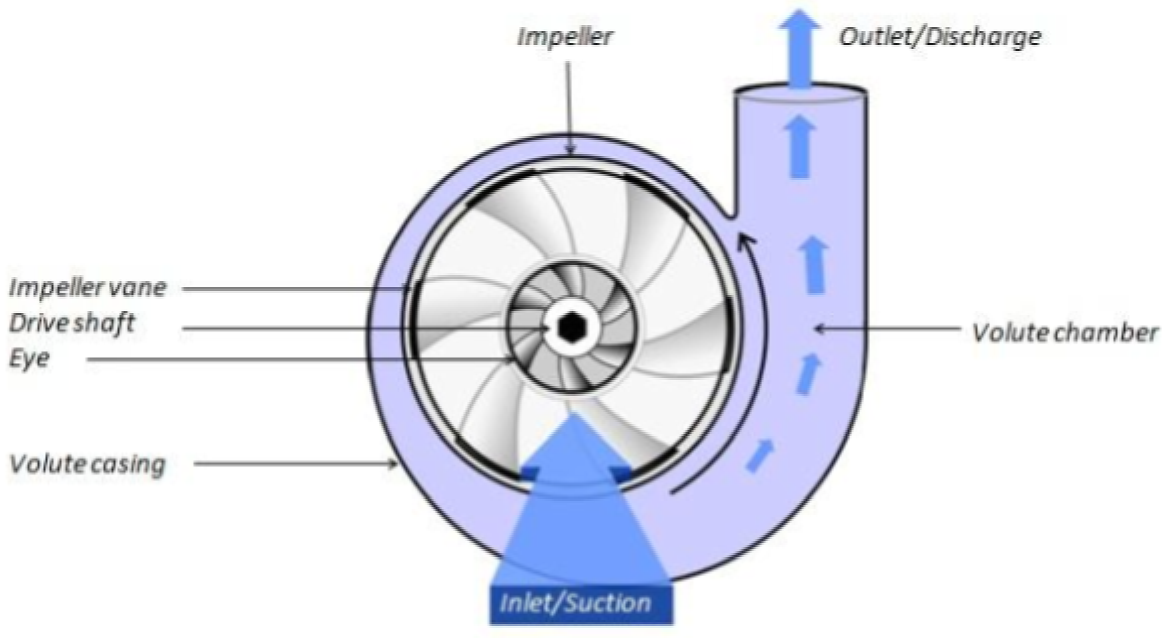

Figure 4: Diagram of a centrifugal pump
Source: Manish Nidhi, M.Sc. Mechanical Design & Manufacturing & Engineering, Tribhuvan University, on Quora

It is crucial that the head (friction) is lesser on the input end of the pump than that on the output end. If not, something called cavitation happens. Cavitation is a phenomenon where the pressure on the suction side of water dips below the pressure of the water. When this happens, the water begins to boil, causing vapor bubbles and damaging the pump (specifically the impeller, which is the part that holds the vanes, pictured in Figure 4).[8] To prevent this, we put minimal amount of filtering before the pump, just enough to minimise wear on the pump, and all other filtering will happen afterward.

Code [10]

The economic and environmental costs are calculated using a versatile, easily adjusted C program, and modeled using a python program (so that we could take advantage of matplotlib.pyplot, an easy, beautiful plotting library). The C program uses a header file that has all of the functions necessary for the calculations, and asks the user for values (in variables) to change from the default. It then calculates the costs to be plotted and analyzed. The C calculator consists of the following variables (*Note: We made all the variables doubles so as to avoid conflicts in trying to operate with integers and floats. We chose double instead of float to utilize the extra memory for most accurate results. Also note that all variables and functions are in italics*):

