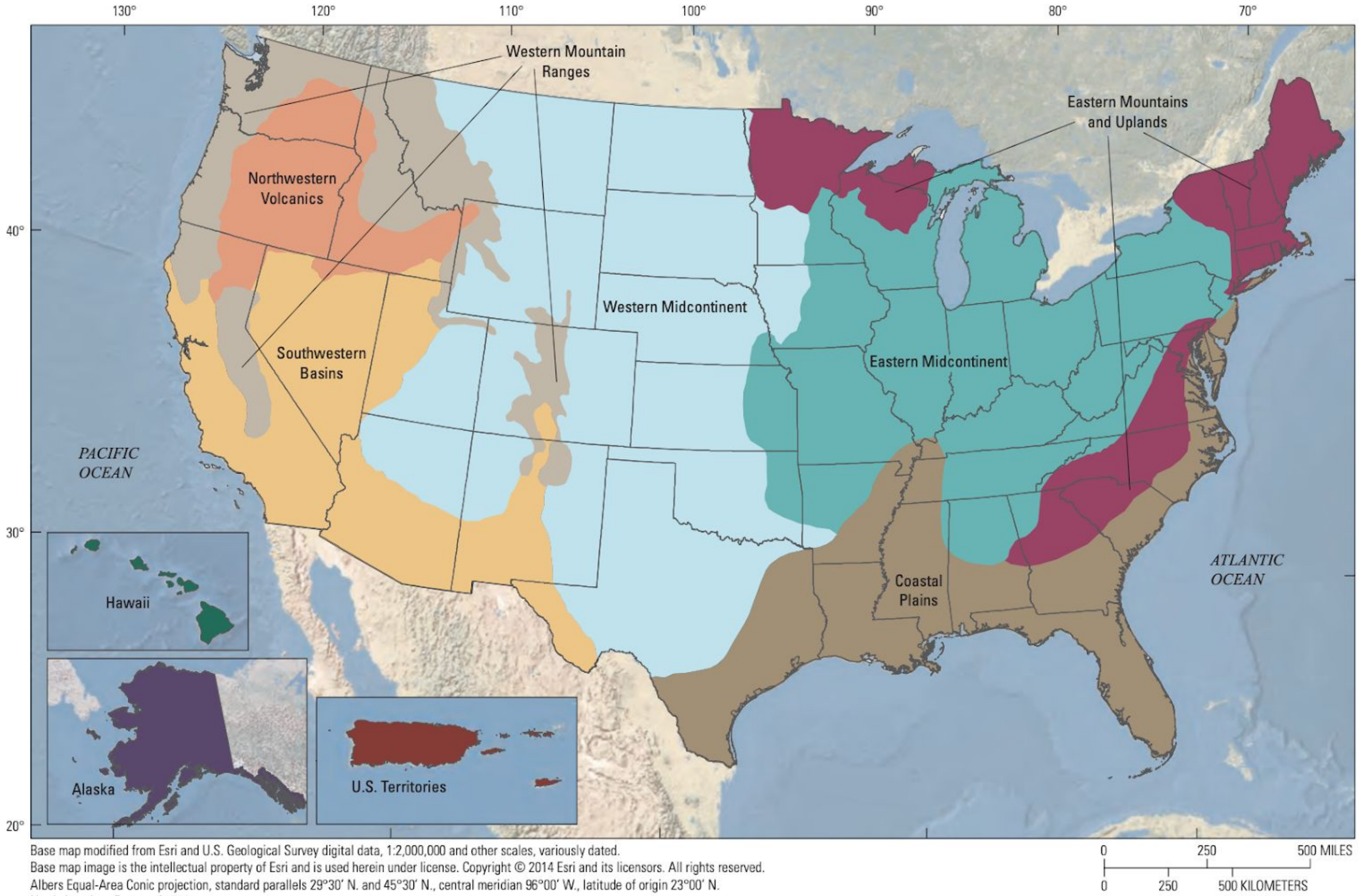
Multiple Effect Water Desalination - Grant Proposal

iCons 1 - Independent Case Study[1]



Base map modified from Esri and U.S. Geological Survey digital data, 1:2,000,000 and other scales, variously dated.
Base map image is the intellectual property of Esri and is used herein under license. Copyright © 2014 Esri and its licensors. All rights reserved.
Albers Equal-Area Conic projection, standard parallels 29°30′ N. and 45°30′ N., central meridian 96°00′ W., latitude of origin 23°00′ N.
North American Datum of 1983

Figure 7. Brackish groundwater regions in the United States and selected U.S. territories; modified from Heath (1984).

