Reducing the Vulnerability of Chemical Contamination in Worcester Drinking Water

An Interactive Qualifying Project
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ABSTRACT

The goal of our project was to provide recommendations to the Worcester city council members and the water division employees to reduce the overall risk of drinking water contamination. We used first-hand observations, interviews, case studies, and public records to determine the most vulnerable areas of the drinking water system. These areas included land use, water treatment, water distribution, emergency procedures, department budgeting and a water quality comparison between Worcester and similar towns. Then we developed cost-effective recommendations to reduce the risk of a contamination. This report aims to improve public safety by preventing such an incident from occurring.

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GLOSSARY

Activated Carbon – a granular carbon used in water treatment which filters by adsorption

Alum – aluminum potassium sulfate, $AlK(SO_4)_2 \cdot 12H_2O$, used to bind small sediment particles together to aid in filtration

American Water Works Association – an international nonprofit scientific and educational society dedicated to the improvement of drinking water quality and supply (AWWA, 2005)

Anthracite Coal Filtration – a hard coal which is used as a fine grain physical filter during water treatment

Arsenic – a poisonous metalloid used in pesticides and herbicides

Asbestos Cement – an inexpensive material used in water and sewage mains

Atrazine – a common herbicide

Backflow Preventer – a mechanism that prevents contaminates external to a piping system from entering the system due to negative water pressure

Barium – a metal used to deoxidize copper

Biofilter – an organism, typically a plant, which can absorb organic contaminates present in the soil

Cast Iron – an iron alloy containing at least 2 percent carbon

Cathodic Protection – a method of preventing corrosion on metals by making the target metal the cathode in an electrical circuit

Center for Disease Control and Prevention – a federal organization whose primary concern is public health

Chlorine – a disinfectant used in water treatment

Coagulation – the process of treating water by mixing water with alum to have solid particles stick together to be more easily filtered

Consumer Confidence Report – a document containing testing results and information about a water system

Cryptosporidium – "A protozoan of the genus *Cryptosporidium* that is an intestinal parasite in humans and other vertebrates and sometimes causes diarrhea that is especially severe in immunocompromised individuals" (Lexico, 2006)

Cumulative Length of Cathodic Protection – a control factor corresponding to the total length of water mains under Cathodic Protection for a given water system

Cumulative Length of Replaced Mains – a control factor corresponding to the total length of replaced water mains for a given water system over a specific period of time

Department of Public Works – a city funded organization whose role is to maintain the city's water, sewer, street and traffic systems

Drinking Water Source Assessment and Protection – a program implemented in response to the Safe Drinking Water Act which encourages source water protection

Ductile Iron – a form of cast iron where carbon forms spherical shapes

Flocculation – see coagulation

Freezing Index – a number correlated to the number of days in a given season where the temperature drops below 0°C

Giardia Lamblia – a single celled parasite associated with the consumption of contaminated water

Heptachlor Epoxide – a pesticide that is not soluble in water and sticks to soil

Hot Spot – a weakened section of pipe

Massachusetts Water Resource Authority – an organization which provides drinking water and sewer services to Boston and its surrounding communities

Metropolitan District Commission – a non-profit municipal corporation, provides potable water and sewerage services on a regional basis

Ozonation – the process of treating water with O_3, a highly reactive oxidizing agent

Perchloroethylene – an organic solvent used in dry cleaning

Phosphate Corrosion Inhibitor – a buffer used to prevent low pH levels in treated drinking water

Public Health Security and Bioterrorism Preparedness and Response Act – a federal law whose intent is to improve the ability of the US to respond to public health and bioterrorism emergencies

Rain Deficit – a number correlated to the amount of precipitation for a given season

Reverse 911 – a telephone system capable of contacting any number of phones simultaneously

Retrofit – the process of protecting preexisting water mains from further deterioration

Sacrificial Anode – a block of a highly electronegative metal, if electrically connected to a metal of less electro negativity, the anode begins to corrode and the metal stops corroding

Safe Drinking Water Act – a federal law that established national water quality standards

Safe Drinking Water Information System – a database containing information about public water systems and EPA violations

Trihalomethane – "A chemical compound containing three halogen atoms substituted for the three hydrogen atoms normally present in a methane molecule. It can occur in chlorinated water as a result of reaction between organic materials in the water and chlorine added as a disinfectant" (Lexico, 2006)

Turbidity – a measure of the quantity of sediment suspended in a solution with water

Water Quality Report – see Consumer Confidence Report

Water Resource Coordinator – the head of the Water Division in the DPW

ACRONYMS

AC	Asbestos Cement
AWWA	American Water Works Association
CCR	Consumer Confidence Report
CDC	Centers for Disease Control and Prevention
CI	Cast Iron
CLCP	Cumulative Length of Cathodic Protection
CLR	Cumulative Length of Replaced Mains
DEP	Department of Environmental Protection
DI	Ductile Iron
DPW	Department of Public Works
DWSAP	Drinking Water Source Assessment and Protection
EPA	Environmental Protection Agency
FI	Freezing Index
GRU	Gainesville Regional Utilities
HS	Hot Spot
IQP	Interactive Qualifying Project
MCL	Maximum Containment Level – or - Maximum Concentration Limit
MDC	Metropolitan District Commission
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
MWRA	Massachusetts Water Resource Authority
PBE	Physical Barrier Effectiveness
PCA	Possible Contaminating Activities
PPB	Parts per Billion
PPM	Parts per Million
RD	Rain Deficit
SDWIS	Safe Drinking Water Information System
THM	Trihalomethane

EXECUTIVE SUMMARY

Access to plentiful and contaminant-free drinking water is a desired goal of all modern nations. Experts consider drinking water to be the highest priority in public health (DeZuane, 1997). Although the United States has one of the cleanest drinking water supplies in the world (EPA, 2005), any public water utility can be affected by incidental contaminations (EPA, 2005). With this in mind, the primary goal of this project was to increase the safety and quality associated with Worcester drinking water by providing cost effective recommendations to the Worcester Department of Public Works and Worcester City Councilor members.

There have been several studies in the past investigating risks associated with contamination of public water supplies. In 2002, due to growing concerns about the vulnerability of public water distribution systems, Congress included a drinking water component in the Public Health Security and Bioterrorism Preparedness and Response Act (Roberson & Morley, 2005). This act required larger water utilities to perform a vulnerability assessment (VA) to determine susceptibility to a contamination by locating potential contamination sources.

The Massachusetts Department of Environmental Protection (DEP) produced a Source Water Assessment and Protection (SWAP) report and found that all ten Worcester reservoirs were highly susceptible to a contamination due to the presence of at least one high risk source in the protection areas (Massachusetts Department of Environmental Protection, 2002). The report also provided recommendations to individually reduce risk in potential contamination sources. However, the report focused only on land protection and did not evaluate other areas of the drinking water system. Therefore, there was a

significant research gap where recommendations could be provided to decrease Worcester's vulnerability to contamination.

In order to fill in this gap, we first analyzed the major physical protection measures around the reservoirs, potential problem areas within the drinking water treatment facility, and weaknesses in the distribution network. In addition to physical problem areas, we investigated vulnerabilities in the emergency contamination procedures. Next, we compared Worcester's water rate, water quality, and monitoring data from the past twelve years to similar Massachusetts towns. We also analyzed the water division's budget from a vulnerability perspective, including the breakdown, source, and stability of funding.

The data were collected from first-hand observations, interviews, case studies, and public records. These provided the basis from which overall conclusions and recommendations could be drawn. These conclusions were accompanied by cost-effective solutions that would decrease vulnerability of the Worcester water supply. These recommendations were, in order of urgency:

- Land Use: $4,000 on guardrail repair and warning sign installation and $64,000 one-time and $1,700 annually on filter strip installation and maintenance
- Piping: $2,000 on pipe breakage analysis and $62,500 one-time and $37,500 annually on cathodic protection retrofit and hot-spot installation
- Treatment Facility: $2,400 annually on additional THM sampling and investigate spectrophotometric in-line sensor installation
- Water Quality Report: develop consistent reporting and provide links to EPA websites on different areas of drinking water quality

- Emergency Procedure: establish an open public forum for communication with the Worcester Water Division to increase public awareness of contaminations
- Decrease Water Consumption: $50,000 for a water conservation education initiative and $150,000 on low-flow shower heads

CHAPTER ONE: INTRODUCTION

Access to plentiful and contaminant-free drinking water is a desired goal of all modern nations. Water is a vital resource and without it, human beings cannot survive. Many experts consider the drinking water supply and its quality to be first priority in public health (DeZuane, 1997). The United States has some of the best water filtration and distribution systems and as a result we are fortunate enough to have one of the cleanest water supplies in the world (EPA, 2005). Despite efforts to maintain potable water such as the passing of the Safe Drinking Water Act of 1974, the risk of contamination in U.S. drinking water supplies is still high (Detay, 1997). A primary example of this was the largest waterborne disease outbreak in the United States in 1993. In Milwaukee, Wisconsin, an estimated 400,000 people were reported to have developed symptomatic gastrointestinal infections as a consequence of exposure to drinking water contaminated with cryptosporidium (AWWA, 1999).

In an ideal world, every local facility would be able to have the most sophisticated filtration systems, maintain perfect protection of drinking water supplies (such as preventing contaminants from fouling reservoirs and wells), and have unlimited manpower to test for contaminants around the clock and be able to respond to emergencies seamlessly. This would reduce the chance of a harmful contamination from reaching the drinking water supply. Unfortunately, the reality is that not everything is being done to eliminate the risk of harmful chemicals from reaching citizens in some communities. This limitation is primarily due to budget constraints that prevent some local water distribution systems from enacting their fullest water protection and treatment plan (AWWA, 1999).

The city of Worcester is an example of a community that has a limited but effective water treatment and protection plan, due to the low number of past contamination incidents. The citizens of Worcester receive their water from a network of ten reservoirs and two emergency wells that supply the water treatment facility in Holden, Massachusetts. In the most recently published annual water quality report, the Worcester Department of Public Works found no levels of contaminants above EPA guidelines under the Safe Drinking Water Act of 1974 (Worcester DPW, 2004). However, even with perfectly clean water, the risk of an incidental chemical contamination still remains. For example, the water supply may be contaminated by industrial spills, local runoff, leaks in the distribution system, or illegal dumping around the reservoirs and wells. These practices may introduce chemicals into the water supply that may have negative health effects producing either acute or chronic exposure.

Although the quality of Worcester's water has been deemed "safe" by the EPA, the risk of harm to the public is still largely unknown. In 2002 in compliance with the Public Health Security and Bioterrorism Preparedness and Response Act, Worcester performed a vulnerability assessment for our water sources. That assessment analyzed the physical preventative measures and standards that protect the city's reservoirs and wells. However, that assessment did not evaluate the effectiveness of Worcester's testing procedure and preparedness in the event of a drinking water emergency.

The major objective of this IQP project was to determine how well a contamination would be prevented, detected, and contained by the current system in Worcester. Specifically, the goal of this project was to provide a risk assessment report to the Worcester council members and water division employees regarding incidental chemical contamination of Worcester's drinking water. This report focused on the adequacy of physical reservoir protection, treatment facility effectiveness, distribution and piping vulnerability, and providing water consumers with water quality information. This analysis revealed room for improvement in the current treatment system and provided cost-effective recommendations to decrease the likelihood of a contamination.

The information collected and conclusions drawn in this project are important because of the significance of drinking water. It is critical that Worcester is able to prevent widespread chemical contaminations because of the social impacts of adverse health effects by such an incident. The target audience of this report was the city council of Worcester and the Worcester Department of Public Works because they have the ability to make the necessary changes to reduce the risk of harm to Worcester citizens.

CHAPTER TWO: LITERATURE REVIEW

This chapter will provide a detailed background for our project. Understanding water management is critical to maintaining a clean and potable drinking water supply. With exposed reservoirs and wells comes an increased responsibility to ensure the absence of impurities in water. There are a number of local and national standards in place to limit the concentrations of chemicals present in these water sources. However, in recent years there have been several chemical contaminations that have been a threat to public health and some have required costly and time-consuming cleanup efforts. The following sections will provide background information to aid in the understanding of how a water system may become vulnerable to a contamination.

Past Risk Assessments

In order to understand exactly what a risk assessment is and what one may learn from one, it is necessary to first define the terms "risk" and "assessment". To begin, it is important to understand that "risk" in this sense is not merely a chance of injury or loss. Instead, it is the specific chance that a risk or injury will occur based upon data collected in a scientific fashion. It is also expressing the degree of relative risk on a qualitative or quantitative scale. Ram et al. (1986) has defined risk as "the probability of injury, disease, or death under certain circumstances" and also notes that risk "may be quantitative, ranging from the certainty that no harm will occur to total certainty that it will". Additionally, Ram states that risk may be described qualitatively using terms "low", "high" and "trivial". So although all human activities may carry some risk, it is important to understand that it is the degree of risk that actually matters, and not whether or not something is "risky". A risk assessment of chemicals in drinking water, therefore, is a very specific evaluation of the probability that people will be affected by chemicals in their drinking water.

Determining the degree of risk associated with a substance, action, or event is described by Ram as a four step process (1986). The first component of a risk assessment is the "hazard identification" phase. This involves researching and gathering data about the target chemical or chemicals. The next component is a "dose-response assessment" phase, wherein a quantitative analysis is conducted to determine the relationship between the amount of exposure and the extent of injury. The third component is the "human exposure assessment" phase, which involves describing the magnitude of the population exposed to the chemical and the duration of their exposure. The final component is the "risk characterization" phase, which is the integration of data and analysis to determine the likelihood that humans will experience any toxicity associated with the substance.

Covello and Merkhofer summarize this process in three steps shown in Figure 1:

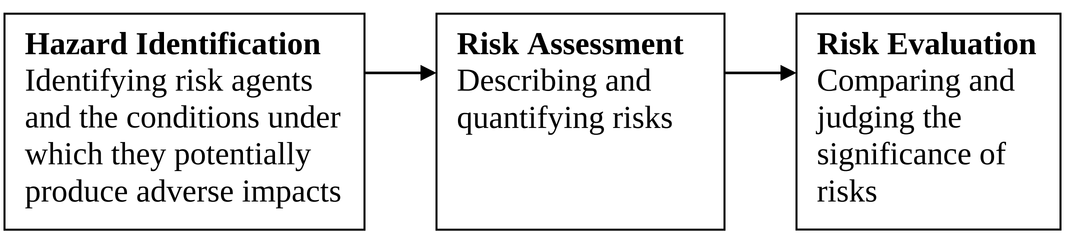

Figure 1. Three-step generic environmental risk analysis
Source: Covello & Merkhofer, 1993.

