Massachusets Department of Environmental Protection

Assessing the Impacts of COVID-19 on Water Usage

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SPONSOR:
Massachusetts Department of Environmental Protection

Abstract

When the world was impacted by the SARS-CoV-2 (COVID-19) pandemic during the year 2020, many aspects of life were impacted in previously unseen ways. With such a world-altering event, naturally understanding how it impacted life is critical: understanding how areas essential for basic life such as food and water are even more important. With water being an integral part of all life, recognizing changes in the water usage systems that supply water to millions of people holds particular importance. Using data provided by the Massachusetts Department of Environmental Protection (MassDEP), our team identified trends and patterns between water usage data from the year 2020 and the years 2015-2019. Furthermore, we looked at the median annual household income in MA and were able to create a spatial map that shows the trends between average income and the changes in water usage. In addition to identifying water use changes in 2020 from previous years, we also investigated the infrastructure surrounding water usage and water supply throughout the state of Massachusetts.

Introduction

The COVID-19 pandemic first impacted Massachusetts on March 10, 2020 when Governor Charlie Baker declared a state of emergency. Subsequently the state required the shutdown of schools and businesses within the Commonwealth and any non-essential travel and group gatherings were restricted. The COVID-19 pandemic measures have had an impact on every part of the water sector, and a particularly important area to look at is the municipal water demands. Municipal water demands cover a wide range of the different water use sectors, including residential, commercial, industrial, and institutional.

When considering the impact of COVID-19 on water consumption, we must consider several factors that may affect the changes in water usage rates in the major sectors of municipal water demand. In order to get a better idea of how the COVID pandemic affected water consumption as compared to the baseline in more recent years, we analyzed data on water consumption for the years 2015-2019 in order to understand how 2020 deviated.

Additionally, another way that 2020 is different from a typical year is the drought conditions in the second half of the year. Therefore, an important year to investigate is 2016 (during which Massachusetts also experienced a severe drought) as it can be used as a control for the effect of a drought on water consumption. Socioeconomic characteristics such as median annual income and property values also play a role in water consumption patterns that we can examine during the pandemic period.

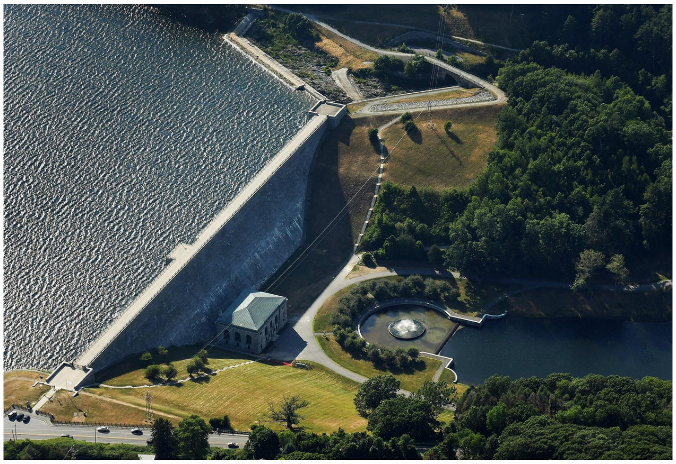

Figure 1: The Wachusett Reservoir, holding 65B gallons of water

In Massachusetts, research investigating the effects of COVID-19 on the water sector has not yet been fully fleshed out at this point. During the periods of lockdown in the midst of the COVID-19 pandemic, several locations around the world show data indicating an increase in household water consumption related to more people staying in place as well as an increase in preventative behaviors such as hand-washing (Abu-Bakar et al., 2021). The data on water consumption rates in MA for 2020 is still being released, which allows us to investigate whether these trends worldwide still hold true in the Commonwealth.

The goal of this project is to identify how the municipal water demands throughout MA were affected due to various factors during the COVID-19 pandemic. Additionally, we sought to provide conclusions as well as recommendations to policymakers and water suppliers about how to adjust the planning of water usage for the future.

Background

This chapter presents information and context for water usage as well as the pandemic and droughts. In order to gain a better comprehension of general water usage, we first discuss existing water usage infrastructure in the two relevant sectors of water usage: nonresidential and residential. We then cover the disruptions in the typical water usage model caused by the COVID-19 pandemic before covering the impacts of droughts on water usage. Afterwards, we spend time looking specifically at how socioeconomic factors might be correlated with changes in water use.

Water Use and Infrastructure

As worldwide focus increased on water usage and management through the twentieth century, many governments and countries began splitting water consumption among multiple sectors for usage. Today, the US splits water usage into several categories: for example, industrial, irrigation, and mining. For the purposes of this report, our team focused on residential (also called domestic) and nonresidential (an umbrella group of industrial, commercial, and municipal) sectors.

Residential water usage refers to the distribution and consumption by a residence or dwelling unrelated to business or industrial products. Residential water usage can be split into two groups. The first and often the sole sector referred to as the domestic water usage is residential: the consumption of water for personal activities such as lawn watering, bathing, food preparation, washing clothes and dishes, maintaining pools, and other similar usages. This type of usage typically refers to houses, apartments, condominiums, and other personal dwellings; these dwellings may also house a single familial unit, multiple familial units, or individuals.

Nonresidential water usage refers to the distribution and consumption of water by three sectors: industrial, commercial, and institutional. These three sectors cover a wide range of different possible consumers; though they all generally fall under banners of being either for-profit businesses offering a service or goods, institutions or groups in academia or research, and manufacturing facilities. Specific examples include retail outlets, restaurants, hotels, schools, factories, and similar facilities.

Figure 2: Watering of a lawn with irrigation would be classified as residential water use.

A second type is included within residential water usage: domestic institutional water usage. Domestic institutional water usage refers to institutions that possess personal dwellings or housing: examples of this would be college dorm buildings or similar entities. For the purpose of this proposal, residential water usage will refer to the cumulative use of both groups. In Massachusetts, residential water usage makes up over half of the metered public water supply (Water Conservation Standards Work Group, 2012) during 2009; so while agricultural, thermoelectric, and other sectors are heavily used in non-metered areas such as rural Massachusetts, residential water usage is a considerable factor in areas such as cities and suburbs.

Massachusetts is fortunate to have abundant freshwater resources; precipitation also places the state in the top half of the wettest states (USGS, 2015). However, the Massachusetts population continues to grow, leading to significantly increased pressure on water resources, particularly in times of stress such as drought periods. In turn, Massachusetts has sought several solutions for water conservation. Recommendations by the Massachusetts Department of Agricultural Resources (Mass DAR) have been made to residential water users such as reducing lawn size, limiting water usage to particular time periods, utilizing drought-resistant fauna in landscaping. (Mass DAR, 2021). However, existing drought conditions coupled with massive policy and communal response due to the COVID-19 pandemic impacted Massachusetts over the last year in ways still to be determined.

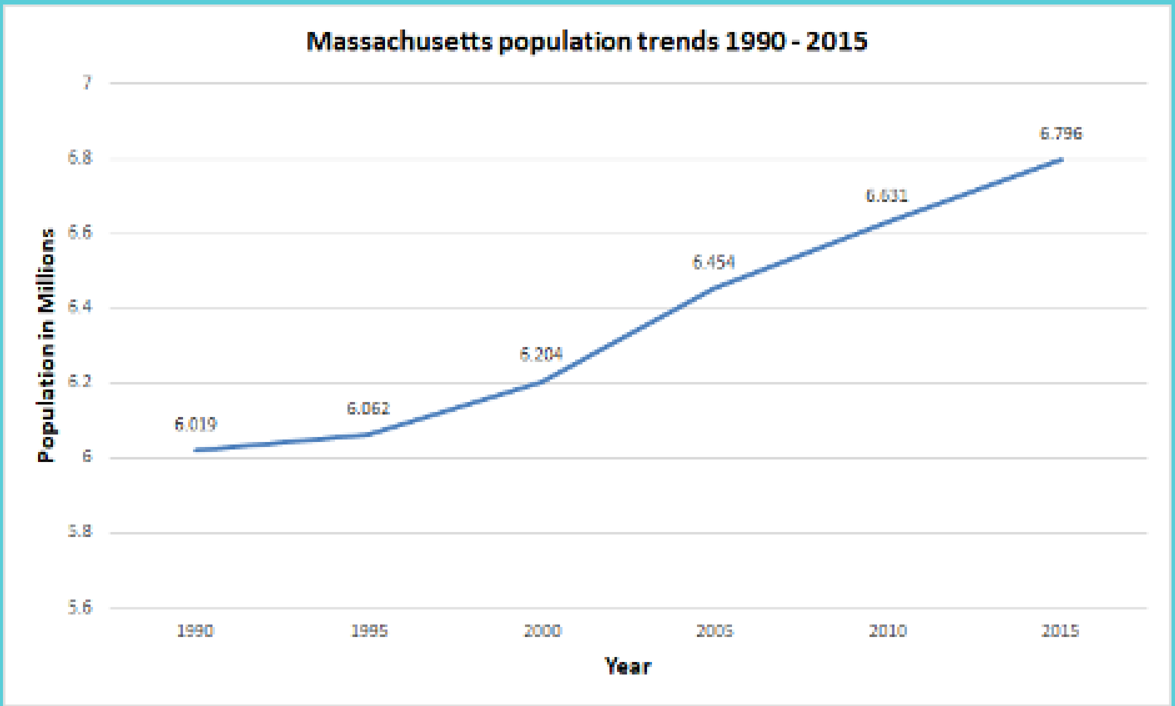

Figure 3: A graph showing the population trends in Massachusetts from 1985 to 2015. (Public Domain)

COVID-19 Effects on Water Usage

In 2020, a pandemic struck the world in the form of the SARS-CoV-2 virus. Coronavirus disease 2019 (COVID-19) is an illness caused by the coronavirus that was first identified in Wuhan, China in December 2019 (CDC, 2020). In combination with the potential for debilitating long-term side effects or death, the coronavirus led to worldwide prevention procedures in an effort to decrease the spread of the virus and limit the potential casualties.

Studies show that particularly in the early months of the onset of the pandemic, people modified their daily activities and water use behaviors, which caused an increase in household water consumption (Lüdtke et al., 2021) (Campos et al., 2021).

Lockdowns and travel restrictions were commonplace in countries all around the world as a way to help slow the spread of the virus and to limit the number of patients being admitted to hospitals with life-threatening symptoms. The restrictions placed on free movement from place to place resulted in changes in resource consumption as a result of the irregular situation causing a pronounced reduction in commuting to both commercial and industrial locations. For the country of Germany, it was found that the shift in lifestyles for German citizens led to 14.3% more household water consumption as compared to prior years during the same time of the year (Lüdtke et al., 2021).

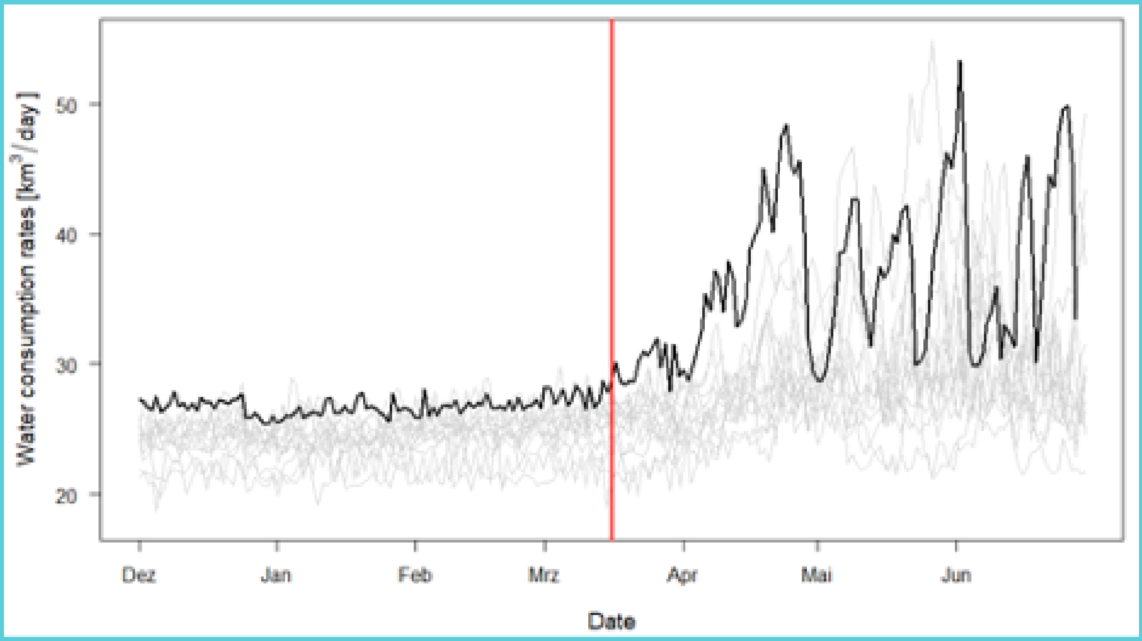

Figure 4: Water consumption rates for different months of the year in Germany showing an increase through May and a decrease associated with relaxing restrictions. The red line indicates when schools and businesses first closed. Data for 2006-2019 in grey, 2020 in black. (Lüdtke et al., 2021)

While COVID-19 resulted in an increase in the residential sector of municipal water demand, the other sectors saw a decrease according to studies around the world. In California, a study found that the state's pandemic response resulted in overall urban water consumption decreasing by about 7.9%, which is a result of an 11.2% decreases in the commercial, industrial, and institutional sectors in comparison to the smaller 1.2% increase in residential water use (Li et al., 2021). COVID-19 has had an impact on all the sectors of municipal water, and we must account for the specific changes in each sector when analyzing locations such as urban areas which have a high concentration of both nonresidential and residential water use.