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[1] Stranton, J. S., Anning, D. W., Brown, C. J., Moore, R. B., McGuire, V. L., Qi, S. L. (2017).

I. Project Summary

A lack of a sustainable water source remains a universal problem faced by communities around the world. The need to find a water source that can be maintained without depletion is paramount for many generations ahead. The primary question is how we can maximize the efficiency and minimize the cost of multiple-effect distillation (MED) at different salinities through temperature and each repeating stage of the distillation process, also known as the number of effects.

For the range of salinities of brackish water, there exists a specific setting of temperature and number of effects used that maximizes the efficiency of the MED system, particular to that sample's salinity. Essentially, the setting of these variables that maximizes efficiency for highly saline water samples is not necessarily the same for samples that are less concentrated. Efficiency is measured by maximizing clean water output and minimizing waste produced, energy consumed, and overall cost.

We hypothesize that at a concentration of 35 ppt, the multiple-effect distillation will be most efficient when seven effects are used at an initial temperature of 85 degrees celsius.

For a concentration of 20 ppt, the multiple-effect distillation will be most efficient when five effects are used at an initial temperature of 75 degrees celsius

Finally, we hypothesize that for a solution with a salinity of 5 ppt, the MED will be most efficient when three effects are used at an initial temperature 65 degrees celsius.

II. Background

The majority of Earth's water is unsuitable for human consumption. For the finite water resources we do have, they are often withheld from the most underprivileged groups. Thus, we wish to compare different variables in the desalination process with the hope of finding a cost-effective, energy efficient method of making water more accessible to the public. As coastal communities face the brunt of effects from climate change through sea level rise, the applications of these desalination methods could help vulnerable communities secure access to clean drinking and bathing water.

Extreme weather events are increasingly common and sea levels are rising, contaminating many sources of coastal freshwater with salt. These bodies of mixed water are known as brackish water. A study[2] on seagrasses found that ocean water has been invading viable water sources along the coast, altering their salinity, and rendering them unusable. There are already methods that exist that desalinate ocean water, namely reverse osmosis, but they are expensive. The goal of this project is to maximize the efficiency of multi-effect distillation to address varying concentrations of brackish water salinity.

The primary method used in this research is multiple-effect distillation (MED). In this process, raw salt water is sprayed onto hot pipes. This generates steam which heats the new waves of water coming in. The evaporated water is ultimately collected when the steam condenses on a cooled platform (see Figure 1). The temperature of the pipes, as well as the number of effects, influence the final salinity of the water and the percent yield from the initial sample. An "effect" is a stage as described above in which contaminated water passes through the plant during the distillation process. Water is typically sent through multiple effects to achieve the best results.

At MIT, researchers are comparing the entropy generation of thermal desalination and comparing the most effective temperatures to be used in multiple-effect systems[3]. MED is a type of thermal desalination. In their study, they are seeking to mitigate energy consumption by using waste heat to power these systems, as there currently lacks data on how to incorporate sustainable

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[2] Short, Frederick T., and Hilary A. Neckles (1999).

[3] Warsinger, D.M.; Mistry, K.H.; Nayar, K.G.; Chung, H.W.; Lienhard, J.H., V. (2015).

desalination processes that consume less energy than the traditional water purification plant. No conclusive evidence has been found for the optimal temperature due to confounding variables of what aspect of the study design is the cause for an increased water output and lack of data on these studies. If research efforts continue, it is possible that a desalination system with a significant decrease in energy use could be implemented as a common practice. Researchers are also looking at the economic impacts of using this method with high salinity wastewater, looking to find the relationship between temperature/number of effects and clean water output[4]. Furthermore, publications by the United States Geological Survey show an influx in brackish groundwater and marked many Southern and West Coast communities as being at "extreme water-supply sustainability risk"[5].

