**Team Control Number**

**10255**

**Problem Chosen**

**B**

**2019**

**HiMCM**

**Summary Sheet**

The implementation and debates of single-serving water bottle bans are of the utmost importance in the modern era as plastic waste accumulation reaches uncontrollable and dangerous levels. In 2013, Concord, MA, initiated the first ban on the sale of single-serving Polyethylene terephthalate (PET) water bottles followed by a ban by the large city of San Francisco in 2014. Most recently, San Francisco Airport was the first airport to ban the sale of single-serving water bottles[1]. The purpose of these bans is to impart beneficial impacts on the environment and society; however, the negative impacts cannot be ignored. We define models to understand the beneficial and negative impacts of a ban on single-serving water bottles. The primary beneficial impacts considered are a) impact on the environment through the reduction of plastic waste, b) reduction in fossil fuel consumption from manufacturing, c) lowering of detrimental effects of plastic waste on sea otters, and d) savings per capita. The primary negative impacts considered are: a) unintended consequence of consumption of bottled beverages with more volume (>1L), consumption of beverages with additives (soda, juices, energy and caffeinated drinks) and b) unavailability of freshwater through bottled water during natural disasters and/or if contamination of water occurs in a city/town to freshwater supply. Our results for these impacts stem from modeling future situations without the ban to indirectly illustrate the consequence of the ban. These models are generated using linear regression, logistic growth model, or through simple mathematical equations.

Based on these models, we illustrate the impact of a ban on a city vs. town vs. an airport with respect to similarities and differences. For example, the impact of a ban on a small business's water bottle sales would be much more significant in a smaller town compared to a big city. Furthermore, the large impacts facing a city/town may not translate to an airport. While the number of water bottle users may be similar to a town on a per/day basis, the cumulative effects could resemble a city. Furthermore, the differences could arise because of the transient/traveling nature of consumers in an airport. Finally, we make recommendations for improving the ban and its unintended consequences, which involve suggestions regarding an increase in water fountains built and maintained through infrastructure changes and materials to replace PET for bottled water, and distribution of reusable water bottles.

[1] Slotnick, David. “Plastic Water Bottles Are Banned at San Francisco Airport Starting This Week - Here's What You Need to Know.” Business Insider, Business Insider, 20 Aug. 2019.

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## 2. Introduction

Around the world, people buy over one million plastic water bottles per minute. The staggering amount of plastic water bottle consumption creates a waste problem affecting every nation, land, and oceans. The issue of plastic pollution caught the attention of the United Nations, who says, "we have become addicted to single-use or disposable plastic — with severe environmental consequences." Like some countries, places in the United States hope to solve the problem through plastic water bottle bans.

To many Americans, plastic water bottles are an essential part of life. Plastic water bottles provide convenience because it comes prepackaged and can be disposed of when empty. Although plastic bottles are more expensive than tap water, Americans have been willing to pay the extra cost to buy plastic water bottles; however, the cost of plastic water bottles extends beyond the pockets of Americans. Plastic water bottles cause significant environmental and economic impacts that few notices.

Legislation to prevent the sale of plastic water bottles has garnered the attention of more people for and against these bans. Opponents of a ban cite the necessity of bottled water in case of emergency and the likely increase in the consumption of unhealthy beverages when without an option to purchase water. Supporters believe water fountains and bottle filling stations along with reusable bottles will provide sufficient convenience, and the environmental impacts are too great to ignore.

While large cities like San Francisco and small towns like Concord, MA, have already enacted plastic water bottle bans, no data exists on the direct effects of the ban. In response, we have attempted to model the impacts of a ban on a city or town. With our models, we can provide insights and oversight in modifying current bans to satisfy post-ban interests while still promoting the environment. Communities looking to enact a ban can determine if enough positive impacts justify banning plastic water bottles.

We approached the problem by accounting for future growth in water bottle sales without a ban compared to the decrease with a ban to definitively determine if a plastic water bottle ban is the best course of action in curbing one source of plastics.

## 3. Interpretation of the Question

Since the town of Concord, Massachusetts, banned the sale of plastic water bottles, other places around the world have followed suit and enacted their bans. As plastic water bottle bans start to become more common, accurate predictions will help improve future bans and provide justification for opponents of a ban. Because most places have recently enacted bans, the lack of actual data creates a necessity for modeling to satisfy the needs mentioned above.

The purpose of our report focuses on the various impacts a ban may have on a city or town and extend the interpretation to a dynamic place such as an airport. Using available information, we need to model the impacts of a ban numerically. While these effects may be positive or negative, the results need to apply to as many places as possible so that we can make recommendations to enhance current bans, and apply the results to determine the effectiveness of future bans.

## 4. Assumptions and Justifications

Assumption 1: Plastic water bottle bans will completely prohibit the sale of all PET bottles less than 1 liter in size.
Justification 1: Although cities will never be able to monitor all transactions to prevent any potential illegal sale of water bottles, we assumed these circumstances will happen so infrequently that their impact on the data is negligible.