Drinking water risk assessments are not limited by the size of the body of water under review and may encompass multiple bodies of water. While the required analysis and use of human resources may differ significantly, all risk assessments attempt to identify the probability of harm. An example of a large scale risk assessment was the investigation of the presence of radon in drinking water by the National Research Council in 1999. The EPA assigned members of the National Research Council to examine the health risks of radon in drinking water, modify the existing model if necessary, review the current methods used to derive radon technical data, and assess the potential health-risk of radon (National Research Council, 1999).

Their report began by stating the health risks of radon and why a national risk analysis was appropriate. They stated that the largest fraction of radioactive gas in air was radon and that an estimated 3,000 to 32,000 deaths each year are caused from lung cancer associated with radon (National Research Council, 1999). Indeed, Martin and Inge Goldstein have estimated that although 90 percent of lung cancers are caused from cigarette smoking, the remaining are likely caused by radon (Goldstein & Goldstein, 2002). The EPA found that Northern states, along with Appalachian and Rocky Mountain states, have higher indoor radon concentrations than other states. This study also prompted further research into estimated lifetime cancer risks through ingestion and inhalation of radon.

This is relevant to our risk assessment because of the way that data was collected and presented. The EPA study was very specific and the recommendations were backed by the data that was collected. The National Research Council first identified the risks from radon, collected data and assessed the risk from it in the United States, and evaluated the data to make recommendations following the model from Covello and

Merkhofer. They showed that although a nationwide radon risk assessment has many aspects, the same basic formula still applies.

In 2002, due to growing concerns about the vulnerability of different public water distribution systems, Congress included a drinking water component in the Public Health Security and Bioterrorism Preparedness and Response Act (Roberson & Morley, 2005). The act mandated that drinking water utilities serving more than 3,300 people must perform a vulnerability assessment (VA). The purpose of this mandate was to gauge the vulnerability of contamination in public water supplies. In 2005, 80 percent of the drinking water facilities including Worcester have completed their VAs and are now researching and developing new methods to increase their security (Roberson & Morley, 2005).

Worcester's Source Water and Protection (SWAP) report was written and published in 2002 by the Massachusetts Department of Environmental Protection (DEP). The report found that all ten Worcester reservoirs were highly susceptible to a contamination due to the presence of at least one high risk source in the protection areas. Additionally, the report identified eleven separate high risk sources in the Worcester watershed including pesticide storage and inadequate stormwater drains. Recommendations were provided to help reduce the threat of each problem area, but they were very short, generic, and not specific to Worcester (Massachusetts Department of Environmental Protection, 2002). Therefore, there was a research gap where more specific land use protection recommendations could be developed to reduce the vulnerability of a chemical contamination.

In compliance with the Public Health Security and Bioterrorism Preparedness and Response Act of 2002, many other drinking water utilities completed their vulnerability assessments within one year. An example of such a water utility was the Mettler Valley Mutual drinking water facility in Los Angeles County, a groundwater source. Mettler Valley's report was divided into two main parts: general information about the site and the calculated risk from "possible contaminating activities" (PCAs).

The vulnerability summary included general information about the locations of possible contamination sources around the site. It was noted that the two most vulnerable activities based on initial observations would most likely be septic systems and agricultural wells (California Department of Health Services, 2002). In addition, local physical obstructions were considered, including the fact that the wellhead was located within a fenced area and that it was adjacent to a major highway (CDHS, 2002).

With these facts in mind, the Los Angeles team completed a risk assessment to analyze the possible risk of contamination from nearby facilities. This chart considered the harm and likelihood of a contamination, the proximity to the wellhead, and the effectiveness of nearby physical barriers. These considerations were weighted by risk using a numerical scale and were summed to produce a total vulnerability score.

The ranking system used by the Los Angeles County Department of Health Services is a simple and easy method to assess the vulnerability of a drinking water system to a contamination. In this particular example, the researchers considered different possible sources of contamination and determined that each item posed a significant risk because the vulnerability score was greater than eight (CDHS, 2002). The advantage of this method is that it quantifies risk in a standardized way. This is a good example of a method to analyze risk in potential sources of contamination in a drinking water system.

Standards for Protection of Surface Water

In addition to a risk assessment, another method to minimize vulnerability to a contamination is to develop an effective water protection plan to physically safeguard water sources. In Worcester, this is accomplished primarily by physically isolating the sources from potential contaminants to minimize the possibility of threats. However, as with other types of protection, the system is imperfect and therefore vulnerable. The following case studies deal primarily with the risk of contamination before treatment within Worcester's surface source water.

The protection of surface water reservoirs is much simpler than the protection of wellheads because of the different ways they can be contaminated. A reservoir is contaminated primarily by runoff from nearby areas, "acid rain", and illegal dumping. In contrast, a wellhead is primarily contaminated from the seepage of contaminants from the surface that can affect the well in a much larger radius than that of a reservoir. An example of a wellhead contamination occurred in Natick, Massachusetts, where the presence of a leak at a dry cleaner located miles away from public wells spurred a drilling and testing of the aquifer located beneath the business (Murray, 2005). The chemical that presented a risk was the solvent perchloroethylene.

While this case seemed rare and highly improbable, according to the EPA, roughly 14,000 oil spills alone are reported every year (EPA, 2006). In the past year alone, there have been several instances where a tanker truck has crashed, leaking its harmful contents into United States water supplies. One of such instances occurred in

Putnam Valley, New York in 2005. In this incident alone, 1500 gallons of home heating fuel escaped from an overturned delivery truck into a nearby stream. (Elan, 2005) The stream was a tributary into the Peekskill area's drinking water supply.

Following the Putnam Valley spill, prolonged cleanup efforts caused the town of Peekskill to tap into a neighboring town's drinking water supply until the spill was contained. The water was not shut down until local residents living near the reservoir reported the smell of home heating oil in the nearby brook. Only several months following the incident, a nearby home oil tank spilled almost 300 gallons of oil into a stream that feeds into another town's drinking water supply. In this case, the town water supply was not shut down, as the spill was adequately contained far upstream from the reservoir (Ryser, 2005).

Needless to say, this case study shows that while a transportation accident may not seem probable, it not only can occur, but has happened recently in a US town. Furthermore, the severity of the spill was downplayed by local officials, who did not seek alternate water sources until residents complained of oil slicks near source waters a week later. Such an overlook is unacceptable and as a result, the health of the general public was jeopardized. Overall, while a quick initial response to the overturned oil tanker helped to prevent the majority of heating oil from heading downstream, an oversight meant that officials were ill prepared to completely clean the site until several weeks later, causing public outrage and potential health risks.

The Consumer Confidence Report and the Citizen's Right to Know

One aspect of reporting where information is inaccurately presented is in the annual Water Quality Report. As part of the 1996 amendments to the Safe Drinking

Water Act, new laws and regulations were placed into effect regarding consumer information and the consumers “Right-to-Know” (EPA, 2005). Among these provisions included the annual mailing of Consumer Confidence Reports (CCRs) to all customers of a public drinking water supply. The purpose of this publication was to provide information regarding levels of contaminants in drinking water and inform the public of any potential health risks associated with drinking their tap water. In addition to this outline, in the event of an emergency where even short term exposure to drinking water could have serious health risks, the public must be informed within 24 hours by “at least one effective means” (EPA, 2005). Any other violation to a national standard must be included in the annual Consumer Confidence Report.

While in theory Consumer Confidence Reports are a helpful method of informing the public of their drinking water quality, these reports are often misleading and downplay serious potential health problems. A 2003 study conducted by the National Resources Defense Council surveyed 19 US cities, grading their compliance to the Right-to-Know amendments to the Safe Drinking Water Act. In one instance in Washington, D.C., the annual Consumer Confidence Report went as far as to claim “Your drinking water is safe!” even though according to EPA guidelines the area had dangerously high levels of cyanide, as well as high levels of several other hazardous contaminants (Olson, 2003).

Water quality reports have also been found to omit critical information. In the same 2003 NRDS study, many cities downplayed the presence of contaminants in drinking water by reporting levels in footnotes, or simply omitting them from the results (Olson, 2003). For example, in 2001, Boston, Chicago, Newark, and Seattle all failed to report that the action levels for lead in the drinking water exceeded EPA guidelines. Also, New Orleans did not provide arsenic, atrazine, barium or cadmium data although their presence was detected (2003). To add to this confusion, the study also showed that while many cities have a high percentage of non-English speaking residents, translated versions of the Consumer Confidence Report are not available (Olson, 2003). The result of inaccurate reporting is a misguided public perception of the water quality.

Recent Developments and Attitudes in Worcester Water Quality

In 1981, Worcester water may have been one of the cities listed in the Consumer Confidence Report discussed in the previous section. A "taste test" conducted by the *Telegram and Gazette,* Worcester's local newspaper, addressed public opinion on the taste of Worcester water. In the categories of aroma, flavor and color, the nine participants in the test rated Worcester's water the lowest quality in every category (Connoly, 1981). The results were an indication that there were significant problems with the water. Testing of water in households revealed concentrations of lead as high as 145 ppb with the EPA safety threshold set at 15 ppb (Worcester DPW, 2004). In the report, chlorine levels were also extremely high, attributing to the poor taste. Chlorine was responsible for the significant presence of lead in the water. The concentrations of chlorine use were exceptionally high because it was the only method at the time used to treat the water entering the city of Worcester.

In partial response to the poor public opinion of water and the high levels of lead and chlorine, Worcester constructed a new water treatment plant. The plant was completed in 1997 and built in Holden, Massachusetts. It provides water to the city of Worcester at an average rate of 24 million gallons per day (Worcester DPW, 2004).

The Worcester Drinking Water Treatment Facility

The responsibilities of local governments not only include the distribution of information, but also taking necessary measures to ensure clean and safe drinking water. In addition to protecting land surrounding water sources, treatment processes are required to remove chemicals and pathogens which may still be present in these supplies. This is a second line of defense against a contamination after physical source protection.

Located in Holden, Massachusetts, Worcester's drinking water treatment facility can produce up to 50 million gallons of potable drinking water per day. The plant receives its water from ten nearby reservoirs, acting as a seven billion gallon holding tank of untreated water. The water is processed with different levels of treatment, including disinfection, filtration, and particle separation to remove and prevent possible contaminants from polluting Worcester's drinking water (Worcester DPW, 2004).

When the reservoir water enters the facility, it is first treated with ozone, acting as a primary disinfectant. Due to its highly unstable and highly reactive nature (Davis, 2004), ozone (O_3) gas must be formed on location to be used in an ozonation process. This eliminates the possibility for storing ozone in tanks or receiving a supply from an outside source. The Holden facility has four ozone generators on site with a capability producing 834 pounds of ozone per day (Worcester DPW, 2004).

After it is disinfected, water at the Worcester drinking water treatment facility enters a stage of pre-filtration involving coagulation and flocculation. Coagulation is the addition of chemicals to water in order to make soluble particles insoluble (DeZuane, 1990). In the Worcester treatment plant's coagulation process, aluminum sulfate (alum) is used, as well as polymers that act as coagulant aids (Worcester DPW, 2004). While the alum coagulates the particles, the polymer has many active sites onto which the colloids can "adhere", making larger particles that can be more easily settled (Davis, 2004).

Flocculation is an essential step to ensure that many contaminants are physically removed from drinking water. This is another mixing process which occurs at a slow rate to ensure that particles collide with one another and increases their overall size. However, the mixing cannot be too turbulent or particles will break apart, defeating the entire purpose of this step (Davis, 2004). To increase the size of the coagulated particles, Worcester's treatment plant flocculates the water after it is treated with alum.

The Holden drinking water treatment facility uses dual media anthracite coal/sand filtration. As water travels downward, the first 60 inches of anthracite coal filtration media traps larger particles due to its porous structure, while the sand acts as a mechanical filter for smaller matter (Davis, 2004). Therefore, this is an effective way to remove the floc that exists in the treated water. One major benefit to using this method of filtration is the use of backwashing. Backwashing is the cleaning of filter media by forcing water upward through the sand and anthracite, forcing filtrate off of the media to be later treated by a wastewater treatment facility (Cleasby, 1999). Not only is this method efficient in the cleaning of the filter, but also economical, because very little media will need to be replaced.

A more effective filter media that Worcester does not use due to budget constraints is activated carbon. This media removes a wider range of chemical contaminants than anthracite coal and sand (DeZuane, 1990). To make activated carbon, sawdust and paper mill waste are heated and vaporized, removing all hydrocarbons and “activating” the carbon. However even after relatively short use, every 90 to 120 days (Davis, 2004) the activated carbon must be regenerated. Typically, spent carbon is regenerated thermally, in which carbon is mixed with a combination of combustible gases and superheated steam. The recovery for this process is approximately 90 to 95 percent (ASCE, 1977). Unfortunately, according to J. Hauri (personal communication, January 20, 2006) activated carbon is typically very expensive due to high energy costs to regenerate the filter media and to control the pollution effluent from combustion.

Many materials that are used in water distribution, including copper, lead, and iron, can be corroded by water that has a low pH (Schock, 1999). To stabilize the pH, lime is added after the water is filtered, as well as an anti-corrosive agent. Not only will this pH adjustment prevent corrosion in the distribution system, but it also creates the most effective conditions for the final disinfection, chlorination.

Unlike ozonation, chlorination is longer-lasting and will provide protection even after the water is distributed (Davis, 2004). However, of particular concern is recent discussion of the health risks associated with certain by-products of drinking water chlorination, particularly trihalomethanes (Mills, 2000). While the EPA does regulate the maximum contamination level of trihalomethanes (THM’s), it is unclear how often these parameters are tested in Worcester’s drinking water sources. If there was a sudden spike in organic matter reaching the chlorination process, it is possible that a sharp increase in THM’s would not be detected until after water has been distributed due to inconsistent testing practices.

Current Public Opinion and Relevance of Risk

After construction of the treatment plant, public opinion of water became more favorable. A survey conducted in 2002 through WPI revealed a positive trend between good flavor and the number of years residency in Worcester (Andersen, 2002). People who lived in the city prior to 1997 were very satisfied with the current quality of water implying an improvement over water from before 1997. People who have moved to Worcester after 1997 remained neutral towards the taste of their tap water because they were less aware of the poor taste prior to 1997. After 1997 the levels of chlorine and lead were lowered significantly due to the addition of the treatment facility.

Although the quality of Worcester water has generally increased, the potential for accidental or undetectable contamination still exists. This problem should be the next step in making Worcester water completely safe for public consumption. The presence of lead and excessive chlorine is under control because there was a public awareness of poor water quality. Now that the public is content with the flavor, there is less pressure to continually refine the water delivery system. Our risk assessment continues to refine water distribution by addressing contamination that has not occurred but has the potential to occur and pose a health threat similar to the threat posed by lead and chlorine.