It is evident that there are pressing societal issues that lend to the importance of this case study. There currently still exists a large gap in knowledge, specifically on what conditions are most efficient in terms of multiple-effect distillation. Research has not been done on the effects of different salinity concentrations, which is another gap that we can fill in the scientific community. Given the chance to complete more research, there are many possible nationwide and global applications that could help these at-risk communities.

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[4] Zhao, Dongfeng, Jianliang Xue, Shi Li, Hui Sun, and Qing-dong Zhang (2011).

[5] Stranton (2017).

III. Methods

This study intends to work with three independent variables: temperature, number of effects, and salinity concentrations. Temperature will alter rates of evaporation and consequently the salinity of the water after treatment in the MED. The number of effects and salinity concentrations are both being tested because they have been found to affect the brine output as well as the final water salinity and percent yield. Further, we want to test how initial salinity concentrations change the effectiveness of different temperatures and number of effects.

Nine different treatments will be created and tested: 3 different temperatures, 3 different numbers of effects, and 3 different salinity concentrations. The temperatures will be 65, 75, and 85 degrees Celsius, the effect numbers will be 3, 5, and 7 effects, and the salinity concentrations will be 5 ppt, 20 ppt, and 35 ppt. The 5, 20, and 35 ppt concentrations are comparable to a range of salt concentrations for brackish water, with 5 being the lowest, 20 being intermediate, and 35 being high. The pressure will be set at 0.197 atm (149.4 torr) so as to boil the water at a lower temperature. We picked this pressure value because it is the exact pressure at which water will boil at 60 degrees Celsius. This pressure value will also remain constant so as to avoid confounding factors when analyzing our independent variables. All of the samples will be created with distilled water and adding a respective amount of Instant Ocean salt mix. These concentrations were picked keeping broader applications in mind, as brackish groundwater might become the sole water sources for some communities. As for the number of effects, 3 is a relatively low number of effects that can be done, 5 is around the average for most MED water treatment plants that test ocean water, and 7 is nearing the maximum for the number of effects that we hypothesize will still be effective and efficient. A similar thinking applies to the temperature values we picked. The temperature of 65 degrees celsius is on the low end, 85 is the high end, and 75 is a common water temperature used by MED plants. Each treatment will be replicated 10 times for statistical significance. A control group will be run with each of the 90 tests which will contain water with no salt concentration. This will ensure that the multiple effect distillation plant works by providing a comparison between the percent yield for zero salinity water and water with varying salinity concentrations. The control treatment will also be a base for analysis of our experimental factors, such that if zero salinity water has a thirty percent yield, we know that seventy percent was lost to the atmosphere or left the system as brine. Ultimately, the control will help us understand the efficiency of the machine without salt. Furthermore, for each treatment, the variables not being tested will be held constant at the intermediate numbers: temperature at 75 degrees celsius; effect number at 4; and salinity at 35 parts per thousand. If, for example, tests are conducted on temperature, only temperature will fluctuate. Salinity and effect number will be held constant so as not to confound the results.

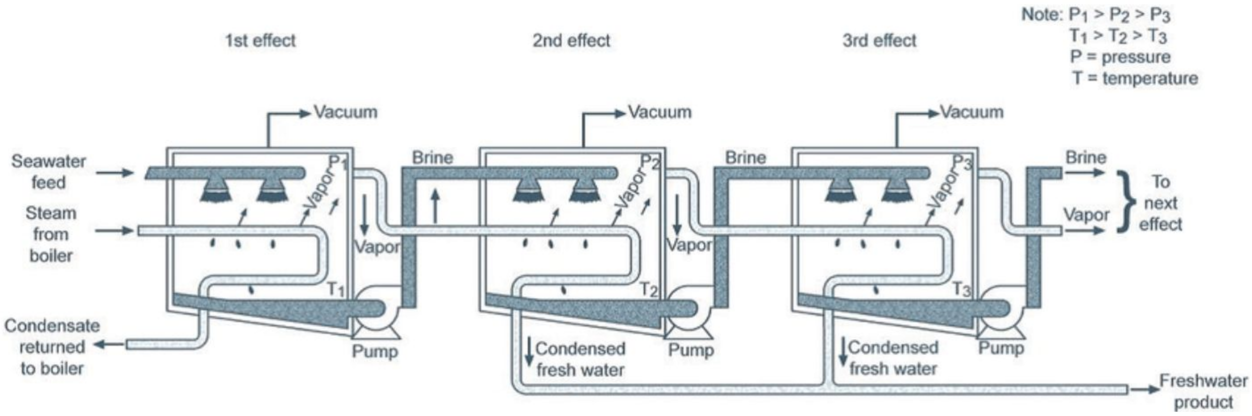

Figure 1. A system diagram of the multi-effect distillation process.[6]