1. *water_input*: The amount of water going into the system (in liters). Default: 1000L
2. *salt_input*: The salinity of the water (in PSU). Default: 35.5PSU (The PSU of saltwater)
3. *num_filters*: The number of filters in the plant. Default: 1 (We only expect there to be one of these)
4. *water_height*: How far above the water source (most likely the ocean) the plant is. Default: 10.0 ft (We would expect the filter to not be more than 10 feet above, although this is best changed per filter)
5. *hrs_per_day*: The number of hours per day the plant runs. Default: 10hrs (The average workday)
6. *maintainence_cost*: The amount it costs to maintain the filters. Default: $\frac{\$19.66}{72hrs/hrs\_per\_day}$ (The filter costs $19.66/72hrs, as it is replaced every 3 days)
7. *employees*: The number of employees running the plant. Default: 24 (The average number of people running a water treatment plant)
8. *employee_salary*: the average (per hour) salary of employees. Default: 10$/hr (An estimate)

9. *init_cost*: The initial cost to build the plant. Default: $0 (This is the cost it initially required to build the plant and start getting it going. The default, zero dollars, is only a temporary value. If no initial value is given, one is estimated based on a building cost of $1,000,000 (an approximate building cost)).[5]
10. *electricity_cost*: The cost of electricity in your area. Default: $0.12 (The average cost of electricity across the US).[6]
11. *pump_hp*: The horsepower of the pumps that are being used in the plant. Default: 25hp (The average hp of centrifugal pumps)
12. *pump_head*: The head of the pump. Head is defined as how high the water is pumped with the friction of pipe and pump taken into account.[7] Default: 244m (The average head of a centrifugal pump).
13. *building_cost*: The cost of a building (this is a default estimate, overwritten if any value is given to init_cost). Value: $1,000,000 (A rough cost for a commercial building).[5]

The calculator would use those variables in certain functions (from the header file) to determine different aspects, such as cost, of the desalination plant. The first of these functions is *energy*, which calculates the electricity used by the mangrove-like method, using the formula $p_{hp} * 0.75 * hrs$, where p_{hp} represents the pump horsepower in hp, and hrs is the hours the plant is run per day. It requires 0.75 Kw of power per hp.

The next function is *pump_cost*, which calculates the cost to run the pump (which is just the cost for electricity), uses the function energy (see previous paragraph). The formula is $energy(p_{hp},\ hrs) * cost_{electricity}$, where p_{hp} represents the pump horsepower in hp, hrs is the hours the plant is run per day, and $cost_{electricity}$ is the cost of electricity. This is the cost to desalinate the water.

The function that converts cost per day of electricity (found using *pump_cost*) to cost per liter is called *filter_cost*. This divides the cost to filter per day by the hours run per day and divides that by 60 minutes to get cost per minute. That is then multiplied by the time to filter one liter (min/L) to get cost per liter of water.

The next function is *filter*, calculating the amount of water produced, is calculated by removing the quantity of salt and subtracting 1% of the water, to represent leaks and such.

Afterward comes *time_filter*, which calculates the amount of time to filter all of the water. This is done by finding how much time it would take to filter all of the water, using $t_{liter} * water_{in}$ where t_{liter} is the amount of time to filter one liter of water, and $water_{in}$ is the amount of water put into the system. That quantity is then divided by the number of filters to distribute the water around the filters.

The function *maintaining* comes next, to calculate the maintenance cost of the filter. This is done with $cost_{maintenance} + (employees * salary * hrs)$, where $cost_{maintencance}$ is the cost to maintain the plant for one day, employees is the number of employees working, *salary* is the employee salary, and *hrs* is the number of hours per day.

The next functions calculate the total cost to run the plant. The first one, *total_cost*, requires the cost of water per day, and adds that to the maintenance cost per day. The other, *total_cost_complex* converts water cost per liter to water cost per day using the time to filter one liter and the hours run per day (mangrove desalination uses the former, distillation the latter).

The next three functions are the distillation equivalent of *filter*, *pump_cost*, and *time_filter* (they only differ in that there are different methods of calculating for each). The function *distill_out* returns the distillation output of water, by removing 1/7 of the input (It takes 1L or water to distill 6L). The *time_filter* equivalent, *time_distill*, multiplies the water input by 63 minutes, as it takes 63 minutes to distill 1L of water. The final, *distill_cost*, calculates the distillation cost (just for filtering water) by multiplying the water input by $1.136, as it costs that much to distill per liter of water.

