Determining Trihalomethane Trends in Water Systems in the United States

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ABSTRACT

Trihalomethanes (THMs) are a class of byproducts that are created when chlorine interacts with organic compounds. In order to reduce exposure to THMs and other byproducts due to potential risks to health, the Environmental Protection Agency (EPA) set regulations to limit concentrations of disinfection byproducts. Through the Safe Drinking Water Act established in 1974, each water system in the United States is required to monitor levels of disinfection byproducts throughout the treatment process and distribution system to verify that it meets these regulations. The purpose of this study was to analyze annual trends of THM concentrations in the United States from 1975 to 2014. I completed trend analysis using national averages per year. There is a decrease in THM concentrations nationally and significant decreases after Stage 2 Disinfectant Byproduct Rule was published.

KEYWORDS

Disinfection byproduct, Stage 2 Disinfectant and Disinfectant Byproduct Rule, trend analysis, chlorine, maximum contaminant level

INTRODUCTION

Drinking water sources include surface water and ground water, which typically contains some form of pathogens and bacteria that have the potential to create illnesses and disease outbreaks (World Health Organization 2004). Because of this risk, drinking water requires strict disinfection before consumption. Chlorine is a widely-used disinfectant in drinking water sanitation processes due to is availability and affordability. Different sources of drinking water also contains varying levels of organic matter that reacts with chlorine during the disinfection process, creating a variety of disinfectant byproducts ("WHO | Environmental Health Criteria 216" n.d.). Trihalomethanes (THMs) is a major class of byproduct created during chlorination processes such as addition of chlorine gas, chloramine, and chlorine dioxide (Krasner et al. 2006)

Disinfectant byproducts are monitored through the Safe Drinking Water Act from the EPA (US EPA n.d.). Implemented in 1975, the Act has regulations to inspect several types of contaminants like disinfectant byproducts and bacteria. It serves as the regulatory framework that binds all drinking water monitoring processes. Although there are over 600 documented disinfectant byproducts (Krasner et al. 2006), the most abundant byproducts are THMs and haloacetic acids (EPA 1977). Regulations for disinfectant byproducts are found under the Microbial and Disinfectants Rule as the Stage 1 and Stage 2 Disinfectant Byproducts Rule (US EPA n.d.), which were added in 1986 and 2006, respectively. These regulations monitor THM byproducts such as bromoform, chloroform, dibromochloromethane, and bromodichloromethane. In 1979, the maximum contaminant level (MCL) for THM was set at 100 micrograms per liter by the TTHM rule for community water systems that use surface and groundwater (Xie 2016). Soon after in 1998, Stage 1 was finalized and changed the MCL for THM to 80 micrograms per liter, lower than the previous limit of 100 micrograms (US EPA n.d.). Many years later, Stage 2 is created and builds off of Stage 1 to provide more stringent regulation for disinfection products to "improve public health protection" (US EPA n.d.). Currently, the maximum contaminant level for total THM concentration stands at 0.08 milligrams per liter of water.

Attention on THMs stems from unknown health risks that could affect safe consumption of water (Morris 1995). While there is not yet a consensus on health outcomes of disinfectant byproduct exposure, some possible health risks have shown in experimental animals that include

carcinogenetic effects such as liver and kidney tumors (Komulainen 2004). The purpose of the regulations is to reduce exposure and provide public health protection from these possible adverse health outcomes associated with THM exposure ("National Primary Drinking Water Regulations" 1998). Using compliance data collected by the EPA, I looked at THM concentration averages per year in the United States, from 1975 to 2014. Success of stringent THM regulations would likely be linked to continuous decrease in national average TTHM concentrations every year.

METHODS

Study site

Disinfectant and Disinfectant Byproduct regulations affect United States' public water systems that are community and non transient non community water systems that disinfect their water using primary disinfectants other than ultraviolet light. As mentioned before, the maximum contaminant level for all systems was 100 micrograms per liter from 1975 to 1986, and was altered to 80 micrograms per liter from 1986 extending to Stage 2 implementation in 2006. Chlorination is used in the United States as the main way to kill coliforms, viruses, *Cryptosporidium, Giardia lamblia,* and various protozoa (US EPA n.d.)