To collect data, water will be gathered from tanks at the end of the multiple effect distillation process. First, the water's salinity will be measured with a hydrometer. This will measure the specific conductivity and temperature of the water which can be converted into salinity. A salinity measurement of the brine water left over after treatment will also be taken. Next, a measurement of the volume of the brine water and of the final potable water produced, to ultimately calculate percent yield, will be taken. Standard lab supplies will be used along with large vats that the distilled water is shipped in. The hired workers will assist in carrying the vats of water to and from the MED equipment.

The initial volume will be 50 liters per treatment (and like mentioned above, we will have 9 treatments with 10 replicates each). This means 4,500 liters of distilled water will be needed. Instant Ocean salt mix will be added in varying concentrations to each distilled water sample. To ensure that the water salinity is

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[6] Metcalf and Eddy (2003)

uniform throughout, we will mix the water we find and then measure its salt concentration before putting it into our machine.

Some sources of error are if the measurements of our salinity are incorrect due to inconsistency of tools. To solve this, we plan on using the highest grade hydrometers that can detect salinity accurately and precisely. One more thing we need to account for is the outside temperature. The majority of water distillation plants are outside because they are so large. To ensure that external factors do not influence our results, we will run the MED on days where the temperature is constant and not cold enough to impact our results. Lastly, we will run 10 replications of each treatment in order to prevent outliers from skewing our data.

An assumption made is that heavy metals do not influence the distillation process. Although we are not including them in our experiment, we do intend to have real world applications. Most plants use ocean water and brackish water, which are not purely salt (they might contain heavy metals and other ions). Our assumption is that our results would not have been affected by such particles and therefore we excluded them from our water samples by using distilled water and Instant Ocean mix.

The collected data will be analyzed in an excel spreadsheet. Minitab Express, a statistical analysis software, is another option for data analysis. The final salinity of water in the different treatment groups and the percent yield of potable water will be compared. The brine that is released from the treatment groups will be measured to determine how much water was lost and not desalinated. The independent variables, temperature, number of effects, and initial water salinity, will be analyzed to see how they each affect the dependent variables: final water salinity, percent yield of potable water, and brine output. Causation between all of the independent variables will be identified to find meaningful data regarding an increase or decrease in one and the respective changes in the dependent variables. Since two of the three variables will be held constant to measure the third, it can be proved that the independent variables somehow affect the dependent variables. For example, if no confounding variables affect our results, and results show that an increase in temperature leads to an increase in potable water yield, this information can be used in plants around the world to maximize their potable water output. Each of three graph models the change in distillation efficiency over the given dependent variable. Distillation efficiency measures the percent of salt of the total in the original sample remaining after multiple-effect distillation.

