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COST-BENEFIT ANALYSIS OF INCREASED WATER TREATMENT PLANT SERVICE GOALS ON REDUCING WATER QUALITY RISK

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HONORS RESEARCH PROJECT

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Abstract

To treat water to make it safe to drink, disinfection processes are used in water treatment plants. These disinfection processes produce disinfection byproducts (DBPs) through the reaction of organic matter and the disinfectant, such as chlorine. DBPs have been shown to pose a cancer risk to consumers. In this report, the focus is on two types of DBPs, trihalomethanes (THMs) and haloacetic acids (HAAs). The cancer risks associated with DBPs are analyzed through ingestion and inhalation pathways. Ingestion and inhalation consist of common water uses like drinking, cooking, or bathing. In addition to this, DBPs have been shown to increase through stagnation as they travel throughout water distribution systems, plumbing pipes, and hot water tanks. Methods for reducing the cancer risks associated with DBPs include consumers utilizing point of use (POU) filtration, whole house water filtration systems, or decreasing dissolved organic carbon (DOC) leaving the water treatment plant.

The cancer risks associated with DBPs found in the city water of Akron, Ohio are calculated in this report. It is important to mention that various assumptions were made in the calculation processes, such as average body weight and average household water usage per day. Other types of assumptions include the assumed number of service connections in Akron that had different POU and whole house filtration systems. The methodology for this research includes obtaining quarterly data at numerous water distribution site locations in the City of Akron and obtaining data and costs for POU filtration and whole house filtration. The next portion of the methodology includes calculating cancer risks from THM and HAA exposure (including stagnation effects), calculating cancer risks when treatment options are utilized (based on the removal efficiency for each filter type), and calculating cancer risks from THM and HAA exposure when the DOC levels are reduced leaving the water treatment plant. From here, cancer risks and filtration costs are analyzed to provide insight to the public and the water treatment staff and leadership on the different cancer risks with the unfiltered water, filtered water, and when DOC concentrations are decreased.

Some conclusions gathered from this research are that a reduction in DOC from the treatment plant will lower the cancer risks for all the consumers in the Akron water distribution system. Additionally, households who have a POU or whole house filtration system save money from the lowered DBP levels associated with a decreased DOC. Net consumer savings of around $230,000 were achieved by a reduction in DOC of 0.1 mg/L. Further conclusions are that whole house filtration systems provide the greatest reduction in cancer risk from DBPs, due in part to the fact that they work for both ingestion and inhalation pathways. For POU devices, the Zerowater water pitcher reduced cancer risk due to ingestion the most but was more expensive. The GE refrigerator filter performed best for POU filters when considering cost and cancer risk reduction due to ingestion. For the POU devices, cancer risk in the water due to inhalation was not impacted since these only treat ingestion pathways. For whole house filtration systems, the RKIN whole house treatment system was the most affordable option, therefore this made it the highest performing whole house system since the same removal efficiency was assumed for all the whole house filtration options. Further analysis on the impact of DOC reduction on THMs and HAAs and further analysis on the efficiency of whole house filtration systems would allow for even more beneficial insight to consumers in Akron and water treatment plant staff and leadership.

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1.0 Introduction

1.1 Problem

Across the world, people lack access to safe and potable drinking water. Additionally, aging infrastructure poses a threat to clean water that runs through systems. People in countries and locations that are still developing especially deal with water quality issues, needing more accessible ways to increase potability of their water supplies. In both developing and developed places, point of use devices may be used to improve water quality. Point of use devices for water treatment include types such as water pitcher filtration, refrigerator filtration, and sink faucet filtration (Anumol et al., 2015)

In the United States, there are existing regulations to keep contaminants in check in water systems (Anumol et al., 2015). To treat municipal water for drinking, disinfectants are added into the water at a treatment plant. Chlorine is one type of disinfectant that may be added to treat the water. Disinfection byproducts, also known as DBPs, are formed during this disinfection process within municipal water treatment plants. DBPs are formed over time when natural organic matter reacts with a disinfectant used to treat water, such as chlorine. DBPs are monitored in the water distribution system to ensure the levels are not in exceedance of any regulations. Two common types of DBPs include trihalomethanes (THMs) and haloacetic acids (HAAs), which will be the two major DBPs of focus in this research project (Chowdhury, 2015).

Once outside of the treatment plant and into the water distribution system, DBPs form and travel throughout the network, eventually ending up in homes through attached service connections. From here, people use the water for all needs, which include uses such as drinking, showering, and cooking. Additionally, DBP concentrations increase due to stagnation effects within plumbing systems and hot water tanks (Chowdhury, 2015). It is important to note that while this research project utilizes information from numerous locations and sources, all the collected data that is being used to analyze DBPs and cancer risk is from the water distribution system of the City of Akron, in Akron, Ohio. There are several assumptions made, which are outlined in Section 2.2, as not all needed data was known to complete calculations within this project.

The main issue focused on in this project is that through exposure, DBPs pose risks to human health, including increased cancer risks. As mentioned above, people use municipal water in several ways, from drinking to bathing. This leaves the consumer vulnerable to DBPs from several different exposure paths – dermal, inhalation, and ingestion. For the purposes of this project dermal pathways are not considered. Ingestion occurs when people drink the water or use it to cook with, while inhalation usually happens when people shower or take baths. Through these ways, the public encounters DBPs and their possible effects. The risks, along with the DBP concentrations, are increased the longer water remains in plumbing pipes and in hot water tanks. This means that there are also stagnation effects for DBPs that must be included in this project to find the most accurate cancer risk numbers (Chowdhury, 2015).

The other problem with DBPs involves how to reduce them. To reduce DBPs, there are a few different methods that can be utilized. The downside is that they all have additional costs. The consumer may reduce DBPs in their water by utilizing whole home treatment systems or point of use systems. These all have costs, with some having high capital costs. Even for the more affordable options, annual costs for replacing filters and maintaining the systems are needed. This means Akron water consumers will be paying extra to reduce DBPs in their water no matter which option they select. There are also varying levels of effectiveness for the different options. They all reduce the cancer risk from DBPs to a different degree, with some being more effective than others.

An alternative to consumers utilizing their own filtration devices involves the City of Akron water treatment plant reducing the dissolved organic carbon (DOC) concentration at the plant. If there is a lower DOC concentration leaving the plant, the amount of DBPs formed in the water would be lowered. This would benefit consumers with and without additional water treatment systems. The problem with this involves the cost. The City of Akron would have to invest large amounts of money to lower the DOC concentration at the plant, which may not be appealing to the city officials.

1.2 Purpose

The purpose of this research project involves a couple of different goals. One important goal is to inform municipal water consumers of the risks associated with DBPs. Since the focus in this project is the City of Akron, the goal is to specifically inform residents in Akron who use and drink city water. Along with this, is the goal of providing these homeowners and residents in Akron with possible solutions to treating DBPs. This includes the effectiveness of a variety of whole home treatment systems, pitchers, and point of use filtration. Cost estimates are also provided to help Akron residents pick options that are affordable to use in their homes. Some options require a larger capital cost up front, which not everyone may be able to afford, therefore alternatives are presented that also help to protect consumers. Whole house treatment filtration options have higher capital costs but require fewer annual fees than replacing point of use filters would. Therefore, it is up to the consumer to decide what is the most viable option using the data provided.

The final goal for this research project is to inform the water treatment plant staff and leadership of what decreasing the dissolved organic carbon (DOC) at the water treatment plant could do for the community. This project works to provide cost estimates of annual savings when the DOC concentration is lowered at the treatment plant for Akron water consumers who implement water filtration. It will also be investigating as to how reducing the DOC at the treatment plant affects consumer cancer risks.

2.0 Methodology

2.1 Approach

The City of Akron does quarterly testing at various sampling sites across the water distribution system to determine the levels of THMs and HAAs at consumers taps. The DOC levels at the treatment plant were also known at the time of this testing. This allows for the THM and HAA levels to be estimated for different levels of DOCs in the treated water entering the distribution system. The cancer risk associated with the ingestion and inhalation of the THMs and HAAs can be found using equations from *Effects of plumbing systems on human exposure to disinfection byproducts in water: a case study* by Shakhawat Chowdhury. The effectiveness of several point of use and whole house filtration systems ability to remove THMs and HAAs and lower the cancer risk for consumers will also be analyzed. All of this will be looked at in scenarios with lowered DOC levels leaving the treatment plant and the cost and benefit of doing so. This will reveal the filters that are most cost effective at reducing the cancer risk and how the price can be reduced and the effectiveness increased if the City of Akron lowers the DOC concentration leaving the treatment plant. A step-by-step list of the approach is shown below:

1. Obtain quarterly testing data of THM and HAA levels at various site locations in the City of Akron water distribution system.
    a. It is important to acquire data for the DOC concentration of water leaving the treatment plant and entering the distribution system for the same time frames as the testing data.
    b. Theoretical THM and HAA levels can be calculated as it is assumed a decrease in DOC will cause a directly proportional decrease in THMs and HAAs at the tap.
2. Find comparable whole house filtration systems and point of use filters along with initial price, cost of upkeep, and manufacturer expected lifetime (MEL) of the filters.
    a. The point of use filters that were selected for this study were selected because there was information on the filter's efficiency and how the filter's MEL changes when the water has different concentrations of contaminants (Brophy, 2016; Anumol et al., 2015).
    b. The cost of maintaining these filters can be calculated at the current and lowered contaminant concentrations.
3. The cancer risk from THM and HAA exposure can be calculated from the sampled DBP concentrations and those calculated at lower DOC concentrations.
    a. Use constants found in Table 1: Contains definitions and assumed/estimated values for each variable parameter used to find the ingestion and inhalation risk, the chronic daily intake equations for ingestion and inhalation, and the stagnation effects from *Effects of plumbing systems on human exposure to disinfection byproducts in water: a case study* by Shakhawat Chowdhury.

   b. Cancer calculations are repeated for the exposure that occurs after the water is filtered. This is repeated for each filter and DOC concentration combination.
4. Using results from Steps 2 and 3, the cancer risk of the water can be found for water coming through each filter and without a filter at all the various DOC concentrations.
5. Compare the cancer risk and cost of unfiltered, unchanged contaminants to all the different combinations of filters and lowered contaminant levels.

2.2 Background Information and Key Assumptions

To complete this analysis, multiple assumptions had to be made. Without these educated assumptions, proper conclusions involving cancer risks and costs could not be completed. Listed below are all the assumptions made during this research project.