Assumption 2: Prohibiting the sale of plastic water bottles corresponds to no consumption of plastic water bottles.
Justification 2: A ban on the sales of plastic water bottles should prevent anyone from buying and therefore consuming water bottles. In special cases, plastic water bottles may be bought in another city and consumed at the location of the ban. These situations are again negligible so we assumed a ban will eventually lead to no consumption of plastic water bottles.

Assumption 3: A future ban will be enacted in 2020.
Justification 3: To predict the impacts of a future ban on plastic water bottles we assumed in all our prediction models that a ban would start in 2020. Starting the ban in 2020 gave us a zero year to start our modeling and allowed us to easily base prediction off of 2019 data.

Assumption 4: All people consume the same amount of water which is equal to the predicted consumed gallons per capita.

Justification 4: Although each person consumes different amounts of water each year, the large population of the United States makes the per capita consumption a good average. We assumed each person consumed this per capita amount per year, so that our modeling stayed consistent.

Assumption 5: In a city, major grocery stores and popular markets sell all of sugary drinks and large water bottles not prohibited by the ban.
Justification 5: Large cities consists of many small shops and stores that sell sugary drinks and large water bottles, but they do not provide data on their sales. Instead we assumed that all of these beverages will be sold by a few stores and markets because they have multiple locations across cities that allow them to sell most of the bottled beverages in the city.

Assumption 6: Models on San Francisco reflect larger cities, while models on Concord reflect towns.
Justification 6: San Francisco's population far surpasses that of Concord's. San Francisco's large population and many stores allows us to use San Francisco as a comparison to other large cities. Concord's small size and population is more comparable to a town.

## 5. Model for Plastic Water Bottles Consumption in US Without Ban

To accomplish this model, useful information includes gallons per capita per year for the past years[2]. We plotted gallons per capita vs. year graph. We then used linear regression to obtain the best fit line to estimate the increase in gallons per capita per year for future years. The graph is shown in Figure 1. Following equation is obtained for the best fit line:

Water (gallons, water bottles)/capita = 1.23*Year - 2444

This equation can be used to predict the water consumed/capita for a given future year using a plastic water bottle. We converted the modeled gallons per capita to ounces per capita by multiplying these numbers to the average amount of ounces in one water bottle (1 gallon=128 US fluid ounces). Since single water bottles can be sold in packs and individually, we assumed that the majority of individual water bottles would be 28 fluid ounces. The result gives us the number of water bottles per capita. The data are shown in Figure 2. We then multiple water bottles per capita by the estimated population size of specific future years (in 2030, estimated population size is 400,000,000 in US) to see the total number of water bottles in that specific year bought. Based on our calculations, we estimated the total consumption of water bottles to reach ~ 98 billion by the year 2030.

[2] Conway, Jan. "Per Capita Consumption of Bottled Water in the U.S., 2017." Statista, 29 Aug. 2019.

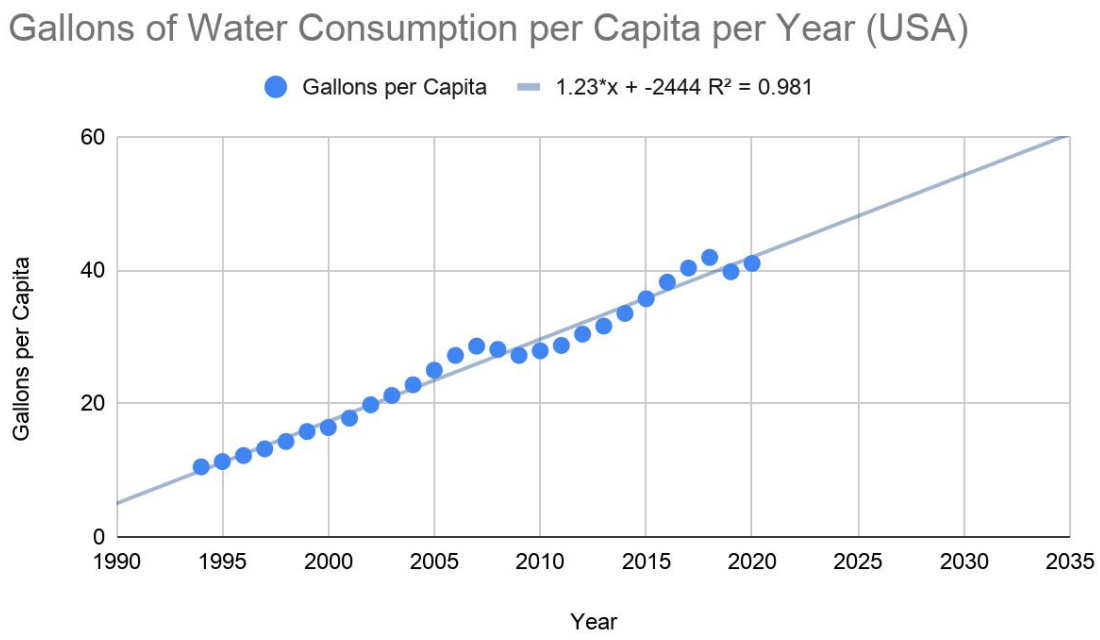


Figure 1: Graph representing the gallons of water consumption per capita per year in the United States since 1994. The line represents the best fit to the data.