Data Sources

I specifically used total trihalomethane (TTHM) data, which is the total sum of the four THMs of the samples.

For TTHM values for the year 1975 to 1977, values were analyzed by the EPA report, National Organics Reconnaissance Survey (NORS) and the National Organic Monitoring Survey (NOMS). Both surveys lead to the promulgation of TTHM regulations and maximum contaminant regulation of 100 micrograms per liter of water (McGuire and Graziano 2002). NORS was used to find national TTHM occurrence and NOMS was a series of surveys to determine the frequency of certain contaminants (Brass et al. 1977).

McGuire and Graziano (McGuire and Graziano 2002) have summarized TTHM analyses on NORS, NOMS, American Water Works Association Foundation (AwwaRF), and Interim

Collection Rule (ICR) surveys that have contain data from 1975 to 1986. I obtained average TTHM values through their analyses. The AwwaRF was a questionnaire sent out to 1,255 water systems that served more than 10,000 people to obtain TTHM averages from 1984 to 1987. ICR was a rule set in 1996 to collect treatment and occurrence information from TTHMs to help aid revisions to the Safe Drinking Water Act. Due to delays to promulgating, it did not begin until 1997, but contained TTHM values from 1997 and 1998 ("National Primary Drinking Water Regulations" 1998).

Table 1. Summary of TTHM Data Sources used in this study. Data was taken from McGuire and Graziano's (2002) and Seidel (2017) TTHM analyses and summaries from EPA National Surveys.

Period	Source	Sample Location	Statistical Summary
1975	NORS	Finished Water	Single Samples
1975 – 76	NOMS (phase 1)	Finished Water	Single Samples
1984 – 1986	AwwaRF	Distribution System	Single Samples
1997 – 1998	ICR	Distribution System	Average of 6 qtr samples
2006 - 2010	6 Year Review	Distribution System	Single samples
2012 – 2015	Seidel (2017)	Distribution System	95th % quarterly samples

I obtained compliance monitoring data from the third Six Year Review from the EPA's database website. This Six Year Review consists of data from 54 states and primary agencies and is the largest Review ever done. It contains TTHM information for years 2006 to 2011 from 167,000 public water systems with over 500,000 entries (US EPA n.d.). I performed my own analysis per year using Microsoft Excel (2016).

Siedel (Siedel 2017) performed their own analysis using AwwaRF, ICR, the Six Year Review, and collected their own TTHM data from 2012 to 2014. They sent requests to community water systems in the United States to collect disinfectant byproduct sum concentration data. I obtained averages for 2012 to 2014 from his summaries.

Data processing

For TTHM averages from 1975 to 1998, and 2012 to 2014, I obtained averages from McGuire and Seidel' summaries. No further data manipulations were done on their data. More importantly, I extracted (a) TTHM average in micrograms per liter (b) Year Sampled and (c) state code for both McGuire and Seidel's analyses.

I performed data analysis on the TTHM database from the third Six Year Review, which contain several variables. I extracted (a) Value (in micrograms per liter), (b) State Code, and (c) Sample Collection Date. Sample Collection Date was formatted "Year – Month – Day, Time." Since my analysis only requires year, I extracted only the year per sample. Using pivot tables, I calculated national average TTHMs per year and per state.

After collecting TTHM averages, I compiled the values onto one spreadsheet on Excel to visualize the data and collect R^2 values.