- There are 100,000 water service connections in the City of Akron.
- A reduction in DOC of 0.1 mg/L costs the City of Akron $100,000.
- The average water usage of a household is 70 gallons per person per day.
- An average household size is 4 people.
- The number of bathrooms in a household is typically one to three.
- Stagnation effects for calculating ingestion and inhalation of DBPs for plumbing pipes, hot water tanks, and water distribution systems (Chowdhury, 2015).
- For ingestion/inhalation risks – average person consumes 1.31 L of water per day with an average body weight of 70.4 kg (Chowdhury, 2015).
- Dermal contact pathway was not calculated as it is a negligible contributing factor to the cancer risk from THMs and HAAs.
- Since HAAs are non-volatile and have a low likelihood of being an inhalation risk, HAA inhalation cancer risk was not calculated or considered (Chowdhury, 2015).
- We assumed 5,000 households (5%) had Brita water pitchers, 5,000 households (5%) had Zerowater pitchers, 40,000 households had GE Refrigerator filters (40%), 500 households (0.5%) had Springwell Whole House Water Treatment systems, 500 households (0.5%) had RKIN Whole House Water Treatment systems, and 500 households (0.5%) had Pentair Whole House Water Treatment systems. This means in the scenario of this project, 48,500 service connections do not use any type of filtration methods.

3.0 Results

The Chronic Daily Intake (CDI) for both ingestion and inhalation pathways can be calculated using the following equations (Chowdhury, 2015).

$$CDI(ingestion) = \frac{(Cw \times IR \times EF \times ED \times CF)}{BW \times AT}$$

$$CDI(inhalation) = \frac{Er \times Ca \times R \times t \times F \times EF \times ED \times CF}{BW \times AT}$$

Table 1, below, shows the assumed values and meanings of each of the variables in the above equations. Among these assumptions, it was assumed that the average person consumed 1.31 liters of water per day and had an average body weight of 70.4 kilograms (Chowdhury, 2015). These values were cross referenced with constants found in *Assessing Inhalation Exposures Associated with Contamination Events in Water Distribution Systems* (Davis, 2016). Exposure factors found below have also been found in the *Exposure Factors Handbook: 2011 Edition* (U.S. EPA, 2011). People that differ from these assumed standard values will have varying posed inhalation and ingestion risks.

Table 1: Contains definitions and assumed/estimated values for each variable parameter used to find the ingestion and inhalation risk

IR =	1.31	Water ingestion rate (L/day)
EF =	350	Exposure Frequency (days/year)
ED =	77.1	Exposure Duration (years)
BW =	70.4	Body Weight (Kg)
AT =	28142	Averaging Time (days)
Qw =	10	Water Flow (L/min)
V =	2	Shower Stall Volume (m^3)
T =	10	Shower Time (min/shower event)
T2 =	40	Heated Water Temp (Celsius)
T1 =	20	Cold Water Temp (Celsius)
ka =	0.021	Air Change (ACM)
Er =	0.77	THM Absorbance through respiratory system
pv =	8.76	THMs transformation rate from water to air phase (%)
R =	0.014	Air intake rate (m3/min)
F =	0.74	Shower frequency (shower event/day)
Sskin =	1.82	Area of body skin exposed to water (m^2)
CF =	0.001	Conversion factor

The CDI is then multiplied by the slope factor SF, which are both specific for the route of intake, to give the cancer risk (Lane et al., 2023). This can also be seen in a study done by Zhou in 2011 where the cancer risk was calculated as shown below (Zhou et al., 2011).

$$\mathrm{Rij} = \mathrm{Eij} \times \mathrm{IURj}$$

This is where Rij is the estimated cancer risk from inhalation, calculated using Eij and IURj. Eij is the exposure concentration for the chemical and IURj is the inhalation unit risk for the chemical. The IUR can be found from the Cumulative Exposure Project and the U.S. EPA'S Integrated Risk Information System (Zhou et al., 2011).

Due to the formation of DBPs in a water system being time dependent, there are morning stagnation effects used to adjust the THM and HAA concentrations used in the cancer risk calculations. This is caused by a decrease in demand for water at the tap during the night. In the morning, water that is currently in home plumbing pipes (PP), hot water tanks (HWT), and water distribution systems (WDS) is older; giving DBPs more time to form (Chowdhury, 2015). Table 2 below shows the estimated factors that were used to adjust cancer risk calculations for the morning stagnation effects.

Table 2: Shows the morning stagnation effects which are used to adjust cancer risk calculations to account for the increased time water spends in a system allowing DBPs to form. These values are added to the measured concentration from sampling stations to be used in cancer risk calculations.

MORNING STAGNATION EFFECTS					
THMs (ppb)			**HAAs (ppb)**		
PP	**HWT**	**WDS**	**PP**	**HWT**	**WDS**
11.1	14.6	6.5	8.6	9.2	6.7

Table 3 below shows the THM concentrations in minimum and maximum months at the twelve district locations in Akron. The THM and HAA concentration data was pulled from the Ohio EPA Division of Drinking and Ground Waters website, where results for various tests over the past two years can be found. The two months investigated were April and July of 2022 (Ohio EPA, 2022). The MAX column from the month of July 2022 is used for the calculations. From there, the morning stagnation effects from Table 2 were added to the MAX values in Table 3, which then produced the THM values in the right three columns. These are the THM values after the effects of stagnation have been applied to the plumbing pipes (PP), hot water tanks (HWT), and water distribution systems (WDS).

Table 3: Shows the twelve districts in Akron, and their minimum and maximum THM concentrations for April and July of 2022. The stagnation effects were added to the MAX column to get the total THM amount.

THMs (ppb)				THMs (ppb)		
Area	**MIN (April)**	**MAX (July)**	**YEAR**	**PP**	**HWT**	**WDS**
DS201	28.4	70.3	2022	81.4	84.9	76.8
DS202	25.9	60.3	2022	71.4	74.9	66.8
DS203	25.9	65.3	2022	76.4	79.9	71.8
DS204	34.9	86.3	2022	97.4	100.9	92.8
DS205	35.1	85.9	2022	97.0	100.5	92.4
DS206	28.7	65.3	2022	76.4	79.9	71.8
DS207	30.5	71.2	2022	82.3	85.8	77.7
DS208	28.1	69.2	2022	80.3	83.8	75.7
DS209	30.1	65.5	2022	76.6	80.1	72
DS210	32	76.9	2022	88.0	91.5	83.4
DS211	25.7	63.2	2022	74.3	77.8	69.7
DS212	36.4	82.4	2022	93.5	97.0	88.9

After this step, using the Chronic Daily Intake equations shown at the beginning of this section, ingestion and inhalation amounts in mg/kg-day were calculated using the adjusted THM values due to stagnation shown above. The same process was applied for the HAAs but was not shown here. The tables for the HAA process are shown in the Appendix. Regarding the HAAs, it is important to note that since HAAs are non-volatile, the inhalation risk was not considered (Chowdhury, 2015). This is because the risks were unlikely to make a difference in the calculations. Therefore, ingestion and inhalation were considered for THMs, but only ingestion was considered for HAAs. HAA values for ingestion are shown in the Appendix.

Table 4: Calculated THM values for ingestion and inhalation using the Chronic Daily Intake equations. The THM values that were adjusted due to stagnation in Table 3 were used here.

	THM Ingestion (mg/kg-day)			THM Inhalation (mg/kg-day)		
Area	**PP**	**HWT**	**WDS**	**PP**	**HWT**	**WDS**
DS201	0.001452	0.001515	0.00137	0.034941	0.036444	0.032967
DS202	0.001274	0.001336	0.001192	0.030649	0.032151	0.028674
DS203	0.001363	0.001426	0.001281	0.032795	0.034298	0.030821
DS204	0.001738	0.0018	0.001656	0.04181	0.043312	0.039835
DS205	0.001731	0.001793	0.001649	0.041638	0.04314	0.039663
DS206	0.001363	0.001426	0.001281	0.032795	0.034298	0.030821
DS207	0.001468	0.001531	0.001386	0.035328	0.03683	0.033353
DS208	0.001433	0.001495	0.001351	0.034469	0.035972	0.032495
DS209	0.001367	0.001429	0.001285	0.032881	0.034383	0.030906
DS210	0.00157	0.001633	0.001488	0.037775	0.039277	0.0358
DS211	0.001326	0.001388	0.001244	0.031894	0.033396	0.029919
DS212	0.001668	0.001731	0.001586	0.040135	0.041638	0.038161

The next calculation involved is converting the THM and HAA chronic daily intake for ingestion and inhalation into a total cancer risk. To do this, a slope factor was used. In Table 5 below, slope factors are listed for different THMs and HAAs (Chowdhury, 2015). These slope factors were summed, and then the summed value of 0.2379 was multiplied against the THM concentrations shown in Table 4. This value gave the cancer risk associated with each DBP and their pathways.

Table 5: Slope factors for different THMs and HAAs (Chowdhury, 2015). These slope factors are used to complete the final step in calculating the cancer risks associated with THMs and HAAs.

SF (Slope Factor)	(mg/kg/day)^-1
$CHCl_3$	0
BDCM	0.062
DBCM	0.084
$CHBr_3$	0.0079
DCAA	0.05
TCAA	0.07
Total Sum =	**0.2739**

Table 6 below has all the cancer risk calculations for THM ingestion. Table 7 shows the calculated cancer risk for THM inhalation. These calculations utilized the slope factor in Table 5, and the adjusted DBP values from the stagnation effects.

Table 6. Shows the calculated cancer risk for THM ingestion for all twelve districts. The cancer risk was calculated by utilizing the slope factors in Table 5 and multiplying those by the respective THM/HAA concentrations.

	THM Ingestion (mg/kg-day)			Cancer Risk (per million)		
Area	**PP**	**HWT**	**WDS**	**PP**	**HWT**	**WDS**
DS201	0.00145	0.00151	0.00137	0.00040	0.00041	0.00038
DS202	0.00127	0.00134	0.00119	0.00035	0.00037	0.00033
DS203	0.00136	0.00143	0.00128	0.00037	0.00039	0.00035
DS204	0.00174	0.00180	0.00166	0.00048	0.00049	0.00045
DS205	0.00173	0.00179	0.00165	0.00047	0.00049	0.00045
DS206	0.00136	0.00143	0.00128	0.00037	0.00039	0.00035
DS207	0.00147	0.00153	0.00139	0.00040	0.00042	0.00038
DS208	0.00143	0.00150	0.00135	0.00039	0.00041	0.00037
DS209	0.00137	0.00143	0.00128	0.00037	0.00039	0.00035
DS210	0.00157	0.00163	0.00149	0.00043	0.00045	0.00041
DS211	0.00133	0.00139	0.00124	0.00036	0.00038	0.00034
DS212	0.00167	0.00173	0.00159	0.00046	0.00047	0.00043

Table 7: Shows the calculated cancer risk for THM inhalation for all twelve districts. The cancer risk was calculated by utilizing the slope factors in Table 5 and multiplying those by the respective THM/HAA concentrations.

