An Assessment of Options for the Future of Brockton's Desalination Facility

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Written By:

Alex Gaines
Mike Kane
Amanda Rodriguez
Carla Romo

Sponsored By:

Marcus Gay, Executive Director
NEWIN SUSTAINING MEMBER 2017

Advised By:

Prof. Jennifer deWinter - WPI
Prof. Seth Tuler - WPI

Abstract

The City of Brockton started using desalination as a water source 9 years ago. However, the facility is underused due to Brockton's limited budget and availability of an alternate source. This project's goal was to develop options for Brockton to leverage the Taunton River Desalination Facility (TRDF). We conducted interviews with city officials and desalination experts, and reviewed materials about uses for desalination and the facility. We found that city officials have a positive attitude about the TRDF, and by law, Brockton is mandated to have a secondary water source. We identified complex opportunities and challenges associated with three options for Brockton to consider: renew existing contract, end contract and connect to an alternative water source, or purchase facility.

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Marcus Gay - Executive Director North East Water Innovation Network

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Prof. Jennifer deWinter - Project Advisor Worcester Polytechnic Institute

Prof. Seth Tuler - Project Advisor Worcester Polytechnic Institute

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Authors: Alex Gaines, Amanda Rodriguez, Carla Romo, Mike Kane
Advisors: Jennifer deWinter, Seth Tuler
Sponsor: Marcus Gay, NEWIN

Brockton has periodically faced water shortages due to recurring droughts and increasing water demand (Shallenberger & Cooper, 2013; Vedachalam & Riha, 2012). To alleviate these shortages, in 2002, Brockton signed a 20-year contract with Aquaria, a joint venture between Inima and Bluestone Energy, to build the Taunton River Desalination Facility (TRDF) (Larocque, 2016; Lynch & Mead, 2016). As part of this contract, Brockton pays an annual rate of $6.5 million and purchases the water at an additional rate of $1.30/1,000 gallons. Currently, Brockton is Aquaria's only customer and the facility is not being used to its fullest capacity due to the City's limited budget.

Goal

The goal of this project is to develop a variety of options for the City of Brockton to leverage the TRDF that reflect the opinions of the facility's stakeholders. To accomplish this goal, our team completed a series of objectives:

1. Explored the history that led Brockton to site a desalination facility and identify the stakeholders involved in this decision.
2. Examined how the TRDF is currently being used and the attitudes of its stakeholders regarding the facility.
3. Explored the current and long term water demands of Brockton.
4. Identified and compare opportunities for alternative uses for the Taunton River Desalination Facility.

Figure 1: Aerial view of TRDF

Methods

To understand the history of the facility and how it is currently being used, we interviewed staff members from Brockton's Water, Financial, and Public Works departments and the engineer who proposed the original idea for the facility.

We also reviewed the following documents to help us understand the history and current use of the TRDF:

- desalination financial model,
- Brockton's annual budget,
- production history of TRDF, and
- plant permits provided by the EPA and DEP

To examine current and projected water demands in Brockton we reviewed reports from Brockton's Water Commission and Metro South Shore Chamber of Commerce (MSSCC). We then interviewed staff members from Brockton's Economic Department, MSSCC and water departments in surrounding municipalities.

Figure 2: Reverse osmosis trains in TRDF

Finally, to develop options for Brockton to leverage the TRDF, we researched uses for desalination in addition to potable water and case studies about desalination for uses besides human consumption. We toured the TRDF to learn about how the facility operates and interviewed staff members from Aquaria. We then came up with three options for Brockton to leverage the TRDF and analyzed them with help of engineers and desalination experts.

Findings & Discussion

Finding #1: Stakeholders believe desalination was the best solution for the City and have a positive attitude about the future of the facility.

Engineers and Brockton officials argue it was the best solution compared to digging new wells or connecting to the MWRA thus "desalination was the way to go." Current city officials believe desalination has helped the City in emergencies and they like having the facility as a secondary water source.

Finding #2: Residents are unaware of the current use of the TRDF and city officials share little information about the facility to them.

Residents developed a negative attitude towards the TRDF when the plant started operating because they believed the City was misusing their money paying for a facility barely utilized. There is almost no effort to provide information to the residents of Brockton about the TRDF and its current use. There is no evidence that the negative public attitude about the facility has improved.

Finding #3: Since the plant started operating in 2008, Brockton has not used the facility to its fullest potential because the water from TRDF is more expensive than Silver Lake.

Brockton only purchases 5% of their water from TRDF and the remaining 95% from Silver Lake (Creedon, 2017). As seen in the graph to the right, since the plant started operating the volume of water purchased annually has varied over the years due to budget constraints; 2010 was the year were they purchased the most water and 2012 the City did not purchase water at all.

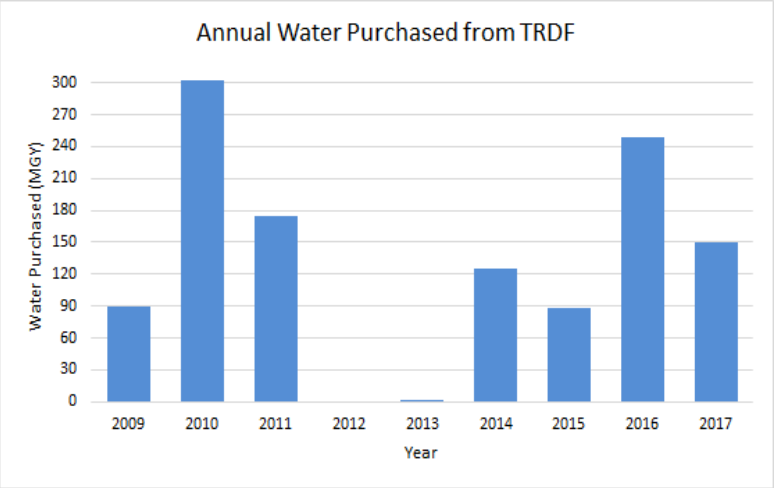

Figure 3: Annual water purchased from TRDF

Finding #4: Due to both legal mandates and environmental precautions, Brockton is required to have a secondary water source.

In 1995, MassDEP issued a consent order, mandating Brockton to find a secondary water source due to depletion of Silver Lake. This consent order is still in effect today, and Brockton uses the desalination facility as their secondary water source. From our interview with Brockton Department of Public Works, we learned that Silver Lake is currently overstressed and thus, the DEP will require Brockton to obtain more water from its secondary water source.

Finding #5: The water demand in Brockton is not expected to increase substantially in the upcoming years.

Population projections show Brockton may decrease in population by 2030. The number of large industries has decreased in Brockton, and the City has no plans to attract additional large industries. Their current goal is to support local businesses from within Brockton. Moreover, as explained by an MWRA expert, each year water consumption per capita decreases as water fixtures (i.e showers, toilets, etc.) become more efficient and consume less water. Thus, in the next 10 years the water demand in Brockton is expected to remain constant at 10 MGD.

Based on these findings, our team decided to further explore three options the City has been considering for the future of the desalination plant. The options are to:

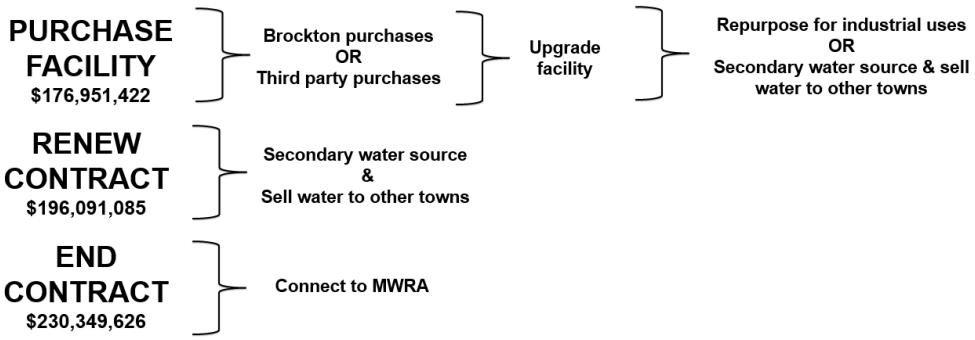

Figure 4: Options and opportunities for TRDF

Option 1 - Purchase TRDF

Brockton has been exploring the option of purchasing the facility, which will then end the contract. As an owner, Brockton could subcontract a third party to operate the facility. Currently, Aquaria's offer is $78 million. The City has until January 2018 to make a decision before the bid goes public. If Brockton purchases the facility, we suggest city officials further look into these opportunities:

- ***Explore the opportunity of having a third party purchase the facility***
  Purchasing the facility represents a large amount of money that Brockton will have to obtain through bonds and debts. To prevent this expenditure, Brockton could explore having a third party purchase the facility. Brockton could then negotiate a contract with this third party to obtain water at an accessible price. By having this third party purchase the TRDF, it would remove the risks of Brockton being directly associated with the facility and reduce City's expenditures.

- ***Upgrade the facility to improve production capacity and reduce operation and maintenance costs***
  From our tour to the facility we learned there are opportunities to upgrade the plant to reduce operation and maintenance costs some of the upgrades include:
  - Addition of reverse osmosis and ultrafiltration train
  - Increase efficiency of reverse osmosis system
  - Replace Gunderboom structure
  - Addition of solar panels

  We also explored the opportunity of expanding the production capacity of the facility up to 7.5 MGD. To do so, some equipment needs to be replaced and added. With help of a desalination expert, expanding the production of the facility will cost around $73 million.

- ***Continue using the facility as a secondary water source and sell excess water to neighboring municipalities.***
  Brockton will remain the largest customer of the TRDF since they are required to have a secondary water source. However, the buyer of the facility could then sell whatever water Brockton does not buy to neighboring communities. From our surveys, we learned commissioners of water departments in municipalities in the area are interested in the long term in connecting to a new water source.

- ***The buyer could provide water of a particular quality to industries in the area***
  From our literature review about alternative uses for desalinated water, our team discovered that some industries that have benefited from using desalination include: electronics, power plants, beverage production, agriculture, and wastewater treatment. Since water is an important driver to site industries, Brockton could develop a plan to attract industries and the TRDF will be the water supply.

Option 2 - Stay in Contract with Aquaria

Brockton has the option of staying in the contract until 2028, renegotiate it, and renew it for 30 more years until 2058. When renewing the contract, Brockton would continue to pay the two rates stated earlier. Brockton will use the TRDF only as a secondary water source, purchasing approximately 2 MGD throughout the next 40 years. This leaves Aquaria in charge of operation and maintenance of the plant and Brockton will be the only customer. If Brockton renews the contract, we suggest city officials further look into the following opportunity:

- ***Continue using the facility as a secondary water source and sell excess water to neighboring municipalities.***
  By Brockton using the TRDF as a secondary water they have the opportunity to sell the water to neighboring municipalities. In the current terms of the contract, only Brockton can allow the connection of new municipalities to the TRDF. Thus, it will be Brockton's responsibility to promote the facility in surrounding municipalities to get more customers for the TRDF.

Option 3: End Contract and Connect to MWRA

After the contract with Aquaria ends in 2028, Brockton has the option to end the contract and locate a different secondary water source. Brockton could connect to the Massachusetts Water Resource Authority (MWRA). The closest connection point for Brockton will be at Quincy. Brockton then will be obtaining water from the Quabbin Reservoir. The costs Brockton will assumed for this connection include:

Table 1: MWRA connection estimated costs

Description	**Estimated Cost**
Entrance Fee	$4.3 million per million gallons
Water Cost	$3.471 per thousand gallons
Construction of Pipeline	$55 million
Permits	$11 million
Additional Treatment to Silver Lake	N/A

Financial Comparison of the 3 options

In all these scenarios, both the TRDF and MWRA will serve as a secondary water source and Silver Lake will remain the City's main water source. The City is planning to obtain 2 MGD from any these secondary water sources, in which case from 2018-2058 all options are estimated to be the following:

Option 1: $176,951,085
Option 2: $196,091,085
Option 3: $230,349,626

Over the next 40 years, purchasing the facility could save the City an estimated $12 million compared to renewing the contract and will save an estimated $53 million than connecting to the MWRA. The Department of Finance has estimated the costs of obtaining less or more than the 2 MGD this is because in the future the DEP might require Brockton to take even more water from their secondary water source. In this case, for option 1, the savings increase as the water obtained increases and in option 3, expenditures considerably increase as the water obtained increases (Condon, 2017).

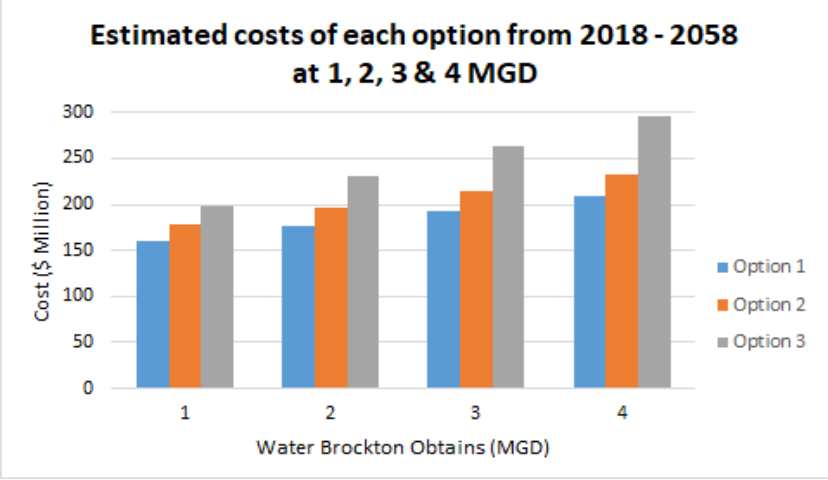

Figure 5: Estimated cost of all options

Project Deliverables

At the end of our project, we delivered the following to NEWIN:

- An in depth literature review of the history of TRDF
- List of individuals contacted during the research projects
- Weekly blog post for NEWIN's web page
- Executive summary of our project

Future Research

After concluding the project, we suggest NEWIN further:

- Investigate available water supplies in the South Shore of Massachusetts
- Investigate opportunities for promoting regional collaboration for water systems in the Metro South Shore
- Help Brockton find potential third parties interested in purchasing the facility
- Assist Brockton with marketing strategies to improve the facility's image
- Guide Brockton in ways to seek public funding to invest in the TRDF
- Explore residents opinion on desalination and the TRDF

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List of Acronyms

BDF:	Brockton Department of Finance
BDPW:	Brockton Department of Public Works
BED:	Brockton's Economic Department
BWC:	Brockton Water Commission
EPA:	Environmental Protection Agency
MCEC:	Massachusetts Clean Energy Center
MGD:	Million Gallons a Day
MGY:	Million Gallons a Year
MSSCC:	Metro South Shore Chamber of Commerce
MWRA:	Massachusetts Water Resource Authority
NEWIN:	North East Water Innovation Network
RO:	Reverse Osmosis
TRDF:	Taunton River Desalination Facility
UF:	Ultrafiltration

Chapter 1: Brockton's Challenges with Desalination

Currently, 1.1 billion people lack access to potable water and 2.7 billion face water scarcity for at least one month of the year (WWF, 2017). Over the last few decades, cities around the world have been facing water shortages due to the increasing demand of water, the pollution of fresh water resources, climate change causing droughts, and depletion of fresh water sources (Carter, 2009; WWF, 2017). As the world's population dramatically increases, fresh water scarcity will only get worse (Arsenault, 2012; Wheeler, 2012; WWF, 2017). Thus, one of the biggest challenges of the twenty-first century is finding alternative sources of fresh water (Pinto & Marques, 2017).

To overcome this challenge, cities that experience water shortages are exploring a variety of water treatment technologies (Kucera, 2014). For cities that are in close proximity to brackish water (water with more salinity than fresh water) such as rivers, lakes, or oceans, a practical technology is desalination (Pinto & Marques, 2017). Desalination takes brackish water and removes salt and minerals to purify it to potable water quality (Kucera, 2014). However, widespread introduction of desalination technology has been a challenge since there are several drawbacks to the technology, which include large energy consumption of the facility, high price of water, periodic maintenance and replacement of equipment, and negative environmental impacts of the process. Addressing these drawbacks is crucial for appropriate implementation of desalination and if they are not mitigated, they can lead to underused facilities (Carter, 2009; Dolnicar & Schäfer, 2009).