IV. Anticipated Results

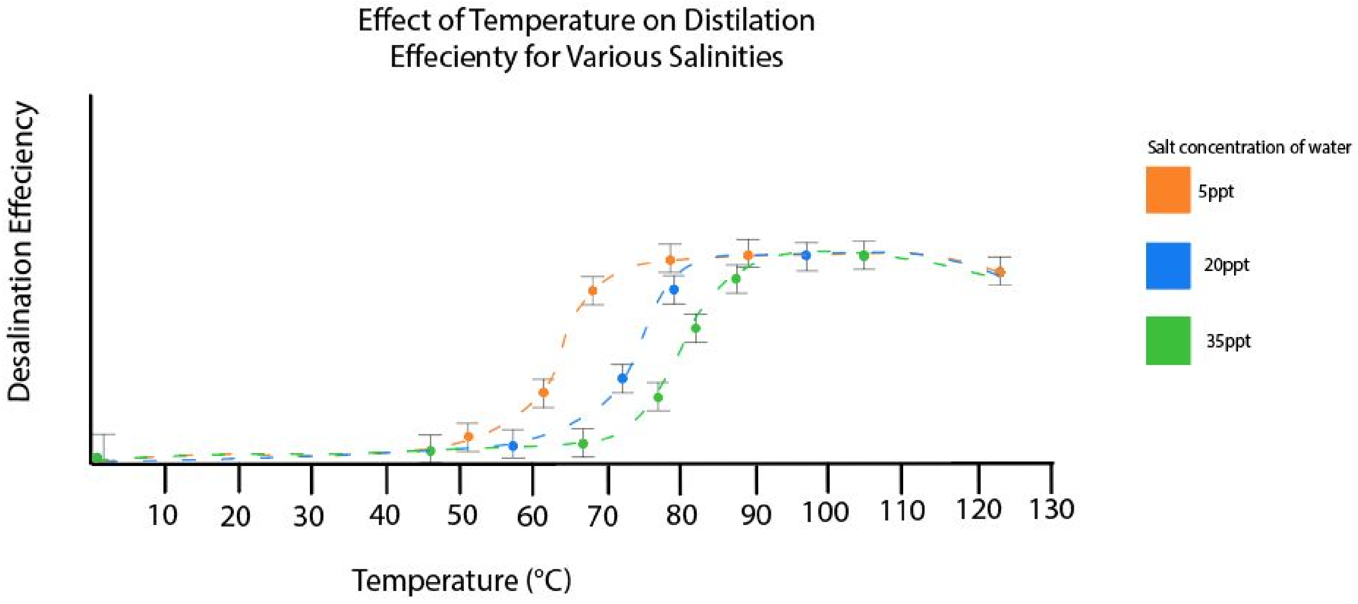

Figure A

The x-axis shows temperature in degrees Celsius and the y-axis shows desalination efficiency. As mentioned in the project summary, desalination efficiency is defined as a value that takes into account the cost of the effects as well as the percent of potable drinking water produced relative to the initial amount of salinity concentration and water initially present. There are no values currently on this axis, as this graph intends to show the trend we expect to see.

This figure is designed to interpret how as temperature increases, the efficiency changes for different salinity concentrations in our MED plant. The spikes in desalination efficiency shown by the logistic curves are placed where we believe the water will boil. The pressure mentioned in the methods section explains that pure water should boil at 60 degrees Celsius. With the increase in solute in the water, the boiling point will also increase. Therefore, the spike for 5 ppt is at 65 degrees Celsius, for 20 ppt it is at around 75 degrees Celsius, and for the 35 ppt it is at 85 degrees Celsius.

It is important to note that the distillation efficiency has a maximum that is the same for all the salinity concentrations, but it takes a different temperature to reach that maximum due to varying boiling points. Furthermore, the efficiency is at zero for all the temperatures before the boiling point because without boiling the water, no evaporation occurs and no water will be collected. On the other hand, when temperatures are significantly higher than that needed to boil the water, excess energy is being used and paid for that would not necessarily yield more potable drinking water from the initial amount of salt water. With higher costs and less overall yields, the desalination efficiency would thus decrease after the maximum point.

The lines drawn are dotted because they are assumed trendlines, but since we will not be testing every single data point, we cannot draw connected smooth lines. The error bars are not specific to our data, they just mark the standard error to show the possible fluctuation in data collection and sampling. Even when taking the error into account, the trends stated above remain clear.