	THM Inhalation (mg/kg-day)			Cancer Risk (per million)		
Area	**PP**	**HWT**	**WDS**	**PP**	**HWT**	**WDS**
DS201	0.0349	0.0364	0.0330	0.0096	0.0100	0.0090
DS202	0.0306	0.0322	0.0287	0.0084	0.0088	0.0079
DS203	0.0328	0.0343	0.0308	0.0090	0.0094	0.0084
DS204	0.0418	0.0433	0.0398	0.0115	0.0119	0.0109
DS205	0.0416	0.0431	0.0397	0.0114	0.0118	0.0109
DS206	0.0328	0.0343	0.0308	0.0090	0.0094	0.0084
DS207	0.0353	0.0368	0.0334	0.0097	0.0101	0.0091
DS208	0.0345	0.0360	0.0325	0.0094	0.0099	0.0089
DS209	0.0329	0.0344	0.0309	0.0090	0.0094	0.0085
DS210	0.0378	0.0393	0.0358	0.0103	0.0108	0.0098
DS211	0.0319	0.0334	0.0299	0.0087	0.0091	0.0082
DS212	0.0401	0.0416	0.0382	0.0110	0.0114	0.0105

Once the cancer risks were obtained for the DBPs, an average value was taken of all twelve districts for each column. Therefore, there was one average value for plumbing pipes for THM inhalation, one for hot water tanks, and one for water distribution systems. The same was true for THM ingestion and HAA ingestion. Six different options were considered, consisting of a Brita water pitcher, a Zerowater water pitcher, a GE refrigerator filter, a Springwell, RKIN, and Pentair activated carbon filtration whole home treatment system. The efficiency of the point of use filters in removing these contaminants was found from *Point-of-Use Devices for Attenuation of Trace Organic Compounds in Water* (Anumol et al., 2015). The removal efficiency of the whole house treatment systems was assumed to be 85%, allowing for the systems to be comparable to each other. The next part of the data involved the POU and whole home treatment options. For each filter, the cancer risk calculations were run to account for the amount of THMs and HAAs removed by the filters. This was done by simply reducing the concentration of THMs and HAAs by the removal efficiency of each filter.

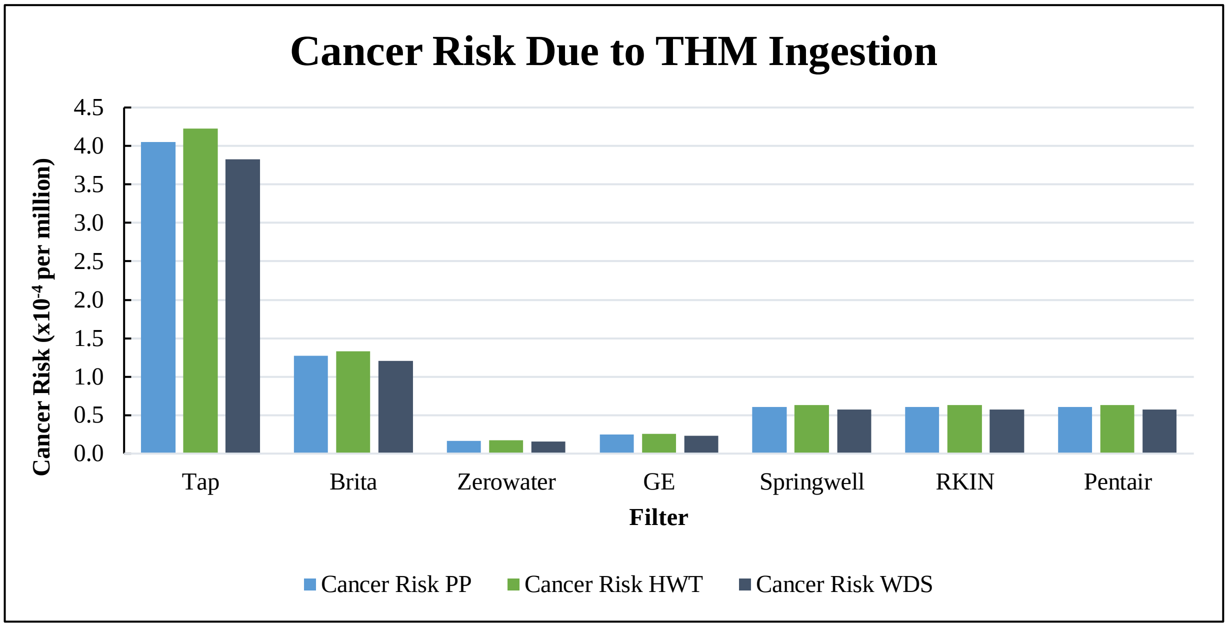

Figure 1: Displays the cancer risk from THM ingestion within the City of Akron water without filtration and the cancer risk with six different kinds of treatment options to reduce DBPs.

Figure 1 above provides the visualization for the cancer risk in Akron water due to only the ingestion of THMs. To the left, the tap water coming directly from the plant without additional filtration at home is shown. The levels are much higher than when treatment options are utilized. Even the worst performing option, the Brita water pitcher, reduces the cancer risk from THM ingestion by about two-thirds. It is important to note that all these treatment options utilize active carbon filtration, which reduces DBPs (Anumol et al., 2015). Overall, while the options have different levels of effectiveness, they all reduce cancer risk.

Figure 2 shown below is the graphic for the cancer risk in Akron water for the inhalation of THMs. As shown previously, the unfiltered tap water is the furthest left. Since the Brita, Zerowater, and GE filters are only used for drinking water, they cannot reduce cancer risk for THM inhalation. This means the levels shown for these three devices is equivalent to the unfiltered tap water cancer risk for THM inhalation, since inhalation from uses such as showering are not treated with water pitchers.

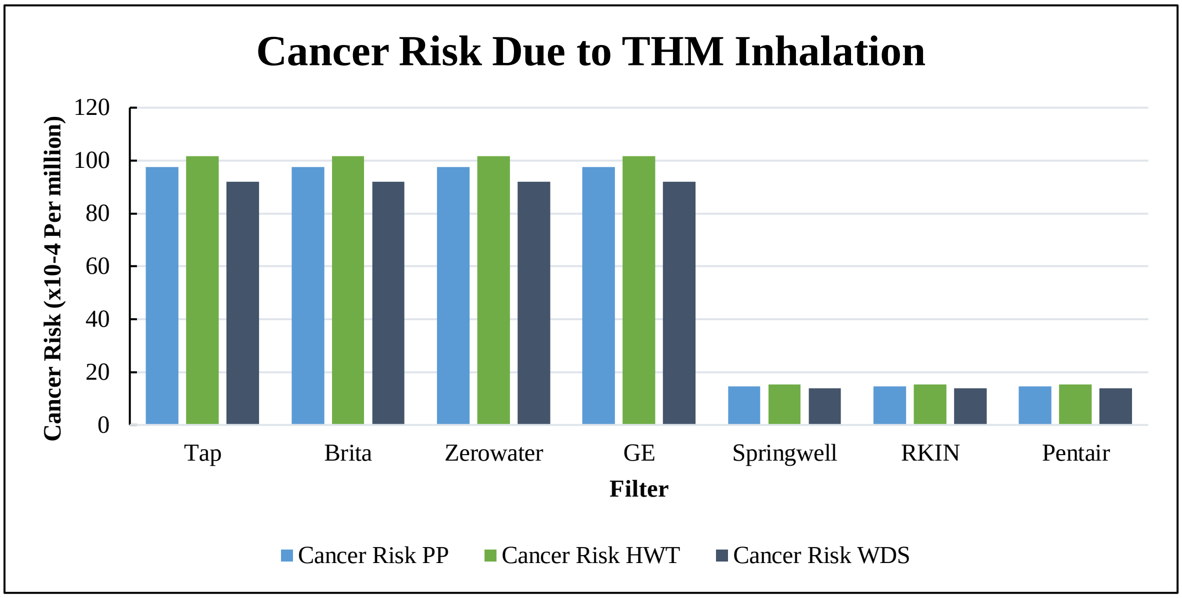

Figure 2: Displays the cancer risk from THM inhalation within the City of Akron water without filtration and the cancer risk with six different kinds of treatment options to reduce DBPs.

For Figure 3 below, the cancer risk due to HAA ingestion is shown. As in the past two figures, the unfiltered tap water is on the left. All the devices are useful in decreasing cancer risks due to the ingestion of HAAs. In both the THM and HAA inhalation charts, Zerowater and GE performed the best, while Brita performed the worst. All three of the whole house treatment systems reduced the cancer risk at nearly the same rate each time.

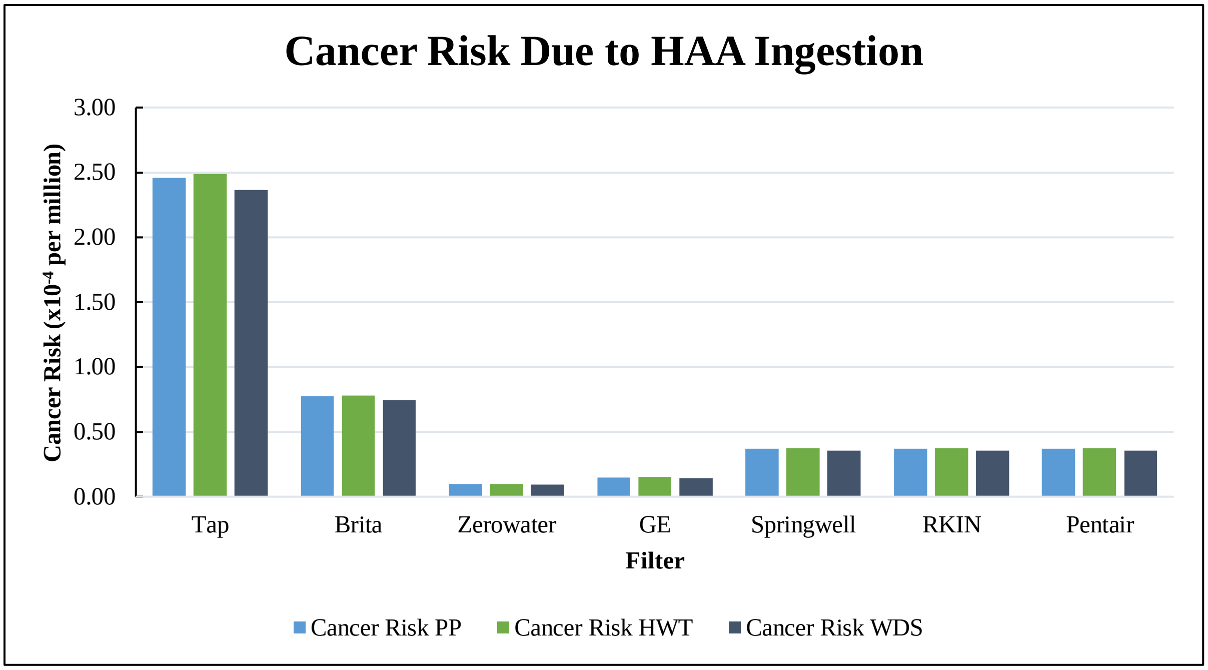

Figure 3: Displays the cancer risk from HAA inhalation within the City of Akron water without filtration and the cancer risk with six different kinds of treatment options to reduce DBPs.