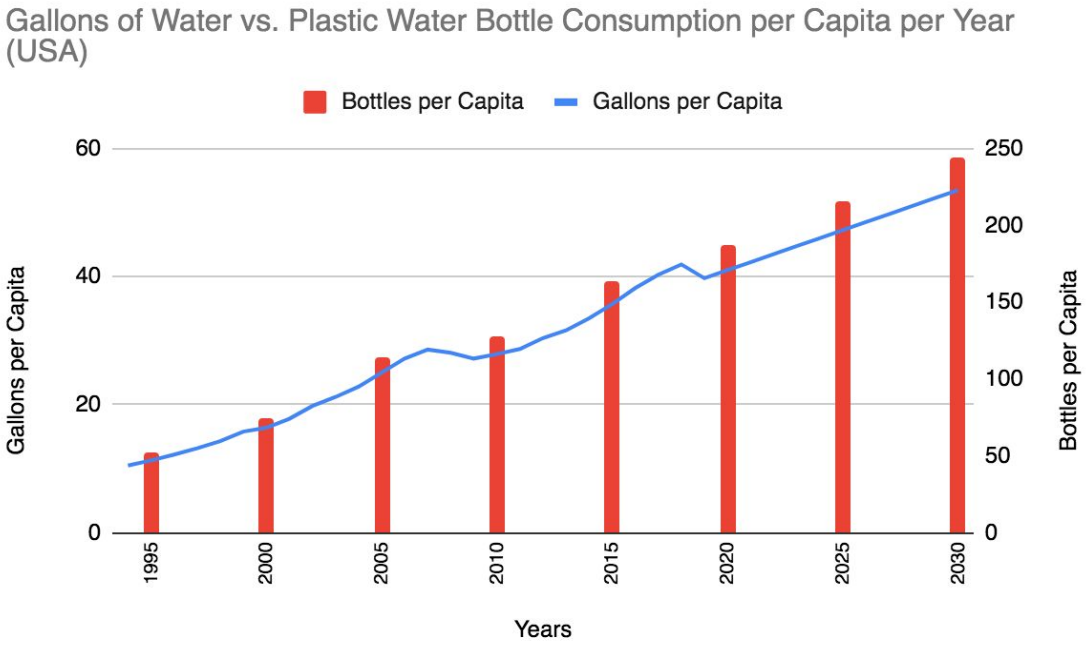


Figure 2: Graph representing the gallons per capitas and the claculated bottles per capita per year in the United States projected to year 2030.

## 6. Impacts of Water Bottle Ban and Models

There are several impacts, both beneficial and detrimental, to a water bottle ban within a town or city. The positive impacts are:
1) reduction in plastic waste
2) decrease in fossil fuel usage
3) prevention of harmful effects of plastic to certain species
4) money saved per capita.

The negative impacts are:
1) Increase in the consumption of unhealthy beverages that contain additives and sugars
2) Increase in plastic usage through other bottled beverages
3) Lack of the availability of water bottles during emergencies.

In the following section, we identify the information and data needed to model and measure these impacts as well as describe the models.

### 6.1 Reduction in Plastic Waste Through Reduction in Future Water Bottles Bought (Environmental Impact)

In order to measure the beneficial impact of reducing the usage of plastic, therefore reducing plastic waste, we need first to determine the decrease in plastic water bottle sales. Cities and towns that enact a plastic water bottle ban will eventually see their water bottle sales decrease to zero. However, bans allow stores to sell their remaining stock of water bottles. Sales and therefore, consumption of water bottles will not immediately decrease to zero, but slowly decrease as stores sell out on these water bottles. Many factors, such as population size, foot traffic, and access to tap water, all work to determine the speed at which the stores in a city or town sell their remaining water bottles. To account for these numerous factors, we decided to demonstrate the amount of time it will take for the consumption rate of water bottles to get to zero by showing the results of different regression rates. A regression rate is defined as the factor by which the consumption is reduced from the previous year. For example, the regression rate at 70% indicates a reduction in consumption by 70% of the previous year, and so on, until the consumption approaches zero.