Recent Studies and Incidents of Massachusetts Contamination

Contamination of a water supply can occur at any time without warning. Worcester has been a victim of sewage line breaks, illegal waste disposal and considerable quantities of hazardous runoff. One of the early first criminal convictions of industrial pollution in the nation was filed near Worcester for the release of dyes and soaps into the Blackstone River, which runs along Main Street through the center of

Worcester (Reinhold, 1971). Even with the implementation of stricter regulations, many leaks and poorly controlled disposal methods remain unchecked.

Although there is a danger of contamination from private sources, the majority of pollutants already exist in the environment and flow into water sources through natural processes. Because the water is not absorbed, it can be assumed that the water will eventually flow to a lower altitude or evaporate if on level ground. Runoff may be a risk due to the difficulty in predicting substances dissolved in the runoff and the concentration of these substances at the final destination of the runoff. Also, runoff is exceptionally unpredictable due to its dependence on rainfall which can not be forecasted accurately until several days prior to its occurrence.

One potential source of contamination is a break in old pipes. In the last two decades alone, Lake Quinsigamond has been subjected to direct contamination, from biological and industrial sources. In 1988, a 150 foot section of a fifteen inch sewer line collapsed and pumped an estimated one million gallons of treated sewage into Lake Quinsigamond (Associated Press, 1988). Two years later, another sewage line broke and released two million gallons of raw sewage into the lake (Associated Press, 1990). Several sewage leaks have occurred as recently as this past year. In July of 2005, a fifty-three year old pipe burst and released about ten-thousand gallons of sewage into the lake (Sutner, 2005). Although it was impossible to anticipate these accidents, preventative measures may have been implemented if a risk assessment had taken place.

Reservoirs are susceptible to contamination because the land surrounding them is often privately owned and uncontrolled. The Quabbin Reservoir is an example of a reservoir that has been contaminated and can not be protected. It supplies water to 2.5

million people (Dumanoski, 1987). This body of water also contains fish with high concentrations of mercury in their tissue. The source of the mercury has not been determined, but typically mercury contamination results from herbicides, paints, mining and battery disposal (Naidu, 2003). Rather than pinpoint the source of mercury, which would consume time and resources, the Metropolitian District Commission (MDC), which is in charge of purchasing land for watershed protection, is attempting to aquire the land surrounding this body of water. However, according to Phil Guerin, this is often difficult due to the size of the reservoirs, the cost of land and the legal issues preventing the acquisition of funds to purchase the land (personal communication, November 21, 2005).

For example, in the spring of 1988, the Kristoff family intended to sell a 26 acre strip of land along the Stillwater River which runs into the Wachusett reservoir. The Kristoff's original intent was to sell to the MDC. The state issued a twenty-two million dollar bond for the purchase of land around reservoirs by the MDC, but months after the bond was issued the money was still not available to the land acquisition staff of the MDC. The Kristoff's put the land back on the open market after months of delays, which was eventually purchased by developers (Dumanoski, 1988).

The most widely used watersheds in Massachusetts are the Ware River and Wachusett Reservoir. Only 32 percent of the land bordering the Ware River and 8 percent of the land bordering the Wachusett Reservoir is publicly owned. The land surrounding reservoirs is susceptible to runoff from fertilizers, pesticides, and other chemicals used by farmers and homeowners. Runoff from developers, who aggressively purchase land around reservoirs (Dumanoski, 1987), is also dangerous due to the possibility of radioactive contamination from unearthed underground deposits.

CHAPTER THREE: METHODOLOGY

Our goal was to provide a risk assessment regarding a chemical contamination of the Worcester drinking water system to the Worcester city council members and water division employees. In order to do this, we first analyzed the major physical protection measures around the reservoirs, with emphasis on Holden Reservoir as a case study. Next, we obtained an overview of the treatment facility in Holden and searched for areas that were susceptible to a chemical contamination. These two areas composed the first line of defense in our vulnerability assessment.

The treatment facility analysis was followed by a thorough investigation of distribution vulnerabilities in the piping system. Additionally, we analyzed the Worcester emergency contamination procedures and the effectiveness of the water quality report. These three areas composed the second line of defense in our vulnerability assessment.

In addition to physical problem areas, we compared Worcester's water rate, water quality, and monitoring data from the past twelve years to similar Massachusetts towns. We also analyzed the water division's budget from a vulnerability perspective, including the breakdown, source, and stability of funding. These areas illustrated social concerns regarding local water divisions by comparing water quality to water budget.

During the course of data collection, we analyzed the data from a practical perspective. Possible informational leads were either pursued or rejected based on their utility with our goal, which was to provide cost-effective recommendations to the city councilors. Therefore, some original areas of analysis were abandoned to allow overall recommendations to be as constructive and relevant as possible.

Methods for Determining Effectiveness of Physical Reservoir Protection

A well-protected water source is the first, and perhaps most important step to providing clean and safe drinking water. This is particularly the case concerning a reservoir, Worcester's main source of drinkable water. While groundwater is protected by soil which acts as a natural barrier and filter, reservoirs are directly exposed to their surroundings and environment; any potential contaminant located near the water has a high risk of entering the drinking water system.

Using Holden Reservoirs 1 and 2 (later defined as "Holden Reservoir") as our case study, we performed an analysis regarding the risk of chemical contamination of the source water. The Holden Reservoir is an excellent example of a "typical" Worcester reservoir. Viewing satellite imagery of the Holden Reservoir compared to the other eight reservoirs, there was an excellent mixture of residential and protected land surrounding it that appeared to be representative of most reservoirs. Also, the intake for the treatment facility is located in the Holden Reservoir. The risk of a contamination reaching the distribution system is therefore greatly increased, as pollutants would have less distance to travel. In addition, there was a local road, Reservoir St, which ran along the western shore of the reservoir. While most reservoirs had streets nearby, this long section of roadway would provide the clearest way to illustrate the dangers associated with transportation near protected water.

After the first visit to the reservoir, we found it necessary to create a standardized way to measure the overall vulnerability of the Holden Reservoir. Our method combined two studies: one conducted by the California Drinking Water Source Assessment and

Protection (DWSAP) program, and the other being our own assessment of Worcester's Consumer Confidence Reports.

In California's DWSAP program, the Department of Health Services first identified all potential sources of contaminants that could affect a given source water. After our initial viewing of the reservoir, we were able to create a list of several potential sources of contamination, including roadways, farms, residential neighborhoods, and streams feeding into the reservoir. In addition to the potential sources of contamination, our assessment goes farther than the DWSAP program to also critique the physical barriers to prevent these sources from physically entering the reservoir. This included guardrails and appropriate signage along roads, stormwater management, and protected land around the source water.

The criteria for our source water protection assessment were then rated on a 1 to 3 scale, based on our findings from multiple visits to the reservoir. This ranking system was based on the method used to critique Worcester's Consumer Confidence Reports. Items earning a 1 needed the most improvement and should be viewed as most urgent to be addressed by the City of Worcester. A rating of 2 indicated items that are demonstrated around the Holden Reservoir in an adequate manner, although there is still room for improvement. Items that received a 3 demonstrated an above average attempt to protect the reservoir, and showed the least room for improvement.

While this number system was very basic, it used the same methodology and metrics as the DWSAP program. While the DWSAP program based a contaminant on multiple criteria, giving items at higher risk a higher number, the 1 to 3 ranking was a simplified way to show which areas were performing well and which were sub-standard.

At the same time, our rankings were less cluttered and easier to understand. The overall goal of this number system was to provide clear, concise results that were not only easy to understand with justified reasoning for our results.

Methods for Evaluating Treatment Facility Vulnerability

The Worcester drinking water treatment facility is a very important part of contamination prevention. To evaluate its effectiveness, we decided to pursue two major concerns: 1) which contaminant(s) are the most likely to cause a problem in the treatment facility and 2) are there any additional technologies that may be beneficial in contamination prevention. To answer these questions, we first obtained information from the 2004 Worcester Water Quality report regarding the different steps in the treatment process and which contaminants have given Worcester trouble in the past. We also interviewed Phil Guerin, the Worcester Water Resource Coordinator to gain insight into possible improvements to the treatment facility. Additionally, we used Worcester budgeting data to provide a reasonable budget framework. Using these sources of information, we created an overview of the current treatment facility to present to an expert in the field of water management and environmental chemistry.

We decided that given our limited time and knowledge of treatment facility design that it would be best to conduct an interview to provide us with likely problem spots in the facility. We consulted and met with Professor James Hauri from the Assumption College Environmental Chemistry department for an interview and asked questions based on the overview that we developed. After the interview, we researched literature and case studies that supported Professor Hauri's opinions, and then made recommendations to improve the water treatment facility in a cost-effective manner.

These recommendations included methods to reduce the threat of trouble contaminants and new highly effective technologies in water treatment.

Methods for Evaluating Water Distribution Vulnerabilities

The next step following collection and treatment was the delivery of water through a complex network of pipes. The water mains are the final vulnerability in a drinking water network and their analysis would prove constructive to our risk assessment. The first aim of reviewing the water distribution network was to assess how much information was available concerning piping at the Worcester Department of Public Works, Water Division. This was accomplished through a series of two interviews with Philip Guerin, the Water Resource Coordinator. The first interview focused on general water main information including the range of piping age, causes of water main breaks, frequency of breaks and problematic areas within the city. The interview also focused on whether water mains in District Five are representative of the city at large because originally we intended to contact the District Five council representative, Paul Clancy, to discuss Worcester's water.

The second interview focused on water main renewal programs used by Worcester, different pipe materials and thicknesses and whether there are any upward trends in pipe breakage rates. This information was crucial to producing charts which showed distributions of pipe age and pipe composition. The next step was gathering data in the form of water main ages. Because Philip Guerin stated District Five to be a good representation of the city at large, data was collected only from that section of the city. Approximately 1100 individual water mains exist there and the data was compiled into pie charts representing water main distributions by year and by structural properties of the pipe.

The data from Worcester on water main age and breakage rates was applied to a case study produced by the Institute for Research in Construction and the National Research Council Canada titled *Considering Time-dependent Factors in the Statistical Predication of Water Main Breaks*. The study used a simple time dependent mathematical model to accurately predict water main breakage rates in three cities. The model is relatively inexpensive to put into practice and could be implemented in Worcester.

The protection of water mains was also a significant concern and methods were investigated to prolong the life of water mains. Considerations such as cost and likelihood of use were analyzed based on prior case studies and research, specifically in Canada where pipe protection has a high priority. This research information was applied to water main composition data to determine which water mains are in need of protection and the total costs associated with implementing a program.

Methods for Evaluating Containment Effectiveness

One of this project's major goals was to analyze how well Worcester would respond to a drinking water emergency. It is the city's responsibility to remove pollutants from the water and also to communicate with its residents to prevent the drinking of unsafe water. Therefore, it was decided that Worcester's preparedness to a drinking water contamination should be examined by current emergency procedures, available treatment options, budget constraints, time necessary to return water to a potable state, and the extent to which the public is informed.

Using a schematic of the process broken down stage by stage as described by the Department of Public Works' (DPW) informational website, we first researched a general understanding of each piece of equipment in the process. Unfortunately, in an interview with Philip Guerin, Worcester Water Resource Coordinator, we were unable to learn which type of chemical contaminants would pass through Worcester's facility due to concerns that may compromise the security of our source water. Recognizing the importance of this issue to the overall project, we decided to consult Professor James Hauari of Assumption College's chemistry department.

In order to determine the time between initial contamination and complete remediation, we investigated two case studies in Wisconsin and Florida to cite differences in response time. After an initial interview with Phil Guerin, we learned that while the city has a drinking water emergency procedure, it was not a public record and not available for our review (See Appendix A). Therefore, these case studies allowed our group to focus on flaws or strengths in their respective city's response which either increased or decreased the amount of time a contamination was remediate. We then made recommendations to the DPW regarding emergency procedure based on our findings.

Methods for Evaluating Emergency Notification Procedures

A very important responsibility in the event of any emergency is to keep the public informed. In a drinking water emergency, this is essential, considering a heightened risk of poor public health that could result from a contamination. We interviewed Philip Guerin to obtain an overview of the current emergency procedures of the Worcester Water Division. In addition, the case studies above were also compared to how each city dealt with public relations, including how these responses affected the impact of each contamination. Based on the conclusions of these case studies, advice was offered to the DPW on how to handle public relations in a drinking water emergency.

Methods for Evaluating the Adequacy of the Consumer Confidence Report

An important method for communicating water quality information to Worcester citizens is through the Consumer Confidence Report (CCR), also known as the Water Quality Report. The purpose of this annual report is to provide water consumers with the source of their water, the current state of water quality, and any potential hazards in the future. Thus, our objective in analyzing this report was to examine Worcester's CCR and provide recommendations to increase public awareness of drinking water quality issues.

To accomplish this, we researched EPA and AWWA recommendation guides for writing a CCR and evaluated the degree to which the Worcester CCR met these recommendations. We developed an adequacy scale from 1-3 and assigned values to each recommendation from the EPA or AWWA. In addition, we also compared the 2004 Worcester CCR with the 1998 Worcester CCR to determine if the latest report could benefit from the inclusion of material from past reports.

Methods for Comparing Worcester to Similar Massachusetts Water Utilities

One major objective of this project was to determine how the Worcester Water Division compares to other cities. The primary purpose for doing this was to establish from a societal perspective how effective Worcester is at preventing a contamination relative to other towns. This provided both a starting ground from which we could assess the relative vulnerability of different parts of the system and provided novel correlation data. The comparison criteria of interest include price of water, number of maximum contaminant level (MCL) violations, number of water monitoring violations, and total water division budget.

First, Worcester's water price was analyzed and compared to other Massachusetts towns. We obtained a recent 2004 Massachusetts Water Rate survey from the consulting engineering firm Tighe & Bond. They compiled water prices in a table format from all public and private water utilities, and based annual water prices on 90,000 gallons/year per capita consumption, which was considered to be average usage. We formatted the data to first reflect all public water utilities to determine how much Worcester charges for water with respect to all towns and then with respect to towns with greater than 50,000 people with surface water sources. We then plotted this data against annual town income to determine if there was a correlation between water price and annual income. The mean water price data was originally analyzed using a one-way mean variance ANOVA test with least significant difference. The purpose of this test was to determine if there was a statistically significant difference between the mean Worcester water price and prices in similar towns. Unfortunately, due to the fact that the data from Tighe & Bond was only the mean price and did not include the actual data, the degrees of freedom in the ANOVA test were zero. Therefore, the test was not performed based on the lack of proper data.