Government agencies like the Environmental Protection Agency (EPA), and Massachusetts Department of Environmental Protection (MassDEP) along with non-profit organization like North East Water Innovation Network (NEWIN), and Massachusetts Clean Energy Center (MassCEC), share the goal of exploring innovative water technologies in Massachusetts (EPA, 2017b; MassCEC, 2017; MassDEP, 2017; NEWIN, 2015). Due to the severe droughts Massachusetts has experienced in previous years, these organizations are actively researching, supporting, and funding new water treatment technologies such as desalination (McGuinness, 2016). Over the last decade, extremely dry countries and states like Saudi Arabia, California, Israel, and Spain, have successfully implemented and keep investing in desalination to an extent it has become their main water source (EPWU, 2007; Jacobsen, 2016; Kasler, 2015; Khawaji, Kutubkhanah, & Wie, 2008). Desalination is not only used for production of potable water, but there is also a growing market in the industrial sector (GWI, 2011). The agricultural, power generation, and manufacturing industries use large amounts of water and desalination has been a suitable alternative to meet these industries large water demand (Beltran & Koo-Oshima, 2006; Clancy, 2013; NEI, 2017; Veza, 2006)

The City of Brockton started using desalination 9 years ago in order to ameliorate the City's water shortages. Brockton has historically experienced water shortages that intensified during the twentieth century when its main water source was depleting (Shallenberger & Cooper, 2013; Vedachalam & Riha, 2012). In 2002, Brockton signed a 20-year contract with the company Aquaria to build a desalination facility by the Taunton River (Lynch & Mead, 2016). In 2008, after the construction was completed, the City started paying a fixed annual rate and a variable rate that depends on the volume of water the City purchases from the facility (Vedachalam & Riha, 2012). However, due to Brockton's limited budget to purchase water and unexpected decrease in water demand, the facility is not being used to its fullest potential

(Crawford, 2013). To increase utilization of the facility, reduce Brockton's expenditures, and potentially help the City generate revenue.

Currently Brockton is purchasing 2 million gallons a day (MGD) of water from the Taunton River Desalination Facility (TRDF) (Staff BWC, personal communication, 2017). Additionally, the City is exploring the option of purchasing the desalination facility, which will be cheaper in the long term than paying the remaining 11 years of the contract with Aquaria (Staff BDF, personal communication, 2017). However, alternative uses for this facility have not been considered by the City because city officials are focused on using the facility as a secondary source in case of emergencies (Staff BDPW, personal communication, 2017).

The goal of this project is to develop a variety of options for the City of Brockton to leverage the TRDF that reflect the opinions of the facility's stakeholders. To accomplish this goal, we explore the history that led Brockton to site a desalination facility and identified the stakeholders involved in this decision. Second, we examined how the TRDF is currently being used and the attitudes of its stakeholders. Third, we explored the current and long term water demands in Brockton. Using this information, we identified and compared opportunities for alternative uses for the TRDF. The City of Brockton can consider these opportunities to reduce their water expenditures, potentially generate revenue, and encourage the growth of desalination technologies in the region.

Chapter 2: History of Brockton's Water Supply

Brockton signed a 20-year contract with the company Aquaria to build a desalination facility by the Taunton River; however, the City has not been using this facility to its fullest capacity. In this chapter, we discuss Brockton's water history, the path that led Brockton to invest in desalination, and a brief overview of the TRDF.

2.1 Water sources in Brockton during the nineteenth and twentieth centuries

During the nineteenth century, Brockton's main source of water was the Brockton Reservoir located in Avon, MA (Jones River, 2016a; MassDEP, 2003). This reservoir provided the City with approximately 0.81 MGD (Creedon, 2017). However, by the end of the nineteenth century, the City struggled to maintain a sustaining and sufficient water supply due to a rapid increase in population, industrial growth, and periodic droughts (Shallenberger & Cooper, 2013). Brockton then started looking for another water source and in 1889, the City was granted the right to use Silver Lake. Starting 1905, Silver Lake became Brockton's main water source and Brockton's Reservoir a supplemental supply (Carini, 2017; MassDEP, 2003).

Silver Lake is located 50 miles west of Brockton and until the 1950's, it provided Brockton with approximately 5 MGD (Carini, 2017; MassAudubon, 2010). During the 1960's, Brockton suffered from a regional drought in which the water demand increased as the water level in Silver Lake decreased. In 1964, the State authorized Brockton to divert water to Silver Lake from watersheds in Monponsett Pond and Furnace Pond. This allows Brockton to control the water flow from these ponds and keeps it artificially high at some times or dramatically low at others to maximize Silver Lake's water level (MassAudubon, 2010; Shallenberger & Cooper, 2013). To understand the new water system at Silver Lake, see Figure 1. With this diversion, Silver Lake provided Brockton with a safe yield of 9.4 MGD, which was enough to meet the City's water demand for the next couple of decades.

Figure 1: Map of Silver Lake water system showing diversion of water from Furnace and Monponsett Ponds to Silver Lake (MassAudubon, 2010).

2.2 Brockton pursues an additional water source

Up until 1975, Silver Lake along with Brockton Reservoir sufficed Brockton's water needs. Nevertheless, by the beginning of the 1980's, Brockton was again in the pursuit of an additional water source (MassAudubon, 2010). Figure 2 summarizes the key events that led Brockton to explore new water sources until the City chose desalination.

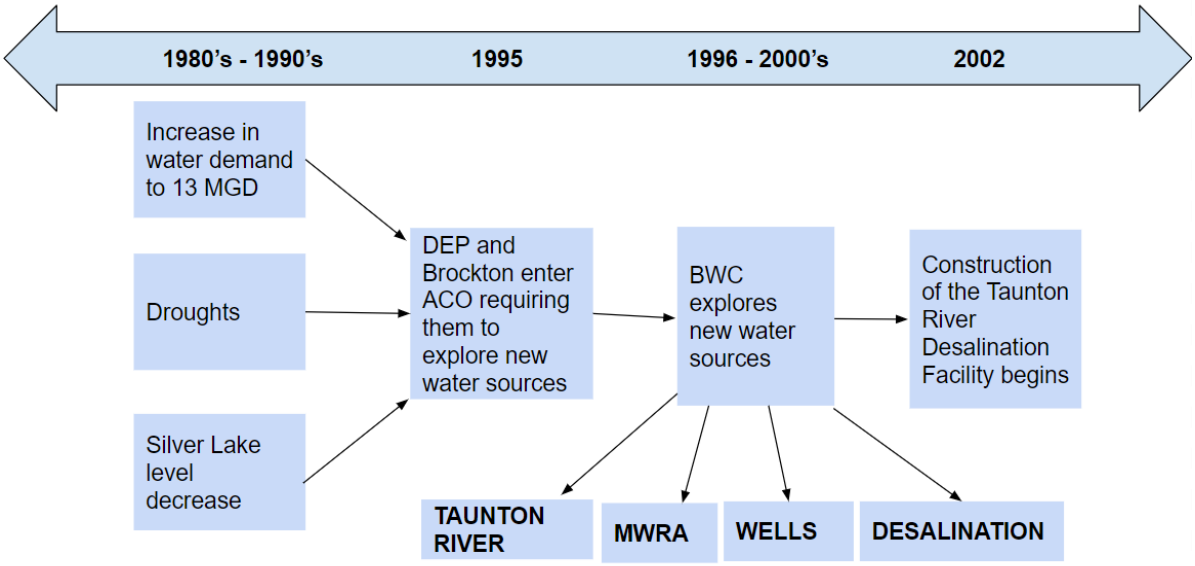

Figure 2: Roadmap of the key event that led Brockton to invest in a desalination facility

During the 1980's, the water demand in Brockton increased dramatically up to a peak of 19 MGD, which was a considerably higher volume than the safe yield for Silver Lake (Carini, 2017). Not only was the water demand higher, but severe droughts that dried surrounding watersheds made it harder for the City to obtain the required volume from Silver Lake. To prevent the depletion of Silver Lake, Brockton imposed strict regulations and prohibited new connections to their water supply system (Staff BWC, 2017; Vedachalam & Riha, 2012). Despite the conservation measures, in early 1990's, Silver Lake's level decreased around 7 feet, affecting not only Silver Lake, but also the surrounding bodies of water in the following ways (Jones River, 2016a; Jones River, 2016b; MassAudubon, 2010). The events unfolded thusly:

1. Lack of flow to Jones River.
2. Severe drawdown of Silver Lake during several months of the year.
3. Decrease in population of fish and other aquatic life.
4. Decrease of water quality in Monponsett Pond and Furnace Pond.

In 1994, the DEP declared an emergency due to Brockton's overstressed water supply. In 1995, Brockton entered into an Administrative Consent Order with the Commonwealth of Massachusetts that required the City to explore new water sources besides Silver Lake (Shallenberger & Cooper, 2013).

The City established the Brockton's Water Commission (BWC) to explore the available options for new water supplies (Crawford, 2013). Brockton considered four alternatives to obtain water, and ultimately decided to pursue desalination in 2002. The alternatives, the decision of BWC, and justifications for the final decision are summarized in Table 1 (Crawford, 2013; Larocque, 2016; Staff BFD, 2017; Vedachalam & Riha, 2012).

Table 1: Alternative Water Sources Considered by BWC and their Criticism

Option	Decision	Criticism
Dig new wells	Disregarded	Underground water highly contaminated.
		Irregular geography of Brockton will complicate digging process.
Bring water upstream from Taunton River	Disregarded	Negative environmental impact of pipeline construction.
Purchase Water from MWRA	Disregarded	High price of pipeline construction.
		Resistance due to potential environmental impacts of MWRA at the time.
		Brockton did not want to negotiate with a public company.
Desalination Facility	Implemented	Opportunity for Brockton to invest with private company.
		Facility with potential to expand and produce large amount of water to attract industries.

2.3 The Taunton River Desalination Facility

In 2002, Mayor Yunits signed a 20-year contract with Inima and Bluestone Energy jointly to build the Aquaria Taunton River Desalination Facility (Larocque, 2016). When Brockton invested in the facility, they were expecting it would (Crawford, 2013):

- Ameliorate Brockton's water shortages
- Promote industrial growth
- With the projection that other towns in the area would purchase water from it

The construction of the facility began in 2002 by the Taunton River, 20 miles South of Brockton. By 2008, the construction of the $70 million facility and the $30 million pipeline was concluded, and the contract came into effect (Crawford, 2013; Larocque, 2016). As part of the contract, the City has to pay two fees: a fixed rate and a variable rate (Larocque, 2016). The fixed rate is $6.5 million that accounts for Aquaria's expenditures related to the facility (COB, 2002). The variable rate is the additional cost the City pays when they purchase the water. This

rate varies annually depending on the operational costs; at the moment the price is $1.30/1,000 gallons (Creedon, 2017; Lynch & Mead, 2016).

As seen in Figure 3, the facility is located on the shore of the Taunton River. The facility has an intake structure, raw water pumping station, three water storage tanks, and a treatment plant that includes a chemical area, ultrafiltration (UF) system, reverse osmosis (RO) system, and finished water pumping station (Figure 3). Raw water is treated though all these units until it reaches potable water standards (Crawford, 2013; Lynch & Mead, 2016). For a more detailed description of desalination and the TRDF operation refer to Appendix A& Appendix B.

Figure 3: Aerial view of Taunton River Desalination Facility (Google Maps, 2017)

After the facility was built, Brockton fixed leaks in the pipelines and installed new meters, which in turn decreased the overall water demand of the City (Engineer, personal communication, 2017). Moreover, the City has a limited budget and does not prioritize its money to buy water from the desalination facility, which is more expensive than Silver Lake. Due to the decrease of water demand and limited budget, Brockton currently does not use the facility to its fullest capacity (Staff BDF, personal communication, 2017). The facility functions primarily as a secondary source for the City to use in emergencies (Crawford, 2013). At the moment, Brockton purchases 2 MGD from the facility. However, in previous years, where they have had a smaller budget, no water was being purchased (Staff BWC, personal communication, 2017).

Recently, Brockton has been considering buying the desalination plant from Aquaria for $78 million dollars, connecting to the MWRA, or continue using the facility based on Brockton's annual budget (Condon, 2017; Larocque, 2017b). This proposal has caused an ongoing debate between the City Council and BWC. Some city officials argue that the desalination facility represents a large amount of money the City should no longer keep spending. Others however, argue that desalination is a suitable option for Brockton and the City should keep it as their backup water source (Larocque, 2017a). Regardless of what decision the City takes, they still have 11 years remaining in the contract or will soon own a large facility that they are not using to its fullest potential.

The North East Water Innovation Network (NEWIN) is a non-profit organization that drives water innovation in the region (NEWIN, 2015). They support the growth of water technologies and work with water organizations on water innovation accelerator programs. The goal of NEWIN is to encourage knowledge sharing and networking between stakeholders in the

water industry sector to accelerate water innovation in the region (NEWIN, 2015). They are particularly interested in the TRDF and exploring options of how Brockton can leverage this facility. This will in turn help NEWIN promote the growth of innovative technologies like desalination in the North Eastern region.

Chapter 3: Methodology: Interviews & Analysis of Literature

The goal of this project was to develop a variety of options for the City of Brockton to leverage the Taunton River Desalination Facility that reflect the opinions of the facility's stakeholders. To accomplish this goal we met the following objectives:

1. Explore the history that led Brockton to site a desalination facility and identify the stakeholders involved in this decision.
2. Examine how the TRDF is currently being used and the attitudes of its stakeholders regarding the facility.
3. Explore the current and long term water demands of Brockton.
4. Identify and compare opportunities for alternative uses for the Taunton River Desalination Facility.

In this chapter, we will discuss how the team accomplished each objective.

3.1 Objective One: Explore the history that led Brockton to site a desalination facility and identify the stakeholders involved in this decision

We sought to understand why Brockton chose desalination from among other water source options. With this knowledge, we were able to understand what the City had envisioned for the future of the facility in 2002, and identify the stakeholders of the decision-making and siting processes.

To understand the history of the TRDF and how it has been used since construction, we first did a **literature review** of articles and editorials published in both local and regional newspapers such as *The Enterprise*, *Wicked Local Brockton*, and *Boston Magazine* over the last ten years. We then **interviewed** one of the reporters from *Boston Magazine*, Amy Crawford, who provided us information regarding the stakeholders involved in the decision, the history of the facility, and the controversy of the facility in 2012 (See Appendix C).

To further understand the history behind the TRDF, we **interviewed** staff members from Brockton's Water Commission (BWC), Brockton's Department of Public Works (BDPW), and Brockton's Department of Finances (BDF). Through these interviews, we learned about the motivations the City had to invest in a desalination facility, what were the other options, who was part of this decision, and what the contract with Aquaria entailed (Appendix C). We were able to get in contact with the engineer who proposed the idea of desalination to the City, and interview him to learn more about the history of the facility and the siting process (Appendix C). The team then did an **archival analysis** of the contract between Aquaria and Brockton. To further understand the terms of the contract, we interviewed John McArdle, a water treatment expert, who explained to us what the contract consists of (Appendix C).

Our team compiled all the information gathered into a timeline of the events that led Brockton to invest in a desalination facility and how the facility has been used until now. We also used this information to identify the majority of stakeholders involved in the decision making and siting processes and determine their opinion when desalination was chosen in early 2000's. Since the desalination facility was proposed in 1996, we were unable to identify all the stakeholders involved and obtain their perspectives on the matter because some of them had retired or passed away.

After meeting with our sponsor, he explained to us that there are four main drivers when siting water technologies. These drivers consisted of social, economic, financial, and technological aspects. With these drivers in mind, we further analyzed the data by sorting it into the four categories. A description of each category is listed below:

- **Social**: Who are the stakeholders, how are they being affected by the TRDF, and criticism of the TRDF. It is important to understand how the facility affects the stakeholders and what their opinion on desalination is.
- **Economic:** Effect desalination facility has on Brockton's industry, jobs, and economic growth. Important to understand how the TRDF directly influences Brockton's local economy.
- **Financial**: Operation and maintenance costs of the facility, cost of repairs, price of water, and City's budgets. Important to understand what expenditures the TRDF represents for Brockton and how the City is financing these costs.
- **Technological**: How the facility operates, current technologies being used, and potential alternative technologies. Important to understand how the water is being treated and consider upgrades to increase efficiency, reduce operating costs, and increase production capacity.