Similar policies of stay-at-home advisories and lockdown procedures in Germany and California were enacted in Massachusetts at the onset of the pandemic, and so research in these places can be used to help compare how the COVID-19 pandemic may have affected municipal water demand in the state. Massachusetts Governor Charlie Baker first took action to slow the spread of the coronavirus on March 10, when he declared a state of emergency to allow for a variety of pandemic response measures to slow the outbreak (Department of Public Health, 2020). These measures limited travel and gatherings which were similar to those employed in places like Germany and California. Due to a lack of available data for MA, the effect of COVID-19 on water use is still unclear, however, according to other places around the world, one would expect to see an increase in suburban and urban household water consumption in parallel with a decrease in consumption in the other major sectors of water consumption, namely the commercial, industrial, and institutional sectors.

Drought's Impact on Water Consumption

Droughts are very severe weather conditions that can result in a lack of water availability, which impacts water consumption behaviors. Droughts are also a more complex weather condition than others such as hurricanes or floods because there is no clearly defined beginning and end to a drought, which can cause uncertainty in policy decisions concerning water usage. In fact, the climatological community defines four types of droughts: meteorological droughts, hydrological droughts, agricultural droughts, and socioeconomic droughts (Vose, 2021). The most pertinent type of drought to water consumption is the hydrological drought, which is when the water levels in streams, reservoirs, and groundwater are lowered after a period of meteorological drought (Vose, 2021).

Hydrological droughts pose a significant threat to all sectors of water, including the residential, commercial, and agricultural. As water levels begin to lower as a result of a drought, local governments find that they must implement water use restrictions across the board in order to ensure that everyone has access to water. This can result in diminished water quality, diminished water pressure for firefighting, increased stress on agriculture, and increased fire risk for both people and infrastructure (Massachusetts Drought Management Plan, 2019). In Massachusetts, the severity of a drought is measured for a specific region, called a drought region. In Figure 5, a map showing the drought status of the different drought regions is shown for the month of September 2020. This image clearly shows that all of Massachusetts experienced a significant to critical drought during the latter half of 2020.

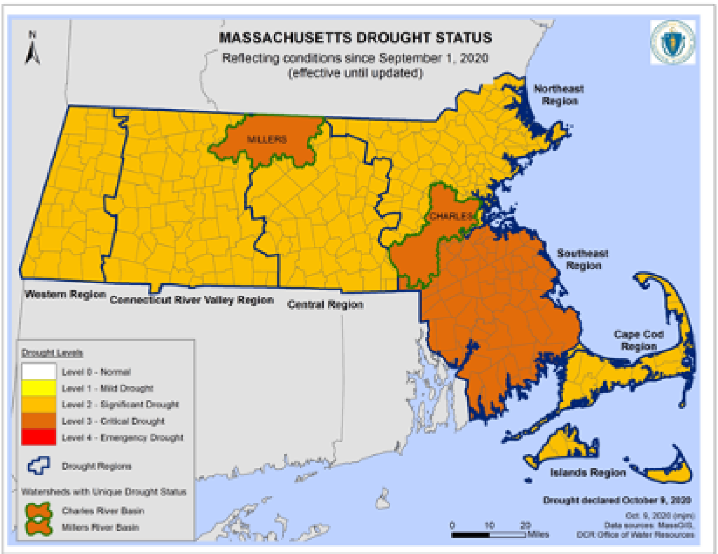

Figure 5: The Massachusetts Drought status map for the month of September, 2020 (Drought Status, 2021).

During periods of drought, water suppliers can take advantage of several factors in order to motivate water conservation in an attempt to diminish the negative effects of the drought. One of the common ways to conserve residential water usage during a drought is to limit nonessential outside water use to certain days and/or hours. This method was studied in Colorado, where it found that the level of water savings increased as expected when the frequency of permitted watering days decreased, as well as when time limits were tightened (Kenney et al., 2004).

Another method is the use of pricing as a conservation tool, by increasing the price of water particularly seasonally and/or based on volumes used in order to deter households from using more. However, this factor has a more pronounced effect on low-income communities, to the point that low-income communities can be up to five times more responsive to prices than higher-income communities (Archibald & Renwick, 1998). Another strategy for suppliers is to consider rebates to customers who implement more water-efficient fixtures in the water infrastructure. The effectiveness of this strategy is debated by several different studies on water consumption, with some finding significant reductions in water consumption, with others finding no significant changes (Maggioni, 2015). Water suppliers can employ several methods to either mandate or encourage water conservation behaviors which are critical during periods of drought.

Background Summary

Understanding water usage and how it has come to exist today is important to identify where it can be improved. It is important to recognize that the COVID-19 pandemic had a significant impact on the municipal water demands of both residential and non-resident sectors, showing a decrease in the more populated urban centers and an increase in the typical residential water demands. Droughts tend to significantly lower water levels available to municipalities and thus require that local governments take action to encourage water conservation using a variety of methods.

Gathered and Relevant Data

General Metrics for Water Use

For our study, we use many terms that may be difficult to understand. Therefore, we have the important terms defined here.

MG: **Mega Gallons**, one MG is equal to one million gallons.

PWS: **Public Water Supply**, is the acronym used to refer to a public water supply system that distributes to at least 25 individuals and has at least 15 connections. For example, in the city of Amherst, the PWS is owned and operated by Amherst DPW Water Division.

RGPCD and UAW: These terms relate to the performance standards of water usage. **RGPCD**, short for **Residential Gallons Per Capita per Day**, represents the average amount of water in gallons an individual from a location uses per day for residential purposes. Examples of such uses could be washing clothes, showering, watering lawns, and other similar actions. **UAW**, short for **Unaccounted for Water percentage**, functions differently. UAW represents "the percent of water entering the distribution system not accounted for from service meter readings or from unmetered municipal uses such as fire fighting and street cleaning" (MassDEP, 2021). In other words, UAW is a figure showing how well a supply system can keep track of all the water pumped into itself.

Water Use Sectors: For this study, we observed eight sectors of water usage: **Total** (TOT), **Residential** (RES), **Residential Institutional** (RESINST), **Commercial** (COMM), **Agricultural** (AGRI), **Industrial** (IND), **Municipal** (MUNIC), and **Other** (OTH). The Total represents all of the water usage sectors combined, while the Other represents water usage that does not fit into any of the other sectors. Residential represents usage by domiciles and residences such as houses, apartments, and other private dwellings. Residential Institutional represents usage by dwellings related to institutions such as colleges or universities. Commercial represents usage by businesses such as shops or corporate buildings. Municipal represents usage by bureaucratic entities such as police or fire stations. Agricultural represents usage by entities such as farmers or crop growers. Lastly, Industrial represents usage by entities such as factories and assembly buildings.

Figure 6: Diagram showing the various water sectors

Datasets Provided by Sponsor

For this study, our data came primarily from the Massachusetts Department of Environmental Protection (MassDEP). Four primary datasets (representing four categories of data) were used as the source for water use metrics necessary for the research and analysis for this report:

Total System: The first dataset provided information on the total volume of water used (in MG) per municipality as well as the population served for the years 2015-2020. This helped represent the actual sum of water consumed each year in that period by the municipalities.

RGPCD/UAW: The second dataset provided information on the RGPCD and UAW figures for each municipality across 2015-2020.

Monthly Volume: The third dataset provided the water usage (in MG) of each municipality monthly from 2015-2020. This helped represent seasonal changes in water use due to climate differences.

Sectoral Volume: The fourth dataset provided the water usage for each water-use sector by each municipality from 2015-2020. This helped show where water was being consumed, and what general purposes it was being used for.

Figure 7: MassDEP Southeast Regional Office

Methods and Tools

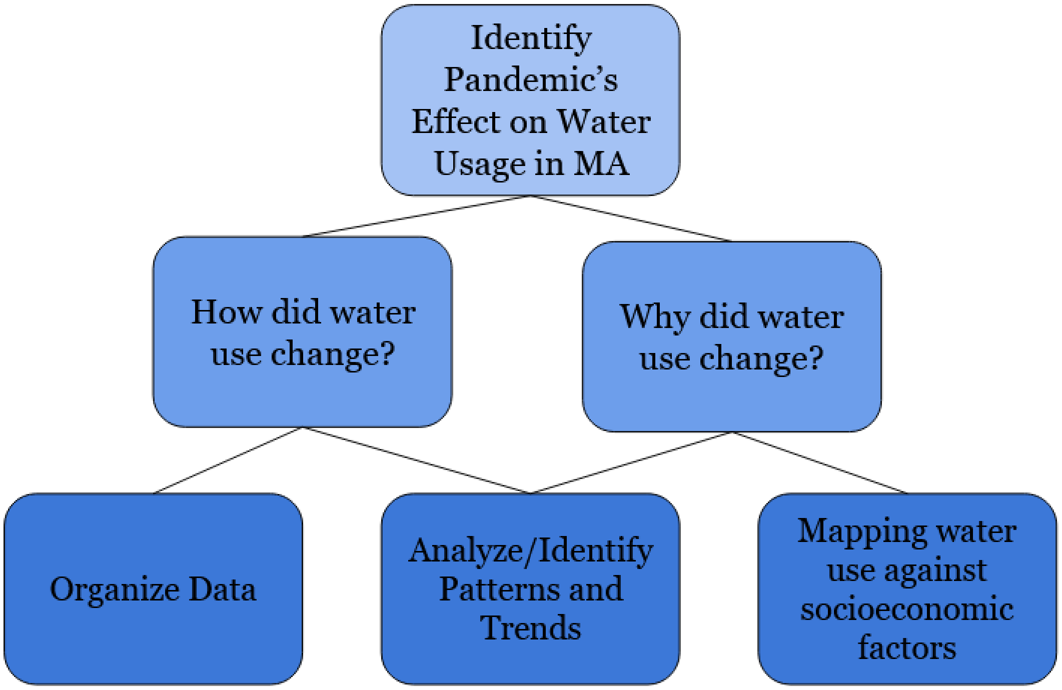

Figure 8: Methodology Outline

The goal of this project is to evaluate the impact of the COVID-19 pandemic on Massachusetts water usage in order to provide relevant conclusions about how water usage changed in the short term and how it might change in the long term to the Massachusetts Department of Environmental Protection (MassDEP) as well as Public Water Suppliers (PWS) and water policymakers in MA.

First, we organize the water usage data gathered by the MassDEP from 2015-2020 and compare and contrast each municipality at the total water consumption annually and per capita water consumption annually.

Second, we focus on a few communities to analyze these categories to provide depth to the generalized data. This step allows us to reference and evaluate data to make accurate observations on any differences in the data, as well as allow us to look at notable trends across major sectors of non-residential usage. We analyze any trends or shifts that the pandemic policies may have caused by comparing the water use sectors. Finally, we built a GIS map of Massachusetts demonstrating and facilitating our analyses of all the data provided and collected. Not only does this objective condense all of our analyses into a much more accessible and readable form, but it also allows us to show any particular points of interest or extremes in the water usage categories that we uncover in our project.

Organizing Data

The Massachusetts DEP provided us with multiple data sources related to water usage. However, these datasets are vast in scope. The size of the datasets necessitates the creation of subsets: smaller data sets that highlight and focus on categories (such as year, month, water sector, etc.) according to what we need to analyze. There are four major datasets that need to be categorized and reorganized with subsets: the Monthly Total water usage, the Total System Information for water usage, the Residential Gallons per Capita Day (RGPCD) water usage, Unaccounted for Water (UAW) percentages, and the sectoral water usage. The most important category for analysis is the percent change between the average of five years (2015-2019) and the year 2020. In order to derive the percent change and other factors of interest, these major datasets must first be sliced into smaller subsets by specific variables. The RGPCD/UAW dataset must be split into six datasets according to the year reported: ultimately producing datasets of only data reported within each year of 2015-2020. This is necessary since calculating the average water usage by RGPCD over 2015-2019 for the percent change cannot be done without first knowing the water usage for each year in that range. For this reason, similar splitting needs to be done for the Monthly Total and Total System Information major datasets. The Sectoral major dataset, however, needs to also be split according to what water sector is reporting the data (For example, entry x reports y amount of water usage in 2015 that falls under the Commercial sector of water usage). Thus, in order to produce the final datasets for graphing and analysis, the creation of eight data subsets will have to take place, with one set for each of the sectors which record water usage. These sectors include total, residential, institutional, commercial, agricultural, industrial, municipal, and others. Of these eight, there are three key components that will be used to compile the final datasets for each major dataset: the data from the year 2016, the data from the year 2020, and the average of the data from years 2015-2019 (which at this point is represented as sets of data from each year 2015-2019). Because 2020, the year the pandemic began, also experienced drought conditions, comparing it to general data may yield a higher chance for error in distinguishing the effects of the drought.