Another way to view the calculated cancer risks from above is a chart showing the cumulative effects. The inhalation and ingestion risk for THMs and HAAs can be added to give a total cancer risk for all six devices, and the unfiltered tap water. This is shown below in Figure 4.

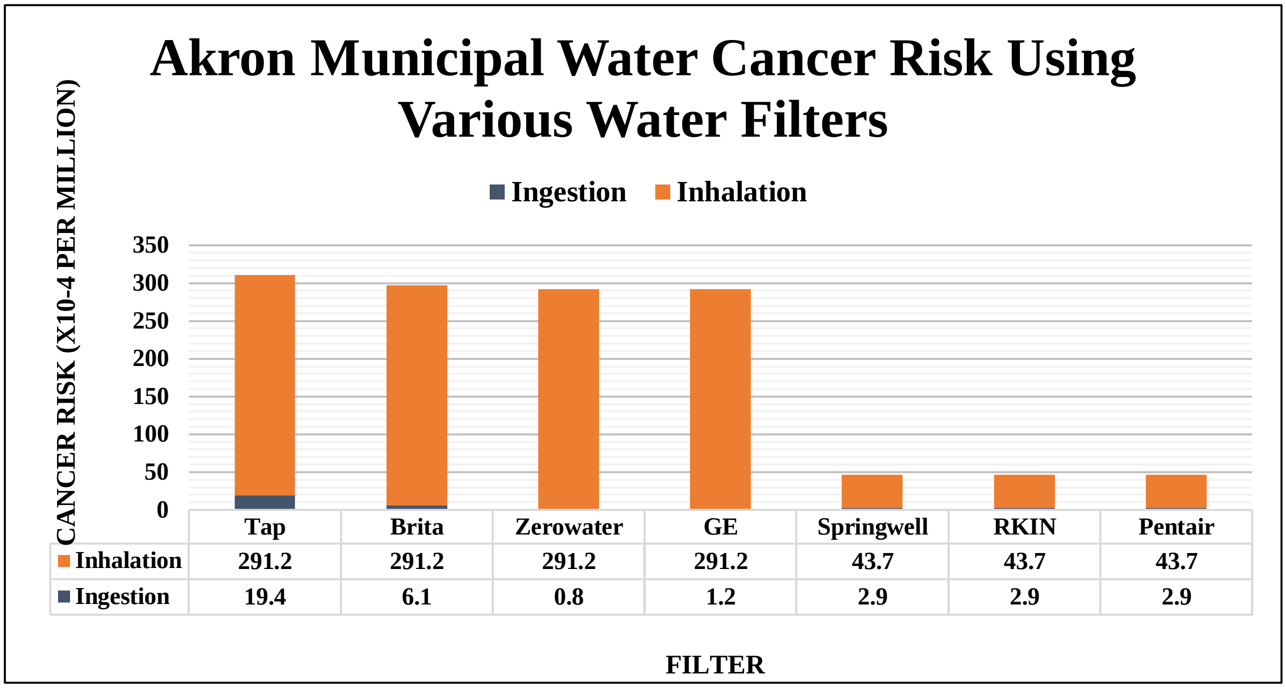

Figure 4: Shows the cumulative cancer risks associated with the inhalation and ingestion of THMs and HAAs. From analyzing the graph, the devices most effective at reducing cancer risks are the whole home treatment systems.

From the above chart, it is determined that the devices that reduce the total cancer risk the most are the whole home treatment options. This is in part due to them being the only effective devices analyzed that can lower the cancer risk due to inhalation, which makes up much of the total cancer risk.

Table 8: Shows the initial cost, the filter replacement cost, the usage, and the maximum days the filter can be used before needing replaced (Anumol et al., 2015; Whole House Carbon Water Filter System, n.d.; Whole House Water Filter System & Filtration Systems - Springwell Water, n.d.; Whole House Water Filter System, n.d.; 30 Cup, n.d.; GE, n.d., Home Depot, n.d.; RKIN 20", n.d.; Standard Pitcher, n.d.)

	Point of Use Filters			**Whole House Filters**		
	Brita	**Zerowater**	**GE**	**Springwell**	**RKIN**	**Pentair**
Usage (L/d)	10	10	10	1060	1060	1060
Maximum days of filter usage	15	15	113.5	182.5	365	182.5
Initial Cost	$21.99	$32.99	$668	$981.79	$802.62	$839
Filter replacement cost	$4.85	$15.00	$44.99	$40.18	$38.28	$40

Table 8 above shows the six filtration devices that were selected for analysis. This table shows the initial cost and filter replacement costs as well as the usage rate and max usage life. This along with removal efficiency data from *Point-of-Use Devices for Attenuation of Trace Organic Compounds in Water* and is used to determine the annual savings of the following filters when the DOC concentration is reduced at the treatment plant (Anumol et al., 2015). This annual savings per user of POU and pitcher filtration can be found below in Figure 5.

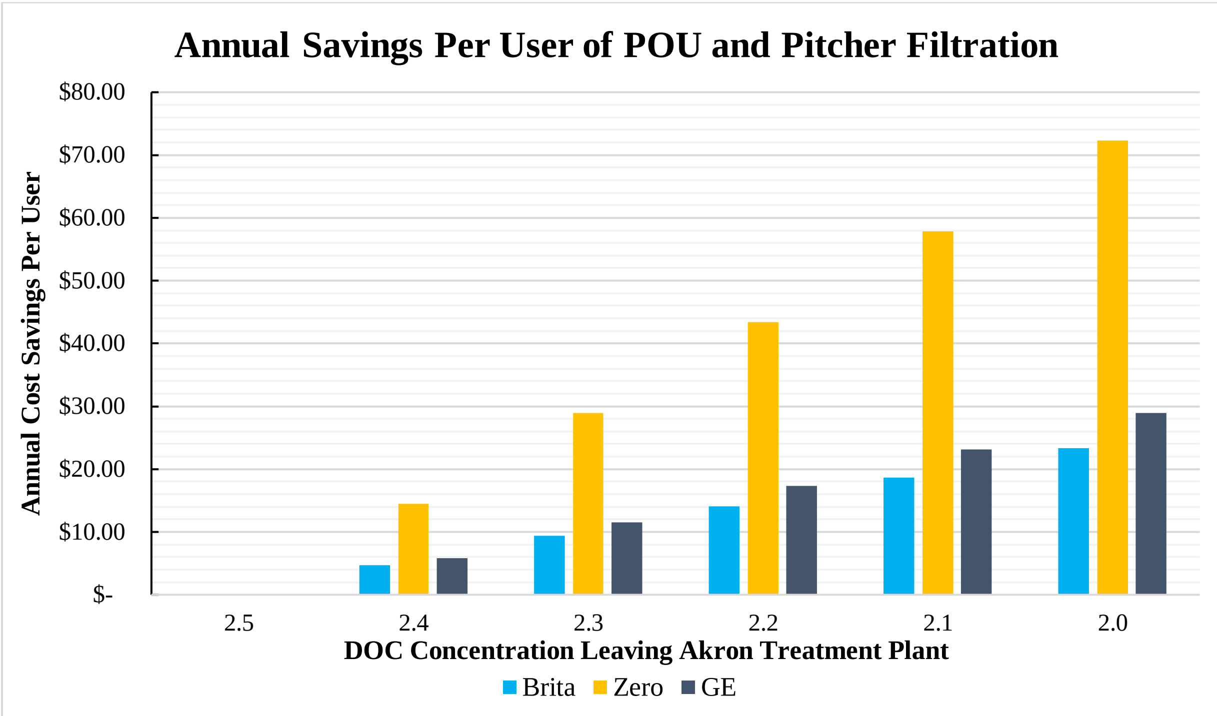

Figure 5: Shows the annual savings that a consumer using POU filters could take advantage of if the DOC concentration leaving the treatment facility were reduced. This cost savings comes from the filter not needing to be replaced as frequently due to the lower contaminant levels.

The same analysis was done for the annual savings of consumers using whole house filtration systems, which is shown in Figure 6. The Springwell and Pentair whole house filtration systems have an extremely close annual savings number as the DOC concentration leaving the Akron water treatment plant is decreased, and both have higher savings than the RKIN system. No matter which option is selected, Akron water consumers are saving additional money with decreased DOC. This can be attributed to the idea that with DOC concentrations being lower, DBPs are also decreased, meaning the filtration systems can increase their longevities if they are not working as hard to filter the water.

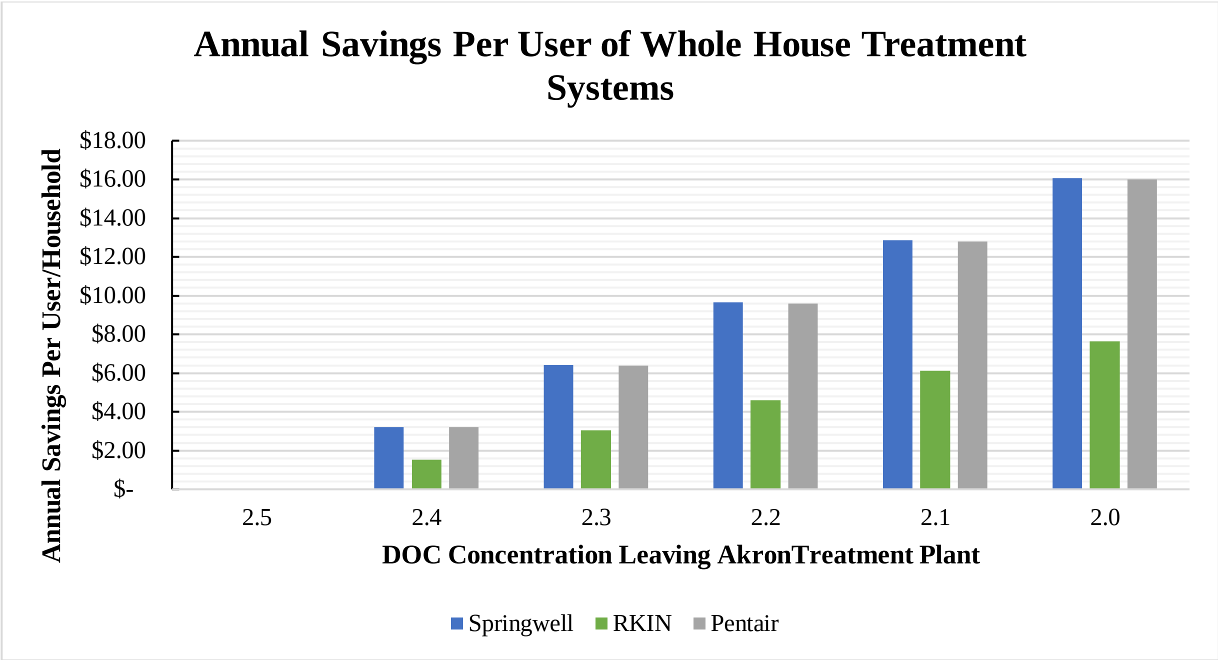

Figure 6: Shows the annual savings that a consumer using whole house filters could take advantage of if the DOC concentration leaving the treatment facility were reduced. This cost savings comes from the filter not needing to be replaced as frequently due to the lower contaminant levels.