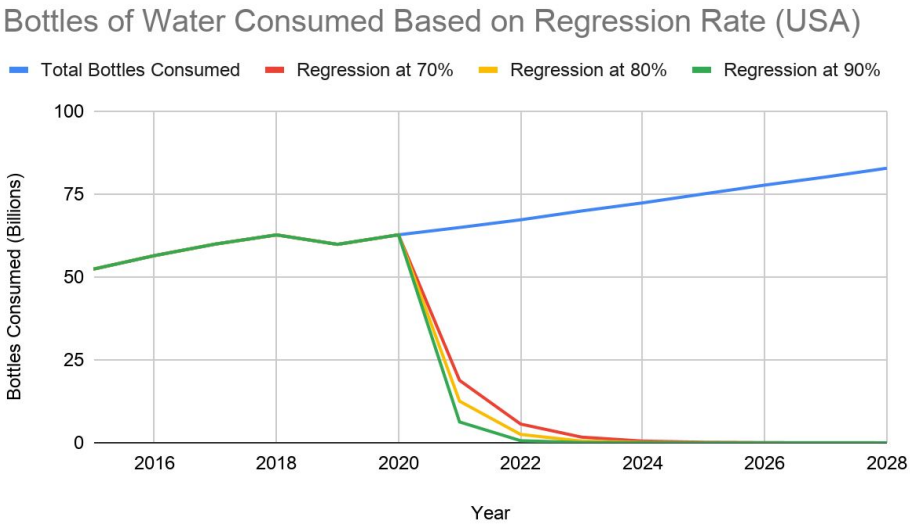


Figure 3: Graph Representing the bottles of water consumed after a ban based on 70%, 80%, and 90% regression rates

As seen in Figure 3, the numbers show the drastic decrease in water bottles over the future years, which would lead to a decrease in plastic usage, bottles not recycled, and a decrease to an overall detriment on the environment. The results on the number of consumed water bottles prevented can be further used to determine the number of chemicals released into the air when bottles degrade. The overall PET in the water bottles would also lower since water bottles are made of PET. As a result, the probability of side effects from PET, like stunted growth, reproduction issues, low energy levels, body balance issues, and inability to process stress, will also decrease. This data shows how these extreme detrimental impacts on the environment can be prevented from the ban.

### 6.2. Decrease in Fossil Fuel Usage: prevention of increase of fossil fuels consumption due to manufacturing

In order to determine the prevention of fossil fuels consumption due to manufacturing of water bottles, we would need to measure the amount of fossil fuels used per year to manufacture total number of water bottles per year. We assume that the number of water bottles manufactured per year are similar to the number of water bottles bought per year, which can be obtained form the information provided in section 4 (figure 2). This assumption is based on the reasoning that all created water bottles are bought or used. In addition, to model the amount of fossil fuels used per year we need to find the grams of PET in an average water bottle. The number of grams of PET in average water bottled can be obtained from literature. Based on information provided by the

International Bottled Water Association, PET resin in each bottle is about 9.89 grams[3]. We will need to find the mass of fossil fuels used to create a unit, for example, 1 kg of PET. To find this, we will obtain this information from a factory that produces PET with fossil fuels and get the data on average mass of fossil fuels used to produce 1 kg of PET. We can now estimate how much fossil fuels is consumed per year for the amount of water bottles used per year using the following equation:

$$Fossil\ fuel\ consumed\ per\ year\ for\ manufacture\ of\ plastic\ bottles\ (kg) = 9.89 \cdot W \cdot F/1000$$

W = Total Number of Water Bottles per Year
F = Mass of Fossil Fuel used to produce 1 kg of PET

### 6.3. Harmful Effects of Plastic on Sea Otters

**(**Environmental Impact)

Using the information modeled based on projected bottles per capita in the United States, and the projected total consumption based on various regression rates, we model the far-reaching effects of the ban. One significant impact induced by plastic water bottles includes the entrance of water bottles into the ocean and other waterways. These bottles thus negatively impact the wildlife through the ingestion of the bottles itself or through microplastics that animals unknowingly ingest and slowly build up in their digestive systems. To model the effects of this, we have chosen to focus on California sea otter, which is currently at a low number. Using the Logistic Growth model, we can predict the rate of growth of the sea otter population and the number of years it will take for the population to reach its carrying capacity. We used the standard logistic growth model to derive an equation from showing the number of sea otters in the population at a given time. The information is as follows.

Equation[4]:

$$P(t) = \frac{C}{(Ae^{-kt}+1)}$$

Current population of sea otters in california (A): 2700[5]

[3] "Bottled Water." International Bottled Water Association, bottledwater.org/education/recycling/pet-facts.
[4] See Appendix A for Derivation
[5] Hatfield, B.B., Yee, J.L., Kenner, M.C., and Tomoleoni, J.A., 2019, California sea otter (Enhydra lutris nereis) census results, spring 2019: U.S. Geological Survey Data Series 1118, 12 p.

Carrying Capacity (C): 16,000[6]
Constant of Proportionality (k)
Time (t)

We vary the constant of proportionality from 0.25 to 0.9, every five years after the ban is implemented in 2020 to show the growth of Sea Otters. The increasing constant of proportionality is assumed to be directly related to a lack of exposure to plastic waste.