The function *build_cost* is the function that estimates the cost of building the plant. If no *init_cost* is given (the *init_cost* is at 0 after settings are exited), this function will run. It multiplies the cost of a pump by the number of filters and adds the approximate cost of a building to it to create a crude estimate.

The functions that calculate the waste factors (there is always waste) are *waste* and *distill_waste*. The former takes 1% of the water input and calls that waste, as this is the function used for mangrove-mimicking filters, and there shouldn't be any waste, but there should be some accommodated for. Because you waste 1 in 7 liters to distill water, we remove one-seventh of the water for waste.

The calculator also checks for the electricity used in distillation the function known as *distill_energy*, approximately 5 kWh per L of water.[9] So, this calculator multiplies 5 by the water input.

The last function the calculator has is called *filter_time_base*. This function calculates approximately how long it takes to filter one liter of water. First, it solves for flow rate, using the flow rate formula $3960 p_{hp}/(distance + head) * 3.7854$, where p_{hp} is the horsepower of the pump, distance is the vertical distance above the water, and head is the head of the filter. This is multiplied by 3.7854 to convert gal/min to L/min. Then, it finds the reciprocal to change L/min to min/L.

The python modeling program creates five graphs, comparing the mangrove-mimicking desalination technique to distillation. The calculated values from the C calculator are then transferred to a text file where they will be read in a python file where the data will be graphed.

MODEL

Figures

The data transferred into the text file are plotted into five graphs, under two figures. The first plotted figure (shown in Figure 5) represents economical impact, including graphs of the amount of water produced per hour, the cost to filter per 100 liters of input water, and the total cost for 200 days. The plots also compare to the current method of distillation (represented by blue dashed lines). All of the values used for the mangrove filter method are listed above in the code section. The values used for distillation that are not mentioned in the above code section are listed below.

1. Distillation columns cost very little to maintain, so we left the cost to maintain distillation columns as $0.
2. In a distillation plant, there are 220 employees, so in *maintaining*, we used 220 for *employees*.

The second figure plotted (shown in Figure 6) models the environmental effect from the filters.