When calculating how the cancer risk associated with the water is affected by a change in the DOC concentration leaving the water treatment plant, it is assumed that a decrease in DOC will cause a directly proportional decrease in THMs and HAAs at the tap. The cancer risk (x10^{-4} per million) for each lowered DOC concentration was then calculated using the lowered THM and HAA concentrations, shown in Figure 7.

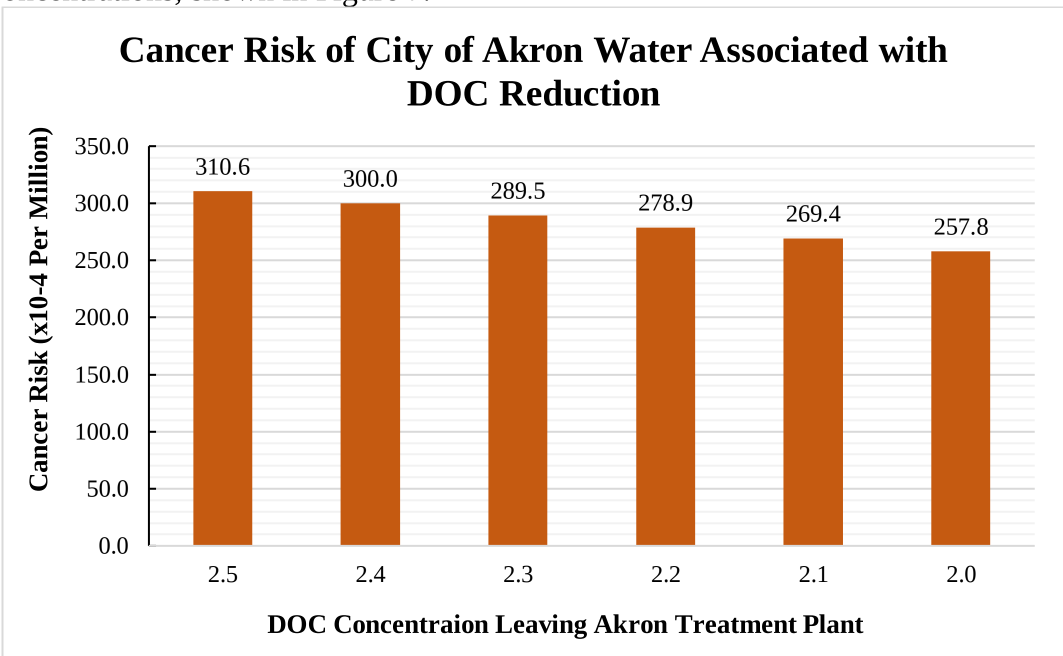

Figure 7: Shows the current cancer risk at 2.5 mg/L as well as the risk at lowered DOC concentrations.

Additionally, the data in Figure 7 can be used to convert the DOC concentration reductions into percentages. The percentages in Figure 8 show how much the cancer risks are being reduced from the original amount of 307.2 as the DOC concentration is increased. With the DOC concentration reduced to 2.0 mg/L, cancer risks due to DBPs are reduced by nearly one-fifth.

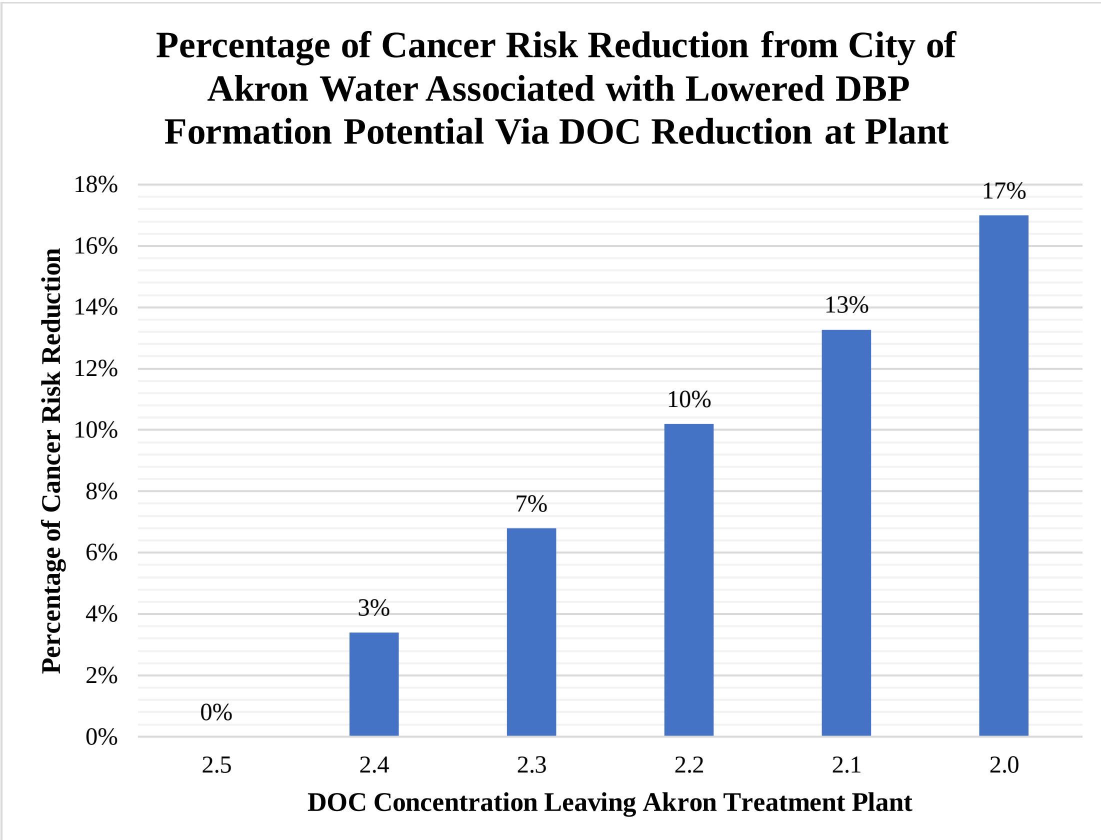

Figure 8: Shows the cancer risk reduction due to the lowered DOC concentration as a percentage.

4.0 Discussion

The final portion of the project included analyzing results gathered from the data in Section 3 and then providing insights to the public.

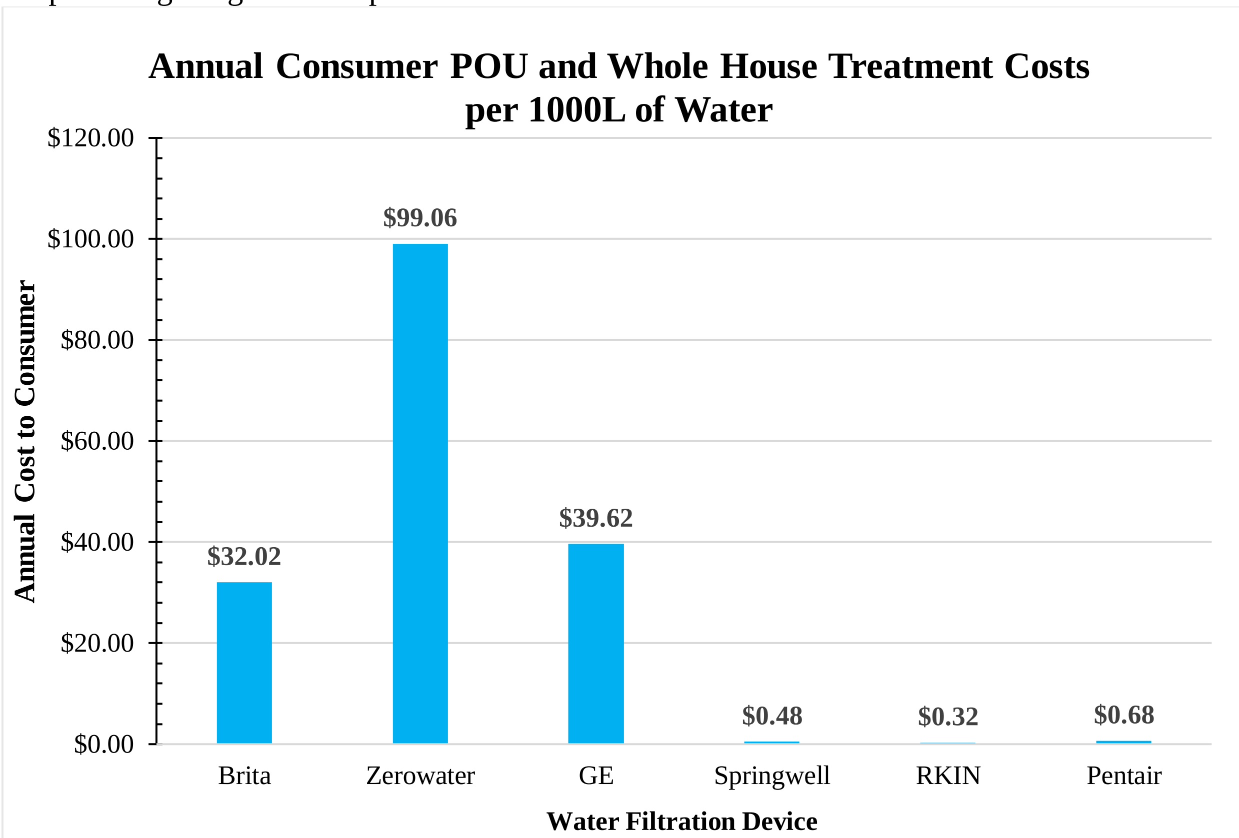

Figure 9, located below, illustrates the cost analysis of using the six different filtration devices. The cost was calculated as an annual cost to the consumer per 1000 liters of water consumed. It is important to note that the POU filters all had a much higher annual cost per 1000 liters of water compared to the whole house filtration systems. The main cost of the POU devices is replacement filters. The whole house devices have a higher initial cost; however, it is spread out over a much larger amount of water being consumed as it is accounting for all water being consumed.