3.2 Objective Two: Examine how the TRDF is currently being used and the attitudes of stakeholders regarding the facility

Moving from the past to the present, after 9 years, stakeholders and Brockton's end use for the plant have changed. Thus, we needed to find stakeholders who are currently drivers for the TRDF and Brockton, to gather their concerns and begin mapping out how to leverage the facility.

We **identified the current stakeholders** of the TRDF by doing a literature review of newspaper articles published over the last year in the local newspaper *The Enterprise*. This analysis led us to identify that the main departments working with the TRDF are: Water Commission, Public Works Department, and Finance Department. Our team then proceeded to **interview** staff members from these departments, asking them about how the facility is currently being used, plans for the future of the facility, and their opinion on the facility (Appendix C). We then conducted an **archival research** on the following documents provided by the interviewees:

- Desalination financial model
- Brockton's annual budget
- Production history of TRDF
- Plant permits provided by the EPA and DEP

Our team then **toured** the TRDF to understand how the plant is operating and we had the opportunity to meet with Aquaria staff members to discuss technical specification of the plant, plans Aquaria has for the facility in the future, and their opinion on desalination(Appendix D). Due to the politics surrounding the desalination plant, it was difficult to obtain information that did not have bias and some interviewees we considered did not want to talk about the plant due to their involvement in Brockton or Aquaria. This in turn limited the people we could talk to and the transparency of the opinions.

To analyze the information from our interviews, literature review, and facility tour, we classified the information in the four categories mentioned in objective 1. We went back and

listened to recorded interviews taking notes on key points about the social, economic, financial, and technological aspects of the TRDF.

3.3 Objective Three: Explore the current and long term water demands of Brockton and surrounding municipalities

Exploring the current and long term water demands in Brockton helped us understand the current water needs of the City, how water demand is expected to change, and whether the City will need additional water sources in the future. This knowledge led us to recognize how the City can currently and in the future use the TRDF to its fullest potential.

We reviewed the Consumer Confidence Report from 2016 published by BWC to identify Brockton's current water demand, water sources, and how water is being used. Through the interviews conducted with staff members from BWC and BDPW, we were able to understand in detail the City's current water supplies (Appendix C). To understand the current industrial water demand in Brockton, we identified the largest industries in Brockton and neighboring towns through a review of data from the US Census. To understand water demands of surrounding municipalities, we **surveyed staff members** from Water Departments in 11 municipalities within a 15 mile radius of Brockton; from these surveys we learned about water sources, water demands, and plans of connecting to secondary water sources in neighboring towns (Appendix E).

We then proceeded to estimate the expected long term water demand in Brockton. To do so, we **reviewed a water analysis report** from the Metro South Shore Chamber of Commerce (MSSCC) that gave us an idea of the expected demographic and industrial growth in Brockton and surrounding municipalities in 2030. To get a better understanding of how Brockton is expected to grow, we **interviewed** a representative of the MSSCC and Brockton's Economic Department (BED). In these interviews we asked questions about industrial growth, plans to improve the economy, projected water demands, and limitations of growth in the City (Appendix C).

We recorded interviews with previous permission of the interviewee's and took notes on key points that will help us predict how the water demand is expected to change in Brockton. We combined information gathered from surveys, interviews, literature review, and archival research to compare current vs. expected water demand in the City based of population, industries, and water needs of surrounding municipalities.

3.4 Objective Four: Develop a variety of options for alternative uses for the Taunton River Desalination Facility

To help the City of Brockton use the TRDF to its fullest potential, we developed a set of opportunities of alternative uses for the plant. This set of opportunities will act as a guide to whether purchasing the facility, renewing the contract, or abandoning the facility altogether could serve a better use than just a secondary source of potable water for Brockton.

To construct this set of opportunities, we first investigated different uses of desalination besides the production of potable water through a literature review (Appendix F). We then reviewed 6 **case studies** about companies that use desalinated water aside from human consumption. These case studies allowed us to understand different uses for desalinated water, what industries could use desalination, the processes required, and benefits of using desalination as a water treatment technology (Appendix G).

Second we **met** with water technology, desalination, and membrane experts to gather insight into these alternative uses for desalination and the viability of implementing them in Brockton (Appendix H). We met with experts of the following organizations:

- DEP
- EPA
- Poseidon Water
- MWRA
- Veiola
- Worcester CleanTech Incubator

During these meetings, we gathered opinions and data about what opportunities are worth exploring for Brockton to better use the TRDF. With these ideas in mind and the current and projected water demands identified in objective 3, our team explored 3 options for the future of the TRDF. We compared these opportunities through a **SWOT** analysis that allowed us to identify the benefits and drawbacks of each opportunity (Appendix I). We further analyzed these options by comparing them through the social, economic, financial, and technological categories discussed in objective 1.

Chapter 4: Findings and Discussion: The Future of TRDF

Once we gathered all the information and data through our interviews, literature reviews, and archival research, our team developed a set of findings and explored options for the future of the TRDF.

4.1 General findings

Our team developed a set of 5 general findings. These findings are intended to help Brockton consider options to better use the TRDF and NEWIN identify opportunities to help Brockton while promoting water innovation. Our major findings are:

1. Stakeholders have a positive attitude about desalination pg. 13
2. There is little information about the TRDF available for residents TRDF pg. 14
3. During the 9 years of operation, Brockton has not used the TRDF to its fullest potential pg. 15
4. Brockton is required to have a secondary water source pg. 16
5. Water demand in Brockton is not expected to change in the next ten years pg. 17

Finding #1: Stakeholders believe desalination was the best solution for the City and have a positive attitude about the future of the facility

From the interviews with Brockton city officials, we discovered that stakeholders involved in the decision-making process of the facility felt desalination was the best choice for the City. Staff from BWC and BDF argue that digging wells was disregarded because of the industrial history of the City that made groundwater "unsuitable for well development" and Brockton's "unusual geography" that made digging difficult. The MWRA, while one of the more feasible options before desalination, was facing opposition from environmental groups complaining about the water withdrawn from MWRA's reservoirs. Brockton did not want to be associated with these opposition and disregarded this connection. Since these two options were not viable, the engineer who proposed desalination argued "desalination was the way to go."

According to staff from BWC, the benefits of desalination were that it would be a "private deal that could give them ownership and more control." Staff from BDF explained that desalination will also remove financial challenges from Brockton such as "risks of permitting and costs if construction overruns" that Aquaria will have to assume. The engineer further emphasized that desalination will ameliorate Brockton's water shortages and in the long term it could provide water to neighboring communities as well.

Not only did we learn that stakeholders involved in siting process of the facility are in favor of the TRDF, but current city officials also have a positive attitude about the facility. The 4 city officials we interviewed are all in favor of desalination and want to continue using the facility. A staff member from BDPW praised the facility because it "helps a lot during emergencies;" he explained that during droughts, Brockton calls Aquaria for more water and they will have it delivered by the next day. According to a staff member from BED, the TRDF has helped Brockton's economy by "preventing the City from dying." He explained that without

a secondary water source, Brockton prohibited new connections to its water systems, preventing new residents or industries from moving in; he argued that without the TRDF, the City was unable to grow and "if [they're] not growing, they're dying." Staff from BWC supports the facility, saying it has helped them during emergencies and that Brockton could benefit from it since "there is potential to sell water to other locations." Staff from BDF also shares the same ideas, as "it should be looked at as a regional asset as opposed to just Brockton or a private asset."

All interviewees further expressed interest in purchasing the facility since it is a needed asset for Brockton. From interviews we understood that current stakeholders see a future for the facility and want to use it to its fullest potential, rather than abandoning the project.

Finding #2: Residents are unaware of the current use of the TRDF and city officials share little information about the facility with them.

During our research on the facility itself, we discovered that there is not very much publically accessible information for the residents of Brockton. This is a problem because in previous years residents had a negative attitude towards the facility and without marketing, this attitude might remain unchanged. If residents' opinion on the facility does not improve, in the long term there might be opposition towards this asset.

We learned that the stigma towards the facility started during the construction of the TRDF. As explained by the engineer who proposed the idea of desalination to Brockton, in order to pay for the fixed rate established by the contract, Brockton increased the water rates in the City during the period of construction (2002-2008). During this time, Brockton also fixed leaks in pipes and installed new meters; these changes reduced the water demand of the City. Therefore, when the facility was ready to be used in 2008, Brockton was no longer needed a high volume from their secondary water source. This infuriated residents who had been paying extra money for a facility that the City no longer needed.

Amy Crawford, a journalist from *Boston Magazine*, mentioned residents were concerned about how well their money was being spent. She explained that in 2012 the City purchased no water which led to the formation of opposition groups in 2013 demanding the local government to stop wasting their money and find a way out of the contract. The engineer thinks that since then people have developed a negative perspective towards the facility.

Currently, city officials share little information about the facility to residents. One person we interviewed felt that Brockton does not inform residents whether the City purchases water from Aquaria or not in order to prevent unrest. He further mentioned that there is a lot of public misconception on desalinated water and part of not informing residents about desalination is to prevent complaints about water quality or flavor. When we asked city officials about how they are informing residents about the facility, they did not give any specific details besides the availability of documents published in Brockton's web page. Once our team looked into these documents, most were meeting minutes that have not been updated. Due to this lack of public outreach, residents are unaware of the current use of the facility or plans to purchase it which is why the stigma might still prevail.

Finding #3: Since the plant started operating in 2008, Brockton has not used the facility to its fullest potential because it is more expensive than purchasing water from Silver Lake.

Through interviews conducted with staff members from Aquaria, BWC, BDPW, and BDF, we discovered that Brockton has been purchasing water from the TRDF over the last 9 years, but in limited volumes. According to a staff member from BWC, Brockton would rather obtain most of its water from Silver Lake because it is significantly cheaper; this is due to the costs of desalination technology and the fact that under the contract with Veolia, the company who operates the Silver Lake Treatment Plant, Brockton does not have to assume any operation and maintenance costs of the facility. He further explained that the City already pays the fixed rate of $6.5 million, which limits the amount of money they spend for the variable rate. Therefore, Brockton cannot afford to depend on the TRDF for the majority of its water and only uses it as an alternative water source.

As established by the contract between Brockton and Aquaria, "Brockton shall have no minimum daily or annual purchase requirement." As part of the agreement, Brockton notifies Aquaria daily the water volume they desire to be delivered the day after and does not purchase water all year round (COB, 2002). According to staff members from BWC and BDPW, Brockton only uses the TRDF as a secondary water source when Silver Lake's level is low. Hence, the volume of water purchased from the facility has varied throughout the years; as seen in Figure 4, the largest amount of water Brockton has bought was in 2010, buying 302 million gallons a year (MGY), and the least amount was in 2012, buying 0 MGY.

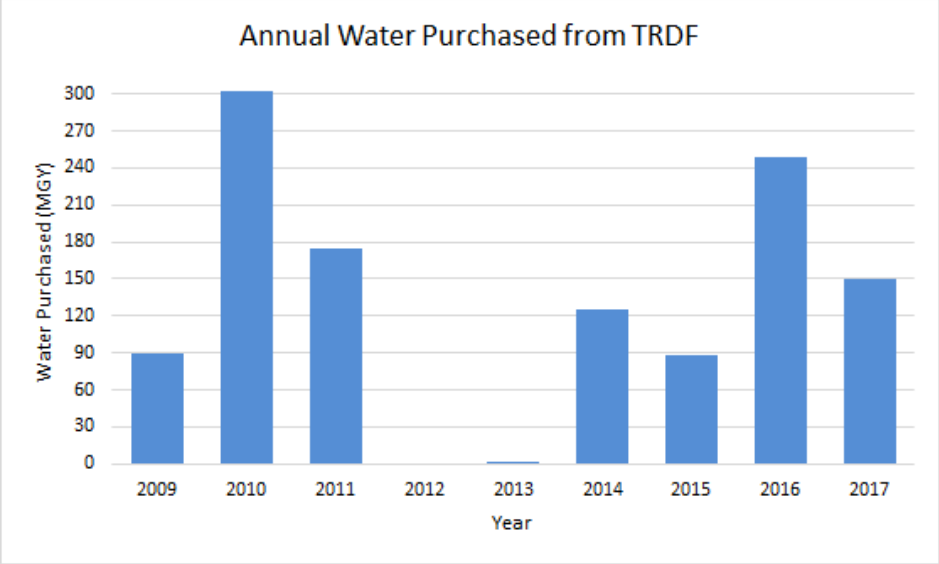

Figure 4: Annual purchased water from TRDF from 2009 until September, 20 2017.

As part of the agreement between Aquaria and Brockton, Aquaria is required to expand the plant's production annually from 1.90 MGD in 2009 to 4.07 MGD in 2028. Nevertheless, the volume purchased by Brockton has not increased in accordance to the increasing production capacity. As seen in Table 2, although the plant production has nearly doubled over this 9 years, the average volume purchased has not changed considerably, fluctuating between 0 - 0.83 MGD. Last year TRDF only provided an average of 6% of the City's demand and the remaining 94% was purchased from Silver Lake. Table 2 summarizes the maximum production by TRDF daily, an average of the volume Brockton purchased, and what percentage of the City's demand the water purchased represents.

Table 2: Production and Purchases from TRDF

Year	Max. Production of TRDF (MGD)	Average volume purchased by Brockton (MGD)	Percent of Brockton water demand purchased from TRDF
2009	1.90	0.25	2%
2010	2.00	0.83	8%
2011	2.50	0.48	5%
2012	3.00	0	0%
2013	3.50	0.57	6%
2014	3.50	0.34	3%
2015	3.56	0.24	2%
2016	3.56	0.68	7%
2017	3.81	0.41	4%

Finding #4: Due to both legal mandates and environmental precautions, Brockton is required to have a secondary water source.

After interviewing several city officials, we were informed that Brockton entered a Consent Order with the DEP in 1995. This order was issued due to the constant droughts at the time that overstressed Silver Lake because the City was drawing more water than the safe yield. As part of this consent order, Brockton was required to establish a board of water commissioners, appoint a full time water system manager, and find new water sources to offset reliance on Silver Lake's water system (Vedachalam & Riha, 2012). This consent order is precisely what led Brockton to invest in desalination facility. As of today, this imposed regulation is still in effect.

The current water demand in Brockton is between 9.5 MGD and 10.5 MGD. According to a staff member from BWC, about 8 MGD are drawn from Silver Lake and the remaining 2 MGD from the TRDF. When we interviewed a staff member from BDPW, he explained that the DEP is considering mandating Brockton to draw less water from Silver Lake. If such order is issued, Brockton will be forced to not only have a secondary water source, but also use it all year round.

A staff member from BDPW explained to us that drawing less water from Silver Lake is necessary to prevent the depletion of Silver Lake. Currently, Silver Lake is 40 inches below the normal water level. This decrease in water level not only affect Silver Lake, but also the surrounding bodies of fresh water such as Monponsett Pond, Furnace Pond, and the Jones River. Over the last year, these ponds have experienced a decrease in water level, aquatic life, water quality, and an increase of bacteria (Jones River, 2016a). Moreover, there is a lack of flow from Jones River into Silver Lake (Jones River, 2016b).

The depletion of these fresh water sources caught the attention of environmental groups in the area who have started protesting about Brockton's misuse of Silver Lake. Groups such as Mass Audubon and Jones River Watershed Association have been actively expressing their concerns about the depletion of Silver Lake. Through a series of articles in their web pages, they have discussed Brockton's lack of initiative to protect Silver Lake and are asking Brockton to better aministrate these fresh water sources.

Finding #5: The water demand in Brockton is not expected to increase substantially in the upcoming years due to plans to foment local industrial growth and projections of little population growth.