RESULTS

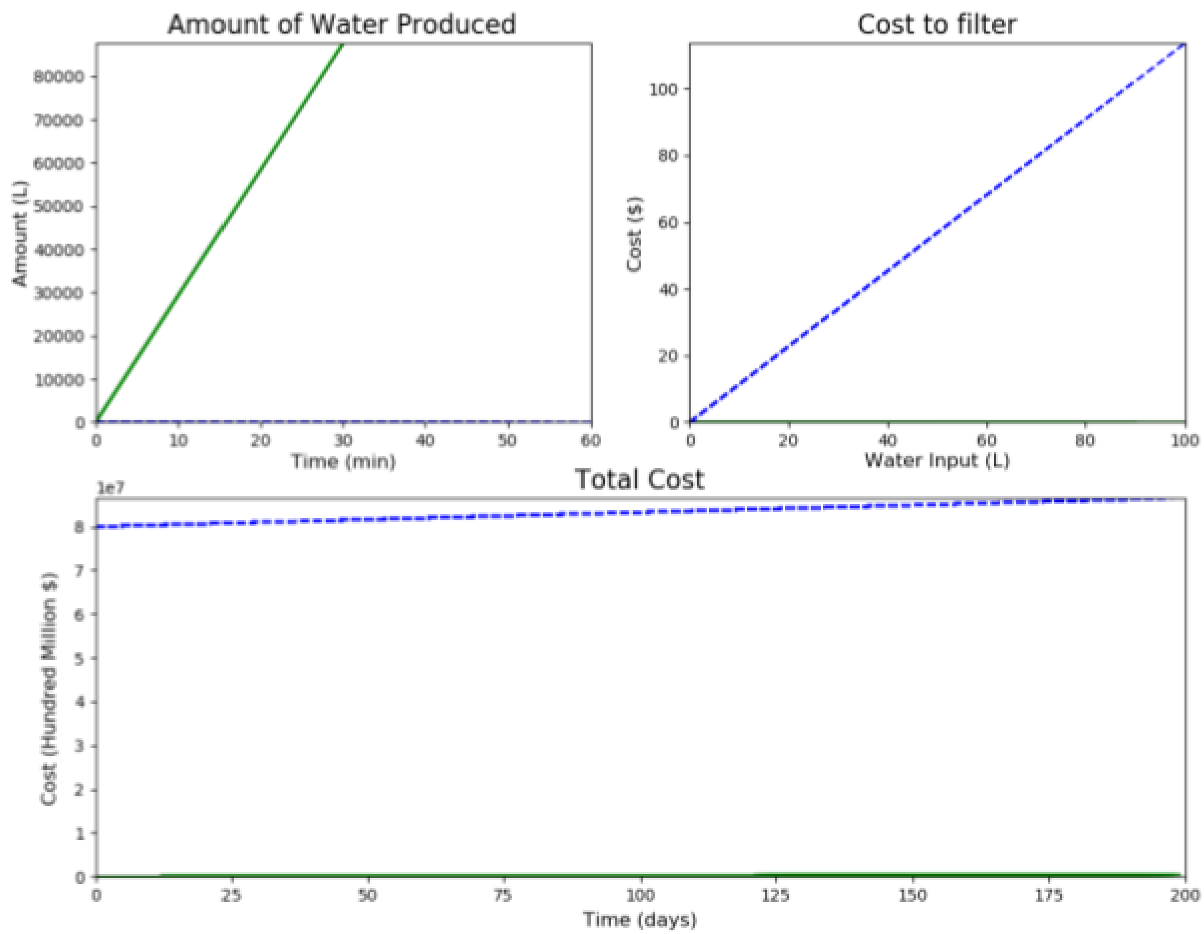

Figure 5: Model Plots -- Economical Impact
Key
Green solid lines: Desalination via mangrove-mimicking filter
Blue dashed lines: Distillation

In the economic plots, the mangrove-like filter seems to be the most economic, by producing the most water and costing the least. In 60 minutes, the mangrove filters would most likely produce 88520L, whereas distillation would produce 0.95L. In the "Cost to Filter" plot, we can see that distillation is orders of magnitude higher in cost than the mangrove-like filter. The mangrove filter requires only the cost of electricity to pump the water, and centrifugal pumps are relatively low cost to run. Distillation, on the other hand, requires the cost to heat the water to boiling, and to cool the water. This would cost much more than running a centrifugal pump. The total cost for distillation is much higher than that of our mangrove filter, even excluding the initial cost to build. This is most likely due to the high cost to run the distillation plant.