RESULTS

Total TTHM Averages

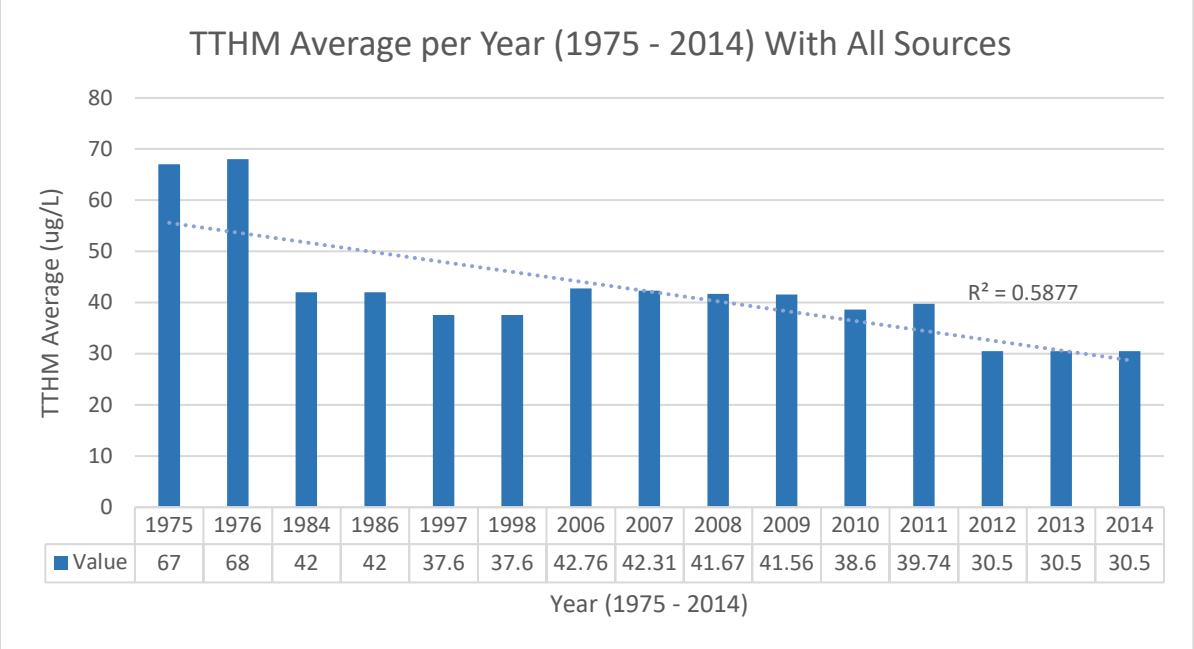
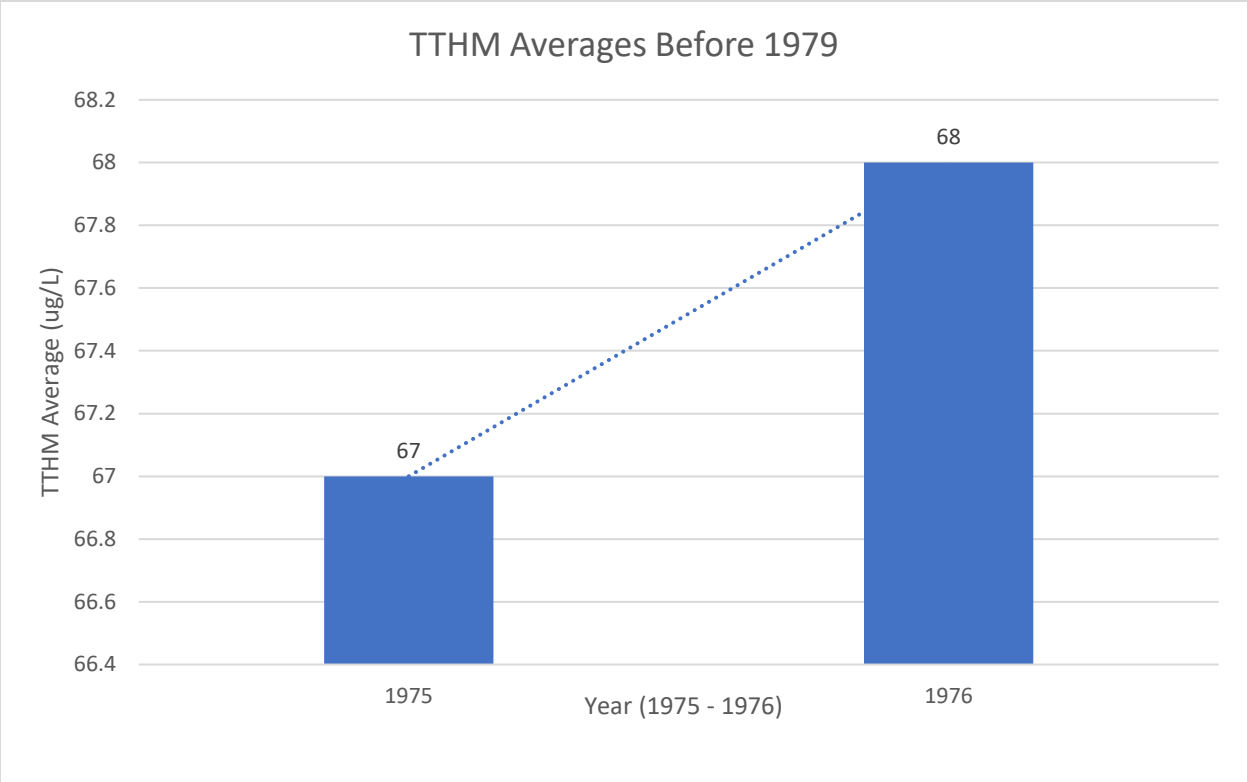