After interviewing staff members from BED and the Metro South Chamber of Commerce (MSSCC), we realized that the water demand is not expected to increase considerably in the next 10 years for two reasons:

1. No expected population growth
2. Little projected industrial growth

Regarding population growth, a staff member from the MSSCC explained that a City's growth is usually limited by water and sewer systems. However, he explained that Brockton has overcome these limitations by expanding their sewer system. Nevertheless, a staff member from BED explained that the City's growth is limited by their education system that is not ready to sustain a large growth. The UMass Donahue Institute did a study in 2015 where they researched the population growth in the South Metro Region. From this study, we learned Brockton has not experienced significant population growth since the 1990's and its population is projected to decrease by 1.5% between 2010 and 2030. This is opposite of the population growth for the rest of Massachusetts, which is expected to increase by 4.0% over the same time period (Figure 5).

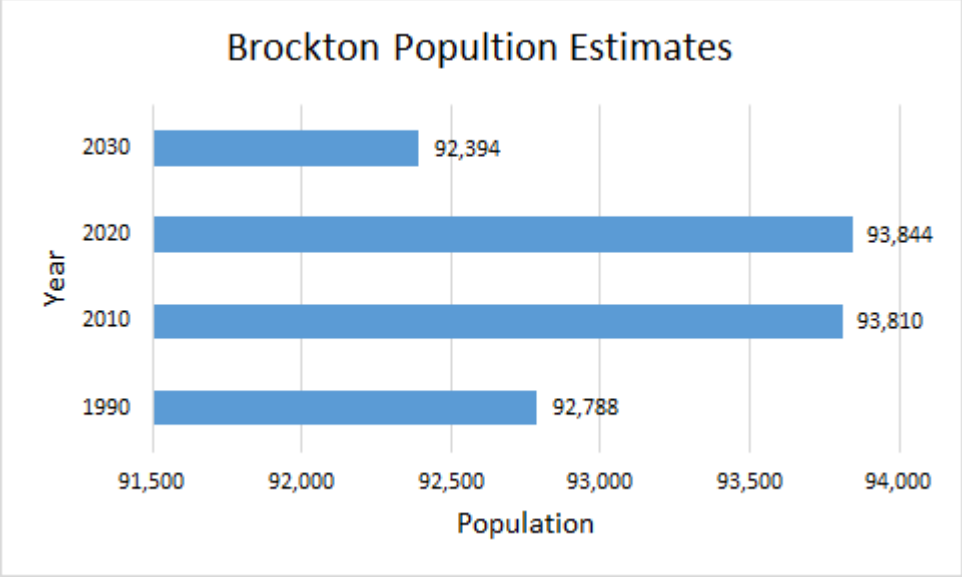

Figure 5: Brockton population estimates (Melnik, Hodge, Martin, Wong, & Goeke, 2015)

Not only is the population not expected to increase considerably, but as explained by a staff member from the MWRA, each year people actually consume less water. This is due to more efficient shower heads, toilets, sinks and other water fixtures. Therefore, if the population is not expected to increase, and assuming water usage per capita decreases over the years, the overall water usage in Brockton will go down.

Regarding industrial growth, Brockton's industry has declined since the 1960's. Brockton used to be an industrial City, but all large manufacturing industries have closed and in 2009 the last large shoe factory in Brockton, iconic for the City, shut down (Allegrini, 2009). A staff member from BED explained that the City's large industries include 3 hospitals, and a lime juice manufacturing company. He mentioned that the City has no plans to attract large manufacturing industries, but is rather focus on helping local businesses grow. He further assured that they are working on plans to bring industries back to Brockton after the closure of shoe factories, but no major industrial growth is expected. With only a local industrial growth and no large manufacturing industries in the area, Brockton is not expecting any large water demand from the industrial sector either.

4.2 Options for the future of TRDF

Based on the positive attitude stakeholders have about the facility, our team understood there is an incentive and desire to continue using the TRDF. Moreover, since Brockton is required to have a secondary water source, Brockton has to either continue using the TRDF or find a new water source. With this knowledge, our team decided to further explore three options the City has been considering for the future of the desalination plant. The options are:

Option 1: Purchase plant 2018 (See pg. 20 for more details and opportunities)
Brockton is looking at the option of purchasing the facility and as an owner, they will subcontract and a third party to operate the facility. At the moment, Aquaria's offer is $78 million and the City has until the end of 2017 to make a decision before Aquaria makes it a public bid (Condon, 2017; Staff Aquaria, personal communication, 2017).

Option 2: Stay in Contract until 2028 and renew 2029-2058 (See pg. 27 for more details and opportunities)
Once the contract expires in 2028, the City can stay with Aquaria and renew the contract for 30 more years. If the City renews the contract, Aquaria will remain the owner of the facility and Brockton will still have to pay a fixed and variable rate from 2029 to 2058 (Condon, 2017).

Option 3: End contract in 2028, and connect to MWRA (See pg. 29 for more details and opportunities)
Once the contract ends in 2028, the City is considering ending the contract and connecting to an alternative water source. The City is looking into the MWRA as the new water source. In this scenario, Brockton will first renew the contract with Aquaria for 10 more years (2029 - 2038) and connect to MWRA by 2039 (Condon, 2017).

Our team developed opportunities within these options to guide Brockton on how to leverage the TRDF. As seen in Figure 6, within each option the City can consider different alternatives to better use the facility.

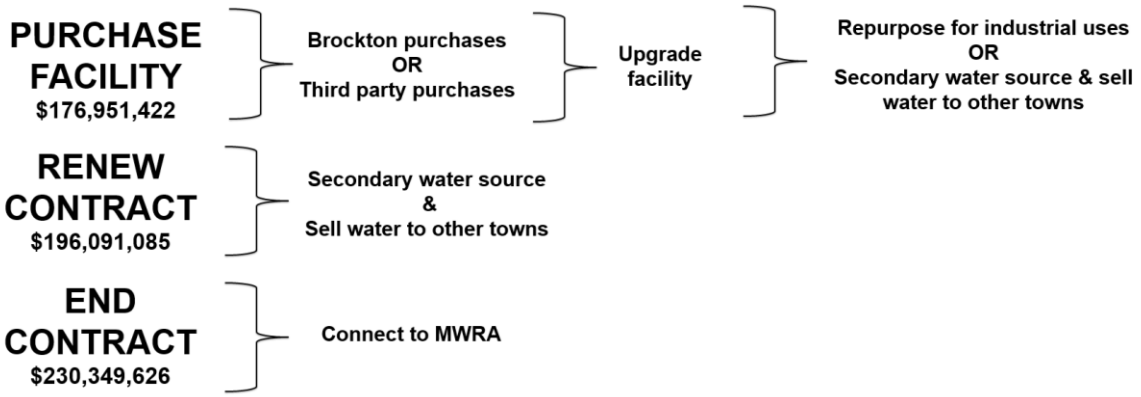

Figure 6: Opportunities for the future of the TRDF

OPTION 1: Purchase plant

Three years ago, Brockton started exploring the option of purchasing the TRDF; throughout these three years, Brockton has been negotiating the price of the facility with Aquaria to its current price of $78 million. This option has several pros, cons, and areas of further research to consider that are summarized in Table 3.

Table 3: Pros and Cons of Brockton purchasing the TRDF

PRO:	**CONS:**
Social: Brockton will have the opportunity to increase the reputation of the facility, which will in turn improve Brockton's goodwill in the region and increase trust with the residents.	**Social:** Brockton will now be directly responsible for everything that happens in the TRDF. They will be at risk of receiving criticism from environmental groups, residents complaining about misuse of their taxes, customer complaining about water quality etc.
Economic: Brockton will have the opportunity to provide jobs to people operating and maintaining the facility.	**Economic:** To afford the facility, Brockton will have to take out state bonds and pay the debt over 20 years.
Financial: From estimated costs, purchasing the facility saves the City $19 M compared to option 2 and $53M compared to option 3.	**Financial:** Brockton will have to assume all the operation, maintenance, and replacement costs, which will have to be budgeted into the City's annual budget. This requires Brockton to consider bond financing.
FURTHER RESEARCH BEFORE BROCKTON CHOOSES THIS OPTION: ● Estimate what the future operation, maintenance, and replacement costs will be in the next thirty years ● Look into funding opportunities from public agencies like Massachusetts Clean Energy Center ● Increase marketing and consider rebranding the facility ● Feasibility of having local engineers operating the facility instead of subcontracting an engineering company	

As explained by a staff representative of BDF, the proposal was approved by the BWC and since June, it has been brought up to the City Council for a vote. Until now, Brockton has not made a decision on this matter and will meet after the mayoral elections in November to decide whether to proceed or not with this purchase. According to staff members from Aquaria, Brockton has until January 2018 to make a decision. If the City does not purchase the facility by then, the bid becomes open to the public and Aquaria will reevaluate the price of the facility.

From **Finding #2**, we learned that there is no marketing about the facility. If Brockton purchases it, they will have the opportunity to increase the goodwill of the facility and make it an asset residents support and other towns want to be part of. Nevertheless, as explained by John

McArdle, the current contract removes all risks from Brockton because all guarantees are held by Aquaria and Brockton is just a customer. If Brockton becomes the owner, they will be held responsible for everything that happens in the facility including such ad complaints of water quality or negative environmental impacts of the facility.

In this purchase scenario, Aquaria will operate the facility for a year and then Brockton will subcontract an engineering firm to operate the facility. Aquaria has agreed to make some repairs on filters, pipeline transmission and intake systems by the end of 2017 (MSSCC, 2017). However, once Brockton purchases the facility, they will have to assume all the operation, maintenance, and reparation costs. As explained by staff from BDF, this represents a large amount of money that Brockton will obtain through bonds they will pay over 20 years. In order to analyze the financial feasibility of this option, Brockton has paid for several engineering studies to estimate the production costs of the facility. However, accurate estimates have been hard to obtain since the facility has never operated at a constant production of 2 MGD. A staff member of BDF explained to us that after these studies, the estimated total price of purchasing the facility and operating it to produce 2 MGD from 2018 to 2058 is estimated to be $176,951,422 (Condon, 2017).

If Brockton purchases the facility, we suggest that they explore these opportunities:

Brockton could explore the opportunity of having a third party purchase the facility

Although purchasing the facility will be cheaper in the long term than the two other options; nevertheless, the estimated $78 million will be one time immediate payment Brockton will have to go into debt to afford (MSSCC, 2017; Staff BDF, personal communication, 2017). To prevent this large expenditure, Brockton could explore having a third party purchase the facility. This third party will be a water treatment company with funds and expertise on desalination. Brockton could then negotiate a contract with this third party where they do not pay an annual rate but rather just purchase the water from the facility. The price of water will be considerably higher than the current variable rate, but because Brockton will only use the TRDF as a secondary water source, it will be cheaper in the long term. Since the bid will be open to the public after January 2018, Brockton could market the facility to water treatment companies.

Socially, having a third party purchase the facility will remove the risks of Brockton being directly associated with the facility in case opposition groups arise. From **Finding #2**, we discovered residents associate the TRDF with mismanagement of their money; a new company will have the opportunity to rebrand the facility and remove this stigma. Financially, a third party will reduce Brockton's debts and if the contract is strategically negotiated, in the long term it will be cheaper for Brockton.

Buyer could upgrade the facility to reduce operation and maintenance costs and expand facility.

From our meeting with Aquaria representatives, our team was able to identify potential upgrades the buyer could make to the facility in order to increase its production and reduce operating and maintenance costs. During the tour of the facility and with the guidance of a desalination expert we were able to identify four crucial upgrades to reduce operation and maintenance costs. These upgrades are:

1. *Reevaluate operating conditions of valves:* through engineering studies, an analysis of the current flows and flux of the valves can be done to test if they are operating at maximum efficiency. Altering the flows and pressures of valves, especially those that feed the RO and UF systems, will be useful to reduce operation costs with no additional capital cost.
2. *Optimization of RO system*: The plant currently operates with a bypass system that allows the water from the UF system to either be sent to the storage tank or RO system. By increasing recovery and flux of the RO, higher purity water can be produced. The RO treated water can be then mixed with UF treated water to potable quality standards. Through this process, less volume of RO water will be needed - that consumes more energy - in order to reduce overall production costs. This can be achieved by the addition of a new RO membrane.
3. *Addition of inter-stage booster pump between RO stages:* permeate throttling is the method used to adjust flows between the multiple RO stages in the RO system. This, consumes a lot of energy and installing an inter stage booster pump will be more cost efficient in the long term. The Inter Stage Booster Pump will balance the flux between RO stages reducing operating costs of RO system.
4. *Addition of solar panels*: Adding solar panels to produce electricity for the entire plant will represent a high capital cost for the buyer. However, solar panels could be installed to produce energy for the offices, outdoors lightning and visitors' area. This will increase slightly reduce electricity costs, but will demonstrate environmental awareness from the buyer. If a private company owns the facility, they could further benefit from state tax credits if solar panels are installed.

For more detailed description about upgrades see Appendix J.

Our team not only considered the option of reducing operation and maintenance costs, but also increase production of the plant through expansion of the facility. The facility's systems currently have the capacity to produce 3.5 MGD, the infrastructure can accommodate production up to 5 MGD, and the finished water pipeline can transport up to 10 MGD (Lynch & Mead, 2016).

To understand what equipment will be needed for expansion while also considering upgrades to reduce operation and maintenance costs, we got help from a financial analyst at a water treatment company. He helped us identify what equipment/systems need to be expanded, replaced, or added in the raw water pumping station, intake structure, storage tanks, chemical area, sludge handling, buildings, finished water transmission line, and RO, UF, and primary treatment systems. The target production of the facility after expansion will be 7.5 MGD, considering the intake permit of 8.9 MGD and an 85% efficiency of the process. In this scenario, the total cost of expansion, for either Brockton or a third party, will be an estimate of $72,967,606. For a third party purchasing the facility, the project cost (expansion & purchase of

facility) is estimated to be around $177,064,367. For a more detailed description of the expansion see Appendix K.

From a financial standpoint, upgrading the facility will represent a large amount of money for the buyer. But in the long term, it will reduce operating and maintenance costs. Regarding the expansion of the facility, this will also represent a large capital cost. Moreover, all the upgrades and expansion involve an in depth understanding of desalination technologies; expertise that water treatment companies that focus on desalination already have. The large expenditures of these upgrades along with the risk of getting involved in an area a municipality does not have expertise on, further emphasize the option of having a third party, who has the experience and funds, to purchase the facility. If the plant is expanded to 7.5 MGD, Brockton will purchase 2 MGD and there will be 5.5 MGD remaining. Thus, it will be primordial to find new customers for the facility or explore the feasibility of the TRDF becoming Brockton's main water source.

Brockton could continue using the facility as a secondary water source and sell excess water to neighboring municipalities.

The buyer, whether Brockton or a third party, could benefit by selling water to surrounding municipalities. In this scenario, Brockton will still be the largest consumer since as stated in **Finding #4**, they are required to have a secondary water source. As explained by a staff member from BDF, the amount of water Brockton will purchase from TRDF is 2 MGD. The current maximum production is 3.5 MGD and if expanded it could be 7.5 MGD; thus, whether the plant is upgraded or not there will still be leftover water to sell to neighboring communities.

Our team researched about the need and interest of neighboring municipalities connecting to new water sources through surveys. We learned that out of 11 municipalities located within a 15 mile distance of Brockton, 9 have municipals wells as their main water supply, and only 3 are looking for a new water source for their communities. Moreover, the water demand of all these municipalities is considerably low compared to Brockton, the highest being 2.8 MGD in Abington and the lowest being 0.38 MGD in North Raynham (Table 4).

Table 4: Municipalities near Brockton and their Water Sources

Municipality	Water Demand (MGD)	Water Source	Interest in New Water Source
Abington	2.8	4 wells	No
Avon	0.6	7 wells	Yes
Bridgewater	1.8	11 wells	No
Easton	2.3	5 wells	No
Hanover	1.5	9 wells	No
Hanson	0.7	4 wells	Yes
North Raynham	0.38	Wells	No
Norton	1.2	1 well	No
Stoughton	2.0	7 wells & MWRA	No
West Bridgewater	0.8	7 wells	Yes
Whitman	1.1	Connected to BWS	Yes

Despite the small need of municipalities connecting to new water sources, staff members from water departments mentioned that they might be looking for new water sources during droughts. According to the National Drought Mitigation Center (NDMC) and the National Integrated Drought Information System (NIDIS), since 2012, Eastern Massachusetts has experienced annual droughts during the spring and summer (NDMC, 2017; NIDIS, 2017). Last year was the worst drought the region has been through in decades. As seen in Figure 7, from July 2016 to April 2017, the region experienced severe to extreme droughts.