Next, to determine the cleanliness and effectiveness of Worcester's chemical monitoring program, quality and reporting violation data was obtained from the EPA. The total number of MCL violations over the past twelve years was plotted against water price for Worcester and similar towns as previously defined. This analysis determined how clean Worcester's water is compared to similar towns and determined if there is a relationship between water health and water price. Similarly, the total number of monitoring violations over the past twelve years was plotted against water price. A monitoring violation is a failure to either adequately sample for contaminants or a failure to provide periodic water quality reports. We excluded towns which use external contractors to perform their water monitoring. This analysis determined how well Worcester has surveyed their system for contaminants and how consistent their reporting was over the last twelve years.

The final comparison that we developed was between the total annual budgets of the water departments from similar Worcester towns. The purpose of doing this was to evaluate how effective the Worcester water department is given their total resources. For example, if the amount of MCL violations was relatively high, then one would not expect the total budget to be as relatively high, else there may be serious problems. The water resource coordinators of ten major Massachusetts water departments were interviewed over the phone and asked to provide their total budget for fiscal 2005. The ten cities were the same from the EPA monitoring violations comparison; towns with greater than 50,000 people, surface water as a primary source, and who did not have contractors perform their water monitoring. The results were compiled into a graph comparing the budgets versus population served, to put Worcester's budget into a better context from which we could draw conclusions.

Methods for Evaluating Water Division Funding Source Adequacy

The Worcester water division's success is dependant upon a large and steady supply of funds. Without an adequate budget, the risk of contamination increases, because of a compromised ability to protect, treat, and distribute the drinking water.

With this in mind, we obtained the fiscal 2005 Water Division budget outline and created our own summary of the budget breakdown. This included the total budget per year, the sources of the funds, and how the funds are allocated. We also found and reviewed some of the water division's accomplishments over the past year to determine how the money is being used in areas other than water protection, treatment, and distribution.

In addition to the budget summary and accomplishments, we also reviewed the probability that the water budget would lose money and fall into debt. Possible threats to the budget were discussed and case studies were reviewed to determine the likelihood of budget problems. After reviewing how the water division uses its money, we came to a conclusion about the reliability of the source of the budget. We also developed three alternative methods to help fund the other recommended expenditures in this report. These were developed from case studies, water utility funding literature, and from our analysis of the current Worcester water department's budget.

CHAPTER FOUR: DATA AND DISCUSSION

The methodology from the previous chapter was implemented during B and C terms from October 2005 to January 2006. The data were collected from different resources including first-hand observations, interviews, case studies, and public records. All collected data was analyzed with the intention of understanding how it fits into the overall picture of the vulnerability of the Worcester drinking water system. Throughout our data collection, we were able to find both strengths and weaknesses of the water system. These provided the basis from which overall conclusions could be drawn.

Comparison of Worcester's Water Division to Similar Towns

One of the most difficult aspects of any enterprise is utilizing a limited budget to maximum effect. Decisions such as the amount of money to spend on salaries, current programs, or future interests are very important to success. The Worcester Department of Public Works' Water Division is funded by the fees that its citizens pay to use water. This money is very important because it contributes significantly to the success of reducing the risk of a contamination. In fiscal 2004, the budget amounted to $24 million, with expenditures broken up into salaries, debt services, benefits, and other charges including reserving funds for land purchasing. This section will analyze some of the budgeting statistics in comparison to similar Massachusetts towns and will search for trends in the data. These areas include water price, water quality, monitoring efficiency, and total budget for the water division.

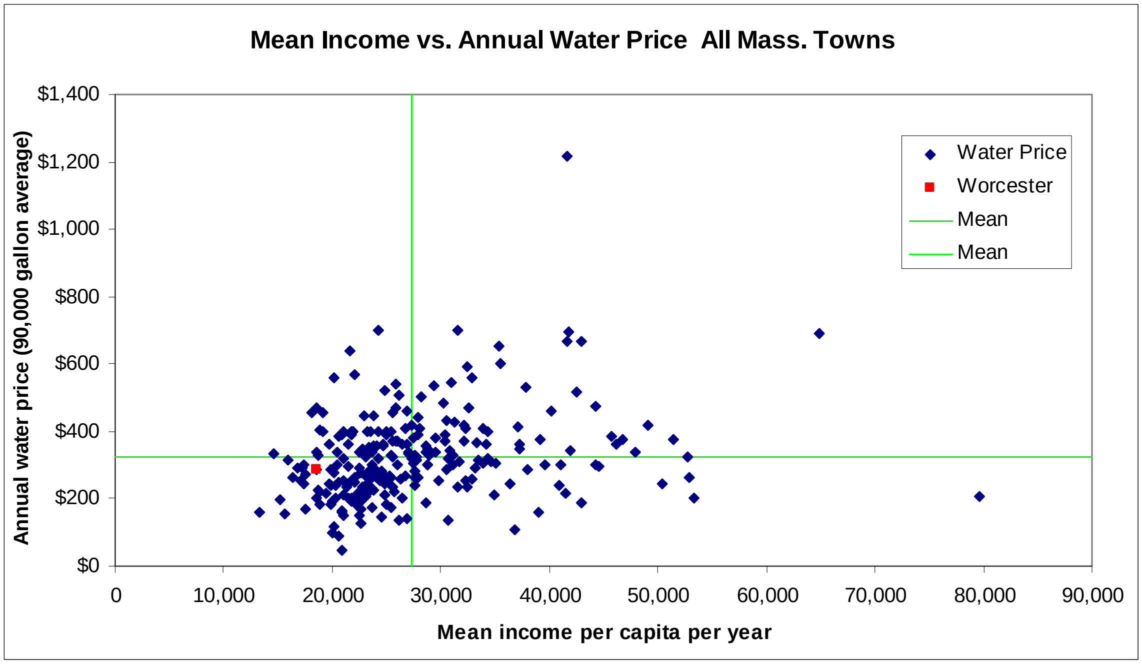

Figure 2. Annual water price vs. Mean Income per capita (90,000 gallon average) for all Massachusetts towns

Source: Massachusetts Water Rate Survey, Tighe & Bond, Westfield, 2004.

The above graph (Figure 2) is a representation of every Massachusetts town's mean income versus their water price. This graph provides the average amount of money that a citizen would spend on water per year for each town. It can be thought of in percent of income terms: the towns in the upper left corner are spending very high amounts on water, and the towns on the bottom right are spending very little relative to their mean income. Worcester is almost directly at the mean for water price. It is also on the significantly lower end of the mean income spectrum, but this by itself has no effect on water quality or price. What is more important are other towns in its income bracket, between $15,000 and $20,000 per year. Once again, Worcester is in the middle, meaning that its citizens are not paying very large amounts of money or very small amounts out of their incomes. Additionally, the graph shows that there is no correlation between the average income and water price. Just because a town has a higher average income does not mean that they will be paying more (or less) for water per year.

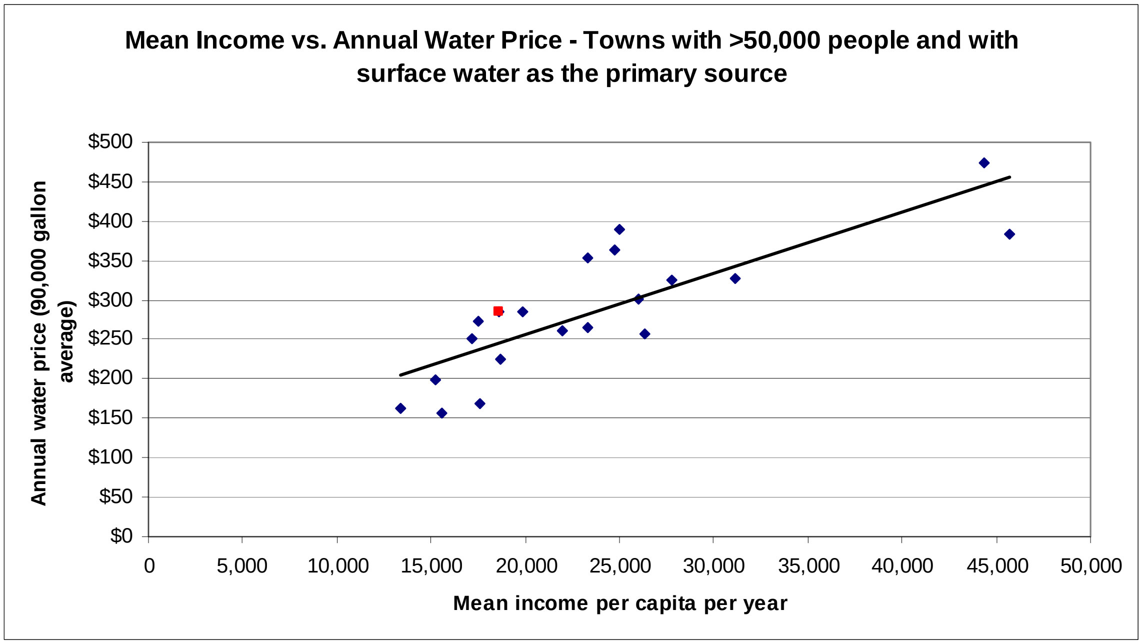

Figure 3: Annual water price vs. Mean income per capita, Massachusetts towns with >50,000 people and surface water as a primary source
Source: Massachusetts Water Rate Survey, Tighe & Bond, Westfield, 2004.

Figure 3 above is the same as Figure 2 but with Massachusetts towns that are more similar to Worcester. This is a more appropriate comparison because larger towns have different priorities and expenditures than smaller towns and thus cannot really be compared. Here again, Worcester appears to be slightly higher than similar towns in its income bracket. It is also certainly not an outlier in the data. This suggests that among larger Massachusetts surface-water towns, Worcester citizens are not charged differently for their water.

The largest difference between the above two graphs, Figure 2 and Figure 3, is that the second graph appears to have a linear trend. This suggests that for towns with over 50,000 people and surface water, the price of water increases as mean income increases. This is interesting because this was not the case with the first graph which contained all Massachusetts towns.

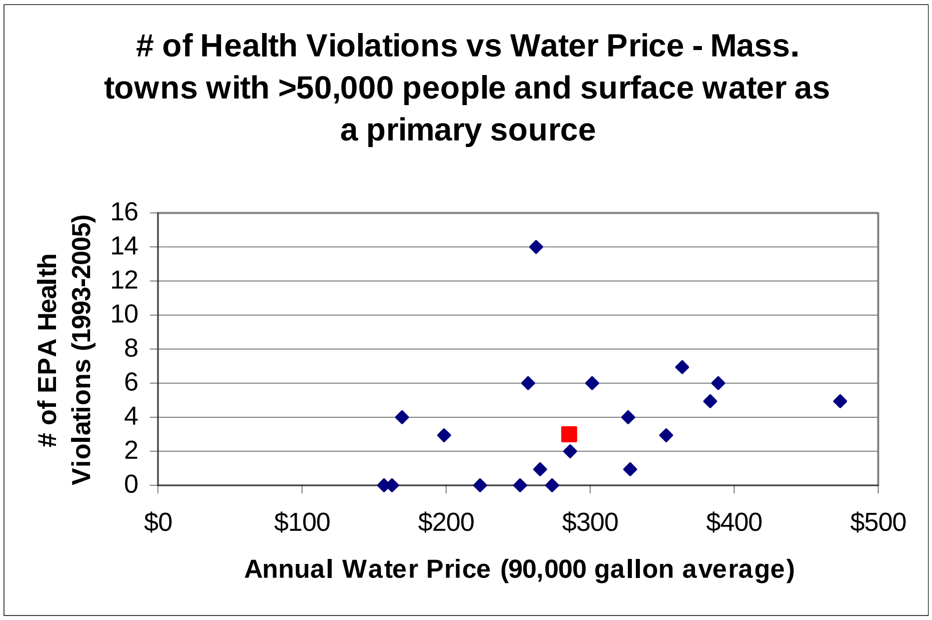

Figure 4. Number of health violations vs water price, Massachusetts towns with >50,000 people and surface water as a primary source

Source: Safe Drinking Water Information System (SDWIS), United States Environmental Protection Agency, retrieved from the World Wide Web on December 5, 2005 from http://www.epa.gov/safewater/dwinfo/ma.htm.

Another interesting comparison of water data is the relationship between water price and quality: for the price that consumers pay, how clean is their water? This is presented in Figure 4 above. A health violation is defined as a detection of a chemical above the MCL level during regular testing, and thus is a good measure of overall quality. Worcester appears to be in the low-middle range with respect to health violations. This suggests that Worcester's water is moderately clean with respect to other large Massachusetts towns. It is important to note that there seems to be no trend in Figure 4. This means that just because a town's water is expensive does not mean that it is cleaner. The outlier on this graph is Malden, which had many coliform and lead/copper violations in the 1990s.

Besides health violations, the EPA also keeps track of monitoring violations that a water utility accumulates. A town may be at fault for one of these if it does not monitor for a certain chemical properly by not taking enough samples, not using the correct equipment, or not monitoring their water for a specific chemical. Additionally, these violations also include improper reporting to the EPA, which usually take the form of late annual reports. Unfortunately, some towns cannot afford some monitoring equipment necessary to test for chemicals required by law and receive the same monitoring violation every year until the problem is solved. This is particularly the case in small population or low income towns where some of the most modern equipment is out of their budget range. Worcester is fortunately not one of these towns. A graph of the number of monitoring violations for large Massachusetts towns is presented below in Figure 5:

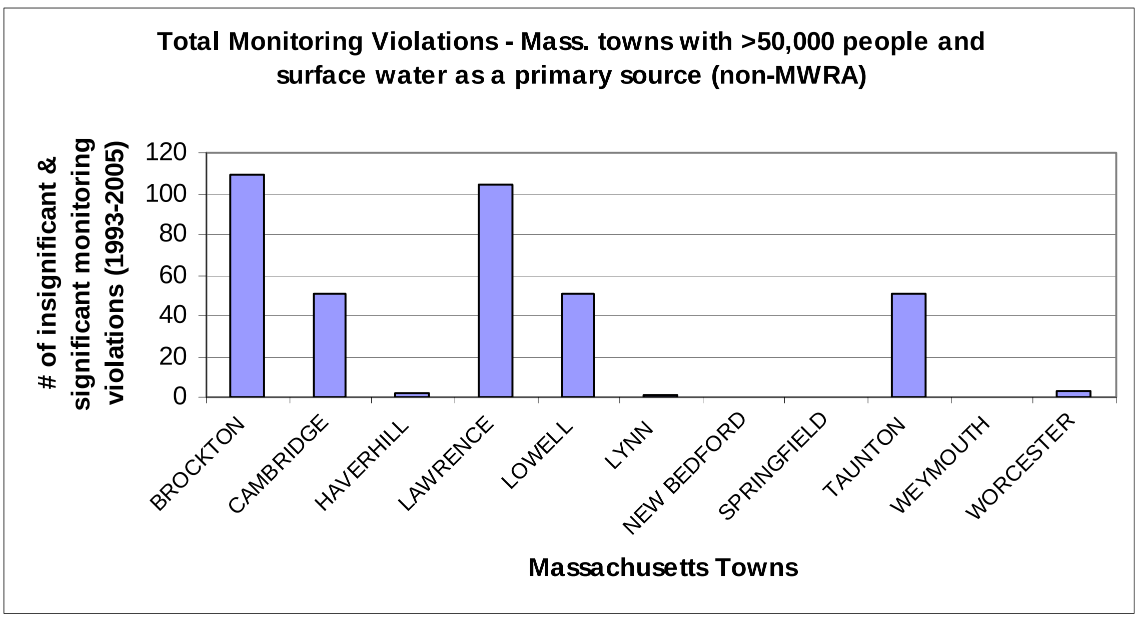

Figure 5. Total number of monitoring violations for Massachusetts towns with greater than 50,000 people, surface water as a primary source, and that do not belong to the MWRA.