Figure 2: Average TTHMs per year. This graph combines all values from McGuire, Graziano, Seidel, and the National Monitoring Surveys such as NORS, NOMS, ICR, and AwwaRF data. There is a decreasing trend over time from 1975 to 2014 in national TTHM averages.

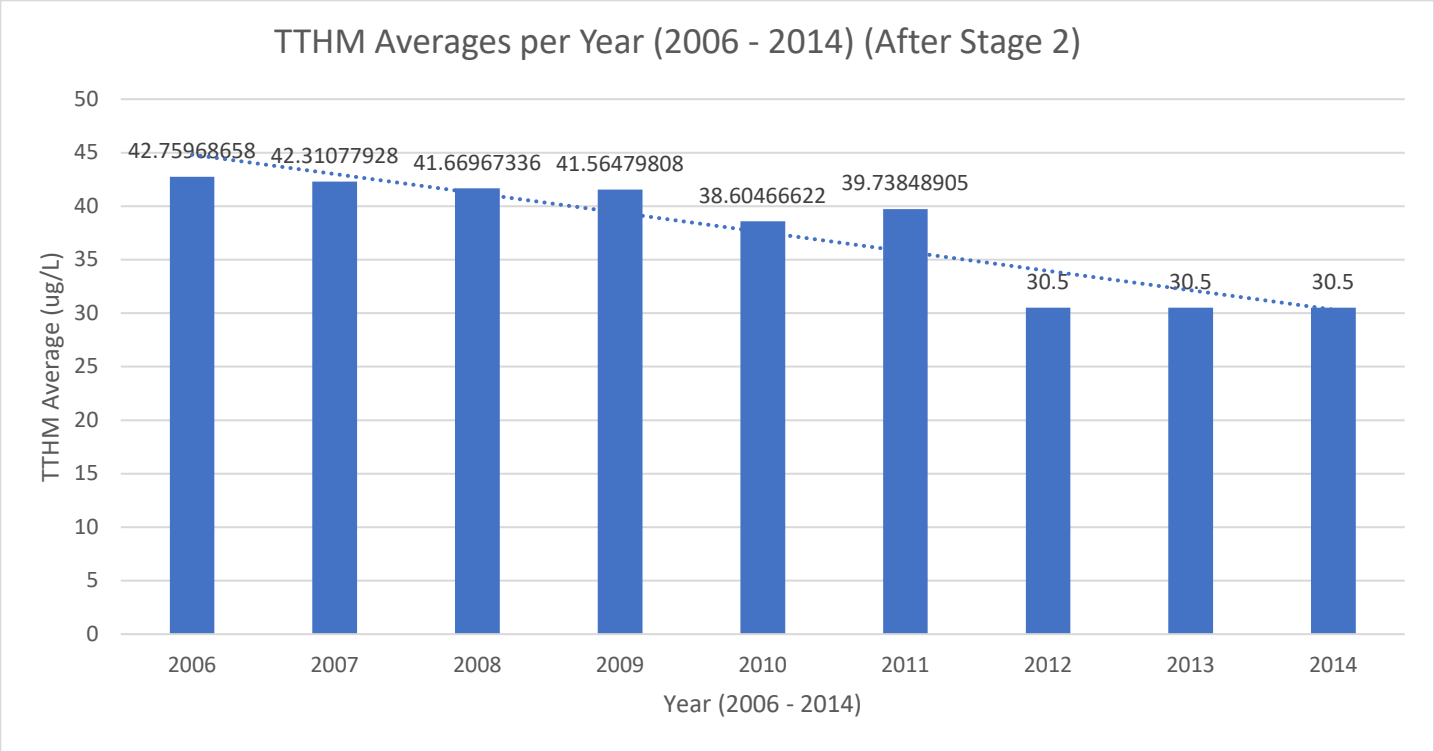
There is a modest decrease over time in national TTHM average concentration from 1975 to 2014. The highest values of TTHM were recorded in 1976 before the implementation of the first Trihalomethane Rule of 100 micrograms per liter.