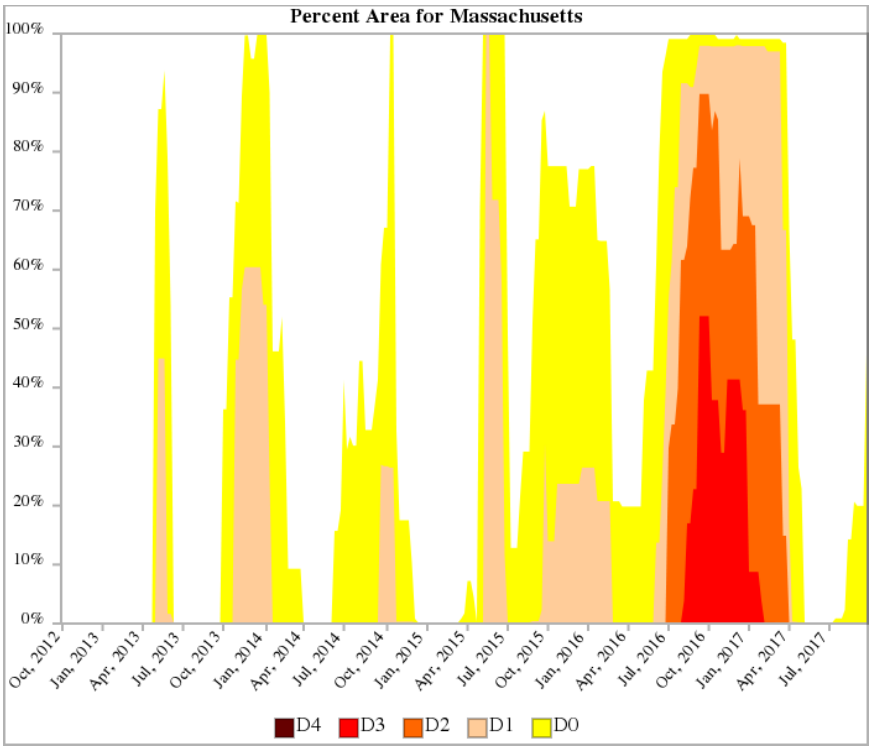

Figure 7: Severity of droughts in Eastern Massachusetts. White indicates no droughts, yellow abnormally dry, pale moderate drought, orange severe drought, red extreme drought. (NDMC, 2017)

During these months, staff members from the water departments explained that they had to impose water usage restrictions in their municipalities, preventing residents from any outdoor watering. Additionally, some of them observed a decline of water level in their wells. Based on this, most staff members assured interest in exploring new water sources in the long term depending on the severity of upcoming droughts.

As explained by a staff member from BDPW, the towns of Whitman and Hanson are already connected to Brockton's water system. The buyer should consider these towns as their first customers since no additional pipeline costs have to be considered. The buyer will also have the opportunity to sell water to municipalities not connected to their water system. In this case, Brockton and the municipality will have to assume the costs of pipeline studies and construction. A staff member from the MWRA gave us an estimate of $870 per foot of pipeline; thus each mile of pipeline will cost an approximate of $4.5 million. Due to the high price of pipeline construction desalination experts suggested Brockton should not look for municipalities further than a 10 mile radius for connections.

Financially, selling water to other municipalities will help the buyer generate some revenue which will help mitigate Brockton's debts. However, the buyer will have to consider that in order to sell the water, the price has to be lower or around the same price of the current water supplies in these towns; this might be a challenge because desalination is usually an expensive water treatment technology. Thus, it would be crucial for the buyer to upgrade the facility in order to increase efficiency and reduce production costs. Socially, creating a network of water supplies in the Metro South Shore will help promote water collaboration within these communities and expand Brockton's relationship with these towns. Economically, increasing the

water supplies in these communities is going to help these communities grow since as mentioned by representative of MSSCC, water is a limitant when cities expand. Moreover, the entire new connections being made will generate jobs in the area both during construction and maintenance of these pipelines.

The buyer could provide water of a particular quality to industries in the area

The buyer of the facility could focus on finding industries in the area that use large volumes of water as potential customers. As a staff member from BED explained, Brockton's major industries include the food production company Concord Food and three hospitals: Good Samaritan Medical Center, Signature Healthcare Brockton Hospital, and Brockton Neighborhood healthcare center. These industries use large amounts of water that they directly purchase from the City. However, the buyer could explore the opportunity of providing water to these industries as direct customers. It would be a viable option for the buyer to identify which industries have plans to expand in the future which will be potential customers.

From our literature review about alternative uses for desalinated water, our team discovered that some industries that have benefited from using desalination include: electronics, power plants, beverage production, agriculture, and wastewater treatment. For detailed description of how desalination is used in these industries and examples refer to Appendix F and Appendix G. From **Finding #5,** we recognized that currently Brockton has none of these industries or plans to attract them in the future. Hence, the buyer could explore the option of selling water to manufacturing industries in neighboring municipalities. As previously mentioned, due to the high costs of pipeline constructions, we do not recommend looking into industries any further than a 10 mile radius.

In our meetings with experts of water technologies, we learned that the accessibility to water is an important driver for siting industrial facilities. Through the appropriate marketing, the buyer could attract large industries who want to purchase large volumes of water to the area. Some of the industries that could benefit from large volumes of water include pharmaceuticals, power generation, microelectronics production, and food production. We recommend looking into industries in the area and developing a plan to attract them.

Selling water to industries will financially represent a larger cost for the buyer since they will have to increase production, construct pipelines, and in some cases improve the technology if water of a particular quality is required (i.e high purity water). However, these industries will become new customers of the plant that will help the buyer generate revenue from the water being produced. Economically, if the buyer is able to attract new industries to the area, the City will benefit through the creation of more jobs, larger investment in the City, and the potential of growing both in population and industries.

OPTION 2: Stay and renew contract

Brockton has the option of staying in the contract until 2028 and then renewing it. In 2028, Brockton will have the opportunity to renegotiate the contract with Aquaria and renew it for thirty years. This option has several pros, cons, and areas of further research to consider that are summarized in Table 5.

Table 5: Pros and Cons of Brockton staying in and renewing contract

PRO:	**CONS:**
Social: Aquaria will remain in charge of the facility and Brockton will only be a customer. Thus, Aquaria will be responsible of any malfunction or complains about the facility and/or water produced.	**Social:** If no marketing is done to improve the attitude of residents towards the TRDF, residents will remain unaware of the facility's use and opposition groups might arise.
Economic: N/A	**Economic:** If facility continues to be used as it has been in the past 9 years, it will not attract any industries or generate jobs since it will only be used during emergencies.
Financial: Brockton will not have to assume all the costs of the facility since it will be operated by Aquaria.	**Financial:** The City of Brockton will still have to pay the fix and variable rate that already represents a large sum of money in Brockton's annual budget.
FURTHER RESEARCH BEFORE BROCKTON CHOOSES THIS OPTION: ● Estimate of new fixed rate in 2028 ● Estimate of new variable rate in 2028 ● Examine what the new terms, if any, of the contract renewal will be	

In this option, Brockton will still pay an annual rate and purchase water at a variable rate. According to City Officials, in the renegotiation of the contract they will try to reduce the annual rate the City pays in order to make it more affordable for the City to purchase the water. They also explained the Brockton will continue using the TRDF only as a secondary water source, purchasing approximately 2 MGD throughout these next 40 years. In this scenario, Aquaria will remain in charge of operation and maintenance of the plant and Brockton will be the only customer. A staff member of BDF explained to us that paying the remaining 11 years of contract, paying 30 additional years after renegotiation, and purchasing 2 MGD of water will cost the City approximately $196,091,085.

Financially, in the long term, this opportunity will be more expensive for Brockton than option 1. However, in the short term it is more accessible for the City to assume these costs without taking bonds. If the City purchases the plant they will need to pay an estimated $78 million and immediately assume all costs of the facility. On the contrary, by renewing the

contract Brockton will pay an annual rate and the volume of water annually as they have already financed the past 9 years.

If Brockton stays and later on renews the contract, we suggest that city officials explore the following opportunity:

Brockton could continue using the facility as a secondary water source and sell excess water to neighboring municipalities.

As mentioned in **option 1**, Brockton could continue using the TRDF as a secondary water but should consider the option of selling the water to neighboring municipalities. Refer to page 23 for a more detailed description of this opportunity.

In the current terms of the contract, only Brockton can allow the connection of new municipalities to the TRDF. Thus, it will be Brockton's responsibility to promote the facility in surrounding municipalities to get more customers for the TRDF. Selling water to surrounding municipalities will help Brockton pay for the fixed rate of the contract; this in turn will help Brockton reduce their expenditures on the TRDF. Socially, selling water to neighboring towns will improve Brockton's relationship with other communities and improve the image of the facility in a regional level, as it will be now aiding other municipalities.

OPTION 3: End contract and connect to MWRA

Brockton has the option of paying the remaining 11 years of contract with Aquaria until 2028, and end the contract to connect to the MWRA. This option has several pros, cons, and areas of further research to consider that are summarized in Table 6.

Table 6: Pros and Cons of Brockton connecting to MWRA

PRO:	**CONS:**
Social: No more complaints about the "wasted" desalination facility from residents.	**Social:** Brockton is at risk of facing complaints from environmental groups arguing about the negative impacts of the pipeline construction.
Economic: MWRA system is reliable and prices are predictable in the long term.	**Economic:** N/A
Financial: Do not have to pay fixed and variable fees to Aquaria once contract ends. After the pipeline is constructed, Brockton will only have to pay the price of water they buy since costs of maintenance are relatively low.	**Financial:** It is the most expensive option, due to having to both stay in the contract and the costs for permitting and building the MWRA pipeline. They will also have to consider additional costs if Silver Lake water is not compatible.
FURTHER RESEARCH: ● Financial cost analysis for other scenarios (i.e. starting permitting and building for MWRA in 2019 rather than 2028 and do not renew contract) ● Look into neighboring municipalities interested in connecting to the MWRA ● Find ways to address the environmental opposition that might arise during the period of pipeline construction ● Explore other secondary sources such as treatment of groundwater	

Consulting with MWRA's director of planning, Stephen Estes-Smargiassi, and staff member from MSSCC we learned that the closest connection point for Brockton will be at Quincy and Brockton will be obtaining water from the Quabbin Reservoir. They further explained that the estimated costs Brockton will assumed for this connection include:

1. **Entrance fee:** $4.3 million per million gallons
2. **Water cost:** $3.471 per thousand gallons
3. **Pipeline cost:**
    a. Specific towards pipeline route, requires engineering investigation
    b. Construction of pipeline: $870 per foot of 24" diameter pipe. The estimated route requires 11 miles of pipeline, which will represent a cost of $55 million.
4. **Permitting costs:** engineering investigation to get permits approved estimated to currently be $11 million

5. **Water treatment consistency:** If the quality of water from Silver Lake is not compatible with that from the MWRA, Brockton will have to invest on improving the quality of water from Silver Lake so that it matches that from MWRA.

From **Finding #4** we discovered Brockton is required to have a secondary water source; thus Brockton needs to stay in the contract with Aquaria while the pipeline to the MWRA is being built. A staff member from BDF explained to us that Brockton could start the permitting and pipeline construction now; however, they are waiting until 2028, when they renegotiate the contract to see if it would be cheaper to connect to the MWRA or renew the contract. The difference in price will ultimately depend on the new fixed rate Aquaria asks Brockton to pay. If contract renegotiation does not favor Brockton, the City will start permitting and pipeline construction in 2028, which will force the City to renew the contract with Aquaria for 10 more years until they can finally connect to the MWRA in 2039. The Financial Department of Brockton also provided estimated costs for connecting to the MWRA. The calculated cost of this option from 2018 - 2058 is to be estimated $230,349,626.

To make this option more economically feasible, Brockton can consider ending the contract in 2028, and start the permitting and pipeline construction now in order for them to be completed by 2029. Like this, the City can save the money spent in the 10 year renewal of the contract that represents an estimate of $100 million according to staff from BDF.

A staff member from the MSSCC explained to us that if other municipalities in the area show interest of connecting to the MWRA, it would make this option more viable. They explained that the MWRA is very open to discuss with Brockton about this opportunity and having other communities help with the permitting and pipeline costs which will significantly reduce Brockton expenditures. Nevertheless, our surveys with staff members from 11 municipalities in the area, none of them expressed interest in connecting to the MWRA. The only town in the area connected to the MWRA is Stoughton that receives 75% of their water supply from this source. Although at the moment, there is no interest of connecting to MWRA, it is a possibility Brockton could explore this option before the contract is renegotiated in 2028.

Financial comparison of the 3 options

The Department of Finances has been currently investigating these options in terms of the costs they will represent for Brockton. In all these scenarios, both the TRDF and MWRA will serve as a secondary water source (2 MGD) and Silver Lake will remain the City's main water source. The City has also estimated drawing more or less water of these sources in case of new mandates or decrease of water demand. Table 7 summarized the costs of each option if Brockton purchases 1 - 4 MGD and Figure 8 compares these costs.

Table 7: Estimated costs of each option from 2018 to 2058 at 1, 2, 3, and 4 MGD

	1 MGD	**2 MGD**	**3 MGD**	**4 MGD**
Option 1 Purchase	160,636,082	176,951,422	193,266,762	209,582,101
Option 2 Renew	177,800,156	196,091,085	214,382,014	232,672,944
Option 3 End/MWRA	197,538,381	230,349,626	263,160,870	295,972,114

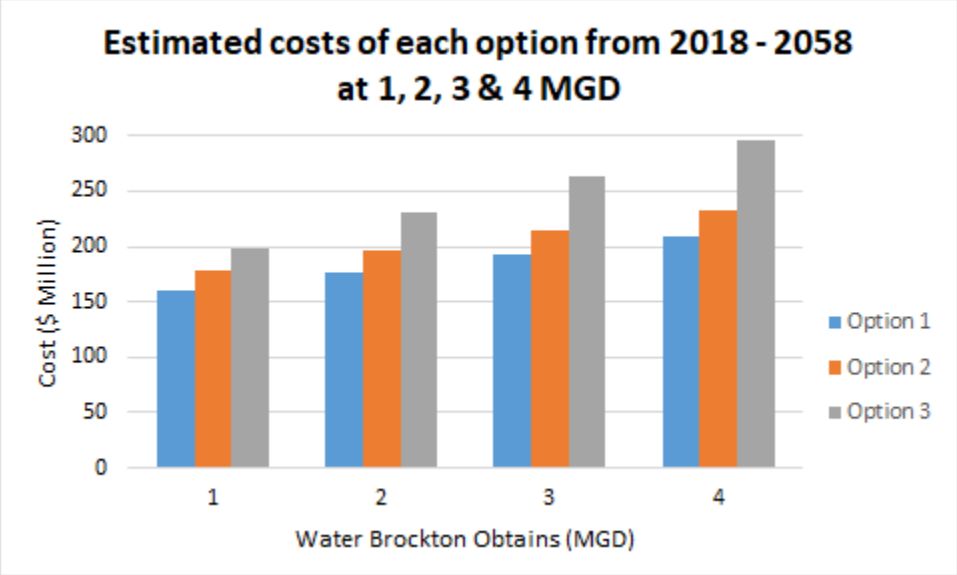

Figure 8: Estimated costs (2018 -2058) for each option

If the City only obtains 2 MGD from either the MWRA or the TRDF, from 2018 to 2058 option 1 will cost $176,951,085, option 2 $196,091,085, and option 3 $230,349,626. Over these 40 years, purchasing the plant saves the City $12 million than renewing the contract and will save $53 million than connecting to the MWRA. As seen in Figure 8, at any volume of water

purchased option 1 is the cheapest option and option 3 the most expensive one. For option 1 the savings increase as the water obtained increases and in option 3 expenditures considerably increase as the water obtained increases (Condon, 2017)

Although option 3 is the most expensive option, it is important to be aware it is the most accurate price estimate. The MWRA has fixed costs and accurate projections of what the costs will be, that have allowed BDF to develop precise estimates of the cost to connect to MWRA. On the other hand, option 1 and option 2 are based on assumptions of what the new variable and fixed rate will be and estimates of operation and maintenance costs.
All these costs are estimates from an analysis by Brockton's Financial Department.