PWSNAME	RAW_FINISHED	ACTION_TYPE	REPORTING_YEAR	PERIOD	VOLUME_MG
BOSTON WATER A	FIN	CONS	2015	TOT	23847.41
BOSTON WATER A	FIN	CONS	2016	TOT	23983.97
BOSTON WATER A	FIN	CONS	2017	TOT	22899.96
BOSTON WATER A	FIN	CONS	2018	TOT	23230
BOSTON WATER A	FIN	CONS	2019	TOT	22677.616
BOSTON WATER A	FIN	CONS	2020	TOT	21416.99

Figure 9: Small sample of data taken from the Total System Information Dataset

To rectify this, we will compare sets of data from 2020 with data from 2016 as Massachusetts also experienced a drought during that year. This will allow us to (within a reasonable margin of error) eliminate the possibility that our analysis misidentifies the effects of the 2020 drought as the impact of the pandemic. Reformatting our data will allow us to create specific datasets and in doing so we will be able to accurately compare and contrast total water usage and per capita water usage. Additionally, we will be able to use data from the year 2016 as a control to distinguish between drought impact versus pandemic impact in data from 2020. Once we have these eight derived datasets, we can begin to recompile them back into the final larger datasets for analysis.

Analyze Patterns and Trends

Our second objective is to compare the sectoral and annual water use data from the Massachusetts DEP for the years 2015-2020 in order to identify trends and patterns. This data encompasses water usage across many municipalities in Massachusetts and will be compiled using the many data subsets that are created from the original data that is provided by our sponsor. In order to gain a better understanding at what areas of water use were impacted due to the pandemic, we need to analyze our encompassed data based on sectoral differences. By creating graphs and visual representations of the new data subsets, we can use tools such as regression analysis

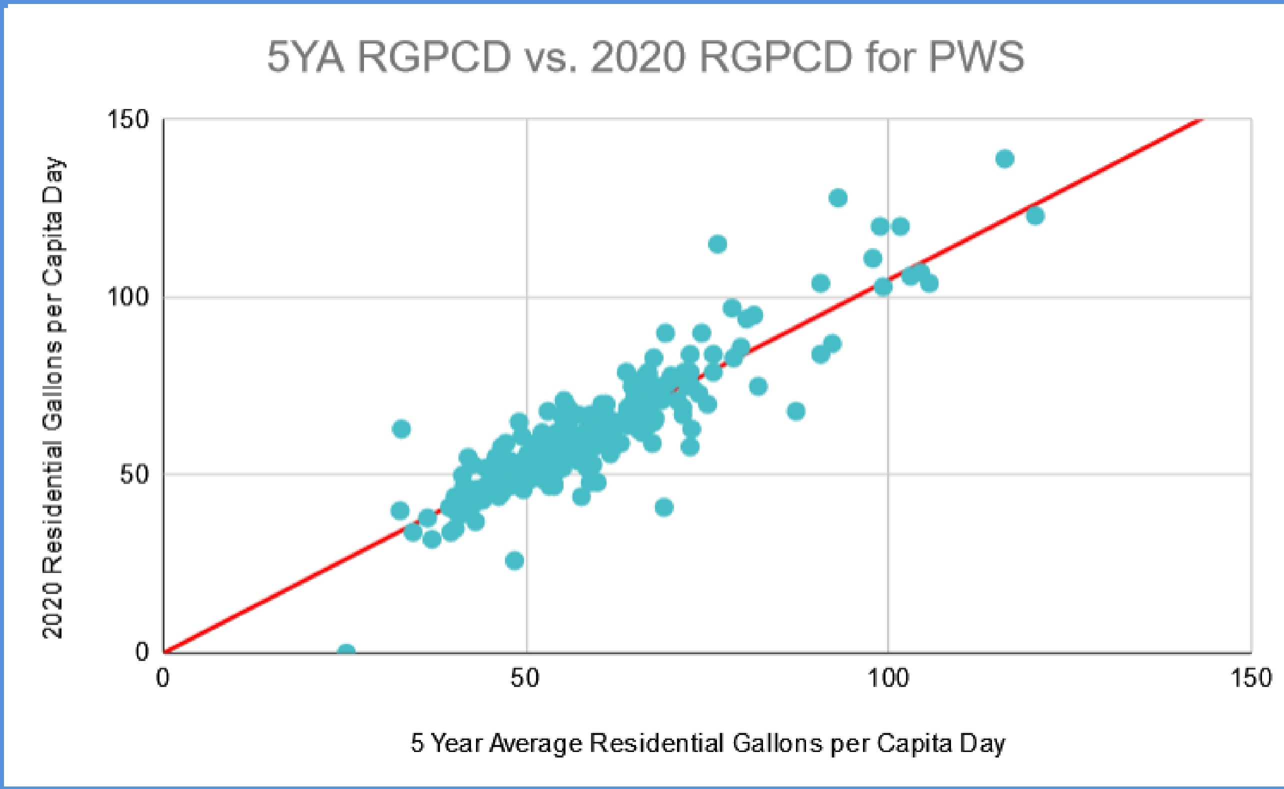

Figure 10: Example of a regression analysis using RGPCD data. This graph depicts the expected 2020 RGPCD value for a given average RGPCD for the 5 years from 2015-2019.

in order to get a mathematical view on how water use changed. With this information, we can better detect not just what cities and towns were impacted, but what types of areas were impacted, which in turn would help public water suppliers better prepare for future disruptions. We take into account the differences between what water use looked like from 2015-2019 and 2020 in order to get a clearer idea of how the pandemic itself creates different impacts on water usage.

We will use our subsets in order to recompile into four overall datasets which will describe the different ways of describing how water use changes, looking at total volume change, seasonal changes, RGPCD, Unaccounted for Water Percentages, and finally the sectoral changes. This information can help us identify which PWS showed the largest increase or decrease in the rate of water use or how many PWS were above an RGPCD threshold of 65 and other information pertinent to water consumption changes in MA.

To show the difference between individual water use sectors, we will analyze our data to look at the number of connections changed in each use sector, such as Residential, Residential Institutions, Commercial/Business, Agricultural/Farms, Industrial, Municipal/Institutional/Non-profits, and others, between 2020 and the average of 2015-2019. Additionally, we will also analyze the sectoral/ total use ratio change (%) in each use sector as well as in mega gallons (MG). Looking at the sectoral ratio change, we will analyze how water use demands changed in homes versus other commercial uses.

By parsing our derived data subsets, we can recompile only the datasets that most aptly describe the different ways in which water consumption changed in MA as a result of the COVID-19 pandemic.

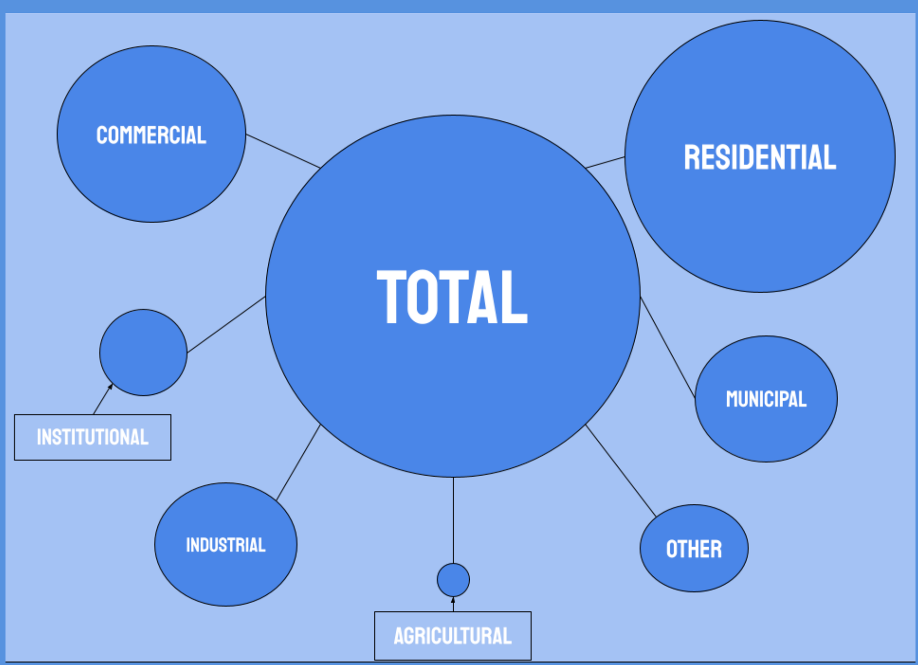

Figure 11: Diagram showing how the different water sectors are divided in MA

Mapping Water Use Against Socioeconomic Factors

The last objective is to investigate how water consumption rates were influenced by socioeconomic factors in 2020. Together with the MassDEP, our team determined it would be best to compare the water usage data to median household income. This was done to determine if water use rates and income levels across Massachusetts correlated. We also considered which municipalities fall under the criteria of Environmental Justice communities: determined by whether the median household income falls below 65% of the median household income for all of Massachusetts. Previous research shows that water use behaviors can vary significantly due to many of these factors, and we must consider how water consumption in MA may differ due to variations in median household income (Wolters, 2013). To examine these differences, we cross-examined our existing data sets with the median household incomes specific to the towns and cities across Massachusetts.

We also conducted research on how water consumption changed in different locations throughout the state through the use of spatial analysis and compare this to the household income to determine what effect it may have on water use behaviors.

In order to compare socioeconomic characteristics to the changes in water use, we used spatial analysis as well as data available from MassGIS (Bureau of Geographic Information Systems). By leveraging the data from MassGIS, we are able to create a spatial map that compares those characteristics to how the water use patterns changed in 2020. By using data provided by the Mass GIS, we can overlay our research on water use patterns with data concerning several socioeconomic factors in order to identify correlations and patterns which would indicate that a factor has a significant impact on water consumption. Through taking advantage of the multilayered data from GIS, we can draw conclusions on how the change in water use might be correlated with the several different socioeconomic characteristics that we focused on (Fischer et al., 1992).

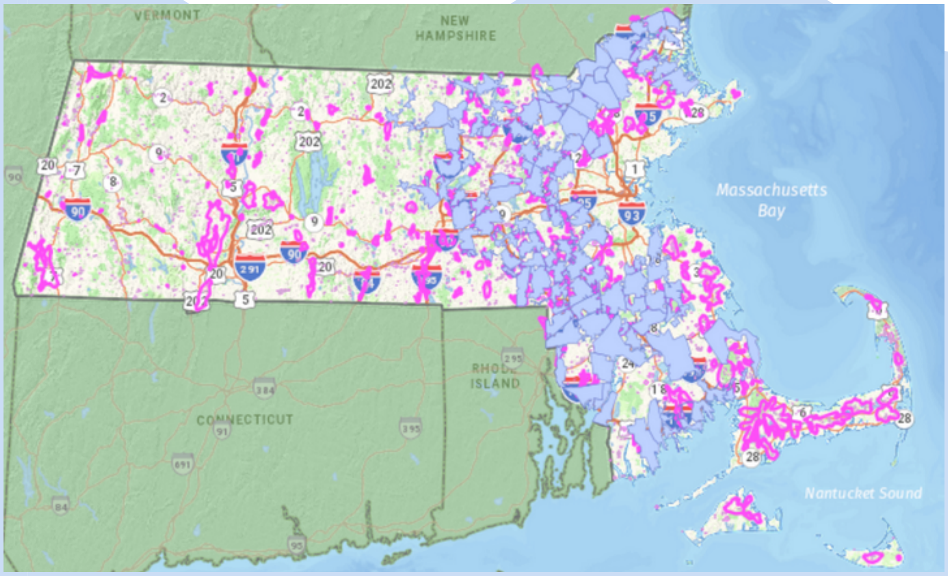

Figure 12: An example of a Mass GIS data layers being overlaid, with one showing the areas served by larger public water suppliers as of January 2004 in light blue and the other showing the different sources for public water supply throughout MA in pink.

Results and Discussion

Once we had completed organizing the data provided by the MassDEP and filtering out all of the necessary details from the large original datasets, we were able to recompile it into several new datasets which then allowed us to analyze how water use changed and the reasons for why it may have changed. We are able to look at the percent changes from the average of the five years prior to 2020, as well as the year-to-year data to determine how changes might have looked on a year-to-year scale. Afterward, we look at both sectoral shifts and how some PWS saw a change in RGPCD over the 2015-2020 time period. We also look to more deeply consider the water use metrics for several towns/cities of interest across MA, as well as analyzing the correlations between RGPCD and median household income across MA.

Figure 13: Quabbin Resevoir

Total Volume Change

When addressing changes in water usage, the most obvious metric to look at first is the changes in the total volume of water being used by municipalities in Massachusetts. Comparing the average total volume of water usage for the years 2015-2019 for most PWS to the total volume for 2020 shows that about 58% of PWS saw an increase in water consumption. When looking at volume changes over 5%, that number drops to about 36%, while those that dropped over 5% amounted to only about 18.5% of PWS in this study. Incidentally, this would mean that roughly 45%, or just under half of PWS saw relatively small changes of +/- 5% in total water volume during 2020.