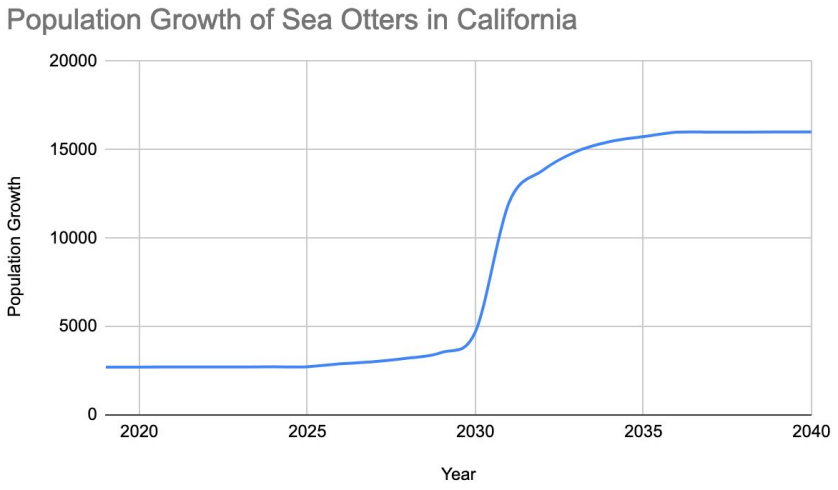


Figure 4: Graph representing the logarithmic growth of sea otters in California in years after a potential plastic water bottle ban

### 6.4 Money Saved per Capita

Figure 2 models the bottles per capita, which can be used to estimate how much money each American will spend on water bottles/year. To see how much one spends on water bottles in 2030, we convert bottles per capita to dollars per capita by multiplying the average cost of one water bottle: $1.45[7]. The result would give us an estimate of how much the average American spends on bottled water by 2030. Although there is some saving, the result is not substantially impactful, as, in the year 2030, each person only saves about $350/yr for expenditure on plastic water bottles. While the United States as a whole will spend a lot more money on plastic water bottles, the individual does not see large savings. As an example, last year, Americans spent $31

[6] Kristin, Laidre L., et al., "An Estimation of Carrying Capacity For Sea Otters Along the California Coast." Marine Mammal Science, Apr. 2001.
[7] Linton, Bryce. "How Much Does Bottled Water Really Cost You?" Watertech, 23 Dec. 2016.

billion on water bottles[8]. While the individual savings are not impactful, the total money saved as a nation can be put use to a lot of other benefit programs, including, perhaps, building a better infrastructure to provide safe and clean tap water.

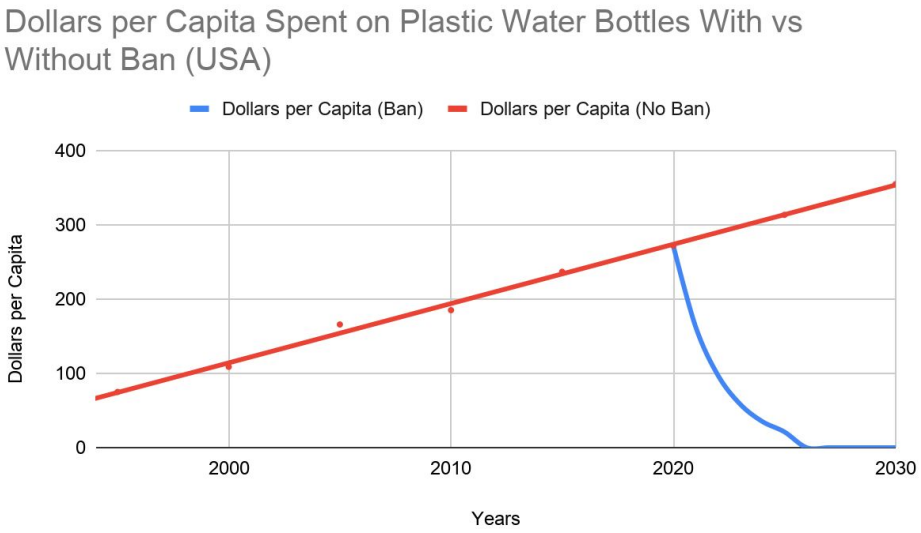


Figure 5: Graph showing per capita expense on plastic water bottles per year in the United States with a ban compared to without a ban

### 6.5 Increase in Less Healthy Beverage Options (with more packaging, more additives including sugar, caffeine, etc.)

With the water bottle ban, an increase of shipments on bottles with various other drinks containing an unhealthy level of sugars, preservatives, unnatural sweeteners, caffeine-containing drinks would occur. As bottled water declines in production and consumption, there is likely going to be an increase in unhealthy beverages (sodas, energy drinks, caffeinated beverages, etc.) made and consumed. The reason is that consumers won't have the healthy option of water bottles. It may become more tempted to obtain less healthy beverages.