Figure 3: TTHM averages before first TTHM rule. Average TTHM values from 1975 and 1976 provided by NORS and NOMS. The first regulation of 100 micrograms per liter had not been implemented and depicts increasing trend due to lack of regulation.



There is an interesting increase by an average of 1 microgram per liter between the years 1975 and 1976. Although these samples were taken before 100 micrograms per liter, TTHM content were projecting a positive trend finished water samples. Samples tested from NORS and NOMS have higher TTHM content (Brass et al. 1977).

Figure 4. TTHM Averages per Year for 2006 – 2014. These values are representative of post Stage 2 Disinfectant Byproduct Regulation. There is a clear decrease in average TTHM concentration overtime and have lower overall concentration values compared before Stage 2.



Post Stage 2 regulation in 2012 to 2014 was low, at a value of 30.5 micrograms per liter of water. This value is close to half as much as the initial sampling average of NORS and NOMS. Including the ICR values, the interval 2012 to 2014, and 1997 to 1998 has the lowest average concentrations out of the averages in this study.

DISCUSSION

Overall trends of TTHM concentrations nationwide were decreasing. The highest average TTHM existed in 1976, with 68 micrograms per liter. The lowest average TTHM samples were taken from 2012 to 2014, meaning that it has been very recent when attaining this low average. This could suggest the possibility of the effectiveness of Stage 2 and its amendments to improve

drinking water quality. Stringent monitoring of drinking water is done following regulations set by the Safe Drinking Water, but this study is not truly representative of the United States' TTHM levels because most of the compliance data from national surveys have been voluntarily submitted by certain states. As a consequence, this study does not fully determine if all water treatment systems in the US have been successful in keeping THM levels below maximum contaminant levels since guidelines were set.

Decreasing Trends

The decreasing trends in TTHM average concentrations after the first TTHM rule of 100 micrograms per liter and post Stage 2 Disinfectant Byproduct Rule suggests that stringent regulations do influence the amount of TTHMs in water systems. With the Interim Collection Rule, despite being a small addition to the Disinfectants and Disinfection Byproducts, saw decreasing trends in TTHM concentrations.

Success of Stage 2 Disinfectant and Disinfectant Byproduct Rule

McGuire and Seidel also noted the decreasing trends in average TTHMs as an effect of Stage 2. Seidel looked into the 95^{th} percentile of TTHM averages, such as values that were highest throughout each dataset per year. He found that the highest values follow the decreasing trends along with the bulk of the values (Seidal et. Al 2017). Despite samples having high TTHM content, the samples mostly fall below the maximum contaminant level over time, and 2012 to 2014 saw the lowest 95^{th} percentiles sample levels.

Broader implications

Stringent regulations play an influential role in lowering TTHMs in drinking water. If the EPA continues to push for more strict and consistent monitoring of water systems, water systems can be more aware about their disinfection byproduct production and take the necessary steps to reduce exposure to THMs in order to avoid potential health risks.

Limitations

As mentioned before, states have voluntarily submitted their data, and were able to choose what data they would like to submit to the EPA (US EPA n.d.). This provides several

complications because different states test and collect water samples differently. There is no standardized method to collect water samples, which leads to massive data sets without structure. With the third Six Year Review dataset, there were several missing TTHM values with different number of samples taken per year. This is an example of inconsistencies in data collection, and this study can bring insight into ways to better manage compliance monitoring data.

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REFERENCES

Brass, H. J., M. A. Feige, T. Halloran, J. W. Mello, D. Munch, and R. F. Thomas. 1977. The national organic monitoring survey: samplings and analyses for purgeable organic compounds. Drinking water quality enhancement through source protection:393–416.