Source: Safe Drinking Water Information System (SDWIS), United States Environmental Protection Agency, retrieved from the World Wide Web on December 5, 2005 from http://www.epa.gov/safewater/dwinfo/ma.htm.

The above bar graph displays the total number of monitoring violations for towns that are similar to Worcester. This graph is different than the other graphs because it excludes towns that are supplied by the Massachusetts Water Resource Authority (MWRA). The MWRA supplies water to a large number of eastern Massachusetts towns and performs its own monitoring. It would not make sense to compare a town that has to do its own monitoring with one that does not, and therefore the MWRA towns are excluded from Figure 5 (including Boston). Worcester is on the far right of the graph and has had a modest three violations over the last 12 years. Considering that almost half of these towns have over 40 violations, this is a very low number and is testament to Worcester's excellent monitoring and reporting history.

The EPA also divides these monitoring violations into insignificant and significant violations. An insignificant monitoring violation means that the water district did not take some of the required samples, whereas a significant monitoring violation means that they did not take a large portion of the required samples. The difference between a significant and insignificant reporting violation is determined by the EPA on a case-by-case basis. Of all the violations in Figure 5, only one was considered significant by the EPA, and it was one of Worcester's three. In 2003, the EPA considered the submission of the water quality report to be significantly late. However, since this was the only significant violation in twelve years, it does not provide enough reason to state that there is a problem with Worcester's monitoring and reporting practices.

There are several overall conclusions that can be drawn from the above four graphs. To start, Worcester citizens are not overcharged for their water, with respect to all Massachusetts towns, towns with similar mean incomes, and towns with similar populations and water sources. In fact, the amount Worcester citizens are charged for drinking water is close to the mean for all cases. Furthermore, the number of health violations over the last twelve years is in the middle-low range in comparison to other large towns. This suggests that the drinking water is well protected and clean, and that the current protection and treatment procedures are effective. The number of health violations is also average for the price of the water, suggesting that Worcester citizens get clean water for the price that they pay. Finally, the number of monitoring violations is low with respect to similar towns, suggesting that Worcester has a reliable chemical monitoring and reporting system.

A final interesting comparison is between total annual water budgets, the amount of funds that the water division is provided with each year. As stated before, almost all of this money (99.4 percent) is from the fees that its consumers pay. As we have seen, the Worcester DPW has an above average treatment and monitoring system based on EPA violations with respect to similar towns. In addition, the fee that Worcester charges is approximately average with respect to all Massachusetts towns and other similar towns like Worcester. But how large is this total budget in comparison to other similar towns? This question is answered below in Figures 6 and 7 and the following paragraphs:

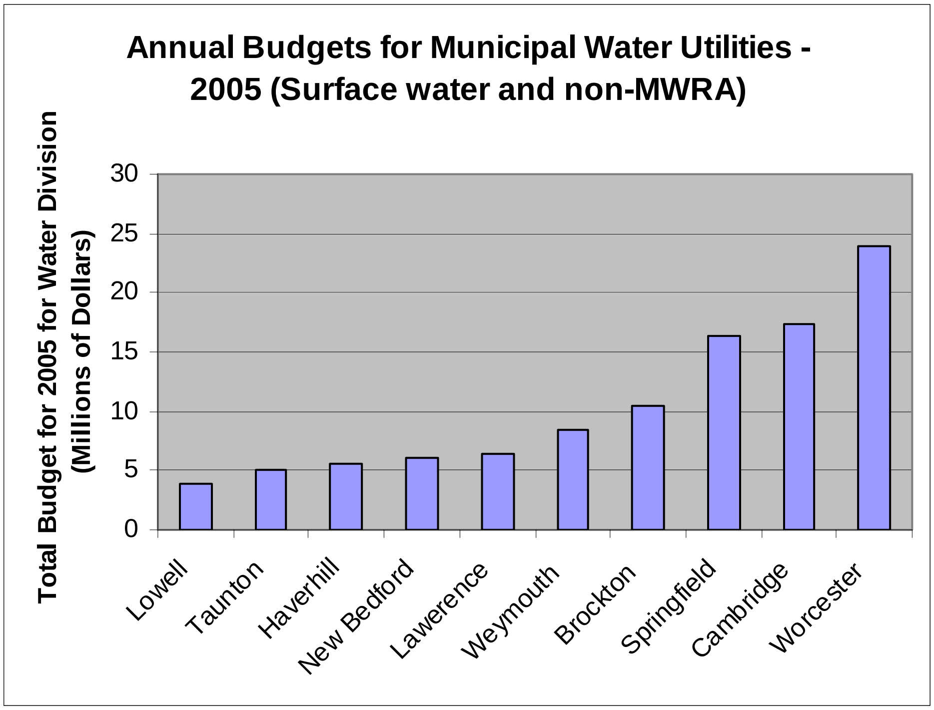

Figure 6. Comparison of annual budgets for water divisions of Massachusetts towns with greater than 50,000 people and who do not belong in the MWRA.

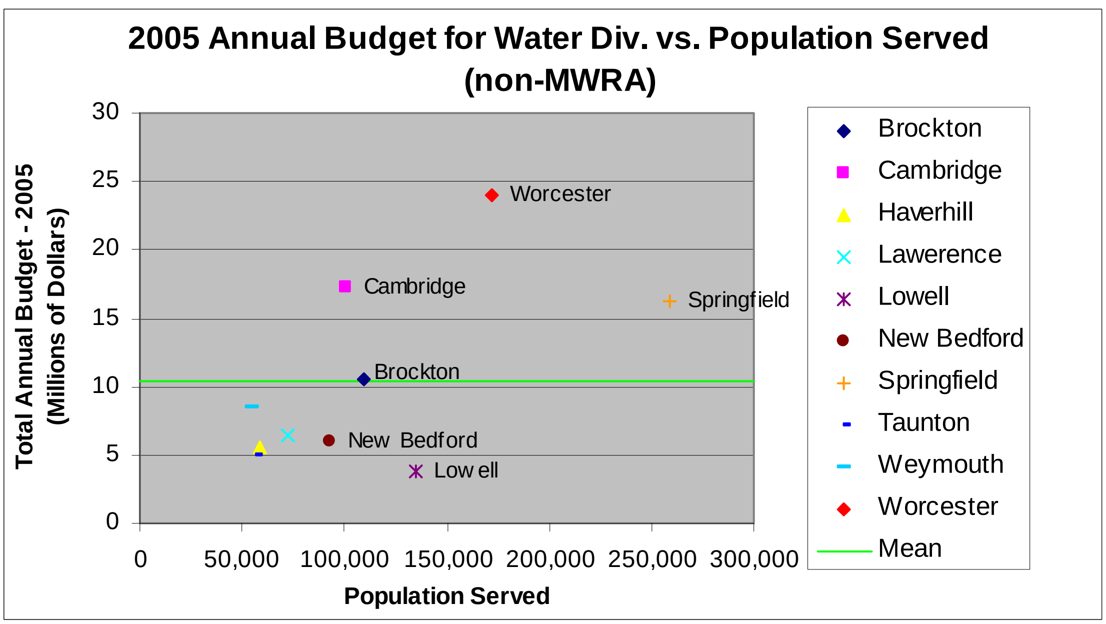

Figure 7. Comparison of annual water budgets and population served between the ten total towns from Figure 6[1]. Mean is $10.3 million.

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[1] Sources: Brian Creden, Brockton Water Commission (personal communication (PC), December 27, 2005); Timothy MacDonald, Cambridge Water Department (PC, December 27, 2005); Larry Pinaro, Haverhill Water Department (PC, January 5, 2006); Robert Fazio, Lawerence Water Works (PC, January 4, 2006); JoAnne Gitschier, Lowell Water Department (PC, January 5, 2006); Charles Kennedy, New Bedford Department of Public Infrastructure (PC, December 27, 2005); Kathy Pedersen, Springfield Water and Sewer (PC, January 5, 2006); Jon Chase, Taunton Water Department (PC, January 4, 2006); Bradley Hayes, Weymouth Water Department (PC, January 4, 2006); Phil Guerin, Worcester Department of Public Works (PC, November 21, 2005).

There are several things worth mentioning among these two graphs. First, in Figure 4.5, it is shown that Worcester's water budget is the largest in Massachusetts for all towns that have their own water distribution systems (Boston is supplied water by the MWRA). Considering that Worcester's water budget is $6 million larger than any other division, at first it may seem that Worcester has an unnecessarily high budget. However, when compared to populations served, the budget becomes more understandable. Figure 4.6 shows that Worcester has the second largest number of consumers, which partly justifies the high cost. Perhaps the most central reason for Worcester's large water budget is from its payment for debt services, which cost the department $10 million per year. Reducing this debt by 50 percent would place Worcester close to Cambridge and Springfield.

Although every city is different, based on this comparison it seems likely that Worcester already has enough total funds to operate its water division. Although the city has an aging infrastructure and large amounts of debt, the water budget is still 33 percent larger than the second largest budget in Massachusetts, and over double the average of similar large towns. However, the fact that Worcester's water budget is high does not imply that it could not benefit from additional funding. These extra funds could be used to support the development of new programs to reduce the risk of a chemical contamination. Based on the findings later in this section, recommendations to increase revenue are provided in the Conclusions and Recommendations chapter.

Informational Adequacy of 2004 Consumer Confidence Report

Due to EPA regulations, Worcester is required to develop and distribute a Consumer Confidence Report (CCR) to its citizens on an annual basis. The primary purpose of that report is to provide water consumers with the information they need to make decisions about their water supply, such as whether or not they should buy additional filtering equipment (EPA, 2005).

From a standpoint of vulnerability to a contamination, these reports are important for two reasons. The first reason is that they provide a summary of the water system to the public and to the EPA, which increases the desire of a water division to maintain a clean record. This record provides an excellent method of tracking progress over time to see how quality has changed. The other reason these reports are important from a vulnerability perspective is that they provide an overview of the majority of equipment and procedures of the water division, giving the public a basic understanding of how everything works. This is beneficial because it may influence some in the public to suggest actions or policies than could be used to improve the water division. It is important to analyze the Consumer Confidence Report to ensure that it provides the best possible information to the public. In our analysis, we will provide recommendations to improve Worcester's CCR.

To assist water utilities in developing these reports, the EPA (Office of Water, 2005) and American Water Works Association (AWWA) have produced guidelines (AWWA, 2005) that water utilities should follow. The guidelines are considered to be the minimum that should be included in the report, and suppliers are strongly encouraged to include as many additional details as possible. The method that was used to evaluate the adequacy of the Worcester CCR in presenting required information was a comparison chart with rating scale. For each recommendation by either the EPA or AWWA, a brief summary of the content that the Worcester DPW included is presented with an adequacy score. The adequacy table is based on a California vulnerability assessment, alternatively using a scale of 1-3 for simplicity (CDHS, 2002). The following explanations define each case:

-Adequacy Score of 3: The information presented in the CCR is adequate to meet the recommendations of the EPA or AWWA. The data is easy to interpret and the explanation of potential problems if appropriate is given.
-Adequacy Score of 2: The information presented in the CCR is marginally adequate to meet the recommendations of the EPA or AWWA. The data is either difficult to understand, unorganized, or improperly worded. The explanation of the meaning of the data is lacking in content or depth and a lay person may find it difficult to understand.
-Adequacy Score of 1: The information presented in the CCR does not adequately meet the recommendations of the EPA or AWWA. The data that is required is not provided or no explanation for the information is provided.

The adequacy scale is only our judgment based on what we think an average water consumer would be able to discern from the content in the report. This method was chosen to easily quantify the adequacy of the report and to shed light upon any lacking areas. The comparison chart for Worcester's 2004 Water Quality Report is presented below in Table 1.

Table 1. A comparison of recommended material to actual content in the City of Worcester 2004 Water Quality Report

Recommendation	EPA	AWWA	Explanation	Adequacy Score
Type (groundwater/surface water), commonly used name, general location without exact locations for security reasons	X		All 10 reservoirs and 2 emergency wells were named with general locations; however, the streets where the two emergency wells are located were named when they should not have been	2
Availability of source water assessment	X		CCR stated when it was prepared and that it is available from the Worcester DPW Operations by calling a phone number	3
Brief summary of potential sources of contamination	X		Listed the potentially threatening land uses, such as "dairy farms, livestock operations, pesticide use and storage" etc.; however, did not provide any "summary" of these potential hazards or explain how a citizen can help reduce the threat	2
Definitions of MCL and MCLG, and optional definitions of TT, MRDL, MRDLG, and AL	X		Provide all definitions in a "Glossary of Terms" on final page, and included additional definitions such as Distribution system, DEP, ppm and ppb	3
Table summarizing data on detected regulated and unregulated contaminants that were detected during the last round of sampling	X		The CCR provided tables for: one microbiological contaminant, six inorganic contaminants, lead and copper, four radioactive contaminants, turbidity, seven disinfection contaminants, and thirteen other water measurements that do not have established limits. There is no other data than this, other than the mention that there were no volatile organic or synthetic organic contaminants found in any of the samples collected. While this covers every contaminant required by the EPA under the Safe Drinking Water Act, for completeness there should have been a table to summarize the data for volatile and synthetic organics. This would have accomplished two things: provided consumers with a better understanding of some of the hazardous chemicals than can occur in drinking water, and provide a clearer understanding of the harmful levels for each contaminant.	2