The approach to model this phenomenon would be: obtain data from two types of populations, a small town in Concord and a big city, such as San Francisco. Go to all of 27 grocery stores in Concord and obtain the data on the investment on large water bottles and sugary drinks and how many were sold per year for five years before the ban and five years after the ban to see the impact of the ban introduced in 2013. The reason why we chose five years is to show if the

[8] Felton, Ryan. "Should We Break Our Bottled Water Habit?" Consumer Reports.

growth over the years shows a direct relationship rather than fluctuating often. This would give a representation of this impact for a small town in the United States, but not for big cities.
For a big city such as San Francisco, one can obtain such data from various brands of grocery stores (Whole Foods, Trader Joes, Safeway, Mollie's Stone, Walmart, Target and a few popular grocery markets) and obtain the data on the investment on large water bottles and sugary drinks and how many were sold per year for 5 years before the ban and 5 years after the ban to see the impact of the ban introduced in 2014. This would give a representation of this impact for a large city in the United States. Following equations can be used:

Concord's increase in average non-water bottled beverages sold/yr from 5 years before to 5 years after ban:

$$\Delta NW_{2008-2018,\,C}/yr = (NW(total)_{2013-2018,\,C} - NW(total)_{2008-2013,\,C})/5$$

Concord's increase in average bottled water greater than 1L sold from 5 years before to 5 years after ban:

$$\Delta LW_{2008-2018,\,C}/yr = (LW(total)_{2013-2018,\,C} - LW(total)_{2008-2013,\,C})/5$$

San Francisco's increase in average non-water bottled beverages sold from 5 years before to 5 years after ban:

$$\Delta NW_{2009-2019,\,SF}/yr = (NW(total)_{2014-2019,\,SF} - NW(total)_{2009-2014,\,SF})/5$$

San Fransicos' increase in average bottled water greater than 1L sold from 5 years before to 5 years after ban:

$$\Delta LW_{2008-2018,\,SF}/yr = LW(total)_{2013-2018,\,SF} - LW(total)_{2008-2013,\,SF})/5$$

NW = Non-water bottled beverages sold (Soda, caffeinated, others)
LW = Large bottled water sold ( > 1L)
C - Concord
SF - San Francisco

### 6.6 Emergency Situations with No Access to Clean Water

There have been many natural disasters and events that require the use of water bottles, such as the hurricanes in the United States, the most recent examples being Hurricane Maria in Puerto Rico, and Hurricane Harvey in Texas and Louisiana. Other emergencies include the Flint water crisis in Flint, Michigan, as well as other lead contamination events in other states. In instances like these, bottled water is critical for the essential need of water for the populations facing emergencies.

To show the negative impact of a water bottle ban during emergencies is more complicated since the resulting health effects are sometimes not observers for years. It is also challenging to quantify the detriment to health. There while we do not present a mathematical model for such situations, we nevertheless discuss potential considerations. The impact of a water bottle ban with the scenario of tap-water contaminated in a city versus the ban when a natural disaster occurs would be different. For contamination in a city, the population of the city has an increased chance of drinking contaminated water due to the water bottle ban not allowing water bottles under 1 L to be bought. This may not be a huge impact since the population can buy water bottles that are large in size, particularly bottles that are 1 L and above. However, there would be a likely increase in buying sugary beverages since that would be the only bottled beverage available, which would ultimately increase the number of bottled beverages with added sugars and additives consumed over the years. This could lead to a long-term negative impact on the population's health through unhealthy drink options. Although this impact is terrible, it may not be as severe if a natural disaster took place in a specific area. If this were to happen, then there's a possibility that people drink contaminated water because they don't have any beverages available to buy, neither sugary bottled beverages or water bottled beverages. This could also lead to dehydration and an increase in occurrences of sickness and even death.

For modeling purposes, we can use data from emergencies that have happened in the past, such as the Flint water crisis, to see how the population bought many water bottles. A higher number would mean that more water bottles banned will lead to an increased risk of drinking contaminated water and buying other unhealthy bottled beverages.

**7. Review of Models**

Population size and other factors differing between a town and a city greatly impact the effects of a ban on water bottles. For example, the current ban on water bottles in Concord and San Francisco faced different levels of opposition and impact. Although many differences do persist, few common impacts remain pertinent to both cities and towns.

In a city, one significant impact on a ban would be the environmental benefits. A water bottle ban would decrease and eventually prevent the number of water bottles bought per year after the ban is enacted. The lowering of waste reflects a decrease in the chance of harmful chemicals found in plastic water bottles from entering the human body or waterways. Waterways will also see a decrease in microplastics that break down in water over time, and negativity affects wildlife. More water bottle usage also creates large amounts of fossil fuel depletion from the production and transportation of water bottles. In a large city with wide-reaching economic power, industries will start to grow, providing alternatives to plastic water bottles. The primary negative impact of a ban includes the increase consumption of more sugary, unhealthy drinks, since there would not be a healthy option, such as water bottles. This would cause an impact on the already growing problem of obesity and the unhealthy consumption of certain drinks; however, these impacts can be mitigated with increased access to drinking fountains and water bottle filling stations.

In a smaller town, the environmental benefits will not be as significant. Entire wildlife species will not be affected by the ban of water bottles in one town; however, a decrease in litter reflected around the town would be seen. Also, the decrease in water bottles would affect PET consumption because this is on the individual person. The fossil fuel impacts will still apply, albeit at a much smaller impact as the town's consumption of water bottles will decrease. Instead of changing the operations of large industries, a small town ban would affect small businesses. However, over time, these businesses can diversify their inventories to include different items in place of water bottles. For example, small businesses can rely on food items, art, gifts, and other products. The consumption of soda would see an increase based on the unavailability of water bottles. However, the town's small footprint could make installing more water fountains or filling stations easier and allow for more frequent placement of these stations.