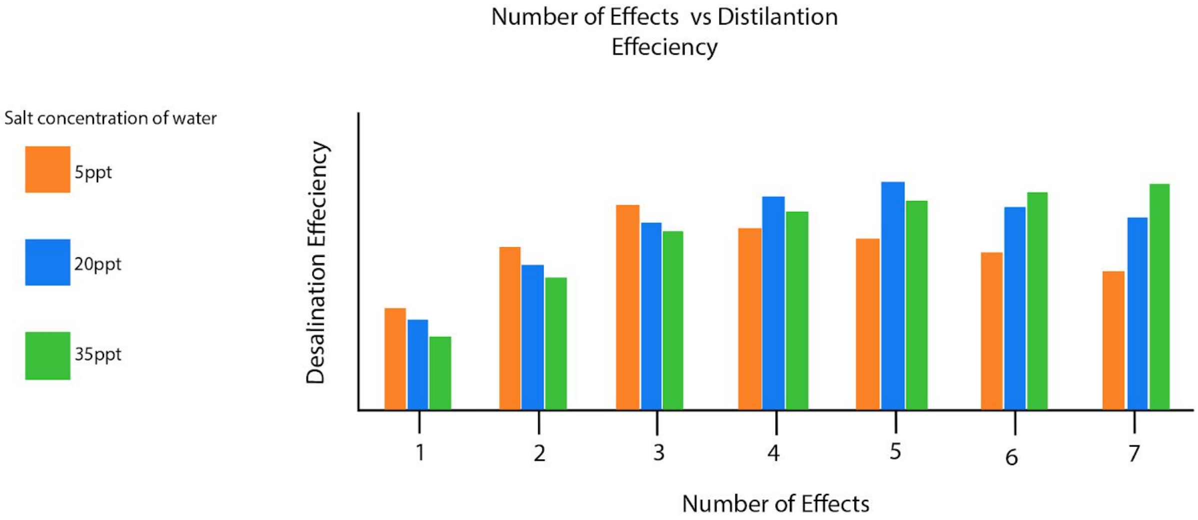

Figure B

In Figure B, The x-axis shows the number of effects and the y-axis shows desalination efficiency. The desalination efficiency is defined the same as in Figure A.

This figure depicts the predicted results of the number of effects on the distillation efficiency of the three salinity concentrations we are testing. The 5 ppt salinity concentration increases rapidly at one effect, maxing out its efficiency at three effects. We believe this to be the case because of the low amount of salt concentration. Therefore, a lower number of effects would remove the already low levels of salt more quickly. All future effects are hypothesized to diminish efficiency because of more resources spent on running more effects with no increase in potable water. When running already clean water (after effect number three) through more effects, there would be no benefit. Following the same trend, 20 ppt would increase in efficiency at a certain number of effects and then decrease after its climax of efficiency. The difference here being that instead of reaching maximum efficiency at three, it would reach it at five. This is because there is more salt to be removed, so more effects are needed to remove all of the salt. Lastly, the 35 ppt peaks at seven effects because all of the effects before it would not fully remove the salt initially present. Overall, it takes more effects to efficiently remove more salt.

In the graph, each successive effect increases the efficiency less than the previous one because there is less water to be desalinated and a lower concentration of salt in each successive stage.

Furthermore, although the maximum water that can be drawn from the initial samples - and thus the efficiency of the effects - is the same for all the samples at the end of all the trials, their maximum occurs at a different number of effects. This is demonstrated by the graph by showing that the 5 ppt reaches a maximum at three effects, and this maximum is the same as that of the 20 ppt and 30 ppt at their respective effects of five and seven.

Lastly, the initial effects have a larger efficiency value for the lower salinity concentrations because if an effect removes a certain amount of salt, then this percent of salt removed will be greater if a smaller amount is initially present. In addition, this means a larger percentage of potable drinking water consequently created with regards to the amount the trial began with. The higher salinity, such as 35 ppt, would not show as much efficiency from only one effect since it would remove a certain amount of salt, but this would not translate to as large of a percent change from the initial as the 5 ppt concentration would show.

V. Timeline

Phase	Description	Approximate Time Needed
Research	Identifying water sources, setting up experimental design, planning for the future, creating a research question and hypothesis	1 month
Logistics and Organizing	Contracting a facility with MED's we can experiment on, setting up a research team to facilitate and monitor each part of the study	5 months
Sample Preparation	Preparing ninety (10 for each of the 9 treatments) water samples using Instant Ocean. Transport them and store them in the lab until we use that sample	0.5 month
Data Collection	Changing out and maintaining effects and other equipment, allow each sample to pass through effects, recording data in a data table, disposal of wastewater, setting up for the next sample trial. Each effect takes around ten minutes and we have 360 effects total to run	5 months
Data Analysis	Creation of graphs, comparison of data collected, calculating statistical significance, affirming with previous studies	1.5 month
Interpretation of Results	Writing a research paper, revising, publishing, circulating among academic circles (peer review)	6 month
TOTAL TIME	--	19 months