Recommendation	EPA	AWWA	Explanation	Adequacy Score
Known or likely source of each detected contaminant	X		For each detected contaminant there was a fairly detailed explanation regarding where they can be found, such as "Inorganic contaminants include a variety of chemicals such as metals, nutrients and minerals. These chemicals can be naturally present in the rocks and soils surrounding a water supply…"	3
Health effects language for any violations, exceedances or when Arsenic levels are >0.01 mg/L	X		Some of the samples exceeded the action level for lead and the effects of lead contamination were clearly stated; no mention of arsenic however it is assumed to be lower than the MCL of 0.01 mg/L because of the statement that "Worcester's water has never exceeded the MCL for any inorganic contaminants" (however a citizen seeking arsenic-specific data would not be able to find anything).	3
Information on Cryptosporidium and Radon (if applicable)	X		Cryptosporidium was mentioned once and it was not described. The sentence that it was used in reads "EPA/Centers for Disease Control and Prevention (CDC) guidelines on appropriate means to lessen the risk of infection by Cryptosporidium and other microbial contaminants are available from…". It was only identified as a microbrial contaminant, and there was no information regarding the threat level or what Worcester does to prevent cryptosporidium. There was no mention of radon in the report.	1
Explanation of violations, length of violations, potential health effects, and steps taken to correct the violations with regards to compliance with drinking water regulations	X		The only information regarding issues of non-compliance were presented in a small box and only the specific incidents were listed. However, in another insert, there was an explanation of one of the non-compliance issues, namely the cross connection control program. A summary of the information should have been included in the actual report to ensure maximal exposure and for completeness.	2

Recommendation	EPA	AWWA	Explanation	Adequacy Score
Explanation of contaminants and their presence in drinking water including bottled water	X		There was a lengthy and well written paragraph that described how contaminants may enter the water supply. It also stated that the presence of contaminants may not indicate a health risk.	3
Warning for vulnerable or immunocompromised populations about Cryptosporidium	X		There was a bold paragraph that explained that immuno-comprised persons should be aware of cryptosporidium and gave a phone number to call to help reduce the risk of illness from it. Information should have been included such as preventative measures and early warning signs that one should be aware of regarding a cyrptospordium contamination.	2
Informational statements on arsenic, nitrate, lead, and total trihalomethanes (TTHMs), if applicable	X		Several paragraphs were devoted to lead contamination and proper steps to help prevent it, as well as TTHMs. There was no information regarding arsenic or nitrates, although they were not detected. However, a simple statement about them should have been included for education purposes	2
EPA's Safe Drinking Water Hotline Number	X		Included.	3
Health effects language if a violation has occurred and a system's actions to restore safe water		X	There was no information regarding emergency procedures in the event of a contamination. Although they suggest including them only if there was a contamination, a general summary outlining the emergency procedures would have been helpful.	1
Notice for non-English speaking residents in their native language on the importance of the information and the need to get it translated		X	There were only two paragraphs in a different language than English, and they appeared to be Russian and another European/Asian language based on the symbols used. These two languages seemed like a strange choice when there are large groups of consumers who speak languages like Spanish.	1
Notice of opportunities for the public to participate; ie meetings		X	No information about public water board meetings or forums; only included contact information of head water coordinator.	1

There are several conclusions that can be drawn from the above analysis. A first conclusion is that the Worcester CCR at least minimally meets all of the EPA's recommendations, with the exception of the inclusion of cryptosporidium and radon information. A first recommendation would be to perhaps add in a paragraph or two into the report suggesting the dangers of cryptosporidium and radon. Also, current methods to minimize cryptosporidium and radon could be included. There is also some room for improvement amongst the EPA's suggestions. For example, there should be more explanation about why some of the listed potential sources of contamination may be dangerous. A table explaining some of the volatile and synthetic organic chemicals and information about arsenic and nitrates would be beneficial.

Comparing the recommendations from the AWWA against Worcester's CCR, one finds that few of the recommendations are included. In fact, none of the three recommendations that the AWWA provides that differ from the EPA's recommendations are found in the Consumer Confidence Report. To better improve the CCR, these recommendations should be implemented into future reports. These include a basic and non-revealing summary of emergency contamination procedures, creating an extensive notice for non-English speaking residents to get the document translated, and providing information to the public about where one can participate in an open forum discussion about water issues.

It is important to emphasize the benefit of creating the best possible Consumer Confidence Report. The CCR provides one method of ensuring that the Water Division is doing the best possible job, by creating a periodic reporting media to the EPA and the public. A thorough CCR may also spark the interest of consumers to get involved in water issues and increases the amount of people thinking about water issues. By including these above recommendations, these benefits can be more easily realized. A summarized and abridged version of these suggestions will be provided in the Conclusions and Recommendations chapter.

Table 2. A comparison of recommended material to actual content in the City of Worcester 1998 Water Quality Report

Recommendation	EPA	AWWA	Explanation	Adequacy Score
Type (groundwater/surface water), commonly used name, general location without exact locations for security reasons	X		All 10 reservoirs and 2 emergency wells were named with general locations; however, the streets where the two emergency wells are located were named when they should not have been	2
Availability of source water assessment	X		Report was mailed to all residents paying for water, but was not available on the internet.	2
Brief summary of potential sources of contamination	X		Discussed a strategy to buy land within the reservoir's watershed areas to prevent contamination, but did not mention any specific sources. Further into the document, specific contaminants cite potential sources, however.	2
Definitions of MCL and MCLG, and optional definitions of TT, MRDL, MRDLG, and AL	X		Provided most definitions in a "Glossary of Terms" before the body of the report, and included additional definitions such as Distribution system, DEP, ppm and ppb. However, MRDL and MRDLG were not defined.	2
Table summarizing data on detected regulated and unregulated contaminants that were detected during the last round of sampling	X		The CCR provided tables for: one microbiological contaminant, six inorganic contaminants, lead and copper, four radioactive contaminants, turbidity, seven disinfection contaminants, and thirteen other water measurements that do not have established limits. There is no other data than this, other than the mention that there were no volatile organic or synthetic organic contaminants found in any of the samples collected. While this covers every contaminant required by the EPA under the Safe Drinking Water Act, for completeness there should have been a table to summarize the data for volatile and synthetic organics. This would have accomplished two things: provided consumers with a better understanding of some of the hazardous chemicals than can occur in drinking water, and provide a clearer understanding of the harmful levels for each contaminant.	2

Recommendation	EPA	AWWA	Explanation	Adequacy Score
Known or likely source of each detected contaminant	X		Report did a very good job of discussing sources of each contaminant found in the drinking water, for example, “Lead usually comes from the lead solder used, prior to 1986, to connect the copper tubing in a house’s water supply lines”. The language used was easy to understand and to the point.	3
Health effects language for any violations, exceedances or when Arsenic levels are >0.01 mg/L	X		The health effects of most violations or potential contaminants were clearly stated, such as those for lead and copper. However, when the synthetic organic contaminant (SOC) Heptachlor Epoxide was detected, the health effects were not clearly stated. Only a generalization was made about SOC’s, stating that health effects “vary, depending on the chemical but could include a risk of certain cancers, liver or kidney damage, and neurological damage”.	2
Information on Cryptosporidium and Radon (if applicable)	X		Cryptosporidium was never mentioned in this report. Meanwhile, radon was briefly described under the section called “Radioactive Contaminants”. Here, it was explained that radioactive contamination could come from “contact with natural deposits of radioactive materials such as radon and uranium”. It was also stated that since surface waters are less vulnerable to such radioactive materials, the source water needed to be tested only every five years for alpha and beta particle activity.	2
Explanation of violations, length of violations, potential health effects, and steps taken to correct the violations with regards to compliance with drinking water regulations	X		If there were violations, the report was very clear in explaining their potential sources and lengths to correct the problem. Also, corrective actions were explained and appeared to be reasonable. For example, when 14 out of 100 samples tested positive for lead, the treatment facility adjusted corrosiveness of the water, and drastically reduced the number of positive samples.	3

Recommendation	EPA	AWWA	Explanation	Adequacy Score
Explanation of contaminants and their presence in drinking water including bottled water	X		There was a lengthy and well written paragraph that described how contaminants may enter the water supply. It also stated that the presence of contaminants may not indicate a health risk.	3
Warning for vulnerable or immunocompromised populations about Cryptosporidium	X		On the first main page, there was a boxed and bolded paragraph stating that immuno-compromised people such as chemotherapy and AIDS patients may be more vulnerable to contaminants in drinking water. However, cryptosporidium was not mentioned as a specific contaminant.	2
Informational statements on arsenic, nitrate, lead, and TTHM (if applicable)	X		Several paragraphs were devoted to lead contamination and proper steps to help prevent it. There was no information regarding arsenic, nitrates, or TTHMs. In fact, there was no mention of arsenic at all in the report.	2
EPA's Safe Drinking Water Hotline Number	X		Included.	3
Health effects language if a violation has occurred and a system's actions to restore safe water		X	In all cases, health effects were addressed if a contaminant was detected. Also, corrective action was explained. For example, when Heptachlor Epoxide was discovered, the report stated that testing of all synthetic organic compounds would be done quarterly rather than twice a year.	3
Notice for non-English speaking residents in their native language on the importance of the information and the need to get it translated		X	There was a notice on the back of the report in several languages, discussing the importance of translating this document. It would have been a good idea, however, to offer a number to call or person to contact for a translated version.	2
Notice of opportunities for the public to participate; ie meetings		X	No information regarding public water board meetings or public forums; only included contact information of several public officials.	1

In order to see the progression and evolution of the Consumer Confidence Report (CCR) since its inception in 1998, we compared the first required report to the most recent one in 2004. A copy of the 1998 water quality report was found in the historical records section of the Worcester Public Library. At first glance, this report appeared to be much larger than the current CCR. The 1998 report was a total of 15 pages, as opposed to the 2004 pamphlet, which was only four pages.

The presentation of the 1998 consumer confidence report was much more user friendly than the most recent publications. The report was 8-1/2 by 11 inches and included a front and back cover, as opposed to the current single folded page pamphlet. Furthermore, the older CCR was more organized, making it easier to read. While the 1998 CCR may appear to be bulky, it was clear that this document contained important information. Therefore, the likeliness of the 1998 report being thrown in the trash and never looked at was much less than the current small pamphlet, which could easily be interpreted as junk mail.

Despite the much larger size, the presentation of data within the report was almost identical to that of the 2004 CCR. Contaminants were listed in identical tables, and testing practices appeared to be consistent, regarding frequency of tests and what chemicals were tested. While raw data was identical, explanation of tests results varied greatly. For example, the health effects of several contaminants including synthetic organic contaminants and volatile organic contaminants were not mentioned in the 2004 report.

To the normal everyday citizen, knowing levels of certain contaminants is useless if they do not know what the results mean, or what potential health risks may be attached to the data. A full and detailed explanation in easy to understand terms is not only essential to a Consumer Confidence Report, it is the entire reason they are distributed in the first place. Over the past five years, it would appear as though the original intent of the CCR has been lost, and it now seems that information is being excluded due to cost. This is the central problem with the current CCR report.

Land Protection Assessment

On January 15, 2006, we visited the Holden Reservoir. At the time, the conditions were snowy and provided an interesting perspective to this risk assessment. As soon as we entered the area around the reservoir, we noticed that the roads were in a less than adequate condition. It was apparent that the street was unplowed despite several inches of snow on the ground, yet a sand and salt mixture had been spread over the entire length of the reservoir. The danger of these conditions was exemplified by a truck immediately in front of our car, which was carrying a large payload including a bulldozer and various small pieces of equipment. The truck was having an extremely difficult time traveling the road, even at a speed of 15 mph. On more than one occasion, the truck appeared to lose control, slipping from one side of the road to another. Our impressions are based on a California vulnerability assessment (CDHS, 2002) and are similar to our CCR adequacy scale. They are presented below in Table 3:

Table 3. Land Protection Assessment

Criteria	Rating	Observations	Example
Proximity of Livestock and Agriculture	**3**	In our investigation of the area, there appeared to be no farms in the area whose stormwater fed directly into the reservoir. Viewing satellite imagery of the area confirmed that there were no farms for miles.	 *Figure 8. Holden Reservoir 1 and 2* Source: http://earth.google.com
Proximity or Residential Neighborhoods	**3**	While the closest residential neighborhood was within half a mile of the reservoir shore, this neighborhood was located well downhill, and its stormwater drains away from the Holden Reservoir.	
Proximity of Roads	**1**	At the Holden Reservoir, a road runs parallel to the shoreline, at times coming within 2 or 3 feet of the water itself. In addition, the road is treated with a sand/salt mixture which may reduce the reservoir water quality.	

Presence of Guardrails in Appropriate Areas	**2**	While most areas that had no natural barrier between the road and the reservoir (trees or large boulders) had guardrails, there were a few areas that had no protection, greatly increasing the chance of a car or truck slipping off the road and into the reservoir. Also, several lengths of guardrail located along Holden Reservoir 1 and the north end of Reservoir 2 were considered inadequate. These guardrails were composed of concrete spikes and cable.	
Vegetation at Shoreline	**2**	Most of the reservoir shoreline was well protected by pine trees, clearly planted and maintained by the city, judging by the complete lack of other pine trees in the surrounding area. The needles from the pine trees help to prevent erosion and filter stormwater entering the reservoir. However, there did not appear to be much planted vegetation that would assist in removing chemical contaminants.	
Use of Catch Basins/ Stormwater Management	**1**	There did not appear to be any catch basins or other man-made diversions to prevent stormwater and contaminants from entering the reservoir.	

Signage Along Roadways	**2**	Scattered along the reservoir shoreline were signs that clearly stated "No Trespassing". There did not appear to be any signs prohibiting vehicles such as oil delivery trucks from using the nearby road, or any signs warning such trucks to be cautious around the reservoir.	
Protectedness of Feeding Streams	**2**	Several streams feed into the Holden Reservoir. Most of these streams' sources can be traced to land that is protected and owned by the City of Worcester. However, all the streams cross under the roadways and most do not even have a guardrail protecting them from passing cars.	

The conditions created by the storm the night before our assessment amplified the dangers of a road that so closely parallels a reservoir. On our two trips to the Holden Reservoir, nowhere was there any signage that restricted the use of vehicles containing hazardous materials such as home heating oil delivery trucks or garbage trucks from accessing this road. Furthermore, there were no signs warning drivers to exercise caution along the stretch of road in question. Such signs or limited access could reduce the risk of a transportation accident like the oil tanker spill in Putnam Valley, New York, where 1500 gallons of heating oil entered a stream which directly fed into a reservoir. There are no houses along the Holden Reservoir road, and it would appear that its sole purpose would provide a shortcut from Tatnuck Square in Worcester to some small neighborhoods north of the reservoir.

As seen above, the guardrail system only provided an adequate level of protection to both the reservoir and the cars and trucks that travel on the road. One particular section of road as well as several stream overpasses did not have any guardrail along the reservoir, even though there were no other physical barriers protecting the waters from traffic. This inadequacy has two major implications: driver safety and public drinking water safety. Not only will the driver's life be put into jeopardy if their car falls into water, but also the water quality of the reservoir will be reduced when various harmful and toxic fluids from a car or tanker truck pollute the source water. Sections protected by old concrete spikes and cables physically prevent cars from entering the reservoir, but do nothing to lessen the force of impact and could severely damage cars or trucks, including tanks holding toxic chemicals. Such instances could result in the reservoir system's complete shutdown, or even poisoning if the instance goes unnoticed or is not properly treated.