For both towns and cities, the impacts that would not be as significant include the amount of money an average American would save from the ban on water bottles, as water bottles are relatively cheap. Most of the impacts stated were assumed to be most prevalent to a potential ban. Although there have been bans recently enacted across the country, the long term effects have yet to be determined.

## 8. Application to Concord and San Francisco

Concord and San Francisco are examples of a town and large city respectively. As outlined in the impacts, a water bottle ban in a town and city have various overlapping and differing impacts. Graphs one and two showing the per capita water bottle consumption and national total consumption can be applied to both Concord and San Francisco but reflecting the relative size of the two places.

Equation model three fossil fuel usage mainly applies to San Francisco, because of the large amount of fossil fuels needed to transport the significant amounts of water bottle bought and sold in a large city. In a town like Concord, fewer water bottles will be bought, so the fossil fuel usage is much lower. Graph four also reflects impacts in a large city. Graph four measures the sea otter population growth which can only be applied to places with a small sea otter population. Towns often do not have large waterways or groups that live in the town.Graph five shows the increase in sales of reusable water bottles. The impacts disphiphered from the graph mostly apply to San Francisco because they show that reusable water bottle sales increase. In a town like Concord, large companies can not be supported so this graph has to reflect a larger city.

The model reflecting the effects of small businesses will succinctly apply to the town of Concord because Concord consists mainly of small businesses. San Francisco does have small businesses, but the majority of the water bottles sold comes from large box stores and convenience stores that are trying to sell their remaining stock. Graph seven applies to both San Francisco and Concord because the people in both towns will save a little bit of money because the amount of water bottles they drank before the ban will decrease to zero.

**9. Impact of Water Bottle Ban in an Airport**

On August 20, 2019, San Francisco International Airport (SFO) banned the sale of single-serving plastic water bottles within the terminals. The ban aligns SFO with the city of San Francisco in banning plastic water bottles. The ban has garnered mixed responses from travelers and business owners. While the impacts of the ban at SFO and the potential ban in other airports have yet to yield data on its effectiveness, we predict the ban will have a similar impact to a ban in a city or town in some facets, but starkly different impacts in other areas.

Major airports see millions of passengers and employees each month[9] that parallel the number of citizens in a city. While exact figures vary by city and airport, overall the difference can be negated when comparing population. Airports also have a large number of shops and stores that sell water bottles like supermarkets and convenience stores that dot the city. Because the avenues of sales are the same between cities and airports, the growth of sales in reusable water bottles, soda or other alternatives will increase. Although an airport's water bottle sales will be more than a town's sales[10], the size of an airport more closely resembles a town. Because a town and city are both compact in size, the installation of water bottle stations and water foundations will cover a large percentage of the town of the airport. This creates a smoother transition to reusable water bottles and makes access to water easier. In general, our model on the usage of fossil fuels in producing and transporting water bottles will remain consistent between a town and an airport, because the fossil fuels required to create a plastic bottle do not change, and water bottles still need transport to an airport.

Contrastingly, many of the large impacts facing a city do not translate to an airport. For example, a decrease in plastic water bottle usage may affect wildlife in the cities surrounding an airport, but the airport itself does not support any wildlife. The amount of money saved by consumers at an airport will increase relative to the number of water bottles bought compared to the amount of money saved by a band in a city because of the higher costs of plastic water bottles in an airport compared to in a city. This difference in cost will be saved by the consumer.

Although many of our initial models reflect similar impacts to a ban in a city, the models do not completely translate. Workers and travelers passing through an airport spend a fraction of the time in the airport compared to at home in a city or town. The decrease in time causes a decrease in buying opportunity which translates to a decrease in sales when compared to the city. To account for his change, our models concerning sales of water bottles or products affected by the sale of water bottles will decrease.

[9] "Air Traffic Statistics 2019." FlySFO, 21 Oct. 2019.
[10] Slotnick, David. "Plastic Water Bottles Are Banned at San Francisco Airport Starting This Week - Here's What You Need to Know." Business Insider, Business Insider, 20 Aug. 2019.

## 10. Recommendations and Adjustments

### 10.1 Recommendations

Since water bottles are a healthier option to other bottled drinks, it would be useful to keep water bottles that are not made out of PET plastic, which is the aspect of water bottles that are detrimental to the environment. Creating a better material to make water bottles that are easily biodegradable will benefit both a healthy option for consumers and the benefit of the environment. Other changes to Condor's water bottle ban include building more water fountains and improving the maintenance of water fountains so people continue to not use plastic bottles and do not drink unhealthy beverages. In large cities like San Francisco, we recommend city leaders find money in the government's budget to provide free reusable water bottles for those who can not afford to buy one. This helps to create equal access to water for everyone while decreasing the use of water bottles over 1 liter in size bought by those who can't afford reusable bottles.