Chapter 5: Conclusion

The desalination facility that serves Brockton is currently not being used to its fullest capacity due to City's limited budget to purchase water. As a result, we were given the tasks of investigating the TRDF, understanding the concerns of its current stakeholders, and exploring the current and expected water demand in Brockton. With this knowledge, our team was able to develop a variety of options in which Brockton could leverage the TRDF.

Some of the findings we were expecting included the plans the City has to either purchase the facility, end the contract, or renew it. From our literature reviews, we were also expecting to find that residents are not well informed about the TRDF and its uses. However, a lot of the findings were quite surprising and unexpected for our team. We found that most stakeholders believe desalination was the best alternative for the City and have a positive attitude about the future of the facility. We also found that the City has been purchasing water from the facility over the last 9 years; however, the volume of water they can purchase is limited by their annual budget. These findings helped us come up with options that Brockton could consider in order to leverage the TRDF. Synthesizing all this knowledge, we were able to provide NEWIN with the following deliverables:

1. Literature review of the history of TRDF
2. Master List of contacts
3. Weekly blog post for NEWIN's web page
4. Executive summary of our project

The findings, recommendations, and deliverables the team constructed will help NEWIN expand their outreach with water innovation stakeholders in the North Eastern region, analyze the opportunity of helping Brockton leverage the TRDF, and promote the growth of water innovation technologies. After concluding the project, our suggest NEWIN that areas of further research should include:

1. Map water supplies in the South Shore of Massachusetts
2. Promote regional collaboration for water systems in the Metro South Shore
3. Help Brockton find potential third parties interested in purchasing the facility
4. Assist Brockton with marketing strategies to increase goodwill of the facility
5. Explore residents opinion on desalination and the TRDF

After all the information learned from the TRDF and Brockton's water resources, we suggest the City of Brockton that areas of further research should include:

1. Prevention of depletion of Silver Lake
2. Increase of marketing of the TRDF to inform residents about the facility
3. Explore funding opportunities to leverage TRDF
4. Work on increasing water collaboration with neighboring towns

We live in a world where fresh water is becoming more scarce every day. Thus it is prominent to look into new water treatment technologies to produce potable water for the world's growing population. Desalination is a growing and promising technology. However, the lessons learned in Brockton show us that having the need for a new water source does not guarantee it is going to be appropriate and easy to implement; there are a lot of underlying economic, social, technological, and financial aspects to take into account. Hence, it is important that organizations like NEWIN keep researching, encouraging, and promoting the growth of water innovation.

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Appendices

Appendix A: Desalination and reverse osmosis

Desalination is the process that removes salt and particles from water. By using desalination facilities, communities are offered a variety of opportunities to purify water from for human consumption, agricultural, and/or industrial purposes. Today, there is a variety of desalination treatment methods; the most common are distillation processes, thermal desalination, membrane-based processes, electrodialysis, among others. The success of each approach depends on the required capital investment, water capacity, and operation and maintenance cost (Summers, 1995). In industry, one of the most common technologies used are membrane processes; these are mechanical processes that purify water through the use of permeable membranes (Kucera, 2014). There is not one process of desalination that is better than the other since they all have their respective advantages and disadvantages; moreover, the better method to use largely depends on the needs of the community (Summers, 1995).

The Reverse Osmosis Process

One of the most common technologies used for desalination is reverse osmosis (RO). RO has been largely proven to be one of the most productive and energy efficient processes; in this process, pressure is applied to separate solids from liquids across permeable membranes (Kucera, 2014). In a simplification of the process, there are 4 main steps to purify the water. First, water flows through a valve at a slow rate; the pace is slow enough that an average fish can swim out of the valve, protecting surrounding marine life (SUEZ, 2012). Second, the water is filtered to remove any large impurities such as algae or sand, leaving only brackish water. Third, the brackish water is sent through a fine membrane-like filter at a very high pressure to remove the salt. The water pressure through the membrane filter is equivalent to that of 100-elephants (providing the pressure) on top of a manhole cover (the filter). This step releases energy, which the facility uses for other systems in the plant. For every two liters of brackish water sent through the system, the process produces one liter of water with twice the amount of salt, called brine, and one liter of demineralized water. The brine is filtered and treated so that it is safe to be returned to the ocean. Fourth, the demineralized water is treated for consumption; this involves purifying and disinfecting the demineralized water through the use of chemicals. Then, the purified water is pumped to communities in order to be distributed to homes for consumption (SUEZ, 2012).

Appendix B: Technical description of TRDF

The TRDF treats brackish water through ultrafiltration and reverse osmosis to produce potable water. This process starts with water flowing through gravity across four levels of screening. The levels of screening are the following:

1. Gunderboom system
2. Bar racks
3. Vertical Wedge wire screens:
4. Cylindrical Johnson-style screens

The gunderboom system prevents the flow of fish eggs and aquatic life into the plant and the other three systems keep large solids (i.e soil, debris, rocks) out. Water flows into the raw water pumping station (RWPS) where three low head vertical pumps send water to the storage tanks. The facility has 3 tanks between the RWPS and the treatment plant. The tanks are the following:

1. Brine tank: 3-MG open top tank
2. Raw water tank: 2.5-MG with aluminum cover
3. Finished water tank: 0.35-MG with aluminum cover

Water flows through gravity from the raw water tank to the water treatment plant. Once it gets to the plant, water is conditioned by the addition of powdered activated carbon, caustic soda, potassium permanganate, and ferric sulfate are added. The conditioned water then enters a mixing tank and a flocculation phase. Water is then treated by the ultrafiltration membranes that have 10% recovery. The permeate water is then pumped to a clearwell. From here, the water can be either delivered to the treated water area or to the RO system depending on the raw water salinity; if the salt concentration is low only UF treatment is needed if high both UF and RO are used. If further treatment is needed, the water is pumped to the RO system that has a 75% recovery.

If the City buys the water, treated water is then transported through a 16 mile long pipeline to the City of Brockton. If not, the water is then discharged to the river. Waste brine from the reverse osmosis system is also discharged into the river during high tides when the salinity of the brine matches that of the river. Currently the facility has the capacity to produce over 3.5 MGD and with the appropriate modifications, it has the potential to produce up to 5 MGD.

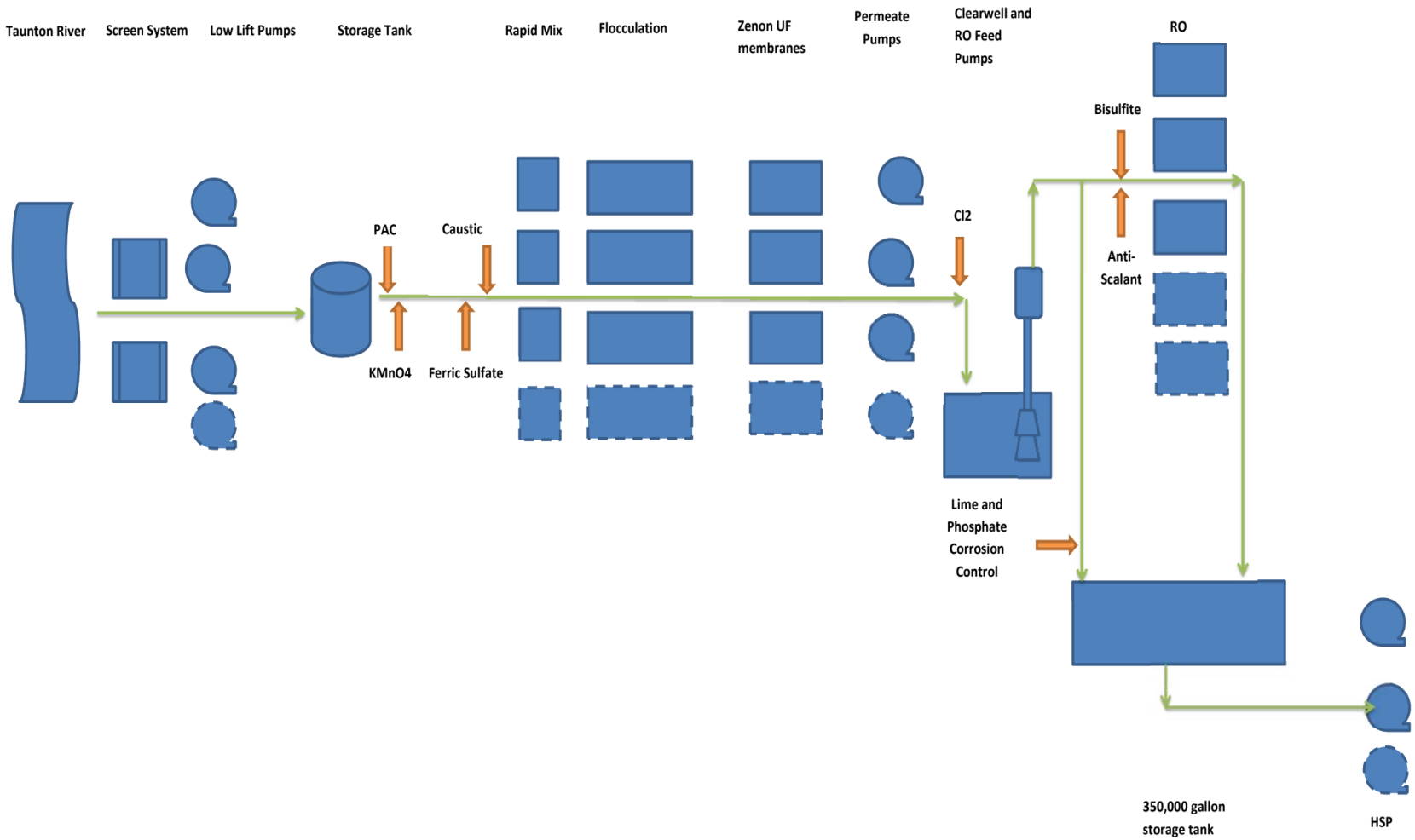

Figure 9: The purification process of the TRDF in detail. (Lynch, J., & Mead, I., 2016)

Appendix C: Interview

Table 8: List of Interviews

Name of Interviewee	Occupation/ Company	Page #
Amy Crawford	Former reporter of Boston Magazine	43
Engineer who proposed desalination	Consultant Engineer	44
John McArdle	Consultant Engineer	45
Stephen Estes-Smargiassi	Director of Planning and Sustainability MWRA	47
Michael Sessine	Silver Lake Plant Manager	49
Staff Member	Brockton's Water Commission (BWC)	50
Staff Member	Brockton's Public Works (BDPW)	52
Staff Member	Brockton's Finance Department (BDF)	54
Staff Members	Brockton's Economic Department (BED) & Metro South Shore Chamber of Commerce(MSSCC)	56

Interview with Amy Crawford:

Hi Amy. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the TRDF that currently serves Brockton. During our research we came across your article "How Brockton Desalination Plant Cost them Millions." Your article had a lot of valuable information and we were hoping you can give us some insight into your research of the facility. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project.

1. What interested you about the situation in Brockton that you decided to do research and write about it?
    a. Was it a controversial and known topic at the time?
    b. How did you hear about it?
2. From your research, what were the reasons that lead the City of Brockton to invest in a desalination facility?
    a. Do you know how the City decided this was a good alternative to solve water shortages?
    b. Do you know who was involved in this decision?
    c. Do you know any details about the contract between Aquaria and the City of Brockton?
3. When you published the article, the desalination facility was not being used by the City. What are some of the factors that contributed to its underuse?
    a. What were some of the complains of people you interviewed towards the facility?
4. You mention that some residents were expressing concerns about how their taxes were being spent, what was the attitude of the residents in Brockton towards the desalination facility at the time you wrote the article?
    a. Where there groups expressing support or protesting against it?
5. What was the politicians opinion on the facility?
    a. Mayor Yunits?
    b. Mayor Balzotti?
6. Do you know of any alternatives Brockton was exploring at the time to better use the facility?
7. In your article we saw that you mentioned/contacted names of people who were involved in the decision making process of the plant and some politicians, do you have any contact information of these people?

Thank you again for your time. We really appreciate all the information you just shared with us. We will like to schedule another interview with you in a couple weeks to discuss the recommendations we have for Brockton to better use the facility. Finally, do you have any recommendations about topics we should research or questions we did not ask?

Interview with engineer who proposed desalination:

Hi Jeff. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the TRDF that currently serves the City of Brockton. The reason we wanted to interview you is because we believe that you can help us understand and provide great insight into the decision and siting processes for water technologies and to better understand desalination and membrane technologies. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project.

1. Could you tell us a little about yourself and your work with the TRDF?
    a. How long did you work for Brockton?
    b. What type of projects are you involved on?
    c. How did you end up presenting the idea of desalination?
2. We've read in articles that you were one of the engineers that proposed the idea of the desalination facility to the City, could you give us an overview of how you came up with this idea?
    a. Who did you work with?
    b. Why was desalination better than other alternatives?
    c. The idea was very innovative at the time and there are not many desalination plants in the area why take the risk?
    d. How was the desalination facility going to help Brockton?
3. How was the siting process for the plant done?
    a. Who determined the location?
    b. Why is it located where it is?
    c. Are there any drawbacks of this location?
4. Could you explain to us how the facility operates?
    a. Explain the freshwater vs. brackish water treatment
    b. What membranes are used?
    c. Is the energy consumption of the facility high?
    d. Is this method considerably more expensive?
5. Do you think desalination was the best solution for the City?
    a. Why?
6. Do you have any ideas about how the City could use the facility to its fullest potential?
7. Do you know about any other uses for the plant besides human consumption?
    a. Was there any other purposes the plant could serve besides drinking water?

Thank you again for your time. We really appreciate all the information you just shared with us. We will like to schedule another interview with you in a couple weeks to discuss the recommendations we have for Brockton to better use the facility. Finally, do you have any recommendations about topics we should research or questions we did not ask?

Interview with John McArdle:

Hi John. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the TRDF that currently serves Brockton. The reason we wanted to interview you is because we believe that you can help us understand and provide great insight into the contract between Brockton and Aquaria, the decision and siting processes for water technologies and help us understand desalination and membrane technologies. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project. The reason we wanted to interview you is because we believe that you can help us understand and provide great insight into the decision and siting processes for water technologies and to better understand desalination and membrane technologies.

1. Could you tell us a little about yourself and your experience on desalination and water technologies?
    a. How long have you been working on water technologies?
    b. What type of projects are you involved on?
2. We saw your presentation on the Water Industry Sales Channel, could you explain who are the participants in the water sales industry channel and what is their role?
3. Could you explain the three different equipment bidding scenarios in water contracts?
4. *Explain contract with Aquaria*. Based on your experience could you give us some insight into what the contract entitles?
    a. What are the benefits of this contract for Brockton?
    b. What are the drawbacks/limitations of this contract?
    c. Where else have you seen contracts like this?
    d. What do you think about this contract?
5. What are different uses for desalinated water through reverse osmosis in the Northeastern region of the United States?
    a. Do you know any plants that produce water for other uses besides potable municipal water?
    b. What are the common uses for water treated with other types of membranes?
6. Since our project focuses on proposing alternative uses for the Taunton's River Desalination Facility besides potable water, we would like to understand the long term impacts of water facilities. When a customer is interested in investing on water technologies, what factors are taken into account for the long term impact analysis of water facilities?
    a. How do contractors analyze the market size, market growth, and long term profitability?
    b. How similar are these analysis/predictions to the actual outcomes?
7. Do you have any experience on repurposing/redesigning water treatment facilities?
    a. Why were these facilities repurposed?
    b. How was the decision of what the new purpose was going to be done?
    c. In the long term, where these facilities better used than before they were repurposed?

8. Just with what we have discussed and about what you know of the situation in Brockton, on top of your head do you have any ideas about what can the City do with this facility?
9. Do you have any suggestions about who else we could contact for our project?

Thank you again for your time. We really appreciate all the information you just shared with us. We will like to schedule another interview with you in a couple weeks to discuss the recommendations we have for Brockton to better use the facility. Finally, do you have any recommendations about topics we should research or questions we did not ask?