Stormwater management around the Holden Reservoir is minimal. There appeared to be no manmade diversions preventing water from being introduced into the reservoir. While this would normally be seen as a major area of concern, Worcester owns almost all of the hillside land in question. Therefore, there is very little development that would cause runoff to become contaminated by fertilizers, livestock droppings, or septic tanks. Similarly, streams feeding into the reservoir along with their sources were very well protected by city owned land where trespassing was prohibited. Such precautions would prevent the careless dumping of used chemicals into such streams, or other incidental contamination of reservoir water.

When looking at the assessment on a macro scale, several conclusions can be drawn regarding the threat of chemical contamination around the Holden Reservoir. The two areas earning the safest ratings were the proximity of livestock and farms and the proximity of residential neighborhoods. Clearly this implies that the reservoir is far-removed from development, thanks largely in part to the quantity of land owned by the City of Worcester. However, the areas of the largest concern were mostly those involving the road which runs alongside the Holden Reservoir's shore. Signage which may alert drivers to use caution in the protected area is not present, increasing the danger of a transportation accident which could in turn contaminate the reservoir.

Effectiveness of Water Treatment

Before the water in the reservoir enters the piping distribution system, it is first cleaned at Holden Reservoir #1 by a modern treatment facility. The facility is located at the lowest point in the chain of ten reservoirs and has its water naturally flow to it via streams from the other nine reservoirs. The treatment facility is very important in preventing a contamination because contaminants may still enter into a very well protected water supply. The Holden plant began operation in 1997 and treats an average of 23 million gallons of water a day (Worcester CCR, 2004). The actual treatment of the water is a multi-step process that involves a number of different filters and chemical additives. The components of the treatment facility are presented below (2004):

- Ozonation, to disinfect and break down organic matter
- Coagulation and Flocculation, to make small particles form into large ones
- Direct Filtration, to remove particles using a coal and sand filter
- pH Adjustment with lime, to make the water less acidic and corrosive
- Disinfection with chlorine, to kill bacteria and other microorganisms
- Blended phosphate corrosion inhibitor, to reduce lead and copper

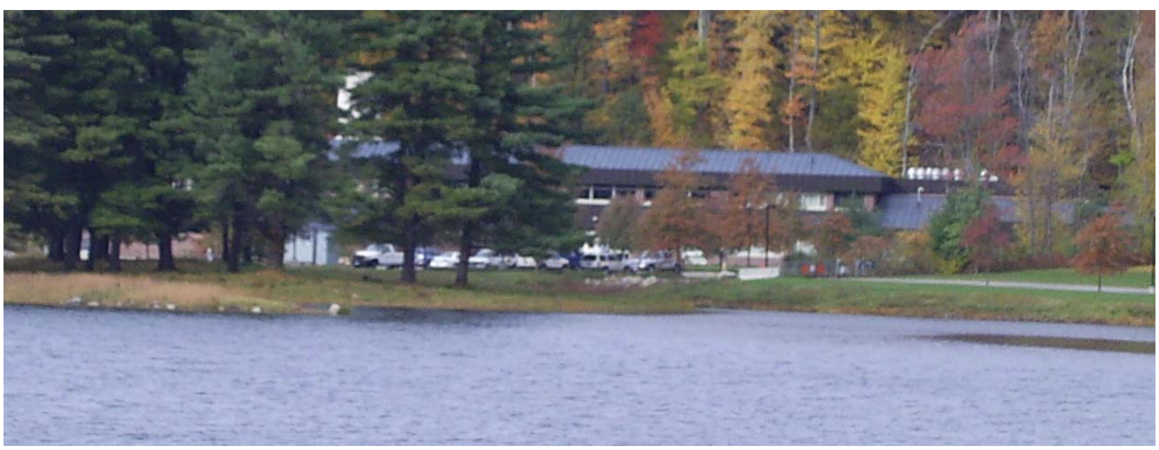

Figure 9. The Worcester DPW Treatment Facility in Holden, Massachusetts

These six components are an intricate system that takes a large employee staff to run and maintain. One initial observation is that the Worcester plant does not use any activated carbon filtration, which can be very useful in the removal of organic compounds (DeZuane, 1990). A likely explanation for its absence is that this technology is very expensive due to high maintenance costs from replacing the filters (Davis, 2004), and that Worcester has very low amounts of organic chemicals in their water from their periodic testing (Worcester CCR, 2004). Phil Guerin stated that in the event of increasing organic compound levels, the facility is able to use activated carbon filters if need be (personal communication, November 21, 2005). Thus, the risk of a long term organic chemical exposure is low due to activated carbon capabilities.

Due to the complex nature of treatment facility, and the fact that different parts of the treatment process may have an affect on other parts, an expert was interviewed to shed light on the effectiveness of the treatment facility. A transcript of this interview is available in Appendix D.

The interview with Professor Hauri provided us with guidance from which we could base our recommendations on. He suggested that from a purely chemical standpoint, the largest threat to the treatment facility would be an excess of trihalomethanes (THMs) that could form as byproducts from chlorination of organics. However, he stated that due to the late introduction of chlorine in the treatment process, the amount of THM buildup should be lowered. His opinion is similar to two studies which investigated THM minimization techniques. One American study concluded that for water utilities serving over 75,000 people, placing chlorination last in the treatment chain resulted in a decrease of total THMs by 20-70 percent (Culp, 1984). Similarly, a Canadian study found that the amount of natural organic matter (NOM) decreased with different levels of physical filtering, resulting in lower THM byproducts once the water reaches final chlorine disinfection (Canadian DEL, 1999).

Additionally, he only felt comfortable recommending the high cost of activated carbon if there was a recurring amount of organic compounds in the water. According to the 2004 Water Quality Report, Worcester has never exceeded the MCL for either volatile or synthetic organic contaminants (Worcester CCR, 2004). The high cost of activated carbon was verified by a Texas case-study which determined that out of twelve effective coagulation, disinfection, and pH adjustment techniques, activated carbon was the third most expensive (Dearmont et al., 1998). Consequently, due to the expensive nature and limited effectiveness of activated carbon filtration, we will not recommend its use in Worcester's treatment facility.

Finally, he stated that the use of real-time photometric detectors could be an effective means to increase response time to a contamination. We found a Polish study which analyzed both flow injection analysis (FIA) and sequential injection analysis (SIA) using spectrophotometric sensors to detect contaminants. The researchers found that using the automatic FIA technique alone yielded 90 percent efficiency in detecting PO_4^{-3}, NO_2^-, NO_3^-, and NH_4^+ (Pyrzynska et al., 2003). The same study found that the dual use of FIA and SIA techniques using different filter media and electrodes resulted in the detection of more complex compounds at concentrations of 15 µg/L or lower, depending on the test. These included herbicides such as 2,4-dichlorophenoxyacetic acid, toxins such as tricholoroethylene, inorganic anions such as nitrates, phosphates, and sulphates, and metals such as lead, copper, and zinc (2003). A recent Japanese study demonstrated the potential sensitivity of modern flow injection analysis techniques. By using a 4 m liquid waveguide flow cell and a photometric sensor, the author was able to successfully detect a nitrite solution with a concentration of 2 nM. The author concluded that the novel flow cell has good precision and the capability for high water throughput (Zhang, 2006). These two studies confirm that photometric sensors can detect a wide variety of contaminants and can be calibrated to be very sensitive. Therefore, they could be effective in an environment where a variety of low concentration contaminants may enter, such as the Worcester reservoirs.

Time-dependent Factors in the Statistical Predication of Water Main Breaks

After water is treated by the facility, it enters a distribution network composed of cast iron water mains. It is important to maintain the structural integrity of these pipes to ensure clean water delivery. In order to improve the current distribution system, we analyzed case studies to find new cost-effective techniques in pipe maintenance. The purpose of this was to provide a cost-effective method to predict pipe breakage therefore reducing adverse health effects and increasing the accuracy of budget planning. In 2001, a study was conducted by the Institute for Research in Construction and the National Research Council Canada titled "Considering Time-dependent Factors in the Statistical Prediction of Water Main Breaks". The study compared the total number of water main breaks to trend-lines established through four time and climate dependent criteria. The study was novel because it used time dependant criteria such as pipe age and seasonal data as opposed to static criteria in past studies such as pipe diameter and pipe composition.

The authors utilized four dynamic criteria to predict water main breakage. These variables included the following:

- Freezing Index (FI) – the effect of winter on water main structure
- Rain Deficit (RD) – the moisture content of the soil

- Water Main Replacement – the cumulative length of replaced mains (CLR)
- Cathodic Protection – the cumulative length of cathodic protection (CLCP)

These four criteria are based on raw data that can be collected easily in real time and software is in development to calculate the model.

The final element in the piping analysis is the time component which is modeled through a time exponential model:

$$N(x) = N(x_0)e^{ax^T} \quad (1)$$

Variable ‘x’ is the vector of time-dependent variables (FI, RD, CLR and CLCP), N(x) is the number of breaks resulting from ‘x’, ‘x_0’ and ‘a’ are constants computed from pre-existing data and T is time.

Although the time data were collected annually, the starting month of data collection used during the year was usually restricted to one season (usually spring) in order to capture the effect of a cold winter on breakage rates. The final piece of information used to construct the model is piping material. These data were only applicable to one city studied because there were a significant number of Asbestos-Cement (AC) pipes in addition to the Cast Iron (CI) pipes. That information is used to distinguish the CI piping trend line from the AC trend line.

This study was conducted to provide a single mathematical model that can be used to calculate water main breakage rates based on time dependent criteria. Previous models were either devoted to static factors such as pipe diameter and composition (Kettler, 1985) or were devoted to only one time-dependent criterion under specific conditions such as frost loads (Rajani, 1996). This prediction model has been shown to be effective in prediction of pipe breakage rates.

*Adelaide, Australia***:** The period studied was from 1985 to 1994. The model omitted FI because the temperatures never dropped below 0° C and it omitted CLR and CLCP because there were no programs implemented to replace or protect water mains during this period. The range of the period of study was from January to December due to the warm climate. Finally, this was the only city to have a significant number of AC pipes and data available on their breakage rates. A separate trend line was calculated for the AC pipes.

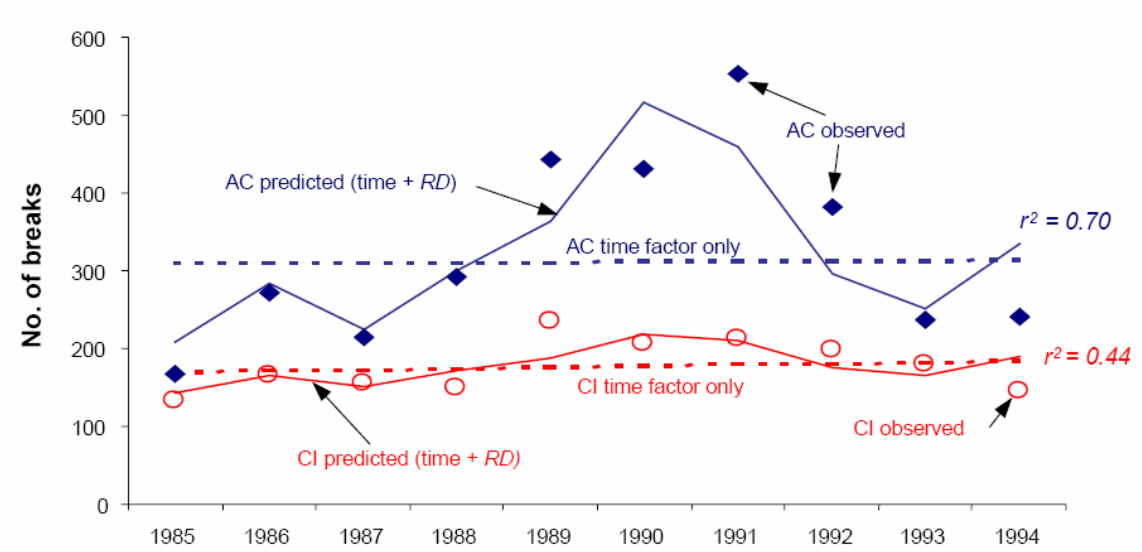

Figure 10. Adelaide, Australia Breakage Rates from 1985 to 1994
Source: Kleiner, et al., 2000.

Ottawa, Ontario: The period studied was from 1973 to 1998. This model did not omit any criteria. CLR and CLCP data were included due to the implementation of replacement and protection programs. The range of this period of study was from May to April due to the higher breakage rates at the end of every winter.

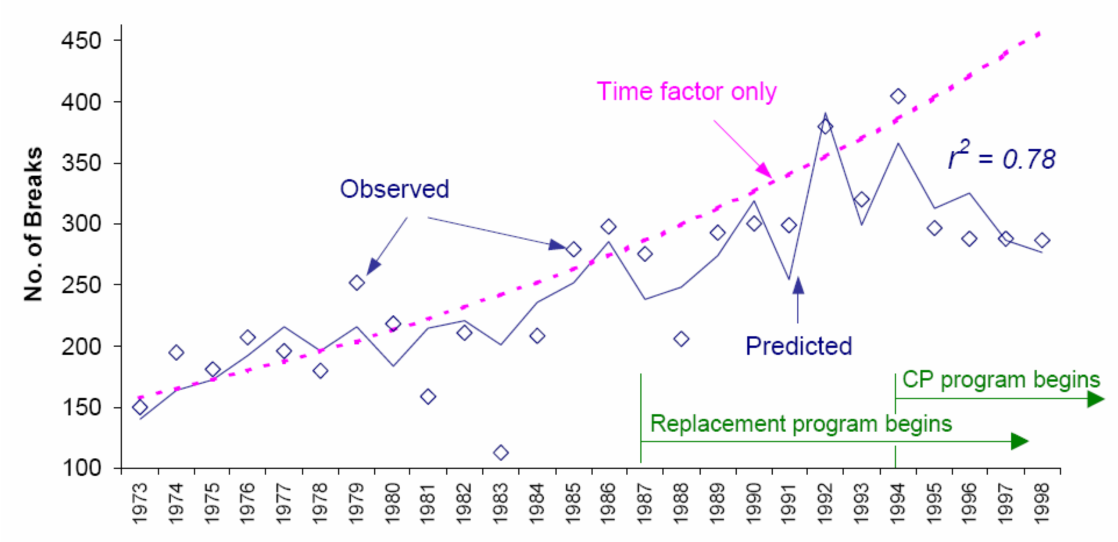

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Figure 11. Ottawa, Ontario Breakage Rates from 1973 to 1998
Source: Kleiner et al., 2000.