This indicates to us that for the majority of PWS in Massachusetts, the 2020 total volume either stayed roughly the same or increased by a notable percentage. Some of the towns and cities that we took an interest in were locations such as Randolph (-17.8%), Amherst (-17.2%), and Boston (-8.2%). These communities represent some of those municipalities that had a larger than 5% decrease in the total volume of water use, and we decided to look more into these examples across some of the other metrics of water consumption that will be discussed later on.

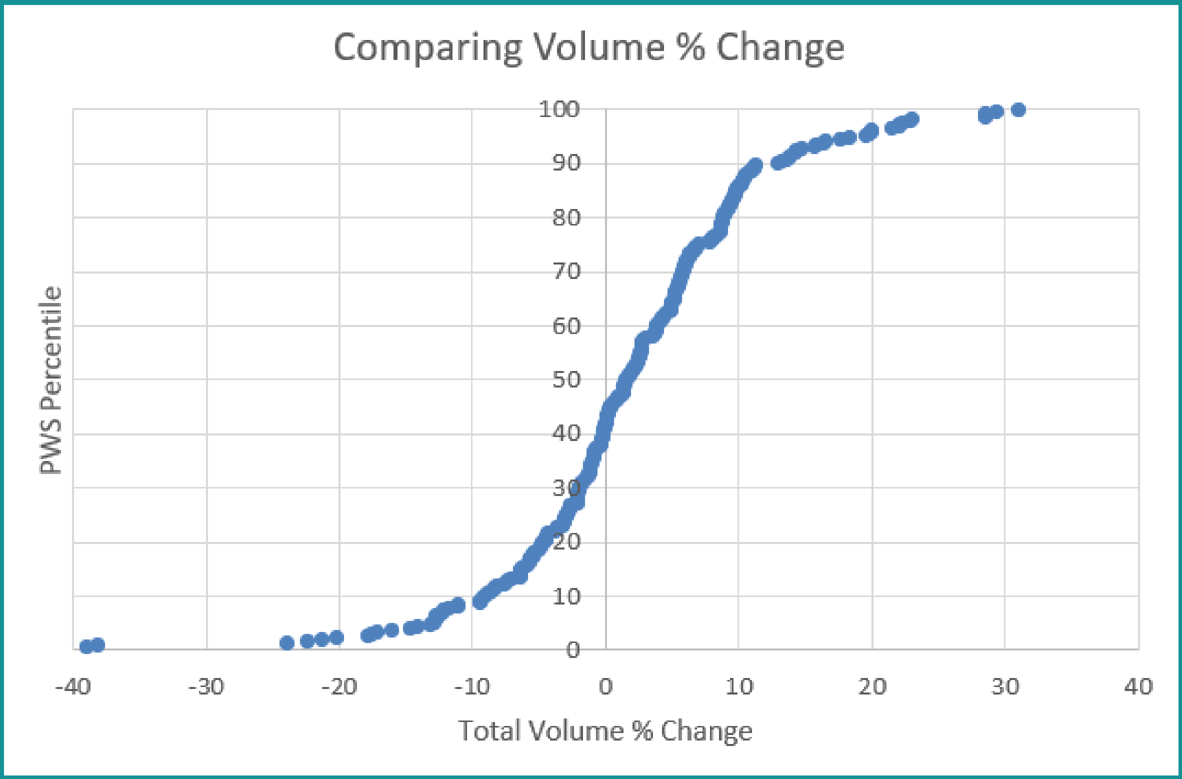

Figure 14: Graph showing the percent change in total volume, order least to greatest.

While comparing the total volume of water use for 2020 to the five-year average can be useful for determining how the percentage of water may have changed, we must also consider how each year looks individually to determine if there are any other pieces of information that may be hiding within the all-encompassing five-year average. When we look at the volume by year, we see a recognizable jump from 2015 to 2016, which can most easily be attributed to the 2016 drought. However, from that point, we see a general decrease that ends in 2019 reaching below 210000 MG for the first time in this measured time period. However, from 2019 to 2020 we see a larger jump even compared to the 2015-2016 jump.

However, this larger jump of a single year from 2019 to 2020 only represents a roughly 3.7% increase in total water volume, which is a notable increase. When examining the average of the five years prior to 2020, we would find that the total volume of water decreased by .15%, which is small enough to be considered no significant change in volume. There may not have been a significant change in water volume, however, that may not be the full context of water changes when we are able to look more closely at the data by year as well as by other metrics of water consumption. The year 2020 was also a drought year in combination with the effects of the pandemic, and we must determine how much of an influence it may have on the water use metrics in MA.

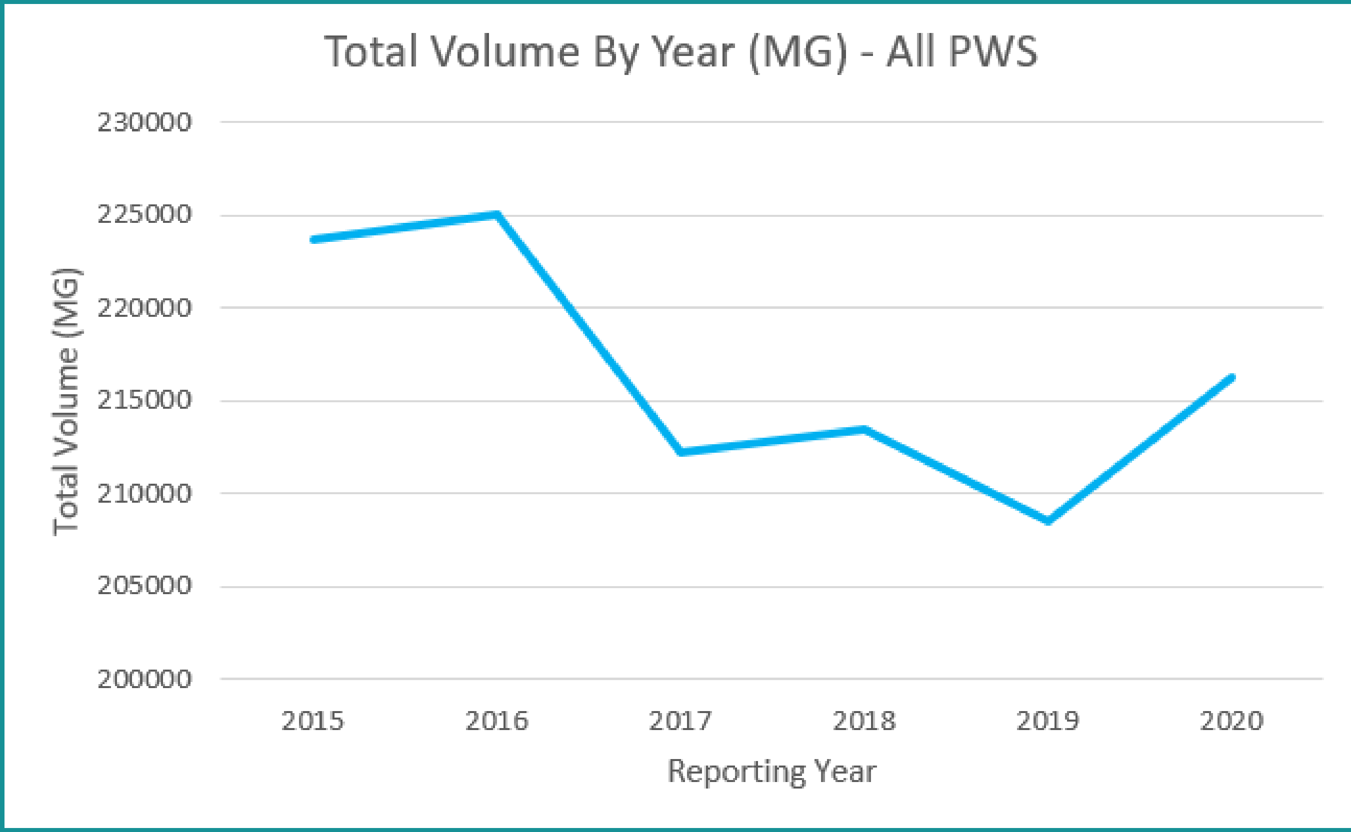

Figure 15: Graph showing the sum of the total water volume of all of the PWS in this study for each year from 2015-2020

Seasonal Volume Change

To help control for the 2020 drought as a confounding variable in determining how the pandemic influenced water usage, we broke the monthly volume of water use into a summer and winter category. The summer category contains the volume for the months from May to September, while the winter category contains the volume from the months January to March as well as from November to December. Both of these categories contain the 5 months that are most easily aligned with the summer and winter seasons in Massachusetts while leaving off April and October to have a more clear distinction between the two categories. In order to identify drought influences on water, we examined the seasonal data for the droughts in both 2016 and 2020 compared to the other years within this six-year period.

Both of the droughts were more severe in the summer category of months, and so we would expect to see the most similarities between the two in this category if the drought influences in 2020 were as strong as those in 2016. However, instead, we found that 2020 was not distinguishable from any of the other years outside of 2016 in the changes to summer water volumes. If the drought were a strong influence on water usage in 2020, then we would expect those changes to be most prominent in the summer category. Because those changes were not found, we are then able to attribute the changes to water usage in 2020 more generally to the pandemic influences rather than drought effects.

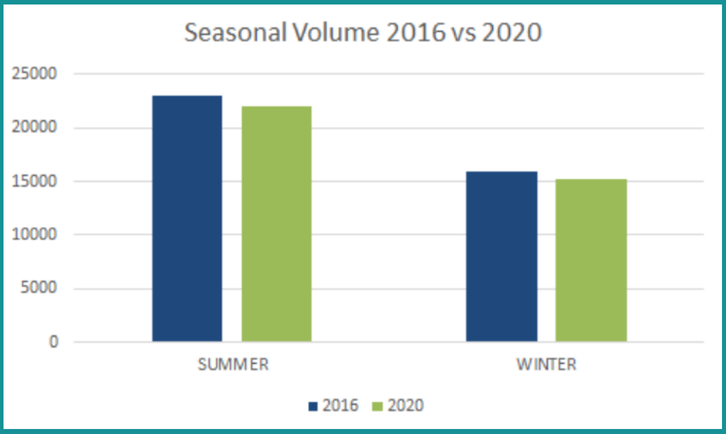

Figure 16: Graph showing the sum of the total water volume (MG) seasonally for all PWS in 2016 and 2020

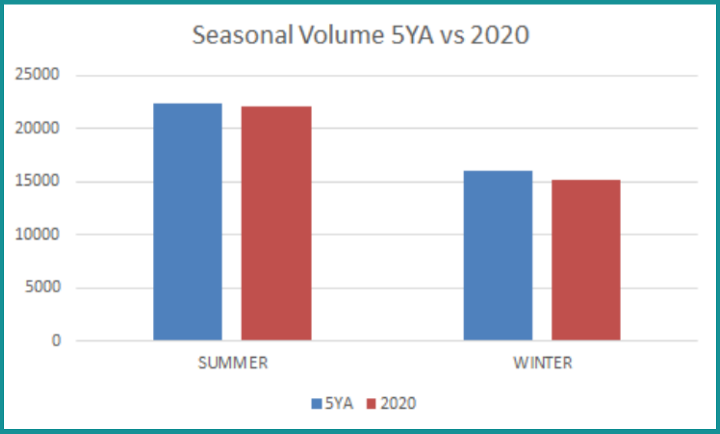

Figure 17: Graph showing the sum of the total water volume (MG) seasonally for all PWS in the five year average and 2020

Residential Water

Residential water use makes up the vast majority of the water that is supplied by PWS in Massachusetts. In most municipalities, the residential sector makes up at least 70% of the total water consumption in that town or city. Necessarily, this means that much of the changes that a PWS would expect to see are related in some way to changes in how much residential water use is either increasing or decreasing within a municipality. The vast majority of overall water changes are reflected in the larger PWS, with the bottom 50% of PWS only making up about 12.8% of the total residential water use. The largest contributor is obviously Boston, making up about 7.5% of residential water use on its own.

When we consider the impacts of COVID-19 in Massachusetts, we look at how government policies and actions impacted how the average person might behave, and how that further extends to their residential water use. For example, in March 2020, MA Governor Charlie Baker ordered the closing of all non-essential businesses for a period of two weeks starting on March 23, as well as issuing a stay-at-home advisory during this time period (Department of Public Health, 2020). Policies such as this one and those similar to it were common throughout the span of 2020 and resulted in many people staying at home for longer periods of time than they would during a typical year. This would necessarily result in larger quantities of residential water use during this period, which can then be reflected in what percentage the residential sector makes up of the total water use.