Interview with Stephen Estes-Smargiassi:

Hello Stephen. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the TRDF that serves Brockton and exploring the option of Brockton connecting to the MWRA. As director of planning and sustainability of the MWRA, we were hoping you could help us understand the process a municipality has to follow to connect to the MWRA and potential estimates of how much this would cost. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project.

1. Could you tell us a little bit about yourself and your work in the MWRA?
    a. How long have you been working for the MWRA?
2. Could you just briefly explain to us how the MWRA water system works?
    a. Reservoirs? Then treat plant? Then sell it to customers?
    b. Are prices constant or they vary across region?
3. What is the process a town or City has to follow in order to connect to the MWRA?
4. What is the furthest point South of Boston that the MWRA serves to?
    a. What City/town?
    b. Are there any reservoirs? What is their capacity?
    c. What are the towns/cities connected to these reservoirs?
    d. Is MWRA their main water source or more like an alternative water source?
    e. What is the water demand from the MWRA?
5. What is the closest connection point for the City of Brockton to the MWRA?
6. Does the MWRA have any plans to expand its connection to communities South of Boston?
    a. What are the plants?
    b. Hav towns in the south expressed any interest?
    c. Would they be interested in investing on water treatment plants?
7. We have been told that for the City to connect to the MWRA there are 5 costs to consider. Could you give us an explanation of what this costs would be and perhaps an estimate?
    a. Fee to connect
    b. Water cost
    c. Permitting
    d. Pipe costs
    e. Improving water standards in Silver Lake
    f. Consider asking estimate of $$ per mile of pipe
    g. Does MWRA or the customer assume the cost of pipeline?
8. After all these are paid by the City the only cost they will then have to assume will be based on the amount of water they purchase ($$/gallon) is that right?
    a. Estimate of the price at which the City will buy the water?
    b. Operation and maintenance costs?

9. If Brockton connects to the MWRA, could they be able to then resell the water to neighboring towns and communities?
10. Does the MWRA operate/own any desalination plants?
    a. Would they be interested in investing in one?
11. Do you think it is a good idea for Brockton to connect to the MWRA? Why?

Interview with Michael Sessine:

Interview via email

1. How old is the WTP?
2. For how long/since when has the facility been providing water to Brockton?
3. What efforts are being made to prevent depletion of Silver Lake?
4. What is the volume of water withdrawn from Silver Lake into the facility?
5. What is the maximum withdrawal permit from Silver Lake?
6. How much water is treated daily?
7. What is the maximum amount of water the plant can treat?
8. How much water does Brockton purchase daily?
9. At what price is the water being sold to the City?
10. What are the operation and maintenance costs of the plant?
11. Is Brockton the only customer of the plant?

Interview with Staff member of Brockton's Water Commission:

Hi --. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the TRDF that currently serves Brockton. We want to interview you because as --- of BWC we were hoping you can provide us some insight into the history of the plant, why the City choose desalination and how the City is currently using the plant. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project. The reason we wanted to interview you is because we believe that you can help us understand and provide great insight to the facility and the current needs of Brockton.

1. What has been your role in Brockton's Water Commission?
2. How long have you been working in the City of Brockton?
    a. Specifically, how long have you been involved in the desalination facility?
3. When desalination was chosen as an alternative water supply the City was facing water shortages, what criteria were used to decide on desalination among other options?
    a. Why were these criteria chosen?
    b. What were the other options that were taken in consideration when making the decision?
    c. What were the pro's and con's of using desalination over others?
    d. Who was involved in this decision making process?
    e. How was the siting process for the plant done?
    f. Do you know what were the long term goals of the facility?
4. We read that Brockton is in a 20 year contract with the company Aquaria for the desalination facility, could you explain what this contract consists of?
    a. Who own the facility itself?
    b. Financially, what is the deal? What is the annual payment?
    c. Under the contract, is the City able to physically alter/ request for alterations in the facility?
    d. Does the City pay for the facility's maintenance?
    e. As part of the contract is the City required to purchase a specific amount of water?
    f. What do you think about this contract? Why?
5. In your opinion do you think desalination was a good choice for the City of Brockton?
6. During our research we read that the City of Brockton is not using the water from the facility, could you give us some insight as to why?
    a. What is the current state of the facility?
7. What is the current water demand in Brockton?
    a. What is the City's main water source?
    b. Does the City need other water sources not only because of the water demand but legal requirements?
    c. What other water sources do you think are beneficial for the City?
    d. Are there any considerable industrial demands?
8. What plans/ hopes does the City have for the desalination facility in the future?
    a. Buying it?

    b. Who is involved in these plans?
    c. What do you personally think should be done?
    d. Have you heard or been part of any discussions about alternative uses that can be given to facility? Perhaps using it for other purposes besides potable water
9. Is there anyone else you can put us in touch who would be helpful to understand the water situation in Brockton and how can the facility be used?

Thank you again for your time. We really appreciate all the information you just shared with us. We will like to schedule another interview with you in a couple weeks to discuss the recommendations we have for Brockton to better use the facility. Finally, do you have any recommendations about topics we should research or questions we did not ask?

Interview with Staff member of Brockton's Public Works:

Hi ----. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the TRDF that currently serves Brockton. The reason we wanted to interview you is because we believe that as --- of BDPW you can help us understand and provide great insight to the water system in Brockton and the current needs of Brockton. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project.

1. Could you tell us a little about yourself and you background?
    a. What is your role as the Commissioner of Public Works?
    b. How long have you been working in the water sector?
    c. How long have you been working for the city of Brockton?
2. Could you explain to us the water system in Brockton?
    a. What are the main water sources?
    b. How old is the piping system?
    c. Is the piping system going to be replaces/improved any time soon?
    d. What's the leakage?
    e. Are there other towns connected to the water supply?
    f. Has the City considered the option of selling the water to other towns?
3. We read that Brockton is in a 20 year contract with the company Aquaria for the desalination facility, what do you think about this contract?
    a. Was it a good choice? Why?
    b. Financially was it a good decision?
    c. Where there other options that could have been better?
4. We have been informed that the Water Commission is considering buying the facility, what do you think about purchasing the desalination facility?
    a. Who would operate the facility is sold the the City?
    b. How would the facility be used in the future? Any long term plans?
    c. Renewing the contract?
    d. Connecting to the MWRA?
5. By law or regulations, is the City of Brockton required to have a secondary water source besides Silver Lake
    a. Have the City explored other options besides desalination?
    b. Have they considered perhaps connecting to a third water source?
6. Does the City have any plans of connecting to the MWRA?
    a. When will this happen?
    b. What would be the cost?
7. How does the City manage water supply during droughts?

Thank you again for your time. We really appreciate all the information you just shared with us. We will like to schedule another interview with you in a couple weeks to discuss the

recommendations we have for Brockton to better use the facility. Finally, do you have any recommendations about topics we should research or questions we did not ask?

Interview with Staff member of Brockton's Finance Department:

Hi ----. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the TRDF that currently serves Brockton. The reason we wanted to interview you is because we believe that as --- of BDF you can help us understand and provide great insight into how the City finances the TRDF and water supply in Brockton in general. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project.

1. What is your role in Brockton. (If Andrew is there, ask him as well)
2. How long have you been working with Brockton. (Ask Andrew as well)
    a. Have you always been working as the CFO?
3. How long have you been involved with the Aquaria Desalination plant?
4. We read that Brockton is in a 20 year contract with the company Aquaria for the desalination facility, could you explain what this contract consists of?
    a. Who owns the facility itself?
    b. Financially, what is the deal? What is the annual payment?
    c. Does the City pay for the facility's maintenance?
    d. As part of the contract is the City required to purchase a specific amount of water?
    e. What do you think about this contract? Why?
5. In your opinion do you think desalination economically a good choice for the City of Brockton?
    a. Do you know what the operation and maintenance costs of the plant are?
    b. Do you know the value of the facility?
        i. When it was built?
        ii. Today?
        iii. By the end of the contract?
    c. What is the cost of other alternatives? (i.e MWRA)
6. In your opinion do you think desalination was environmentally a good choice for Brockton?
7. During our research we read that the City of Brockton is not using the facility as its full capacity, Can you give us some insight into why?
    a. Is the facility solely and necessarily a secondary water source?
    b. What is the current state of the facility?
    c. What budget does the City set aside for water and for the facility?
8. What is the current water demand in Brockton?
    a. What is the City's main water source?
    b. What is the cost of the water from Silver Lake compared to Aquaria Desalination plant?
    c. Does the City need other water sources not only because of the water demand but legal requirements?
    d. What other water sources do you think are beneficial for the City?
    e. Are there any considerable industrial demands?

9. What plans/ hopes does the City have for the desalination facility in the future?
    a. Buying it?
        i. What do you think will change if Brockton decides to buy the plant? Pros/Cons.
        ii. If Brockton buys the plant, are there any plans to make major changes?
        iii. Could the City of Brockton resell the plant?
        iv. If Brockton does not buy the plant, what are the other options?
    b. Who is involved in these plans?
    c. What do you personally think should be done?
        i. Do others think otherwise?
    d. Have you heard or been part of any discussions about alternative uses that can be given to facility? Perhaps using it for other purposes besides potable water. Can you give us reasons why these might not be used?
10. Is there anyone else you can put us in touch who would be helpful to understand the water situation in Brockton and how can the facility be used?

Thank you again for your time. We really appreciate all the information you just shared with us. We will like to schedule another interview with you in a couple weeks to discuss the recommendations we have for Brockton to better use the facility. Finally, do you have any recommendations about topics we should research or questions we did not ask?

Interview with Staff member of BED and MSSCC:

Hello ---. We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating the projected water demands in Brockton and as --- of --- we are hoping you could help us understand the populational and industrial growth in Brockton, the economic development in Brockton and plans the City has to promote growth in the future. Before we start may we record this interview? The recording would be used for us to go back and take notes. You can stop us from recording at any time and we will destroy the recording once we conclude our project.

1. What has been your role as --- in ---?
    a. How long have you been working in --?
2. What was the economic development of Brockton during the early 2000's ?
3. What is the current economic situation of Brockton?
    a. What are the major industries in the area and surrounding cities?
    b. Has the economy of the City improved in the past years?
    c. What is the employment rate?
    d. Could you provide us names of the largest industries in the area?
4. What are the main drivers for Brockton's economy?
5. What efforts are being made to help Brockton grow?
    a. Does the City have any plans to attract industries?
    b. How is the City planning to do so?
    c. Does the City have plans of partnering with other towns in the area?
6. What is the expected industrial growth in Brockton? Why?
7. What is the expected population growth in Brockton?
8. Are there any limitations that can prevent Brockton's growth?
9. How is the water demand expected to change in Brockton?
10. Do you think Brockton is going to substantially grow industrially and economically in the future?

Thank you again for your time. We really appreciate all the information you just shared with us. We will like to schedule another interview with you in a couple weeks to discuss the recommendations we have for Brockton to better use the facility. Finally, do you have any recommendations about topics we should research or questions we did not ask?

Appendix D: Questions asked during tour of Taunton River Desalination Facility

INTAKE

1. How many MGD can the intake handle?
2. What are the levels of screening in the intake structure?
3. How often are screens in the intake replaced?
4. What is the water composition in the intake?
5. Does the water composition of the intake vary?
6. What type of pumps are used to pump water from the intake to raw water storage?

HIGH-LIFT PUMPS

1. What is the model of this pumps?
2. What is the flow and pressure?
3. What is the energy consumption of these pipes?

ULTRAFILTRATION SYSTEM

1. What model of membranes are used?
    a. What material are they made of?
2. When were they last replaced?
3. When are they going to be replaced again?
4. What (model) pumps are used to the pump water to the UF system?
    a. Operating pressures?
    b. Energy consumption?
    c. Flows?
5. What is the permeability of the membranes?
6. What is the expected life of the membranes?
7. What is the production capacity of the UF system?
8. What is the efficiency of the membranes?

REVERSE OSMOSIS SYSTEM

1. How many RO trains are there?
2. When were they installed?
3. When were they last replaced?
4. What types/model of membranes are used?
    a. What material are they made of?
5. What is the transmembrane and differential pressure?
6. Are there any energy recovery devices?
7. What is the expected life of the membranes?
8. What is the production capacity of the RO system?
9. What is the efficiency of the membranes/ RO process?
10. What is the average permeate TDS?
    a. What is the TDS the plant expects the permeate to be?
11. What is the model of the pumps to feed the RO system?
    a. Energy consumption of the pumps?
    b. Flows?

c. Pressures?

FINISHED WATER TRANSMISSION PIPE

1. How old is the pipe?
2. How long is the pipeline from the treatment facility to Brockton?
3. What is the pressure of the water leaving the plant?
4. Is a pumping station required?
5. What is the capacity of the pipeline?

ELECTRICITY

1. What is the electrical utility that serves the plant?
2. What is the annual electrical cost of the plant?
3. What is the electric rate $/kW?
4. Has there ever been an electrical failure?
    a. What is the backup source?
5. What is the energy consumption to produce 1,000 of water?
    a. With UF
    b. With UF and RO
6. Has Aquaria considered the option of installing solar panels?

CUSTOMERS

1. Who are the current customers of the facility?
2. Is the Aquaria seeking to get more customers?
3. What efforts are being made to obtain more customers?

BRINE

1. Where is the brine discharged?
2. How is the brin treated before discharge?
3. What is the volume of brine discharged?

GENERAL QUESTIONS

1. With the current design and equipment, what is the maximum volume of water the facility can currently produce?
2. To produce the max amount of water, how much water has to be taken from the River?
3. Are there any upgrades Aquaria is currently considering on doing?
4. What is the plant's recovery?
5. How many people work in the facility?
6. If you were given $10 million to spend on upgrades for the facility what would you use it for?
7. Does the facility operate on the daily?
    a. If no water is purchased, what happens to the water?
8. What efforts are being made to reduce environmental impact of the facility?
9. What is the current capital cost of the plant?
10. What units consume the largest amount of energy in the plant?
    a. Why do they consume this much energy?
    b. Is there anything being done to reduce the energy consumption?

c. Are there any energy recovery units in the plant?

11. Are there plans to increase the plant's capacity?
12. Do you think the TRDF has helped Brockton?
13. Could you explain to us the contract between Aquaria and Brockton?

Appendix E: Surveys to staff members of municipalities within 15 mile radius of Brockton

We are a team of undergraduate students from Worcester Polytechnic Institute completing a research project sponsored by the North East Innovation Network (NEWIN). My team and I are investigating water demands in the Metro South Shore of Massachusetts. As part of the water department in --- I was hoping you could help me by briefly answering the following questions:

1. What is the water demand in ---?
2. What are the main water sources in ---?
3. Is --- currently in need/ looking for an additional water source?
4. Do you think -- will be in need of an additional water source in the future?
5. Is --- connected to the MWRA?

Appendix F: Alternative uses for desalination

Desalination technologies have considerably grown over the last decades to provide water to arid regions in the world (Kucera, 2014). However, from the entire water withdrawn in the United States, only 12% is consumed by humans and the rest is used in power generation (45%), irrigation (32%), and industrial purposes (EPA, 2017a). Thus, desalinated water can serve many purposes aside from potable water. These are some of the alternative uses for water produced from desalination facilities and reverse osmosis plants.

1. **Cleaning of microelectronics**

   One of the industrial uses of desalinated water is for cleaning semiconductors and other microelectronics as they are being manufactured. In very-large-scale integration (VLSI) manufacturing processes, where electronics chips are built up layer by layer, the chips have to be cleaned and rinsed of their impurities as more layers are added (Springer Netherlands & Sugawara, 1993). If these impurities are not cleaned off during the manufacturing process, the chips will fail and hundreds of thousands of dollars are lost. To clean and rinse the chips, ultra pure water must be used. Ultra pure water is water that meets certain specifications, such as having a very high specific resistance (18MΩ) and a low particle count (20 particles per mL) (Springer Netherlands & Sugawara, 1993). If the water does not meet these specifications, using this water for cleaning will also cause the chips to fail.

   To make ultra pure water, the water is first desalinated, in the same manner used for brackish water. Then additional processes are applied to this desalinated water, making it "ultra pure" by removing ions and dissolved gases (Springer Netherlands & Sugawara, 1993). Due to these additional processes, getting ultra pure water is expensive and any increase in efficiency in the process, whether that comes from making pure water or from VLSI manufacturing, leads to saved costs.