Komulainen, H. 2004. Experimental cancer studies of chlorinated by-products. Toxicology 198:239–248.

Krasner, S. W., H. S. Weinberg, S. D. Richardson, S. J. Pastor, R. Chinn, M. J. Sclimenti, G. D. Onstad, and A. D. Thruston. 2006. Occurrence of a New Generation of Disinfection Byproducts. Environmental Science & Technology 40:7175–7185.

McGuire, M. J., and N. Graziano. 2002. Trihalomethanes in US Drinking Water: NORS to ICR. American Water Works Association Journal.

Morris, R. D. 1995. Drinking water and cancer. Environmental Health Perspectives 103:225–231.

National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts. 1998, December 16. . https://www.federalregister.gov/documents/1998/12/16/98-32887/national-primary-drinking-water-regulations-disinfectants-and-disinfection-byproducts.

Organization, W. H. 2004. Guidelines for Drinking-water Quality. World Health Organization.

Siedel, C. J., C.C. Samson, T. Bartrand, A. Ergul, and R. S. Summers. 2017. Disinfection Byproduct Occurrence at Large Water Systems After Stage 2 DBPR. American Water Works Journal.

US EPA, O. (n.d.). Table of Regulated Drinking Water Contaminants. Overviews and Factsheets. https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants.

US EPA, O. (n.d.). Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules. Policies and Guidance. https://www.epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules.

US EPA, O. (n.d.). Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules. Policies and Guidance. https://www.epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules.

US EPA, O. (n.d.). Six-Year Review 3 of Drinking Water Standards. Overviews and Factsheets. https://www.epa.gov/dwsixyearreview/six-year-review-3-drinking-water-standards.

WHO | Environmental Health Criteria 216: Environmental Health Criteria 216: Disinfectants and Disinfectant By-products. (n.d.). . http://www.who.int/ipcs/publications/ehc/ehc_216/en/.

Xie, Y. 2016. Disinfection Byproducts in Drinking Water: Formation, Analysis, and Control. CRC Press.