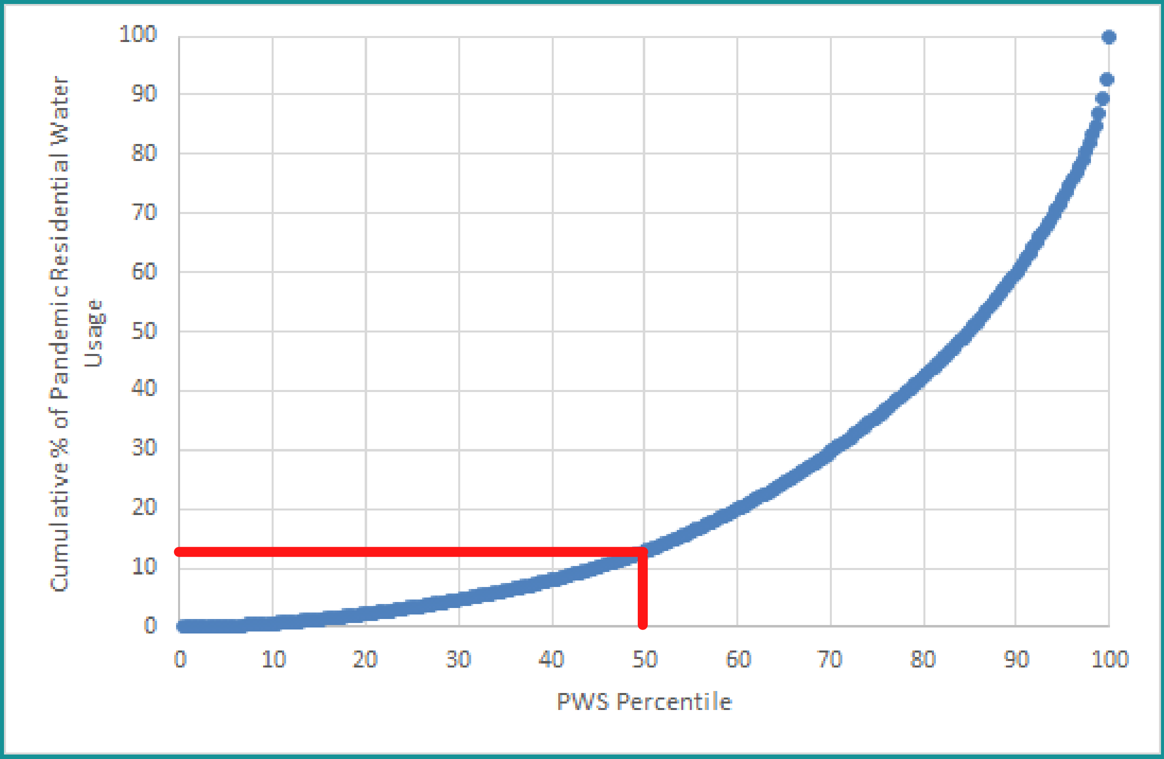

Figure 18: Graph showing the cumulative percentage of residential water use in 2020

Sectoral Water Use

Even in towns and cities where the total volume of water might not have changed significantly, one of the key impacts of the pandemic that we looked into was how the water usage may have shifted between sectors. From the background research, we expected to see the residential water consumption increase due to stay at home advisories, and then a correlated decrease in the other sectors such as commercial or industrial. This is because these sectors rely on people leaving their homes to enter their workplace or commercial centers which would be greatly diminished when dealing with pandemic policies put in place by the state. When we look at how sectors shifted in 2020 compared to the average of the five years prior, we find that this expectation is met.

In particular, we find that the residential sector increased by roughly 4% compared to the previous five years, and that increase was met with proportional decreases in the commercial, industrial, and municipal. The commercial sector fell by about 2%, with the industrial and municipal sectors each decreasing by 1%. The institutional, agricultural, and other sectors do not represent any significant portion of the overall water usage, and this is also reflected in the almost unnoticeable changes between 2020 and the five-year average.

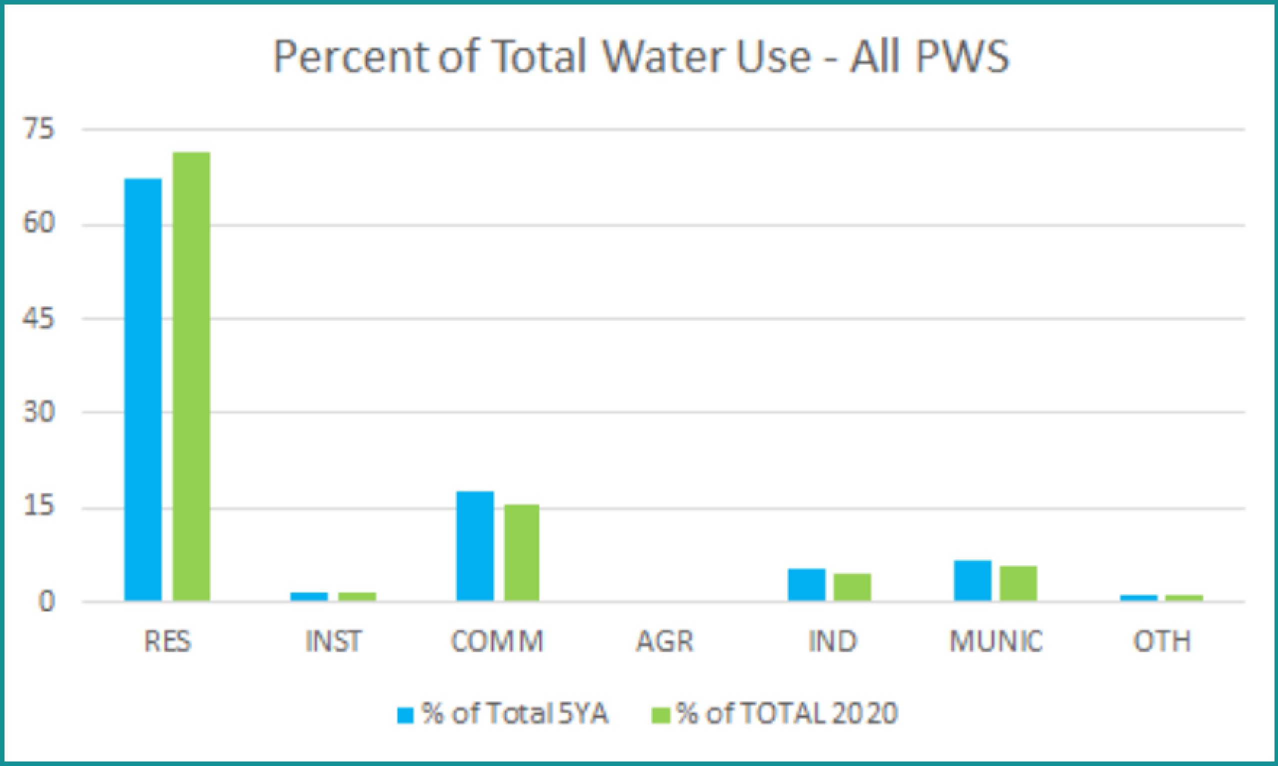

Figure 19: Graph showing the change of each sector's percent of total water use between the five year average and 2020

The residential sector makes up the largest proportion of water usage in Massachusetts by far, making up 71.3% of the sectoral water usage in 2020. Due to the fact that the sectoral water volume is so skewed towards the residential sector, when we consider the percentage change of water volume in 2020 compared to the five-year averages, any small increases in the residential sector are reflected as much larger decreases in the other non-residential sectors. The physical volume of water that shifted from the nonresidential sectors to the residential sector is roughly the same precisely because the total amount of water did not change significantly when we compare the 2020 data to the five-year averages. This fact is represented by the more proportional shifts in looking at what percent each sector contributes to the total sectoral water volume.

However, the percentage changes in the nonresidential sectors can help emphasize how significantly each sector changed. Based on the graph, both the industrial and commercial sectors were most affected by the residential shift, followed closely by the municipal sector. These findings are expected and are illustrated in figure 20, however, we are also able to pull meaningful information from the smaller nonresidential sectors, namely the residential institutional sector and the other sector. While these sectors are not as large as their counterparts, they do provide information about how institutions and more miscellaneous water consumption also decreased notably in 2020 compared to the five-year average.

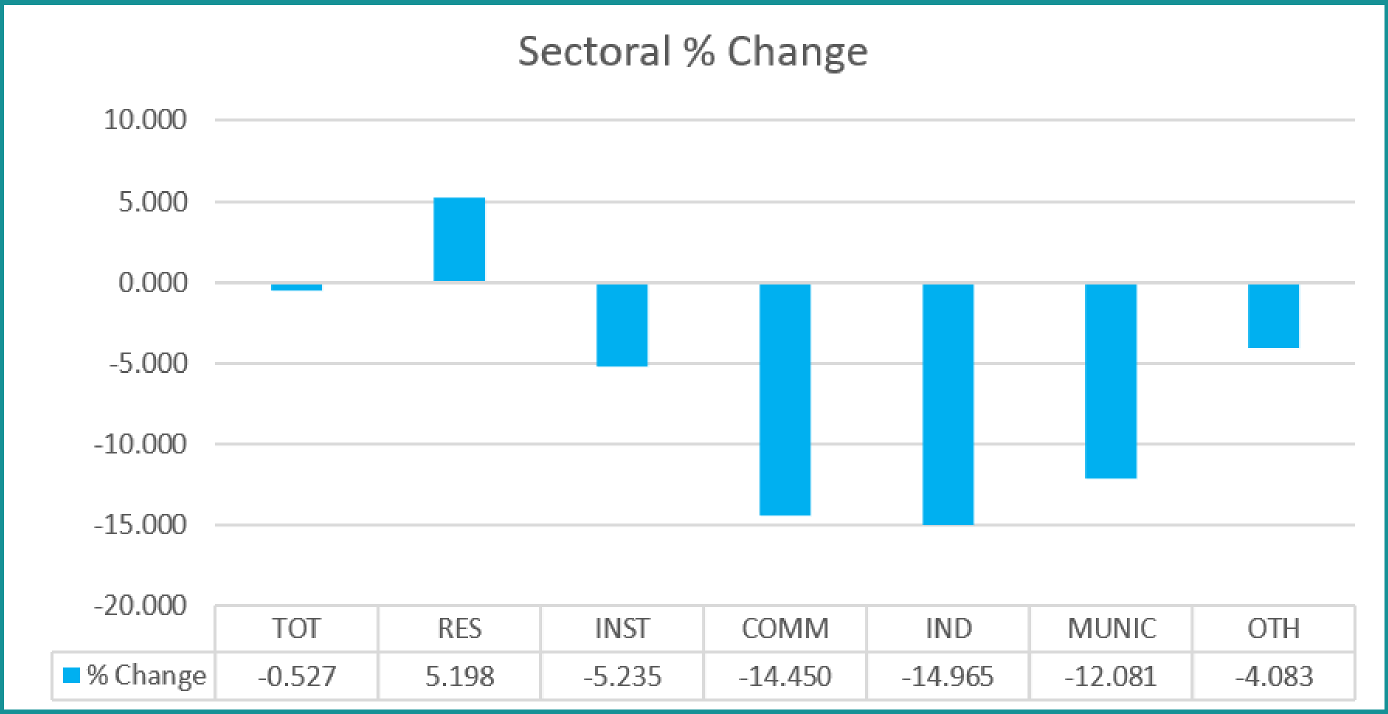

Figure 20: Graph showing the percent change of each sector's water use between the five year average and 2020. Note that the agricultural sector is not presented due to scaling, however the sector increased by roughly 33.4% in 2020. Agriculture is an incredibly small percentage of water in MA, and is not impactful on our results.

RGCPD and UAW Comparison

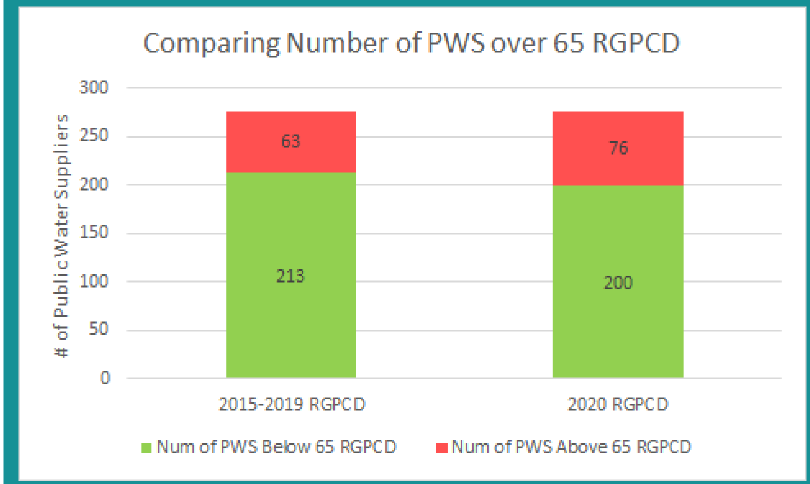

Figure 21: Graph showing the relative counts of PWS over and under 65 RGPCD

This stacked bar chart displays two bars: one for the Five Year Average (5YA) of reported Residential Gallons per Capita per Day (RGPCD, representing the average amount in gallons the average person uses each day in their residence in a particular municipality) from 2015-2019, and the other for the reported RGPCD from 2020. Each bar represents 280 Public Water Suppliers (PWS) selected for reporting data for all years from 2015-2020. These PWS are separated into two groups. The red group represents the PWSs who reported RGPCD above 65 (65 being the standard threshold approved by the MassDEP to determine if a municipality has a high RGPCD). Conversely, the blue group represents the PWSs whose RGPCD was reported below 65.