2. **Power Generation:**

   Many large power generation plants, such as steam turbine electricity plants, require some form of fresh water to boil. Due to the large amount of water required in these plants, some facilities have started using water from desalination plants instead of obtaining it from a naturally occurring sources. Moreover, the waste heat from the power plant can in turn be used to power desalination facilities saving a large amount of energy, reducing the costs, and cooling the plant. Because the waste heat from this technique is not going directly back into the environment as it conventionally would, it is considered safer and more eco-friendly (Martin, 2014).

3. **Pressure Retarded Osmosis:**

   There is a fairly recent technology developed for power generation, currently under investigation, called pressure retarded osmosis (PRO) (Chu, 2014). This technology generates power by combining two sources of water of different salinity, such as a freshwater river and seawater. The process works better when higher concentrations of salt are used. Therefore, brine would produce even more power than seawater. There is research being done to see if using PRO alongside a desalination plant to generate power and freshwater is economically viable (Chu, 2014). However, this technique has not been

implemented yet, as the technology has not been developed enough to be viable (Faversham, 2016).

4. **Agriculture:**

Agriculture uses the largest amount of water worldwide; thus, a lot of research has been done to start using new water sources, such as desalination, in the agricultural sector. Agriculture uses large amounts of water and due to the large costs of desalination, it is not a technology widely used in this area. Desalinated water is a good option for irrigation of crops that consume a large amount of water (i.e horticulture), high value crops (i.e roses or greenhouses), or crops that grow close to bodies of brackish water since transportation and waste disposal costs are lower (Beltran & Koo-Oshima, 2006).

5. **Beverage Industry:**

Desalinated water or desalination techniques can be used as a source of drinking water sold in bottles. Through the process of reverse osmosis, water bottling companies purify brackish water to drinking water quality. Although the process is a little more expensive than treating municipal water, it is an alternative that has been explored by water companies. This treatment is generally used in the beverage industry to purify water to drinking quality (Freid, 2016).

6. **Wastewater Treatment:**

Many industrial water waste facilities, such as mining companies or refineries, collect polluted, contaminated, and hazardous water in large basins that are unsuitable to be returned back into bodies of water in which they came from due to the environmental risks these possess (Bartels, 2017). At times during heavy rainfall the basin containing the polluted may run of overflowing, causing an environmental hazard because the polluted water may contaminate nearby water supplies for towns (Evoqua, 2017). One solution to combat this issue is having an RO facility to be able to treat the waste water once the basin becomes full. Since RO technologies have been shown to reduce/treat hazardous water and still be cost efficient, it has been a viable solution for water waste facilities and towns that may have to share their water supply with industries (Bartels, 2017).

Appendix G: Case studies of alternative uses for desalination

Table 9: List of case studies for Alternative Uses for Desalination

Industry	Location	Company	Process	Benefits
Cleaning of Microelectronics (Clancy, 2013)	USA	Intel	Treat municipal water through reverse osmosis to produce ultra pure water. They treat 1.25 gallons of tap water to produce 1 gallon of ultra pure water.	Reduced overall cost of producing the chips.
Coal Plants (Yinbiao & Jianli, 2011)	China	Shenhua Group	They produce energy from coal and invested in an evaporative desalination facility to provide water for the plant's main boilers, which can take over 3 MGD	Reduces negative environmental impact of facility Improves relationships with neighboring towns because they sell additional water Allows facility to be sited in a place with no access to freshwater
Irrigation (Beltran & Koo-Oshima, 2006)	Spain	N/A	Small scale desalination plants across the coastal region to provide irrigation water to farms within 35 miles of the sea. These desalination plants treat brackish water, seawater, and waste water to fresh water quality	40% of water produced from desalination in Spain is used for irrigation Farms have a steady water source all year round Farms can be located in places with no access to fresh water (i.e ocean)
Irrigation (Askenazi, 2007)	Israel	N/A	Sea water is treated through reverse osmosis in the Ashkelon Seawater Reverse Osmosis Plant to potable quality.	Has actually not been really successful a lack of minerals that RO membranes remove have decreased crops quality
Production of Bottled Water	Hawaii	Koyo	Water is taken from a glacier 2000 feet	Large market because people view this water as

(Russo, 2016) (Tedeschi, 2005)			below the surface of the Pacific, desalinated it, and sold for $2/ bottle. They use a deep sea pipeline that was originally for research purposes, but was mostly unused.	more environmentally friendly and healthier.
Treatment of Waste Water (Bartels, 2017)	Singapore	N/A	Sewage water is treated through reverse osmosis until it meets quality standards to then be discharged to fresh bodies of water. The island currently has to treatment plants that treat up to 23 MGD of wastewater.	Has allowed the City to meet fresh water standards to discharge waste water. Facilitates handling of waste water by treating large volumes of water.

Appendix H: Outline of meeting agenda with Poseidon Water, Worcester Clean-Tech Incubator, & EPA

Meeting Agenda

1. Introductions
    a. Name, Major, Interest in Project
    b. Explain IQP
2. Explain Project
    a. History of water in Brockton
        i. Water shortages
        ii. Depletion of Silver Lake
        iii. DEP emits Consent order
            1. Establish water commission
            2. Find alternative water source
        iv. Options City considered
            1. Wells
            2. MWRA
            3. Taunton River
            4. Desalination
        v. Explain contract
            1. Concession Contract
        vi. Explain current use of facility
            1. 2 MGD
            2. City has a limited budget
3. GOAL: Find ways in which Brockton can leverage the TRDF
4. Our research and options being considered
    a. Industrial uses of desalination:
        i. Microelectronics
        ii. Agriculture
        iii. Treat wastewater
        iv. Food and beverage industry
        v. Power generation
    b. Sell water to neighboring towns
    c. Sell facility to third party
    d. MWRA
5. Questions to ask
    a. How do you think Brockton could leverage the facility?
    b. Is there anyone else you can put us in contact with?
    c. Where else do you think we could do more research?
    d. What do you think will make our project better?
6. Thank you

Appendix I: SWOT analysis

Option 1: Brockton Purchases Facility

Table 10: SWOT Analysis for Option 1

Strengths: ● Contract with Aquaria will terminate and Brockton will be able to save money than if they were to pay the remaining 11 years of contract.	**Weaknesses:** ● Brockton is currently not able to finance the project and they will have to obtain municipal bonds to do so ● Brockton will have to assume all operation, maintenance and reparation costs of the facility ● No data on operation and maintenance costs of the TRDF at 2 MGD; thus it is hard to predict the actual costs of water production for Brockton.
Opportunities: ● Brockton can sell water to neighboring towns ● Brockton can sell water to industries directly ● By selling water to either towns or industries Brockton will be able to generate some revenue ● By connecting the water systems between communities Brockton can improve relationships among municipalities in the South Shore ● As an owner, Brockton will be able to rebrand the facility (i.e change name, logos) to make it an asset residents no longer associate with misuse of money ● The TRDF could become a regional asset	**Threats:** ● Brockton will have to assume all complaints about the facility which can deter the City's image and reputation ● Residents of Brockton might oppose the purchase and Brockton will have to address this opposition ● From reviewed case studies we learned that there is a lot of stigma against desalinated water due to misconception about the desalination process. Thus, Brocton might have to invest on educational programs to reduce the stigma

Option 2: Brockton stays in contract until 2028 and renews it until 2058

Table 11: SWOT Analysis for Option 2

Strengths: ● Aquaria remains responsible for everything that happens in the facility removing social and technological risks from Brockton. ● It will be easier for Brockton to finance this option since they just have to factor the fixed and variable rates within their budgets.	**Weaknesses:** ● It is more expensive than option 1. ● Since Aquaria owns the facility it will be Brockton's responsibility to find new customers that can only connect through Brockton's current water system. ● Stigma against the TRDF from residents will remain unchanged. ● No accurate prediction of what the projected fixed and variable rates will be in the next forty years.
Opportunities: ● Brockton will continue to use the TRDF as secondary water source in order to comply with the DEP's mandate. ● If expansion of the plant continues the TRDF might produce enough water to become Brockton's main water supply. ● Brockton can sell excess water to neighboring communities ● The TRDF could become a regional asset	**Threats:** ● Do not know what residents will think of staying in contract for an extra thirty years. ● Opposition might arise from residents complaining about the minimal use given to the facility. ● As in previous years, Brockton's budgets might not allow the City to purchase large volumes of water all year round from the TRDF.

Option 3: End contract and connect to MWRA

Table 12: SWOT Analysis for Option 3

Strengths: ● Brockton will not be the owner of this water source and all risks and responsibilities lie in the MWRA. ● Potentially cheaper/more environmentally friendly to run. ● Estimated costs of this option the most accurate compared to other options.	**Weaknesses:** ● Financially it is estimated to be the most expensive option ● Will take up to 10 years to permit and construct the pipeline. ● Various engineering studies are required to determine pipeline route; all these studies will be under Brockton's expenses.
Opportunities: ● Brockton could find other municipalities in the area interested in connecting to the MWRA to assume pipeline costs together. ● Brockton would then be a part of a collaboration of networks.	**Threats:** ● Opposition from environmental groups might arise during the pipeline construction to connect Brockton's water system to the MWRA connection point in Quincy. ● Water produced at Silver Lake might not be compatible with that of the MWRA; in this scenario Brockton will need to invest in further treatment to Silver Lake's water

Appendix J: Upgrades of the TRDF

In our tour of the facility we were able to identify several upgrades that will help reduce the operation and maintenance costs of the facility. The most important upgrades were listed in page 22. However, with the guidance of desalination experts, Aquaria staff members, and the technical memo from CDM Smith, our team identified four additional upgrades that are worth looking into. These are listed below:

1. **Replace Gunderboom System:** currently the facility uses this system as the first layer of their intake to protect aquatic life from entering the facility's system. However, the Gunderboom system needs to be removed by professional divers every November and reinstalled in March. This represents a large maintenance cost. Aquaria staff mentioned that they are currently looking into installing a Baudrey system that will be significantly cheaper.
2. **Include energy recovery devices:** Energy recovery devices can be installed in the RO system to reduce the energy consumption of this system. Energy recovery devices are usually installed in seawater treatment plants rather than brackish water plants to save 40% of the energy. Adding an energy recovery device requires additional pumps and connections; thus a cost - benefit analysis should be first carried out before proceeding to instal these devices.
3. **Improve efficiency of pipes at the raw water station**: the pipes at the raw water station represent a large amount of energy. There are four vertical pumps that bring water from the raw water pumping station into the raw water tanks. These pumps are estimated to consume 20% of the total energy from the facility. A desalination expert explained to us that improving the efficiency of these pumps can reduce the energy consumption to 10%.
4. **Addition of Chemicals after RO:** In the current design of the plant chemicals are added before the RO and UF systems. These dramatically shortens the life of the membranes. Chemicals should be added after RO to prevent damaging the membranes.

Appendix K: Expansion of TRDF

A financial analyst helped with estimated costs of the expansion of the facility to 7.5 MGD. This expansion is based on the 8.9 MGD intake permit and 85% recovery of the plant. Increasing the intake will require a lot of permitting so with the existing permits, the maximum production will be 7.5 MGD. Some additional processes, not included in the current design of the plant but that are worth exploring, have been considered for this expansion calculation. These are the following:

- Additional raw water coming from groundwater (fresh or slightly brackish)
- Solar panels as energy source
- Addition of multimedia filter between flocculation tanks and UF system
- Replumb RO feedwater pump before chemical addition

To estimate the costs of the expansion, the financial analyst identified equipment that needed to be replaced, installed, expanded, and added within 9 areas of TRDF. The following lists, show the modification or additions of equipment in each area.

Area 1: RWP, Intake, Discharge

- Replace Gunderboom with year-round mesh
- Addition of 1 Redundant influent control valve
- Expansion of skylights in RWPS
- Addition of 1 low-lift pump
- Addition of 1 low-head power turbine for effluent
- Noise insulation in high-service pumping areas
- Install fire protection system in RWPS
- Install drainage system in RWPS
- Deep production groundwater well

Area 2: Storage Tanks

- Expand product water tank from 0.35 MGD to 2.5 MGD

Area 3: Chemical Storage and Feeds

- Replumb RO feedwater pump before chemical addition
- Install level monitors in chemical tanks
- Install chemical leaks alarms in chemical storage area
- Install chemical transfer pumps where missing
- Replace copper chemical feed lines
- Plumbing to switch from hypochlorite to chloramines
- Replace gaskets on sodium hypo storage
- Replace gaskets on caustic soda storage
- Expand caustic soda tank
- Expand permanganate storage tank
- Expand lime feed system
- Emergency shower and eyewash station

Area 4: Primary Treatment

- Add 3-4 rapid mix tanks
- Add 3-4 flocculation tanks
- Replumb flocculation tanks for recirculation and higher residency time
- Add single-stage Multimedia/BGAC Filter before UF membranes
- Repurpose backwash supply tank (for UF system) for new filter
- Expand backwash supply tank with associated pumps/plumbing

Area 5: Ultrafiltration System

- Add 1 new UF train
- Replace keystone valve seats
- Add 4 additional permeate pumps

Area 6: Reverse Osmosis System

- Addition of 24 pressure exchangers and piping
- Add 4 new RO trains (increase recovery to 85%-90%)
- Add partition to clearwell
- Add 4 vertical turbine transfer pumps for RO feedwater
- Add 4 centrifugal RO feed pumps with VFDs/just-in-time systems
- Replace leaking valves on RO trains and feed header

Area 7: Sludge Handling

- Expand sludge handling facility
- Install second dewatering centrifuge
- Add 1 sludge trailer
- Add 1 sludge decant tank

Area 8: HVAC & Buildings/Site - Other

- Acquire additional land for expansion
- Solar Panel Installation
- Add backup power generators
- Add noise insulation in high-service pimping areas
- Expand control room and transfer electrical controls, Scada, CMMS, etc. to ECR
- SCADA system update
- Upgrade PLCs connected to SCADA system
- Replace fire communications with fiber optics
- Upgrade leased telephone line to cellular service
- Valve automation and integration with ECR
- Auxiliary steps
- Potential additional transformers x 3
- Improve electrical surge protection
- Improve indoor/outdoor site lighting with LEDs, motion sensors, etc.
- Build fence/electric gate
- Add CCTV cameras and intruder detection
- Landscaping

- Build access road to RWPS & secondary site

Area 9: High-Service Pumps and Transmission Line

- Replace existing 2 high-service (high-lift split case) pumps with VFD/just-in-time systems & add 2 more
- Replace check valves/flow control valves for high service pumps
- Water transmission line relocation (2 miles of pipe)
- Repair finished water transmission line joint connections
- Add booster station for increased plant capacity
- Install flushing systems
- Improve air valve manholes

A rough estimate of the subtotal cost of all the replacements, installations, additions, and expansions of this equipment is $47,075,875. Considering the following fees: 10% for engineering, 15% for administration and 30% for contingency the total expansion cost estimate is $72,967,606.

Appendix L: Authorship

Table 13: Authorship

Section	Primary Writer	Primary Editor
Abstract	Amanda	Carla
Executive Summary	Amanda & Mike	Carla
Chapter 1	Carla	Mike & Amanda
Chapter 2	Amanda, Carla & Mike	Mike & Amanda
2.1 Water in Brockton	Amanda	Mike & Amanda
2.2 Alternative water source	Carla	Mike & Amanda
2.3 TRDF	Mike	Mike & Amanda
Chapter 3	All	Mike & Amanda
3.1 Objective 1	Carla	Mike & Amanda
3.2 Objective 2	Mike	Mike & Amanda
3.3 Objective 3	Carla	Mike & Amanda
3.4 Objective 4	Alex	Mike & Amanda
Chapter 4	All	Carla
Finding 1	Amanda	Carla
Finding 2	Mike	Carla
Finding 3	Alex	Carla
Finding 4	Carla	Carla
Finding 5	Carla	Carla
Option 1	Carla	Carla
Option 2	Amanda	Carla
Option 3	Mike	Carla
Financial Comparison	Carla	Carla
Chapter 5	Carla	Mike