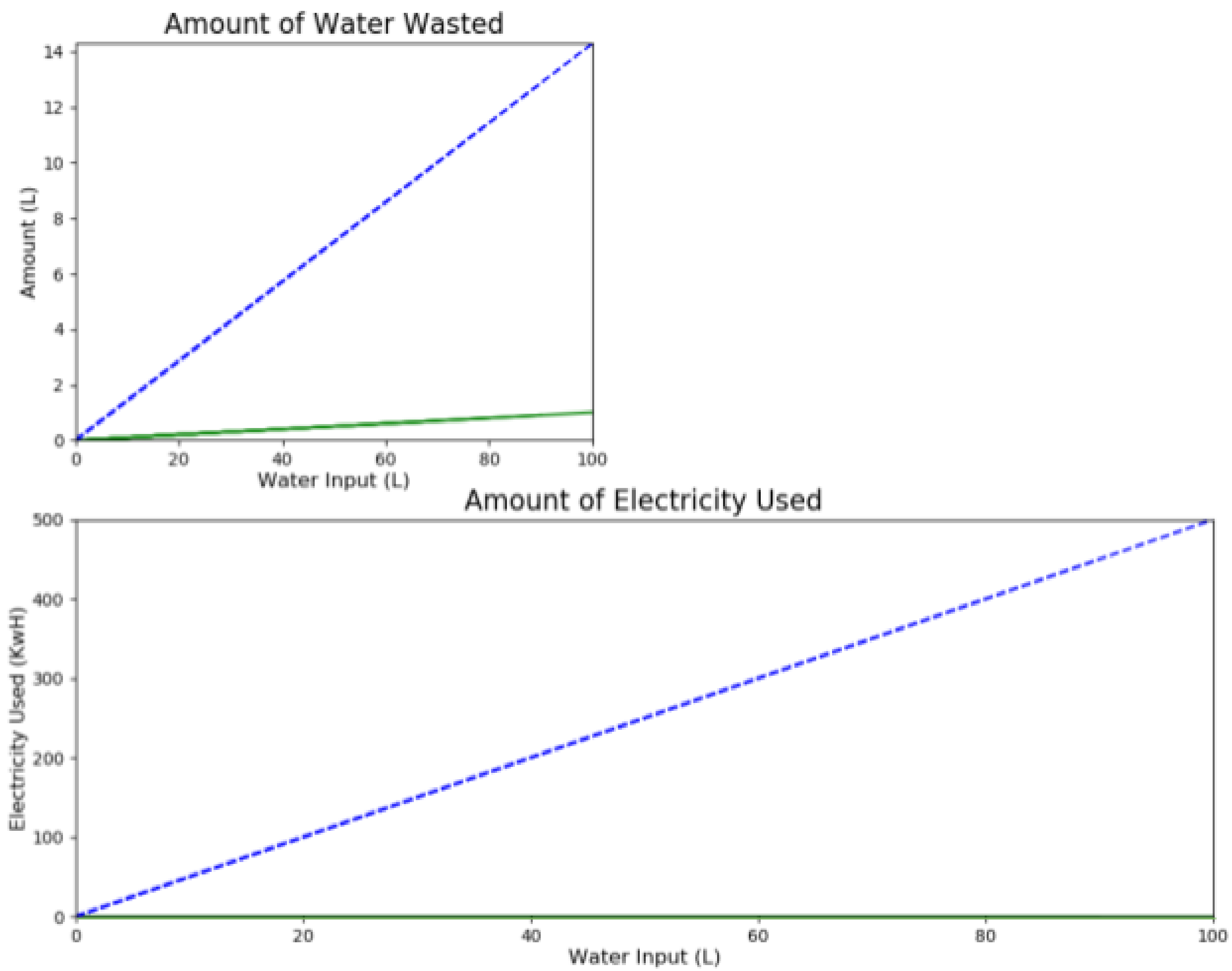

Figure 6: Model Plots -- Environmental Impact
Key
Green solid lines: Desalination via mangrove-mimicking filter
Blue dashed lines: Distillation

Figure 6 illustrates the environmental impact of the filters. The water wasted in distillation is much higher per liter due to cooling. Distillation uses one liter of water to cool every 6 liters of distilled water. There should be no water wasted in the mangrove filter method, but 1% was removed to account for leaks. The electricity used is much greater in a distillation system, as the energy required to heat up large amounts of water is sizeably larger than the energy required to run a pump.

CONCLUSIONS & DEVELOPMENT

Our model began as a simple C calculator that was able to calculate the costs of the filter, but required manual entry of many of the variables that we now calculate. We then added the Python graphing program for a visual representation of the numbers that we were getting. After this point, we began researching distillation to see how our filter compared to the current method of desalination. We decided to compare the mangrove-like filter to distillation, and that was the next big change. Finally, we decided to create a header file to keep better track of the functions, which at this point, we were calculating the time to filter one liter, cost to build the filter, cost to maintain the filter, etc. In the future, we plan to test with different input values and see how the graphs change and the relationship to distillation changes.

To summarize our project, distillation is expensive and inefficient, which is cost-prohibitive for developing countries. The mangrove filters would provide much more water than distillation and be more cost-effective. If created and implemented, more people would have access to clean water than they currently do, and the world would have a method to turn its largest water source into a drinkable alternative.

REFERENCES

[1] “Progress on Drinking Water, Sanitation and Hygiene.” World Health Organization, World Health Organization, 22 Feb. 2018, www.who.int/water_sanitation_health/publications/jmp-2017/en/.