APPENDIX

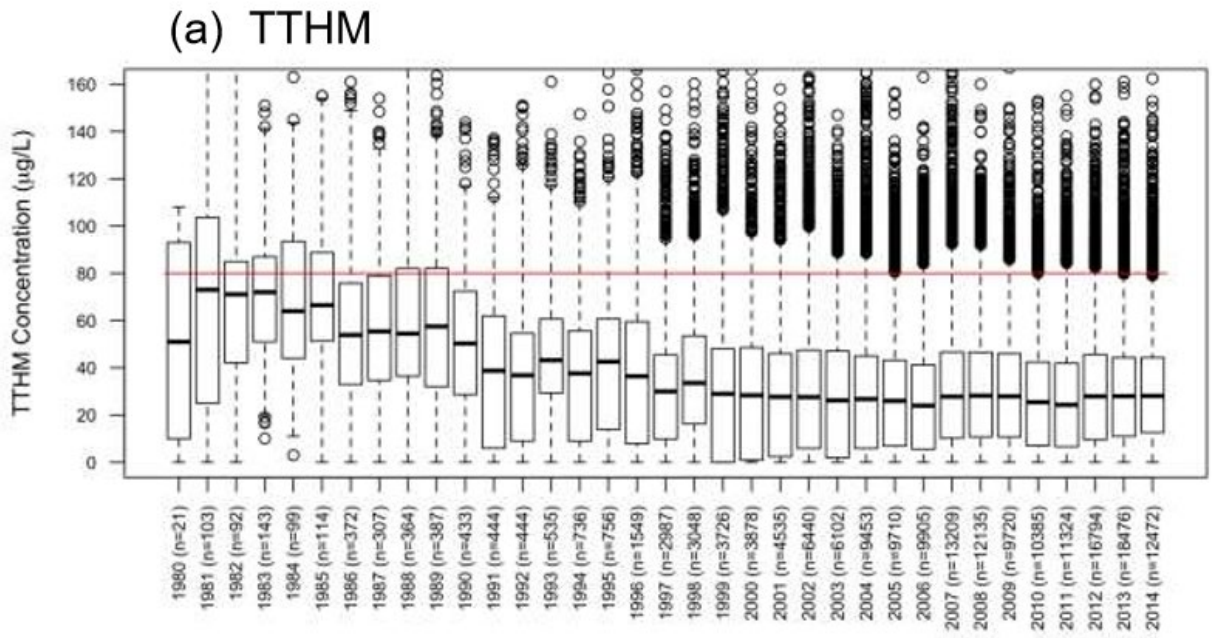

Figure A1. Boxplot of TTHM averages over time from 1980 to 2014. Seidel collected data through personal surveys and national monitoring surveys to analyze national average TTHMs per year. This comprehensive plot was taken from Seidel's publication, "Disinfection Byproduct Occurrence at Large Water Systems After Stage 2 DBPR."

Row Labels	Average of Value
2006	42.75968658
2007	42.31077928
2008	41.66967336
2009	41.56479808
2010	38.60466622
2011	39.73848905
Grand Total	**41.12715463**

Figure A2. Average TTHMs from 2006 to 2011. Using my own pivot table on Excel, I calculated annual means for each year between 2006 and 2011 with data from the third Six Year Review.

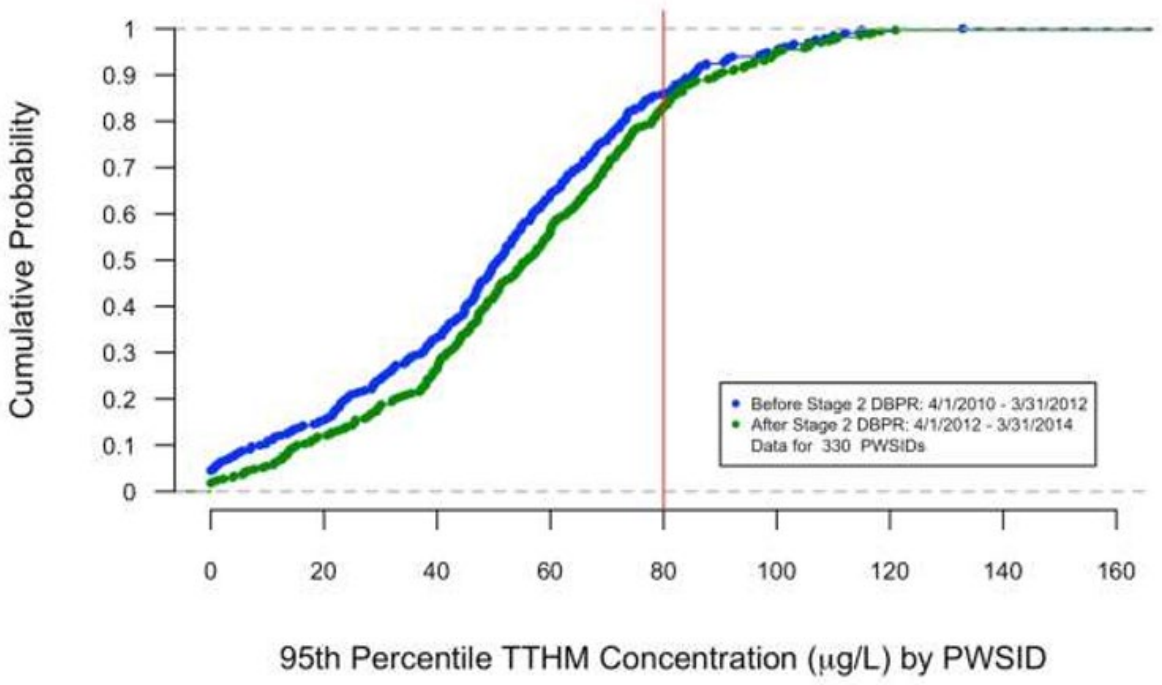

Figure 3A. 95th Percentile calculations from 2010 – 2012, and 2012 – 2014. Seidel created this graph to show the influence of Stage 2 DBPR. Overtime, the 2012 to 2014 data, which came post Stage 2 Disinfectant showed lower TTHM averages when compared to the first year interval.