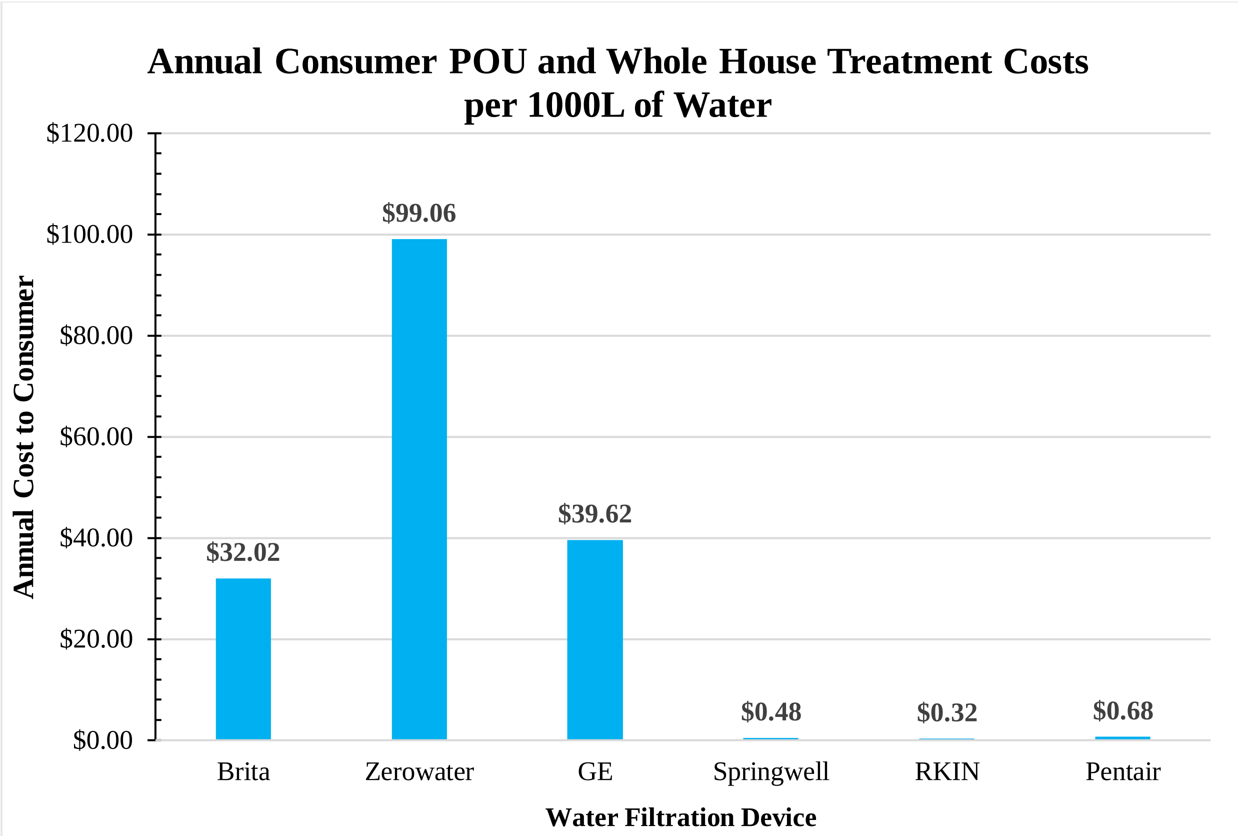

Figure 9: Shows the annual cost per 1000 liters of water consumed for both whole house and point of use treatment systems. This is factoring in the initial cost of the device as well as filter changes per manufacturer's recommendations.

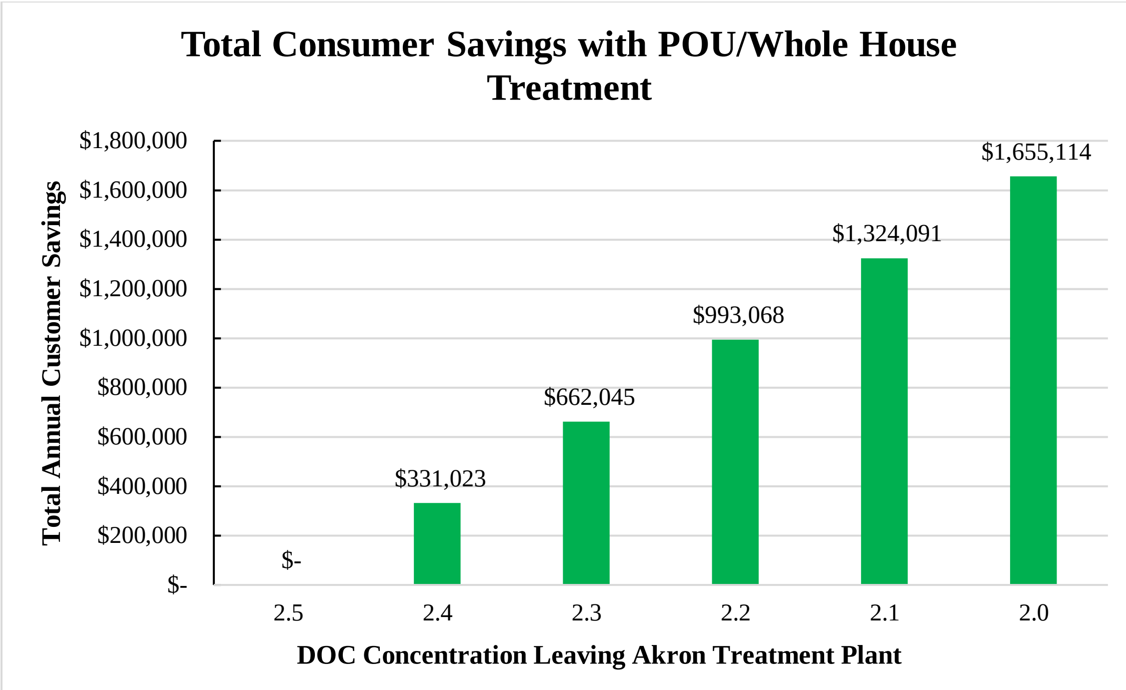

Figure 10: Shows the total consumer savings based on increasing the life of filters due to a lowering of the DOC concentration leaving the treatment plant. It is assumed that 5,000 households (5%) had Brita water pitchers, 5,000 households (5%) had Zerowater pitchers, 40,000 households had GE Refrigerator filters (40%), 500 households (0.5%) had Springwell Whole House Water Treatment systems, 500 households (0.5%) had RKIN Whole House Water Treatment systems, and 500 households (0.5%) had Pentair Whole House Water Treatment systems.

Figure 10 above displays the total consumer savings based on increasing the life of filters due to a lowering of the DOC concentration leaving the treatment plant. It is assumed that 5,000 households (5%) had Brita water pitchers, 5,000 households (5%) had Zerowater pitchers, 40,000 households had GE Refrigerator filters (40%), 500 households (0.5%) had Springwell Whole House Water Treatment systems, 500 households (0.5%) had RKIN Whole House Water Treatment systems, and 500 households (0.5%) had Pentair Whole House Water Treatment systems. These savings do not come without a cost to the City of Akron. It is also assumed that the water treatment plant is capable of reducing the DOC concentration entering the distribution system at a cost of $100,000 per 0.1 mg/L reduction.

Figure 11 below shows the savings to customers minus the cost to the city of reducing the DOC concentration. An interesting trend is that for what the city spends to reduce the DOC concentration, 2.31 times that amount is passed on to consumers as savings by allowing the filter life to be extended. These savings could be even larger if more people in the system installed and used POU or whole house filtration systems.

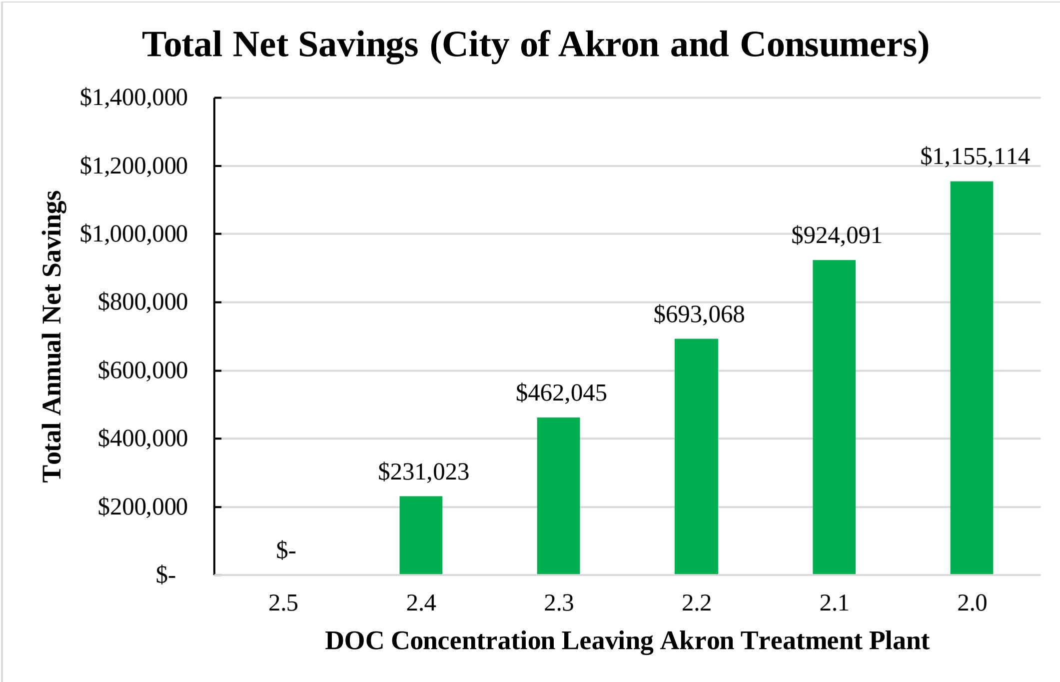

Figure 11: Shows the net savings, which is the savings to consumers less the cost for the treatment plant to reduce the DOC concentration.

It is shown in Figure 8 that if the City of Akron were to change their water quality goals and treat water to 2.0 mg/L of DOCs before the water enters the distribution system, the cancer risk due to THMs and HAAs of every user could be reduced by 17%. This would come at a cost of $500,000 to further treat this water. Additionally, a reduction to 2.0 mg/L could have a total savings to the consumers of $1.655 million, as seen in Figure 10. This is the largest reduction that was analyzed in this study, however, any reduction in the DOC will have savings and health benefits passed on to the consumers of the water. If these health benefits and savings were advertised to users, more might purchase filtrations devices, causing even more savings and decreased cancer risk among the community.