For the 5YA, there were exactly 215 PWS (around 76.7857% of the total PWS selected) who reported below 65 RGPCD while exactly 65 PWS (around 23.2143% of the total PWS selected) reported above 65 RGPCD. For 2020, exactly 202 PWS (around 72.2143% of the total PWS selected) reported below 65 RGPCD and 78 PWS (around 27.7857% of the total PWS selected) reported above 65 RGPCD. This shows that there was an increase in the number of PWS reporting above 65 RGPCD from the average of the years 2015-2019 to 2020. Therefore, there was a slight increase in water usage residentially in 2020. Similar data is reported for UAW, with the threshold set by the state being a UAW that is larger than 10%.

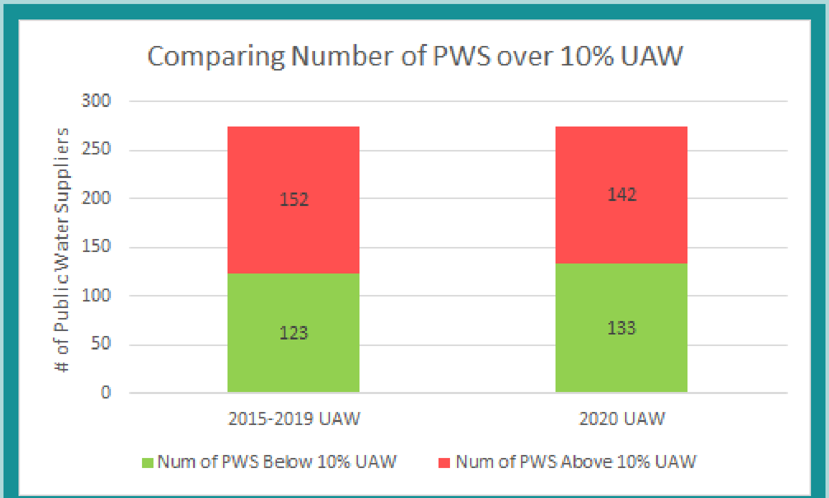

Figure 22: Graph showing the relative counts of PWS over and under 10% UAW

Mapping Residential Use against Median Household Income

In this study, our team took interest in determining how median household income might correlate with pandemic water usage in 2020. We made use of the ArcGIS software to combine the data from MassDEP on Residential Gallons per Capita Day (RGPCD) with information from the American Community Survey estimates on median household income in Massachusetts. We qualified RGPCD based on three criteria: under the state threshold of 65 RGPCD, over 65 RGPCD but less than 83 RGPCD (the national average for RGPCD in the US), or above 83 RGPCD. For median household income, we used two different criteria to classify high or low municipalities. If a municipality had a median household income lower than 65% of the state's median household income, we classed it as low (hatched in pink). If a municipality fell within the top 15% of the highest median household income, we classed it as high (hatched in mint).

The main correlation our team identified in the map related low-income cities with lower RGPCD usage, while higher-income cities tended to have low to middling levels of RGPCD usage. Most of the lower-income municipalities exist in the western side of Massachusetts, therefore population density and size might play a role in their correlation with low RGPCD values. On the other hand, the higher income municipalities cluster around but do not include the major metropolitan area of Boston and Cambridge. Our team suspects this ring is formed as a side effect of individuals commuting into Boston for work: instead of living directly within the metropolitan areas, households instead occupy more suburban areas and commute into Boston and Cambridge for job purposes. While our team notes these correlations holding true for Massachusetts on a surface level, a closer look is needed to definitively link residential water usage and median household income.

Figure 23: A snapshot showing the metropolitan area of Boston: residences in the city tend to be apartments or other cramped options, in order to fit amongst skyscrapers and existing buildings.

Mapping Residential Use against Median Household Income

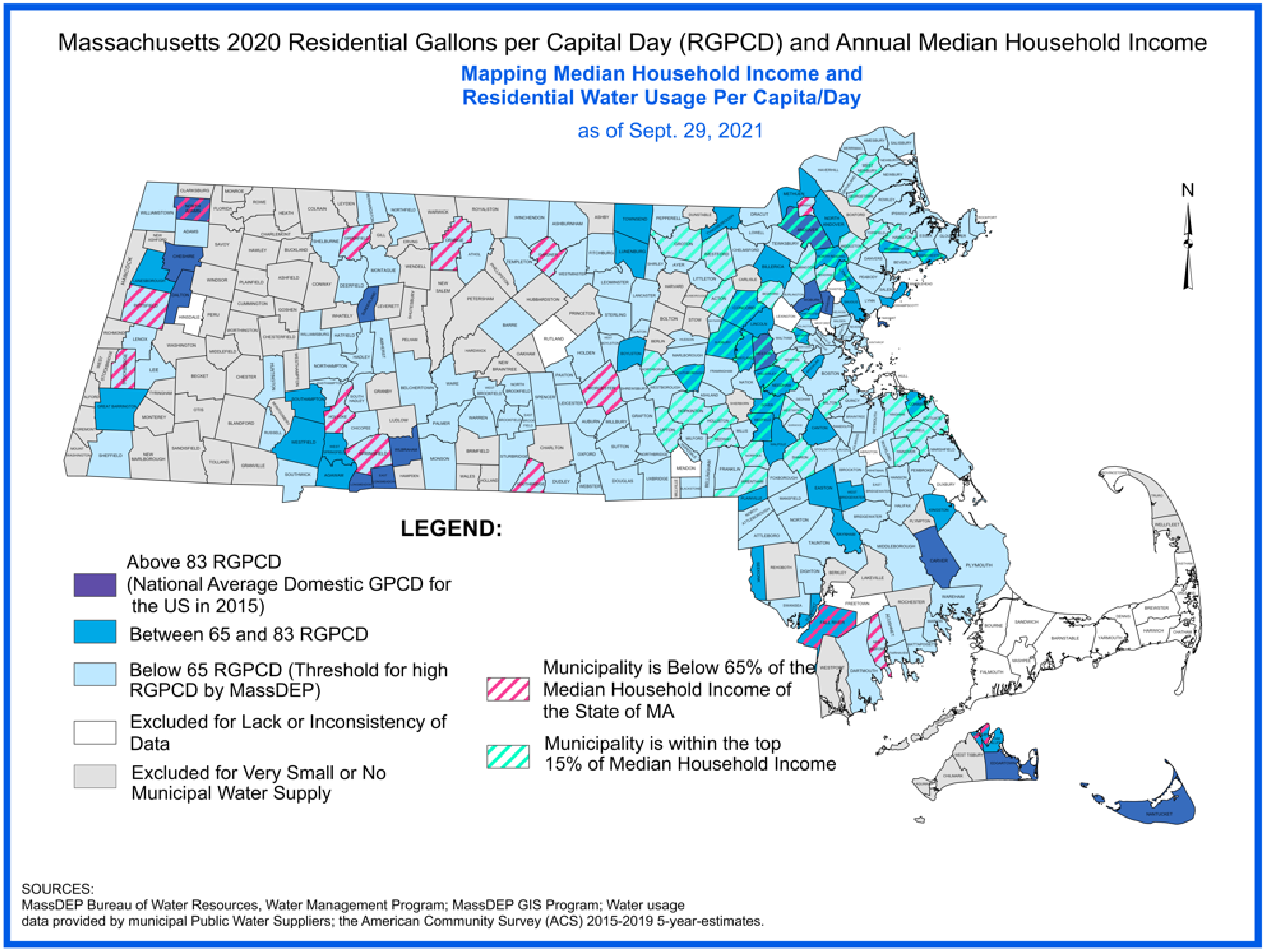

Figure 24: ArcGIS map that we created showing towns/cities less than 65% of the state median household income and top 15% median household income, compared to different levels of RGPCD

Municipalities of Interest

During our data analysis, we decided to take a closer look at four specific municipalities across Massachusetts. This included Amherst, Boston, Randolph, and Wellesley. We investigated these locations as they are some examples of the various towns and cities in Massachusetts. Looking at these certain municipalities helps identify how cities with different socioeconomic factors reacted in terms of water use due to the COVID-19 pandemic. Amherst has a population of 40,258. Consisting of that population, roughly 30,000 are students attending the various colleges and universities in the town. For this reason, we believed looking at Amherst would show us how a town with a very high student population changed its water consumption in 2020.

In contrast, Boston has the largest population in Massachusetts and is also the capital. Moreover, Boston consists of many offices, restaurants, and hotels, all falling under the commercial water sector. For this reason, Boston is an example of how a high population, metropolitan city was affected. Randolph was another municipality we investigated as it has a similar population size to Amherst, of 34,352. Randolph also has a median household income of $82,510, which is very similar to the median income of the state of Massachusetts, which is $81,215. Lastly, we chose to look at Wellesley because the median household income of this municipality was significantly higher than that of Massachusetts, at $189,248. Wellesley would therefore provide us with an example of a higher-income town.

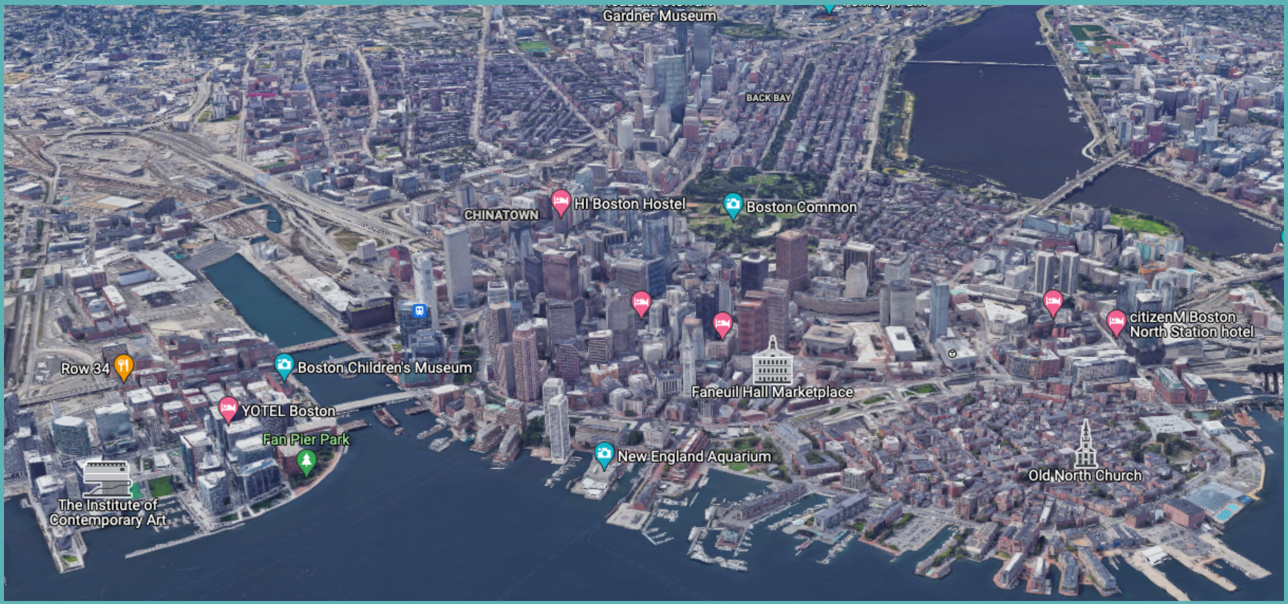

Figure 25: A Google Maps 3D screenshot of Boston, MA

Municipalities of Interest

Changes in Total Usage

The first set of data that we looked at for the municipalities was the Total Volume. With this data, we were able to graph the amount of water (in MG) the municipality was using each year from 2015-2020. Looking at Figure 26, we saw that from 2015-2019, Boston saw a gradual decrease in water use but it stayed in the range of 22500-24000 MG. Suddenly, in 2020, Boston's total water use decreased significantly to almost 21000 MG, a percent decrease of -8.19%. Similarly, in the year 2020, Amherst and Randolf also experienced a decrease in total water usage compared to the five-year average of 2015-2019. Looking at Figure 27, Amherst saw a percent decrease in total water usage of -17.17%, with Randolph at a percent decrease of -17.85%.

On the other hand, when we graphed the total water usage data for the municipality of Wellesley, we noticed a slight increase in 2020 from the five-year average, about 4.37%. This slight increase in total water usage can be contributed to Wellesley's median household income as well as the fact that Wellesley had no water restrictions in effect for 2020. In Figure 19, we can see that during the drought years of 2016 and 2020, the total water usage increased slightly in Wellesley. This could be due to the fact that more residents found the need to water their lawns as there was less rainfall. And because there were no water restrictions in effect, residents ended up consuming more water than in the years where there was no drought.