VI. Materials and Budget

Material, other resources	**Cost ($)**	**Source**
Instant Ocean salt mix (50 60 lb boxes, makes 10,000 lbs sea water which is ~1200 gallons)	2099.50	Instant Ocean That Pet Place
Hydrometer	3,405	Mettler Toledo
Lab space and basic lab supplies - UMass Lab Fee applied	400	According to SPIRE finance summary
Transportation of samples from analysis lab to plant and going to places as needed (diesel, 6mpg) - Driving around 10,000 miles during experiment	0.46/mile = 4,600	Calculation based on current diesel price, semi-truck mpg, and typical distance driven per person per year
Distilled Water (55 gal. x 22)	2,722.50	Deionized water
Multi-effect distillation machinery (rent) (Size: 5,000 m^3 @ $ 0.85 / m^3 with 10% profit for renters)	4,250 * 1.1 = 4,675	Fawzi Banat
Thermometer	553	Southern Labware
Publishing fees - UMass Open Access Policy	0	UMass Open Access Publishing Sites
Energy costs (1.5 kWh/m^3 @ $0.1137/kWh = $0.1706 / m^3)	853 / h For 150 hours = 127,950	Electric Choice and MED Study
Manual Labor (Team of 10 for 200 hours)	12/hr/person = 24,000	Group Discretion
Water Testing - UMass Water Resource Center	Assumed part of lab space fee	UMass Labs and Services
TOTAL COST (USD)	**= 170,405**	Calculations (rounded for potential other costs)

VII. Key Personnel

Floyd is an environmental science major. Environmental science is key to understanding the methods and implications of our study on desalination. His expertise will help guide the group to a useful research question and methods that will help us answer our hypotheses. For example, he can make informed predictions on how temperature, salinity, and the number of effects will impact distillation efficiency. Additionally, he knows why we want to study these factors. Temperature and the number of effects directly impacts the cost and economic viability of the distillation method. Salinity will help determine a potential future for the technology in the treatment of brackish water, an increasingly common phenomenon connected to rising sea levels and climate change more generally. We can focus our research on why multi-effect distillation is a viable option over other methods such as reverse osmosis and how we can set up an experiment that will look at salinity and temperature with the fewest assumptions possible.

Callista is a geology major, and geology is essential to understanding aquifer systems and how they function and interact with surface water. This includes saltwater infiltration, which our study focuses on, and the implications of using brackish groundwater sources as an alternative to fresh groundwater. She will be able locate and map areas where our system could be implemented as a viable alternative to the area's current source of water. Having worked in a hydrogeology lab, she has experience testing ground and surface water for various quality indicators, and will be able to conduct tests to ensure that the treated water is safe for consumption. Furthermore, her background in environmental science will also provide knowledge on how our proposed desalination plant would have an impact on the local ecosystems and how to properly dispose of the waste brine water, potentially repurposing it to be used for other means.

Ravid is a biochemistry major. Biochemistry involves tackling various scientific challenges from a molecular and cellular level. With his expertise in the field and his macro and micro lens of analysis, Ravid's job is to understand how the process of multiple-effect distillation works, and by doing so to predict what the effects of temperature, number of effects, and salinity concentrations will have on the efficiency of the plant. For example, understanding how intra and intermolecular forces of water and solutes are affected by the independent variables will ultimately help our group analyze data and in turn decide how to maximize desalination rates and purity. Furthermore, understanding the molecules at play will help our group better determine the steps our experimental procedure should follow to ensure the safety of the environment (regarding disposal of potentially harmful brine) and the workers of the experiment.

Audrey is a public health major and environmental health is a key aspect to her studies. When considering the broader impacts that our work will have, Audrey's role in this case study is keeping in mind the health effects of the water that we are delivering, as well as making sure that our process of obtaining samples is ethical and safe for human health. Her strengths in environmental health allows her to be insightful when it comes to our entire procedure. Through ensuring the integrity of the data collection process and enforcing our responsibility as scientists to dispose of the waste properly, the study has as minimal of a negative impact on the environment as possible. It is also of utmost importance to make sure that our clean water meets the standards before even thinking to use it for public consumption. Audrey's skills ensure that the integrity of our results is to the highest degree for the health and safety of people who may need this water most.