In summary, when explaining problems and possible resolutions within this project, the first step of the process to be aware of is that when municipal water is treated, disinfection products are utilized. Through using disinfection processes, disinfection byproducts are created. DBPs have been shown to increase cancer risks, therefore they pose a threat to human health (Chowdhury, 2015). To analyze the problem and help provide the public with insight on protecting their health from ill effects of DBPs, numerous sources involving DBPs and water treatment were utilized. With gathered data and equations, calculations for finding the cancer risks for ingestion and inhalation associated with two major DBPs, THMs and HAAs, were attained. Stagnation effects were also considered in this project, as they increase the amount of DBPs (Chowdhury, 2015). From here, risks were analyzed and evaluated along with costs. Multiple activated carbon filtration systems were investigated to determine capital and annual costs involved with utilizing these products. Whole house filtration and point of use filtration were considered for this project. An additional path considered in this project was the possibility of the City of Akron reducing DOC concentrations at the treatment plant.

In comparing whole house treatment to point of use filtration, all the options provided a reduction in cancer risks compared to the unfiltered tap water coming from the water treatment plant. For water pitchers and the refrigerator filter, since the water from these devices is ingested, they did not protect against THM inhalation. Additionally, inhalation for HAAs was not considered. Overall, while all the options reduced the risks of cancer from THMs and HAAs, the whole house filtration systems proved to be the most effective overall. The Brita water pitcher provided the worst reduction risk for cancer, so may not be the best option overall for decreasing the public's cancer risks. While the whole house treatment options are the most effective, they also have higher capital costs than the point of use options. As shown in Figure 9, the whole house treatment systems do have much lower annual costs than the other options, therefore high capital costs may be offset in the following years. Additional results included annual savings for consumers if the City of Akron decided to reduce DOC at the plant. The more the DOC was reduced, the more Akron water consumers saved. Net savings were also considered, as Akron would have to spend money to decrease DOC.

With all this in mind, the final insights for the public from this research project are to utilize an activated carbon filtration system if using City of Akron water. To achieve the highest quality of water within a household, a whole house treatment system should be considered. If the costs of this option are too high for the consumer, any of the POU devices explained above provide benefits and help to reduce cancer risk to some degree. Additionally, if Akron lowered DOC concentration at the plant, consumers would benefit from large health and financial savings, as selected treatment devices would be able to last longer and continue working at high effectiveness.

5.0 Conclusions

For any water system, introducing stricter water quality goals is a decision that needs to be looked at thoroughly and carefully. If the City of Akron were to lower DOC concentrations at the treatment plant, this would reduce DBP formation throughout the system and lower the concentrations of these contaminants at consumers taps. When looking at how these changes in contaminant levels could affect consumers cancer risk due to THMs and HAAs and how various household and POU filtration systems could be affected, it can be concluded that:

- A reduction in the DOC at the plant will result in lowered cancer risks for all consumers in the water distribution system and can be seen in Figure 7 and Figure 8. A reduction of 0.5 mg/L at the plant corresponds to a 17% reduction in the cancer risk due to exposure to THMs and HAAs.
- Every consumer that has a POU or whole house filtration system could save money by the lower contaminant levels allowing them to extend the life of their filters before replacing them. This savings per user can be seen in Figure 5 and Figure 6. The total savings of all consumers in the system can be seen in Figure 10.

- The net savings of consumers, accounting for the cost of more treatment at the plant, is $231,023 per 0.1 mg/L of DOC reduction and is shown in Figure 11. This will vary based on the assumptions for the number of service connections utilizing different types of filters.

Analysis of the various chosen filtration devices and their effects on reducing cancer risk as well as their operational cost reveals:

- Inhalation exposure of THMs and HAAs is a much larger contributing factor to cancer risk than the ingestion pathway. This causes whole house filtration systems to be much more effective than point of use filters in reducing cancer risk due to DBPs. This can be seen in **Error! Reference source not found.**.
- Figure 1 and Figure 9 can be used to see the cost of each filter per 1000L and the reduction in cancer risk due to THM Ingestion. For point of use filters, Zerowater reduces the risk the most but is much more expensive per 1000L. The GE filter is the highest performing when considering price per 1000L and the cancer risk reduction due to ingestion alone.
- Figure 9 illustrates how the RKIN whole house system is the lowest cost per 1000L. This is the highest performing whole house system as they were all assumed to reduce the cancer risk by the same amount.

Further analysis in the following areas would be very beneficial to making more informed decisions for consumers and the City of Akron:

- Modeling to more accurately show how a reduction in DOC concentration will affect the THM and HAA concentrations at various locations in the distribution system.
- Data on how efficient whole house filtration systems remove contaminants and how their efficiency and filter longevity is affected by a lower concentration of contaminants in the water.
- A survey of what filtration devices consumers in the City of Akron use, if any, to get a more accurate cost benefit analysis.

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Appendix

IR =	1.31	Water ingestion rate (L/day)
EF =	350	Exposure Frequency (days/year)
ED =	77.1	Exposure Duration (years)
BW =	70.4	Body Weight (Kg)
AT =	28142	Averaging Time (days)
Qw =	10	Water Flow (L/min)
V =	2	Shower Stall Volume (m^3)
T =	10	Shower Time (min/shower event)
T2 =	40	Heated Water Temp (Celsius)
T1 =	20	Cold Water Temp (Celsius)
ka =	0.021	Air Change (ACM)
Er =	0.77	THM Absorbance through respiratory system
pv =	8.76	THMs transformation rate from water to air phase (%)
R =	0.014	Air intake rate (m3/min)
F =	0.74	Shower frequency (shower event/day)
Sskin =	1.82	Area of body skin exposed to water (m^2)
CF =	0.001	Conversion factor

Equation for Ingestion:	**CDIing = (Cw*IR*EF*ED*CF)/(BW*AT)**
Equation for Inhalation:	**CDIinh = (Er*Ca*R*t*F*EF*ED*CF)/(BW*AT)**

MORNING STAGNATION EFFECTS					
THMs (ppb)			**HAAs (ppb)**		
PP	**HWT**	**WDS**	**PP**	**HWT**	**WDS**
11.1	14.6	6.5	8.6	9.2	6.7

THMs (ppb)				THMs (ppb)		
Area	MIN (April)	MAX (July)	YEAR	PP	HWT	WDS
DS201	28.4	70.3	2022	81.4	84.9	76.8
DS202	25.9	60.3	2022	71.4	74.9	66.8
DS203	25.9	65.3	2022	76.4	79.9	71.8
DS204	34.9	86.3	2022	97.4	100.9	92.8
DS205	35.1	85.9	2022	97.0	100.5	92.4
DS206	28.7	65.3	2022	76.4	79.9	71.8
DS207	30.5	71.2	2022	82.3	85.8	77.7
DS208	28.1	69.2	2022	80.3	83.8	75.7
DS209	30.1	65.5	2022	76.6	80.1	72
DS210	32	76.9	2022	88.0	91.5	83.4
DS211	25.7	63.2	2022	74.3	77.8	69.7
DS212	36.4	82.4	2022	93.5	97.0	88.9

	THM Ingestion (mg/kg-day)			THM Inhalation (mg/kg-day)		
Area	PP	HWT	WDS	PP	HWT	WDS
DS201	0.001452	0.001515	0.00137	0.034941	0.036444	0.032967
DS202	0.001274	0.001336	0.001192	0.030649	0.032151	0.028674
DS203	0.001363	0.001426	0.001281	0.032795	0.034298	0.030821
DS204	0.001738	0.0018	0.001656	0.04181	0.043312	0.039835
DS205	0.001731	0.001793	0.001649	0.041638	0.04314	0.039663
DS206	0.001363	0.001426	0.001281	0.032795	0.034298	0.030821
DS207	0.001468	0.001531	0.001386	0.035328	0.03683	0.033353
DS208	0.001433	0.001495	0.001351	0.034469	0.035972	0.032495
DS209	0.001367	0.001429	0.001285	0.032881	0.034383	0.030906
DS210	0.00157	0.001633	0.001488	0.037775	0.039277	0.0358
DS211	0.001326	0.001388	0.001244	0.031894	0.033396	0.029919
DS212	0.001668	0.001731	0.001586	0.040135	0.041638	0.038161

HAAs (ppb)				HAAs (ppb)		
Area	MIN (April)	MAX (July)	YEAR	PP	HWT	WDS
DS201	15.9	45.6	2022	54.2	54.8	52.3
DS202	25.3	41.4	2022	50	50.6	48.1
DS203	29	31.6	2022	40.2	40.8	38.3
DS204	32.8	43.9	2022	52.5	53.1	50.6
DS205	31	47	2022	55.6	56.2	53.7
DS206	24.1	37.1	2022	45.7	46.3	43.8
DS207	29.2	36.8	2022	45.4	46	43.5
DS208	22.9	43.3	2022	51.9	52.5	50
DS209	24.5	43	2022	51.6	52.2	49.7
DS210	25.9	48.3	2022	56.9	57.5	55
DS211	22	40.1	2022	48.7	49.3	46.8
DS212	31.9	41.9	2022	50.5	51.1	48.6

	HAA Ingestion (mg/kg-day)		
Area	PP	HWT	WDS
DS201	0.000967	0.000978	0.000933
DS202	0.000892	0.000903	0.000858
DS203	0.000717	0.000728	0.000683
DS204	0.000937	0.000947	0.000903
DS205	0.000992	0.001003	0.000958
DS206	0.000815	0.000826	0.000782
DS207	0.00081	0.000821	0.000776
DS208	0.000926	0.000937	0.000892
DS209	0.000921	0.000931	0.000887
DS210	0.001015	0.001026	0.000981
DS211	0.000869	0.00088	0.000835
DS212	0.000901	0.000912	0.000867

SF (Slope Factor)	(mg/kg/day)^-1
CHCl3	0
BDCM	0.062
DBCM	0.084
CHBr3	0.0079
DCAA	0.05
TCAA	0.07
Total Sum =	**0.2739**