### 10.2 Adjusted Model

With the increase of water fountains built and maintained, our model of the change in sugary drinks bought 5 years before the ban to 5 years after the ban would be predicted to be a smaller number because the variable of sugary drinks bought after the ban would be less. This would be due to easier and better access to water to promote the consumption of water rather than. It would replace the no other option decision consumers have when water bottles are not available to them since they would now have easy access to well-maintained water fountains. We encourage that numerous fountains are built inconvenient places such as parks, advised to high school and college campuses, stadiums, malls, and other general public places.

The replacement of the PET material used to make plastic water bottles, which is detrimental to the environment, with an easily biodegradable and safe material would allow water bottles to be sold in a way that is not detrimental to the environment. It would promote Figures 1 and 2 as no plastic would be used for water bottles, but would still allow the sale of water bottles, which are critical resources for situations such as emergencies and buying a healthy drink. Figures 1 and 2 show that the number of plastic water bottles would increase without the ban, which therefore shows the amount of plastic that could be prevented from the ban. However, with this solution, water bottles can still be bought, and the determinants of plastic would be eliminated since bottles would be made out of a different material.

Specific examples of bottles that use better materials for the environment that cities could incorporate include water bottles made out of easily recyclable paper made by Paper Water

Bottle™[11]. Another water bottle that is made out of PHA, a material that is biodegradable and deconstructs into carbon dioxide, water, and organic waste in several environments, such as landfills, composts, and even the ocean. This bottle is called Cove [12] and would impact our model on the effect towards sea otters, as a material that breaks down in the ocean would prevent bottles from potentially harming sea otters and other marine species.

## 11. Strengths and Weaknesses of Our Models

### 11.1 Strengths

We provide several different models that show various impacts of a water bottle ban, ranging from plastic usage, the effect on marine life, human health, and fossil fuel depletion. In some of our models, we accumulated data from the Concord, and San Francisco bans relate to bans in similar environments of towns and cities. Models in section 5.1 use actual data on water bottle consumption in the United States over the past years.

Our recommendations to improve current bans and promote future bans include specific examples of products that contain our suggestions for better materials, such as Cove and Paper Water Bottle.

### 11.2 Weaknesses

Although we have data from online sources used in our models, there are assumptions we made that decrease the accuracy. For example, in Figure 2 that shows Plastic Water Bottle Consumption per Capita per Year, we assumed that all consumers only bought bottled water in the 28-ounce size. However, water bottles could be sold in other ways, anywhere from sizes of 8 ounces to 30 ounces per Year. Overall, we contain linear models that may not show the most accurate representation of the impacts of the ban, as there is likely to be fluctuation.

[11] "Compostable. Biodegradable. Recyclable. Renewable." Paper Water Bottle。
[12] "Environment & Materials." Cove

## 12. Conclusion

We created models on the primary negative and positive impacts of a bottled water ban to highlight certain benefits and flaws in the ban to make recommendations on improving future and current bans. Our models predict on the effectiveness of the ban, and we recommend other communities follow with bans of their own.

The models consisted of scatter plot graphs with best fit lines to predict future measurements, such as future number gallons consumed, bottles purchased, and plastic used. We used equations to find change in variables, such as change in sales of unhealthy beverages and large water bottles 5 years before and after the ban in San Francisco, California and Concord, Massachusetts, which could be used to estimate the change in sales of these measurements in a small town like Concord or a big city like San Francisco. We also used equations to find fossil fuel usage for a given year, which a ban would impact by helping to prevent the number of fossil fuels estimated in the equation. We derived an equation to find the correlation between sea otter population and total number of water bottles. Finally, we made recommendations for improving the ban and its unintended consequences, which involve suggestions regarding increase in water fountains built and maintained, materials to replace PET for bottled water, and distribution of reusable water bottles.

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## 14. Appendix

### 14.1 Appendix A

Derivation of Logistic Growth Equation

Logistic Growth Equation:

$$\frac{dP}{dt} = kP(1 - \frac{P}{C})$$

$$\int \frac{1}{P(1-\frac{P}{C})} dp = \int k\ dt$$

$$\int \frac{1}{(1-\frac{P}{C})} dp = kt + c$$

$$\frac{C}{P(C-P)} = \frac{B}{P} + \frac{D}{C-P}$$

$$C = (C - P)B = BD$$

$$\text{If } P = C \qquad \text{If } P = 0$$

$$C = PB \qquad C = CA$$

$$B = 1 \qquad A = 1$$

$$\int (\frac{1}{P} + \frac{1}{C-P}) dp = kt + c$$

$$ln|P| - ln|C - P| = kt + c$$

$$ln\left|\frac{P}{C-P}\right| = kt + c$$

$$ln\left|\frac{C-P}{P}\right| = -kt + c$$

$$\frac{C-P}{P} = Ae^{-kt}$$

$$C = PAe^{-kt} + P$$

$$C = P(Ae^{-kt} + 1)$$

$$P(t) = \frac{C}{Ae^{-kt}+1}$$