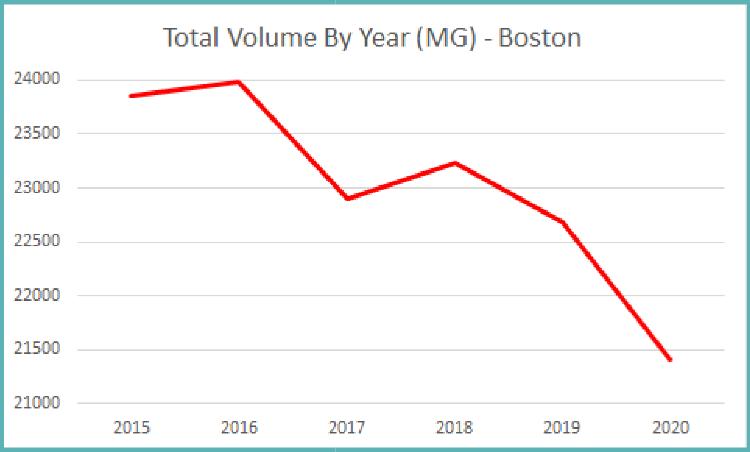

Figure 26: Boston's Total Volume Consumption from 2015-2020

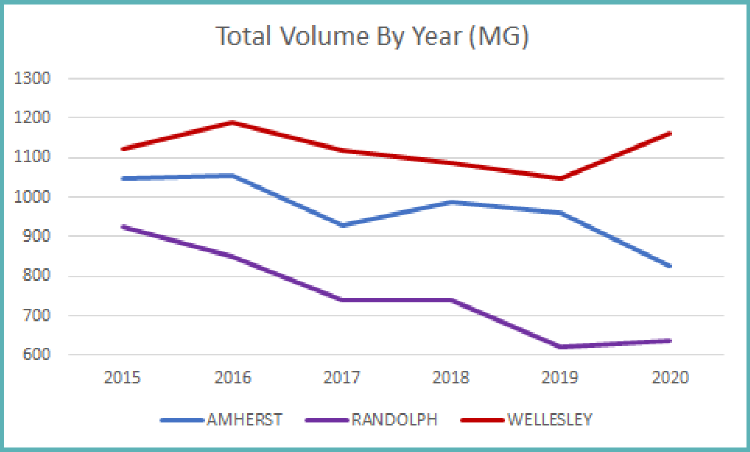

Figure 27: Amherst, Randolph, and Wellesley's Total Volume Consumption from 2015-2020

Changes in the Sectoral Data

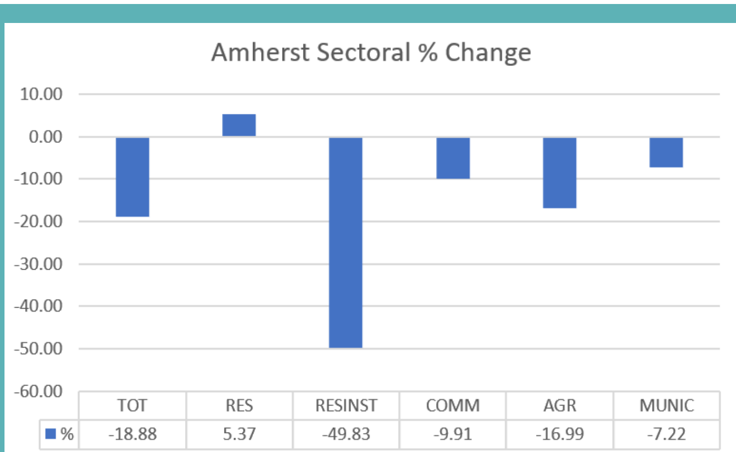

Figure 28: Amherst's Sectoral Percent Change in 2020 from the 5YA

Next, we can take a closer look at the sectoral change of each municipality in order to determine specific water use changes. Figure 28 is a graph representing the percent change of each water sector in 2020 from the 5-year average. Taking a look at Amherst, we noticed a slight increase in residential water usage, similar to the pattern of the residential change in all of the PWSs in Massachusetts that we discussed earlier. We also saw a decrease in all other non-residential water sectors. The most notable change was the significant decrease of -49.8% in the residential institutional sector. Like we discussed earlier, Amherst has a very high student population. When we researched the impacts of COVID-19, we found out that most colleges and universities were shut down and moved to online education (Higher Education Responses to Coronavirus (COVID-19), n.d.). In addition, many of the students in the universities were out-of-state students, leading to them going home when the schools were shut down. This could explain why we saw the large decrease in the residential institutional sector in Amherst during 2020.

Next, we looked at the sectoral data for the city of Boston. Figure 29 also represents Boston's percent change of each water sector in 2020 from the 5-year average. In this graph, we noticed there was a large decrease in the commercial sector of -22.8%. This percentage would equivalate to a total decrease of 1,128 mega gallons of water in the commercial sector during 2020. Approximately 47% of the labor force in Boston is working in the commercial sector (American FactFinder - Results, 2020). With such a large labor force in the commercial sector, the shift towards working from home caused by the COVID-19 pandemic led to a substantial drop in the number of people working in that sector. This drop in the total workforce could be a reason why we saw a large decrease in the commercial water sector for Boston in 2020.

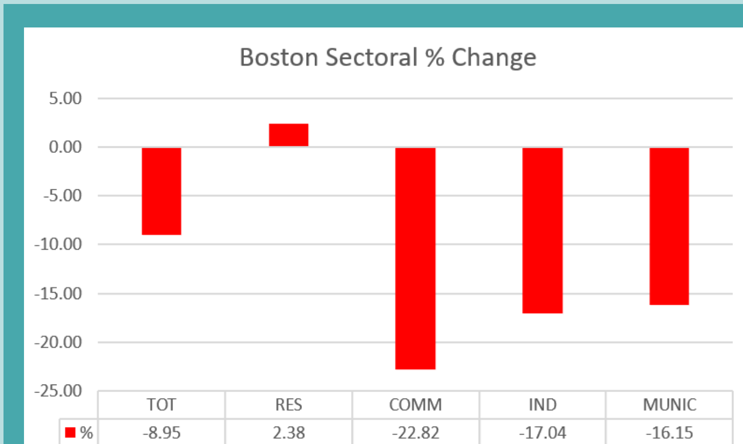

Figure 29: Boston's Sectoral Percent Change in 2020 from the 5YA

Changes in the Sectoral Data

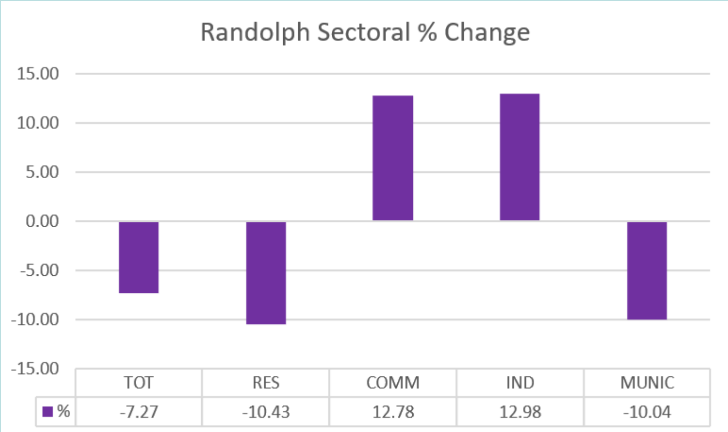

Figure 30: Randolph's Sectoral Percent Change in 2020 from the 5YA

Next, we took a closer look into the sectoral changes in Randolph, which was comparatively different from the total sectoral change in Massachusetts. Looking at Figure 30, we notice a decrease of -10.4% in the residential water sector, while both the commercial and industrial water sectors slightly increased about 12% each. While doing some further research, we found out that Randolph's water council meeting on June 17th, 2020 discussed information pertaining to "discolored, dirty, murky, and sediment-filled water... coming out of the distribution system" and into homes (Randolph Water and Sewer Division, 2020). This contamination could have caused fewer people to drink water at their homes and instead purchase bottled water (Rosinger & Young, 2020). This could explain why Randolph saw a decrease in the residential water sector and an increase in the commercial and industrial water sectors.

Lastly, we looked at the sectoral changes for Wellesley. We noticed that the total water use went up slightly, and residential water use increased significantly. Figure 31 shows that the total water use went up 4.3% and the residential water use went up 11.4%. In Wellesley, 40% of the households have children under the age of 18 living with them (Bureau, n.d.). Also, many of the schools in Wellesley had to be moved to online learning (COVID-19, 2021). This would lead to a lot of families having children in their house that would normally be at school. With these children being at home, they would be drinking more water in their residences and is likely the reason why residential water use increased significantly. In addition, Wellesly has a substantially higher medium household income than the state of Massachusetts. (Bureau, n.d.) Further study showed us that higher-income households are generally less affected by changes in water prices (Grafton et al., 2011), leading to a smaller consumption response and likely factored into Wellesley's slight increase in total water use.

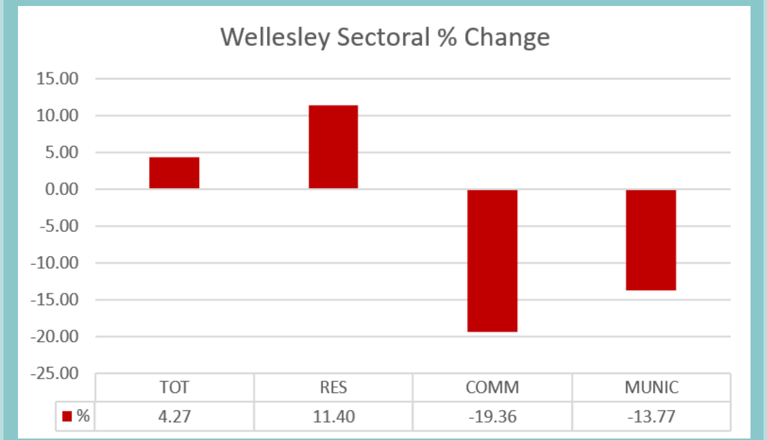

Figure 31: Wellesley's Sectoral Percent Change in 2020 from the 5YA

RGPCD per Municipality

Moving forward, we took a look at the RGPCD for Amherst, Boston, Randolph, and Wellesley. Taking a look at Figure 32, we notice that Wellesly's RGPCD, for all years, rests well above the other three municipalities. Like we discussed earlier, Wellesley has a very high median household income. In part with the fact that wealthier people use up to three times the amount of water than nonwealthy people (Wealth Is Most Reliable Predictor of Water Use in Los Angeles, 2015), we can assume that wealth could be the driving factor in why we saw such a high RGPCD for Wellesley. In addition, the RGPCD increased slightly in 2020 from the 5-year average for all the municipalities except for Randolph, which went slightly down. This slight decrease is mostly insignificant but could be contributed to the contaminated water we discussed earlier, the same reason why we saw the slight decrease in the residential sectoral water usage. Lastly, Amherst, Boston, and Wellesley had a slight increase in their RGPCD in 2020, similar to the trends we saw in their residential sectoral water usage and the trends in the total RGPCD for all the PWS's.