[2] US Department of Commerce, and National Oceanic and Atmospheric Administration. “How Much Water Is in the Ocean?” NOAA's National Ocean Service, 1 June 2013, oceanservice.noaa.gov/facts/oceanwater.html.

[3] “How much does a water desalination plant cost?” Quora, Quora, 19 May 2015, https://www.quora.com/How-much-does-a-water-desalination-plant-cost/.

[4]”Can You Drink Distilled Water?” healthline, healthline, 2 Apr. 2019, https://www.healthline.com/health/can-you-drink-distilled-water#side-effects/.

[5] “What Is an Average Commercial Building Cost per Square Foot?” BuildingGuide |Steel Buildings| America, 2 Apr. 2019, www.buildingsguide.com/faq/what-average-commercial-building-cost-square-foot/.

[6] Jiang, Jess. “The Price Of Electricity In Your State.” NPR, NPR, 28 Oct. 2011, www.npr.org/sections/money/2011/10/27/141766341/the-price-of-electricity-in-your-state.

[7] “Lift, Head & Flow.” Lift & Head, 2 Apr. 2019, www.onestopfire.com/head.htm.

[8] “EXPLORE the WORLD of PIPING.” A Centrifugal Pump Is a Machine Used for the Purpose of Transferring Quantities of Fluids and or Gases, from One Place to Another, 2 Apr. 2019, www.wermac.org/equipment/pumps_centrifugal.html.

[9] “Energy Requirements Of Desalination Processes.” DESWARE, 2 Apr. 2019, www.desware.net/Energy-Requirements-Desalination-Processes.aspx.

[10] Resources used in programming

1. “Water Distillation Plants: Distilling Water for the Masses.” ALL ABOUT WATER FILTERS, 22 Jan. 2019, all-about-water-filters.com/water-distillation-plants/.
2. "How much does it cost to collect, purify, and distribute distilled water?" Quora, Quora, 23 Feb 2017 https://www.quora.com/How-much-does-it-cost-to-collect-purify-and-distribute-distilled-water
3. “Drinking Water Treatment - Distillation.” EXtension, articles.extension.org/pages/31572/drinking-water-treatment-distillation.
4. “The Cost of Desalination.” Advisian, www.advisian.com/en-us/global-perspectives/the-cost-of-desalination.
5. “What Is the Difference Between Water & Air Cooled Condensers?” Murphy & Miller, Inc., 27 May 2017, www.murphymiller.com/water-cooled-vs-air-cooled-condensers/.
6. “Average Water Treatment Operator Hourly Pay.” PayScale, www.payscale.com/research/US/Job=Water_Treatment_Operator/Hourly_Rate.
7. "A new approach to meet the growing demand of professional training for the operating and management staff of desalination plants" ScienceDirect, March 2008, https://www.sciencedirect.com/science/article/pii/S0011916407006133
8. Deionized Water System, Tap Water Inlet, 90 Liters/Hour, www.mrclab.com/productDetails.aspx?pid=85881.
9. “Running COSTs of Wastewater Treatment Plants.” Running Cost of Wastewater Treatment Plant- CostWater.com, www.costwater.com/runningcostwastewater.htm.
10. “Energy Requirements Of Desalination Processes.” DESWARE,DESWARE www.desware.net/Energy-Requirements-Desalination-Processes.aspx./

ACKNOWLEDGEMENTS

Thank you to **Mr. Garcia** for always being there for us and being an excellent supportive coach. We could not have done this project without your assistance and time. We really appreciate what you've done for this team

A big thank you to **Mr. Lehr, Ms. Keeny, Ms. Ross, Mrs. Aguilar, and Mrs. Ezzat** for critiquing our interim presentation and helping us improve. It was much appreciated.

A big shout out to **Mr. Lehr, Mrs. Huff, and Mrs. Aguilar** for taking their time to rifle through our final report and give us feedback on it for better results. We are hugely grateful.

OUR DRIVE FOLDER & CODE

bit.ly/mangrove-madness