	THM Ingestion (mg/kg-day)			Cancer Risk (per million)		
Area	PP	HWT	WDS	PP	HWT	WDS
DS201	0.001452	0.001515	0.00137	0.000397816	0.000415	0.000375
DS202	0.001274	0.001336	0.001192	0.000348944	0.000366	0.000326
DS203	0.001363	0.001426	0.001281	0.00037338	0.00039	0.000351
DS204	0.001738	0.0018	0.001656	0.000476011	0.000493	0.000454
DS205	0.001731	0.001793	0.001649	0.000474056	0.000491	0.000452
DS206	0.001363	0.001426	0.001281	0.00037338	0.00039	0.000351
DS207	0.001468	0.001531	0.001386	0.000402215	0.000419	0.00038
DS208	0.001433	0.001495	0.001351	0.00039244	0.00041	0.00037
DS209	0.001367	0.001429	0.001285	0.000374358	0.000391	0.000352
DS210	0.00157	0.001633	0.001488	0.000430072	0.000447	0.000408
DS211	0.001326	0.001388	0.001244	0.000363117	0.00038	0.000341
DS212	0.001668	0.001731	0.001586	0.000456951	0.000474	0.000434

Average PP	Average HWT	Average WDS
0.00040523	0.000422334	0.000382747

	THM Inhalation (mg/kg-day)			Cancer Risk (per million)		
Area	PP	HWT	WDS	PP	HWT	WDS
DS201	0.034941	0.036444	0.032967	0.009570456	0.009982	0.00903
DS202	0.030649	0.032151	0.028674	0.008394724	0.008806	0.007854
DS203	0.032795	0.034298	0.030821	0.00898259	0.009394	0.008442
DS204	0.04181	0.043312	0.039835	0.011451627	0.011863	0.010911
DS205	0.041638	0.04314	0.039663	0.011404598	0.011816	0.010864
DS206	0.032795	0.034298	0.030821	0.00898259	0.009394	0.008442
DS207	0.035328	0.03683	0.033353	0.009676272	0.010088	0.009135
DS208	0.034469	0.035972	0.032495	0.009441126	0.009853	0.0089
DS209	0.032881	0.034383	0.030906	0.009006105	0.009418	0.008465
DS210	0.037775	0.039277	0.0358	0.010346439	0.010758	0.009806
DS211	0.031894	0.033396	0.029919	0.008735687	0.009147	0.008195
DS212	0.040135	0.041638	0.038161	0.010993091	0.011405	0.010452

Average PP	Average HWT	Average WDS
0.00974878	0.010160282	0.009207939

	HAA Ingestion (mg/kg-day)			Cancer Risk (per million)		
Area	PP	HWT	WDS	PP	HWT	WDS
DS201	0.000967	0.000978	0.000933	0.000264885	0.000268	0.000256
DS202	0.000892	0.000903	0.000858	0.000244359	0.000247	0.000235
DS203	0.000717	0.000728	0.000683	0.000196465	0.000199	0.000187
DS204	0.000937	0.000947	0.000903	0.000256577	0.00026	0.000247
DS205	0.000992	0.001003	0.000958	0.000271727	0.000275	0.000262
DS206	0.000815	0.000826	0.000782	0.000223344	0.000226	0.000214
DS207	0.00081	0.000821	0.000776	0.000221878	0.000225	0.000213
DS208	0.000926	0.000937	0.000892	0.000253645	0.000257	0.000244
DS209	0.000921	0.000931	0.000887	0.000252178	0.000255	0.000243
DS210	0.001015	0.001026	0.000981	0.00027808	0.000281	0.000269
DS211	0.000869	0.00088	0.000835	0.000238006	0.000241	0.000229
DS212	0.000901	0.000912	0.000867	0.000246802	0.00025	0.000238

Average PP	Average HWT	Average WDS
0.00024566	0.000248594	0.000236376

		Point of Use Filters			Whole House Filters		
	Sample	Brita	Zerowater	GE	Springwell	RKIN	Pentair**
MEL%	50.00	100.00	100.00	100.00	100.00	100.00	100.00
Filter Lifetime (L)	500.00	151.40	151.40	1135.62	3785411.78	1892705.89	1514164.71
Amount Treated (L)	**250.00**	**151.40**	**151.40**	**1135.62**	**3785411.78**	**1892705.89**	**1514164.71**
Usage (L/d)	10.00	10.00	10.00	10.00	1060.00	1060.00	1060.00
Theoretical days of usage	**25.00**	**15.14**	**15.14**	**113.56**	**3571.14**	**1785.57**	**1428.46**
Recommended filter replacement (months)	2.00	2.00	2.00	6.00	6.00	12.00	6.00
Maximum days of filter usage	**25.00**	**15.14**	**15.14**	**113.56**	**182.50**	**365.00**	**182.50**
Initial Cost	$100.00	$21.99	$32.99	$668.00	$981.79	$802.62	$839.00
Filter replacement cost	$20.00	$4.85	$15.00	$44.99	$40.18	$38.28	$40.00
Cost in Initial Year	$392.00	$138.86	$394.55	$812.60	$1,062.15	$840.90	$919.00
Cost Per Year after	$292.00	$116.87	$361.56	$144.60	$80.36	$38.28	$80.00
Annual Cost per 1000 Liter*	$80.00	$32.02	$99.06	$39.62	$0.48223	$0.31628	$0.68183

*For whole house filters this takes into account the initial cost spread over the manufacturers media replacement timeline: Springwell 10 yr, RKIN 10 yr, Pentair 5 yr

**Replacement filter cost estimated to be $40.00

*** Filter Lifetime obtained from manufacturer

Consumer cost to treat 1000L	$ 0.093

	THM Ingestion	Tap	Brita	Zerowater	GE	Springwell	RKIN	Pentair
Before Filtration	Cancer Risk PP	0.0004052	0.0004052	0.0004052	0.0004052	0.0004052	0.0004052	0.0004052
	Cancer Risk HWT	0.0004223	0.0004223	0.0004223	0.0004223	0.0004223	0.0004223	0.0004223
	Cancer Risk WDS	0.0003827	0.0003827	0.0003827	0.0003827	0.0003827	0.0003827	0.0003827
	Cancer Risk Reduction %	0%	68.57	95.96	93.93	85.00	85.00	85.00
After Filtration	Cancer Risk PP	4.0522849	1.2738357	0.1637123	0.2459737	0.6078427	0.6078427	0.6078427
	Cancer Risk HWT	4.2233361	1.3276057	0.1706228	0.2563565	0.6335004	0.6335004	0.6335004
	Cancer Risk WDS	3.8274747	1.2031667	0.1546300	0.2323277	0.5741212	0.5741212	0.5741212
	Obtained From Brophy							

	THM Inhalation	Tap	Brita	Zerowater	GE	Springwell	RKIN	Pentair
Before Filtration	Cancer Risk PP	0.0097488	0.0097488	0.0097488	0.0097488	0.0097488	0.0097488	0.0097488
	Cancer Risk HWT	0.0101603	0.0101603	0.0101603	0.0101603	0.0101603	0.0101603	0.0101603
	Cancer Risk WDS	0.0092079	0.0092079	0.0092079	0.0092079	0.0092079	0.0092079	0.0092079
	Cancer Risk Reduction %	0%	0%	0%	0%	85.00	85.00	85.00
After Filtration	Cancer Risk PP	97.4877540	97.4877540	97.4877540	97.4877540	14.6231631	14.6231631	14.6231631
	Cancer Risk HWT	101.6028150	101.6028150	101.6028150	101.6028150	15.2404223	15.2404223	15.2404223
	Cancer Risk WDS	92.0793882	92.0793882	92.0793882	92.0793882	13.8119082	13.8119082	13.8119082

	HAA Ingestion	Tap	Brita	Zerowater	GE	Springwell	RKIN	Pentair
Before Filtration	Cancer Risk PP	0.0002457	0.0002457	0.0002457	0.0002457	0.0002457	0.0002457	0.0002457
	Cancer Risk HWT	0.0002486	0.0002486	0.0002486	0.0002486	0.0002486	0.0002486	0.0002486
	Cancer Risk WDS	0.0002364	0.0002364	0.0002364	0.0002364	0.0002364	0.0002364	0.0002364
	Cancer Risk Reduction %	0%	68.57	95.96	93.93	85.00	85.00	85.00
After Filtration	Cancer Risk PP	2.4566213	0.7722389	0.0992475	0.1491169	0.3684932	0.3684932	0.3684932
	Cancer Risk HWT	2.4859444	0.7814566	0.1004322	0.1508968	0.3728917	0.3728917	0.3728917
	Cancer Risk WDS	2.3637650	0.7430495	0.0954961	0.1434805	0.3545647	0.3545647	0.3545647
	Obtained From Brophy							

	Akron Municipal Water Cancer Risk Using Various Filters (Additive)						
Ingestion	19.4	6.1	0.8	1.2	2.9	2.9	2.9
Inhalation	291.2	291.2	291.2	291.2	43.7	43.7	43.7

	Point of Use Filters			Whole House Filters		
	Brita	Zerowater	GE	Springwell	RKIN	Pentair
Usage (L/d)	10	10	10	1060	1060	1060
Maximum days of filter usage	15	15	113.5	182.5	365	182.5
Initial Cost	$21.99	$32.99	$668	$981.79	$802.62	$839
Filter replacement cost	$4.85	$15.00	$44.99	$40.18	$38.28	$40

	Total Savings Per User					
DOC from Plant	Brita	Zero	GE	Springwell	RKIN	Pentair
2.5	$ -	$ -	$ -	$ -	$ -	$ -
2.4	$ 4.67	$ 14.46	$ 5.78	$ 3.21	$ 1.53	$ 3.20
2.3	$ 9.35	$ 28.93	$ 11.57	$ 6.43	$ 3.06	$ 6.40
2.2	$ 14.02	$ 43.39	$ 17.35	$ 9.64	$ 4.59	$ 9.60
2.1	$ 18.70	$ 57.85	$ 23.14	$ 12.86	$ 6.12	$ 12.80
2.0	$ 23.37	$ 72.31	$ 28.92	$ 16.07	$ 7.66	$ 16.00

Cancer Risk of City of Akron Water Associated with DOC Reduction	
DOC from Plant	Cancer Risk of Tap Water (per million)
2.5	310.6
2.4	300.0
2.3	289.5
2.2	278.9
2.1	269.4
2.0	257.8

Percentage of Cancer Risk Reduction from City of Akron Water Associated with DOC Reduction	
DOC from Plant	% Risk Reduction Due to Lowered DOC
2.5	0%
2.4	3%
2.3	7%
2.2	10%
2.1	14%
2.0	17%

Costs to Consumer to Treat 1000L	
Brita	$32.02
Zerowater	$99.06
GE	$39.62
Springwell	$0.48
RKIN	$0.32
Pentair	$0.68

DOC from Plant	Total Customer Savings
2.5	$0.00
2.4	$ 331,023
2.3	$ 662,045
2.2	$ 993,068
2.1	$ 1,324,091
2.0	$ 1,655,114

DOC from Plant	Net Savings
2.5	$0.00
2.4	$ 231,023
2.3	$ 462,045
2.2	$ 693,068
2.1	$ 924,091
2.0	$ 1,155,114