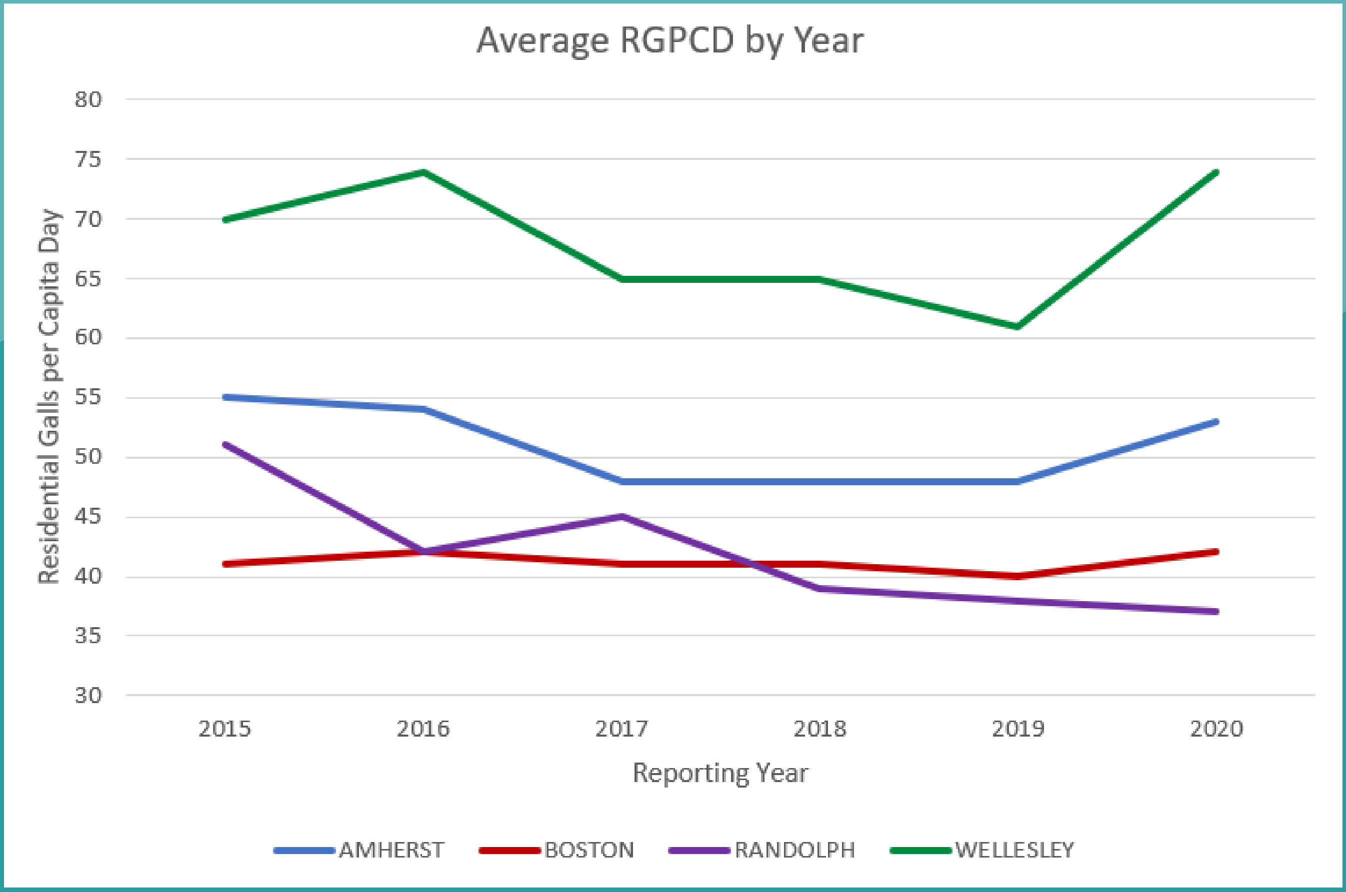

Figure 32: Average RGPCD for Amherst, Boston, Randolph, and Wellesley

Conclusion and Recommendations

Overall, during the pandemic in Massachusetts, we found that the volume of water consumption was not significantly impacted when compared to the average of the data from 2015-2019. However, it is important to note that prior to 2020, there was a clear decreasing trend in water volume that was then almost entirely erased by the 7694 MG (3.7%) increase in 2020 compared to 2019. Therefore, while comparing 2020 to the five-year average allows us to conclude that the water volume did not change significantly, we will note that it also deviated from the original trend of the data, and the years following 2020 should provide greater insight into how much of a role the pandemic played in influencing the total volume of water in MA. We also concluded that the water use changes in MA in 2020 are most effectively attributed to the pandemic influences rather than drought influences due to the lack of significant differences in the summer season between 2020 and the other years within the time period of this project. The clearest result of our project was finding the shift of water from the nonresidential sectors to the residential sector during the pandemic. This result is consistent with the findings of the studies outside of Massachusetts mentioned in the background of this report and met our expectation that MA would have similar shifts between water use sectors.

We are able to so clearly see the shift towards the residential sector in 2020 compared to the five-year average precisely because the total volume of water did not change significantly during this time period. This allowed us to more easily see the proportional changes between sectors as described in figures 19 and 20, which showed the residential sector being the only sector to grow significantly in opposition to the nonresidential sectors in which the decrease was more spread out. This also reveals the multiple impacts of the pandemic on water use behaviors, with the rise of the virtual workforce likely playing a role in the commercial, industrial, and municipal shifts, and the shift to online education likely playing a role in the institutional shift. With more people staying within their residential households, the residential sector was likely to increase significantly. In contrast, because those same people were not traveling to commercial or industrial areas within municipalities as frequently, those sectors were just as likely to decrease. Overall, we can conclude that the policies and mandates enacted as a result of the pandemic are most directly responsible for the shifting of water from the nonresidential sectors to the residential sector in 2020.

Recommendations

Our recommendations from this report are less direct and more inspiring for further insight. Our team recommends multiple studies on highlighted topics that we flagged as we worked on this project.

The first study our team recommends is a study into how median household income might relate to water usage. While our team mapped out these factors and identified some correlations, there were no immediately obvious revelations gleaned. Specifically, we think it would be of benefit to understand not just the correlation between numbers, but also if there is a social correlation as well. We are presently unsure what the context of the correlations we found are, and whether they are valid or not. Behavioral and communal environments may play a large role in this potential relationship, and thus a study in pursuit of this idea would be beneficial.

Secondly, our team also recommends a study on how the shift from in-person to online education may have impacted water usage. At a base level, more students (in lower or higher education) at home makes an easy assumption on a rise in residential usage and a decrease in institutional usage. However, other factors come into play as well. For lower education, parents might suddenly face issues with needing adequate childcare. For higher education, not all students originate from even the same state as the institution they attend. While some students may move back to their families in the same municipality if possible, others may choose to reside off-campus near their institution. Some students may not have returned, instead, remaining in their previous family residences out of state. These ideas have possible implications for water usage in both the residential and institutional sectors, and possibly the commercial or industrial sectors. Amherst provides a good example of this phenomenon; the city is primarily built around their college campuses, and our team notes in its section how the loss of college students possibly led to our observations in its water use changes. A study focusing on this idea would help bring light to these changes, as well as confirm our postulation.

Finally, we recommend a study on how the shift to a more virtual workforce may impact water usage. Our team found that the water sectors that saw the largest decrease in the total volume of water consumed were the commercial and industrial sectors. These sectors would be most affected by employees no longer making the commute to their places of work and therefore using less water as a result. While we were able to see the clear shifts in water use in a commercial hub like Boston as we discussed previously, we also saw large increases in the residential sector of Wellesley. We hypothesize that this larger increase might also be attributed to larger numbers of people being able to work from home in a higher-income community such as Wellesley. Therefore, a study into how a larger virtual workforce impacts the water use sectors would likely be focused on the impacts to the commercial and industrial sectors, and the corresponding impacts in places that are more likely to have citizens working from home.

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References

1. Abu-Bakar, H., Williams, L., & Hallett, S. H. (2021). Quantifying the impact of the COVID-19 lockdown on household water consumption patterns in England. Npj Clean Water, 4(1). https://doi.org/10.1038/s41545-021-00103-8
2. American FactFinder—Results. (2020, February 13). Archive.Ph. http://archive.ph/3SBFj
3. Bureau, U. C. (n.d.). Census.gov. Census.Gov. Retrieved October 12, 2021, from https://www.census.gov/en.html
4. Campos, M. A., Carvalho, S. L., Melo, S. K., Gonçalves, G. B., dos Santos, J. R., Barros, R. L., Morgado, U. T., da Silva Lopes, E., & Abreu Reis, R. P. (2021). Impact of the COVID-19 pandemic on water consumption behaviour. Water Supply. https://doi.org/10.2166/ws.2021.160
5. Centers for Disease Control and Prevention. (n.d.). About COVID-19. Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/cdcresponse/about-COVID-19.html.
6. COVID-19: Schools for more than 168 million children globally have been completely closed for almost a full year, says UNICEF. (2021, March 2). https://www.unicef.org/press-releases/schools-more-168-million-children-globally-have-been-completely-closed
7. COVID-19 State of Emergency | Mass.gov. (n.d.). Retrieved April 9, 2021, from https://www.mass.gov/info-details/covid-19-state-of-emergency
8. Department of Public Health. (2020, March). Governor Charlie Baker orders all non-essential businesses to cease in person operation, directs the Department of Public Health to issue stay at home advisory for two weeks. Mass.gov. Retrieved October 1, 2021, from https://www.mass.gov/news/governor-charlie-baker-orders-all-non-essential-businesses-to-cease-in-person-operation.
9. Devine, P. (2012). In J. Goodwin (Ed.), Sage secondary data analysis (pp. 211–214). essay, SAGE.
10. Drought Status. Mass.gov. (2021). https://www.mass.gov/info-details/drought-status#past-drought-declarations-maps-and-history-.
11. Fischer, M. M., & Nijkamp, P. (1992). Geographic information systems and spatial analysis. Annals of Regional Science, 26(1), 3. https://doi-org.ezpxy-web-p-u01.wpi.edu/10.1007/BF01581477
12. Grafton, R. Q., Ward, M. B., To, H., & Kompas, T. (2011). Determinants of residential water consumption: Evidence and analysis from a 10-country household survey. Water Resources Research, 47(8). https://doi.org/10.1029/2010WR009685
13. Halich, G., & Stephenson, K. (2009). Effectiveness of Residential Water-Use Restrictions under Varying Levels of Municipal Effort. Land Economics, 85(4), 614–626.
14. Higher Education Responses to Coronavirus (COVID-19). (n.d.). Retrieved October 11, 2021, from https://www.ncsl.org/research/education/higher-education-responses-to-coronavirus-covid-19.aspx
15. Johnston, M. P. (2014). Secondary Data Analysis: A Method of which the Time Has Come. Qualitative and Quantitative Methods in Libraries, 8.
16. Kenney, D. S., Klein, R. A., & Clark, M. P. (2004). USE AND EFFECTIVENESS OF MUNICIPAL WATER RESTRICTIONS DURING DROUGHT IN COLORADO. Journal of the American Water Resources Association, 40(1), 77–87. https://doi.org/10.1111/j.1752-1688.2004.tb01011.x
17. Kohl, E., & Knox, J. A. (2016). My Drought is Different from Your Drought: A Case Study of the Policy Implications of Multiple Ways of Knowing Drought. Weather, Climate, and Society, 8(4), 373–388.
18. Li, D., Engel, R. A., Ma, X., Porse, E., Kaplan, J. D., Margulis, S. A., & Lettenmaier, D. P. (2021). Stay-at-Home Orders during the COVID-19 Pandemic Reduced Urban Water Use. Environmental Science & Technology Letters. https://doi.org/10.1021/acs.estlett.0c00979

References

19. Lüdtke, D. U., Luetkemeier, R., Schneemann, M., & Liehr, S. (2021). Increase in Daily Household Water Demand during the First Wave of the Covid-19 Pandemic in Germany. Water, 13(3), 260. https://doi.org/10.3390/w13030260
20. Maggioni, E. (2015). Water demand management in times of drought: What matters for water conservation. Water Resources Research, 51(1), 125–139. https://doi.org/10.1002/2014wr016301
21. Massachusetts Department of Environmental Protection. (2021). Public Water Supply Tools, resources & performance standards. Mass.gov. Retrieved October 1, 2021, from https://www.mass.gov/service-details/public-water-supply-tools-resources-performance-standards.
22. Massachusetts Executive Office of Energy and Environmental Affairs, Massachusetts Drought Management Plan (2019). https://www.mass.gov/doc/massachusetts-drought-management-plan/download
23. Massachusetts Water Use. (n.d.). Retrieved April 9, 2021, from https://www.usgs.gov/centers/new-england-water/science/massachusetts-water-use?qt-science_center_objects=1#qt-science_center_objects
24. Mass DAR. Water Use and Water Conservation | Mass.gov. (n.d.). Retrieved April 9, 2021, from https://www.mass.gov/service-details/water-use-and-water-conservation
25. MassGIS. (2005). MassGIS Data: Public Water Supply Service Territories. https://docs.digital.mass.gov/dataset/massgis-data-public-water-supply-service-territories.
26. Metzger, A. (2016, August 31). Quabbin Reservoir has lost 10 billion gallons of water due to drought. Greenfield Recorder. Retrieved October 1, 2021, from https://www.recorder.com/quabbin-running-low-OK-4449325.
27. Randolph Water and Sewer Division. (2020, June 17). Water Meeting Council Notes 6-17-20. https://www.randolph-ma.gov/sites/g/files/vyhlif4906/f/uploads/water_meeting_council_notes_6-17-20.pdf
28. Proposed Revisions to Water Conservation Standards, based on comments received. (2012). Retrieved April 16, 2021, from https://www.mass.gov/doc/water-conservation-standards/download
29. Renwick, M. E., & Archibald, S. O. (1998). Demand Side Management Policies for Residential Water Use: Who Bears the Conservation Burden? Land Economics, 74(3), 343. https://doi.org/10.2307/3147117
30. Rosinger, A. Y., & Young, S. L. (2020). The toll of household water insecurity on health and human biology: Current understandings and future directions. Wiley Interdisciplinary Reviews: Water, 7(6), e1468. https://doi.org/10.1002/wat2.1468
31. Sivakumar, B. (2021). COVID-19 and water. Stochastic Environmental Research and Risk Assessment, 35(3), 531–534. https://doi.org/10.1007/s00477-020-01837-6
32. US EPA, O. (2016, May 10). Climate Impacts on Water Utilities [Overviews and Factsheets]. US EPA. https://www.epa.gov/arc-x/climate-impacts-water-utilities
33. Vose, E. (2021). Did You Know? National Climatic Data Center. https://www.ncdc.noaa.gov/monitoring-references/dyk/drought-definition.
34. Wealth is most reliable predictor of water use in Los Angeles: Study. (2015, April 6). http://news.yahoo.com/wealth-is-most-reliable-predictor-of-water-use-in-los-angeles--study-184853474.html
35. Wolters, E. A. (2013). Attitude–behavior consistency in household water consumption. The Social Science Journal, 51(3), 455–463. https://doi.org/10.1016/j.soscij.2013.10.003
36. Yang, W., Hyndman, D. W., Winkler, J. A., Viña, A., Deines, J. M., Lupi, F., Luo, L., Li, Y., Basso, B., Zheng, C., Ma, D., Li, S., Liu, X., Zheng, H., Cao, G., Meng, Q., Ouyang, Z., & Liu, J. (2016). Urban water sustainability: Framework and application. Ecology and Society, 21(4). http://www.jstor.org/stable/26270037