VIII. Relevance of Proposed Study and Broader Impacts

In recent years, climate change has greatly impacted our coastal cities. With larger scale hurricanes, bouts of drought, flooding, and rising sea levels, these challenges threaten water sources in the area. Whether it be complete depletion of a source or salt-water contamination, these changes could cut off reliable access to safe drinking and bathing water for entire communities. Clean water is a necessity and a human right, but in the face of our changing climate, water supplies are at more of a risk than ever. The implications of our study in being able to take water from these contaminated areas where the salinity of the water is too high to be safe for use would allow for a solution to these issues. We can find an energy-efficient way to mass produce clean water from water that was already within the area and provide communities with the supplies that they need. In our mass production, we can also send water to communities whose source has been depleted as a result of climate change. Fundamentally, our study seeks to find a solution to the problems that have already been created with the

Our results could also influence other scientists to begin developing experiments that would aim at energy efficiency from the angle of energy source. With the newfound knowledge of the most effective settings to use for the plant (such as temperature, salinity, and number of effects) and how to better use the plant for different salinities (such as for brackish water), the next step would be cost adjustments and potentially a way to incorporate heat and energy output from other machinery as input for the MED in order to reach the desired efficiency of the machine.

Research on heavy metal contamination in water may also be influenced by our study. Although our study does not focus on such factors, the effectiveness of salt removal may correlate with an effectiveness of heavy metal removal. This is based on the prediction that water leaves behind the heavy metals when it is evaporated in the plant. Since these metals are also an enormous problem in some societies and prevent people from having access to clean drinking water, understanding how to potentially use desalination methods to remove metals would be profound. Metaphorically speaking, this would kill two birds with one stone, but more importantly, it would open the door to understanding how salinity and heavy metals interact during the distillation process, which would ultimately make the process even more efficient.

The primary beneficiaries to a cost-effective method of desalination would be coastal cities whose water supplies have become contaminated from rising sea levels as well as those groups that lack access to clean water. Furthermore, businesses that use desalination plants could reduce their energy costs and support the fight against climate change, maybe even through a net zero carbon footprint. Our study seeks to find a cleaner, more accessible means of getting fresh water to those in need.

From our findings, this means of water desalination could be pivotal in creating and maintaining a source of clean water that will not be depleted. The United States Geological Survey has found that the groundwater of coastal areas has already been impacted by the rising sea levels.[7] An influx of brackish water in these coastline cities puts our communities at risk of losing a dependable water source. By using this brackish groundwater as an input for MED systems or even taking ocean water and desalinating it, we run no risk of depleting a water source or being unable to maintain a steady output of clean water. In addition to this issue along coastal states, the USGS also found many areas inland in the United States that have naturally occuring sources of brackish water. The increased availability of groundwater will benefit Americans who live further from oceans or in arid climates.

As mentioned above, various communities would be provided access to cheap, clean water. It would be an effective alternative to depleting ground water sources which would have vast detrimental effects if they run dry, such as aquifer collapse. Large agricultural industries can also use this method of brackish groundwater, in order to relieve pressure from freshwater aquifers used by local residents. In a broader sense, it would show that change is possible. Problems with water are not insurmountable, and our work would give people hope. Furthermore, the reasoning behind our study (helping those without access to clean water) would potentially give people a moral obligation to support water desalination (through funding or spreading the word about its importance).

The primary way we would communicate our findings to other scientists would be through publishing articles. This would make sure the people who run the

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[7] Stranton, J. S., Anning, D. W., Brown, C. J., Moore, R. B., McGuire, V. L., Qi, S. L. (2017).

plants learn from our results and strive for minimizing energy costs and environmental footprints. Regarding the general public, the use of social media and news outlets would be the best way to communicate our findings. This would be primarily to let the public know about the new methods discovered in hopes of people pushing new legislation to be enacted regarding water desalination. Doing talks across the state or country would also be beneficial, and potentially would have a narrower audience that would be informed more in depth. Using these methods combined would have the ideal result of a well-educated public that is eager to make this technology widespread, in order to address the needs of these communities.[8]

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[8] Marella, R.L., 2020

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