*Edmonton, Alberta***:** The period studied was from 1961 to 1998. This model omitted CLCP data because during this period there were no programs implemented to protect pipes. CLR data were included due to the implementation of a replacement program. The range of this period of study was from January to December because monthly breakage rates were not available, only annual breakage rates.

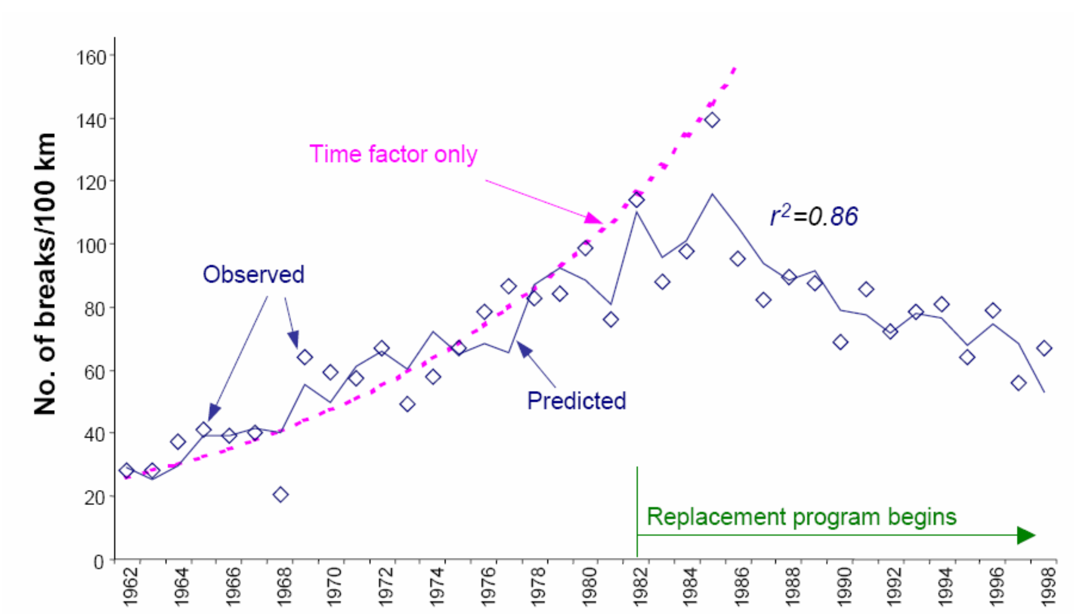


Figure 12. Edmonton, Alberta Breakage Rates from 1961 to 1998
Source: Kleiner et al., 2000.

The three cities produced a broad range of r^2 values for the time exponential model used. Since all studies contained CI pipes, the AC water main model in Adelaide, Australia will be ignored. The city of Adelaide, Australia did not have as strong a correlation between the predicted number of water main breaks and the observed water main breaks. With an r^2 of 0.44, the prediction was much weaker than in Ottawa (r^2 = 0.78) and Edmonton (r^2 = 0.86). The smaller time frame and resulting smaller data set compromised the statistical significance of the trend lines. It may be inferred that the FI has the strongest impact on water main breaks and should always be included in any statistical model of water main breaks. The r^2 values for Ottawa and Edmonton are large enough to confirm that the model used is reasonably accurate in predicting pipe breakage rates.

Quantifying the Effectiveness of Cathodic Protection in Water Mains

In 2002, a study was conducted by the Institute for Research in Construction and the National Research Council Canada titled "Quantifying the Effectiveness of Cathodic Protection in Water Mains". The study analyzed two different systems of Cathodic Protection implemented in Eastern and Southern Ontario water utilities. The study used a life cycle water main cost analysis to justify the implementation of these systems.

To begin, the type of cathodic protection used in most water distribution systems is a sacrificial anode system. This method involves electrically attaching a metal with a higher conductivity than Cast Iron (CI) to a CI pipe it protects. The anode is buried in close proximity to the water main and is electrically connected via a wire to the underground water main. With the soil acting as an electrolyte, the magnesium anode develops a more negative electrical potential than the water main. The result of this potential difference is that the water main ceases to corrode and the anode begins to corrode. After about 15 years, the anode has completely disintegrated and corrosion begins again on the CI water main.

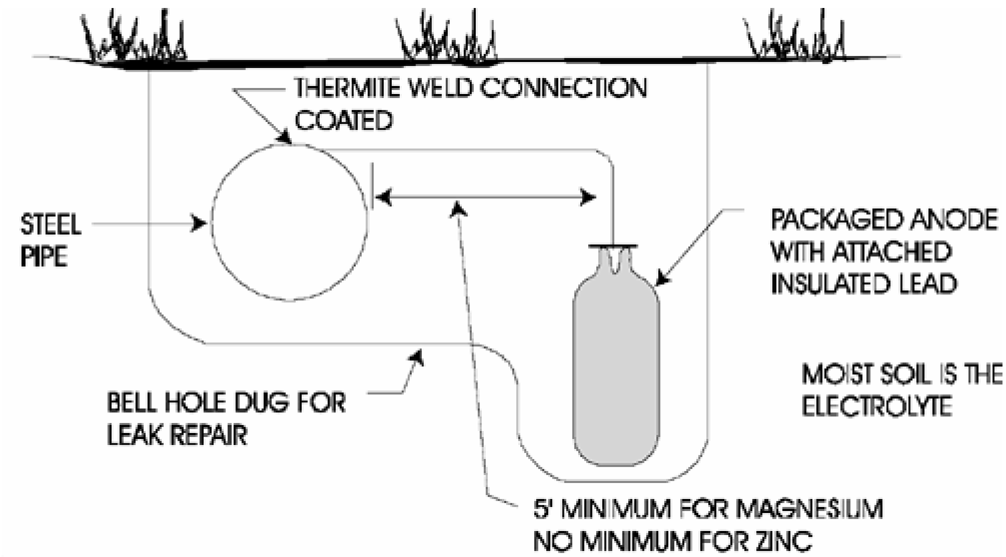


Figure 13. Sacrificial Anode Cathodic Protection
Source: Office of Pipeline Safety, 2006

The two systems used were Hot Spot (HS) protection and Retrofit protection. The anode in these systems is usually magnesium and typically a 32 pound anode is used to protect a 20 foot length of pipe. The HS system involves attaching a sacrificial anode whenever there is a water main break and repair. The purpose is to counteract electrical "hotspots" where stray currents may be more abundant and cause a more rapid disintegration of the pipe. When the anode protects the extended length of pipe, the breakage rates in that area will go down considerably because the hotspot has been neutralized. Once the anode is completely deteriorated it is not replaced and corrosion of the water main begins again.

Retrofit protection involves a systematic placing of sacrificial anodes at locations along the distribution network that are at an age where cathodic protection would produce the greatest benefit to cost. This type of protection has a transitional period of several years during which water mains will continue to break at normal rates. This is due to the most deteriorated pipes breaking because of their previously weakened state. After this period ends, the remaining water mains drop significantly in breakage rates. The protection continues until the sacrificial anodes are completely deteriorated. They are replaced immediately to ensure continued corrosion protection.

Both systems have a lag time of one year before the corrosion stops completely on the CI pipe. The sacrificial anode system only protects the exterior of the water main.

Hot Spot Protection Study: The water utility that implemented a HS protection system is located in Eastern Ontario. The total length of piping was 634 km of CI water mains ranging from six to twelve inches diameter. The piping was installed between 1946 and 1970 and the protection program was implemented in 1990. Every water main breakage repair was followed by an installation of a 32 pound magnesium anode.

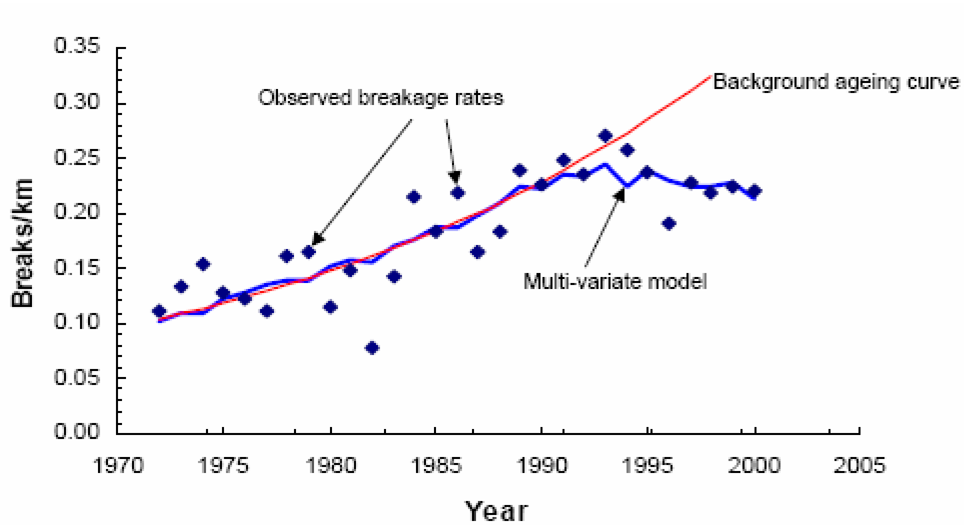


Figure 14. CI Pipe Breakage Rates Following Implementation of HS Protection
Source: Kleiner et al., 2002

There is a clear drop in breakage rates following the HS protection program in Figure 14. An economic model can be constructed given the cost of one breakage event is estimated to be $5000 and the installation cost of one HS anode was taken as $300.

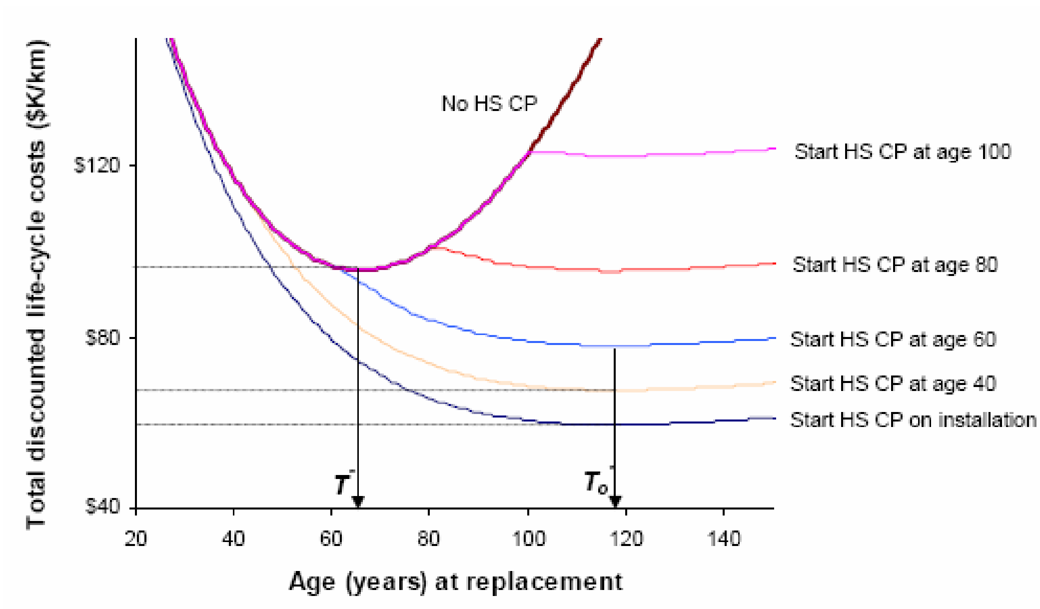


Figure 15. Effect of HS Protection on Life-Cycle Costs of Water Mains
Source: Kleiner et al., 2002.

The cost of replacement pipe was estimated to be 300,000 dollars per kilometer. The optimum time for HS protection placement is 67 years, meaning if the pipe breaks when it is 67 years old, the benefit to cost will be maximized. If the pipe breaks at 40 years, the total cost would be less but the HS protection would have less of an impact then on a 67 year old pipe. If the pipe breaks several decades after the 67 year peak, there is very little savings because the pipe is already in a much weakened state and will not benefit from cathodic protection.

Retrofit Protection Study: The water utility that implemented a Retrofit protection system is located in Southern Ontario. The total length of piping is 86 km of CI water mains ranging from six to twelve inches diameter. The piping was installed between 1970 and 1987. Table 4.4 describes the number of pipes fitted over a period of 27 years.

Table 4. Percentage of Pipes Fitted for Protection from 1970 to 1997
Source: Kleiner et al., 2002.

1970-1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
0.0%	1.5%	3.7%	1.2%	5.2%	1.1%	4.2%	4.1%	6.2%	3.5%	2.3%	0.0%	0.7%	1.9%	0.0%

The total percentage of pipes fitted for protection by 1997 is 35.6 percent.

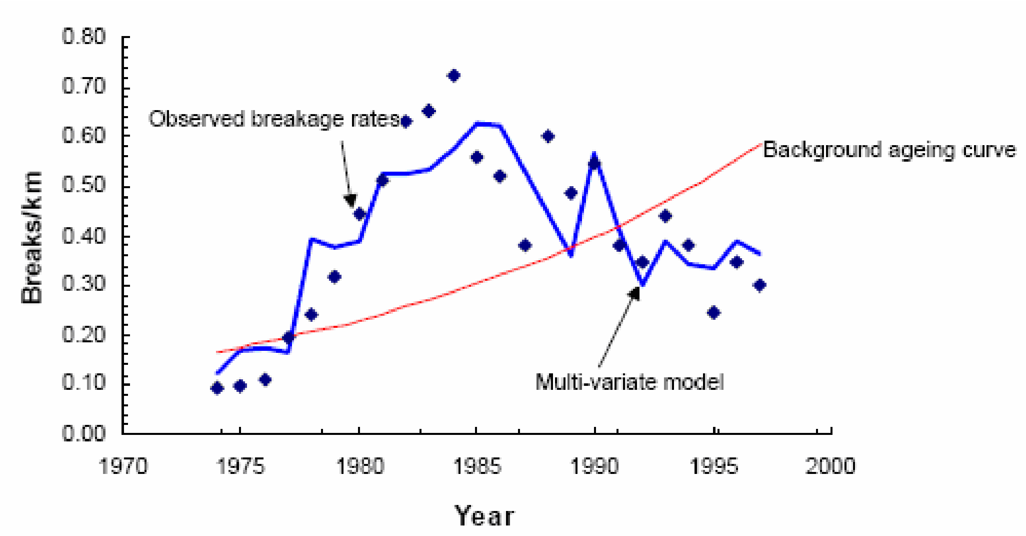


Figure 16. Breakage Rates Following Implementation of Retrofit Program
Source: Kleiner et al., 2002.

The visible benefits of the Retrofit program were not evident until 1985, as seen in Figure 16. An economic model can be constructed given the cost data from above. The cost of Retrofit is $30,000 per kilometer including the cost to replace the anodes.

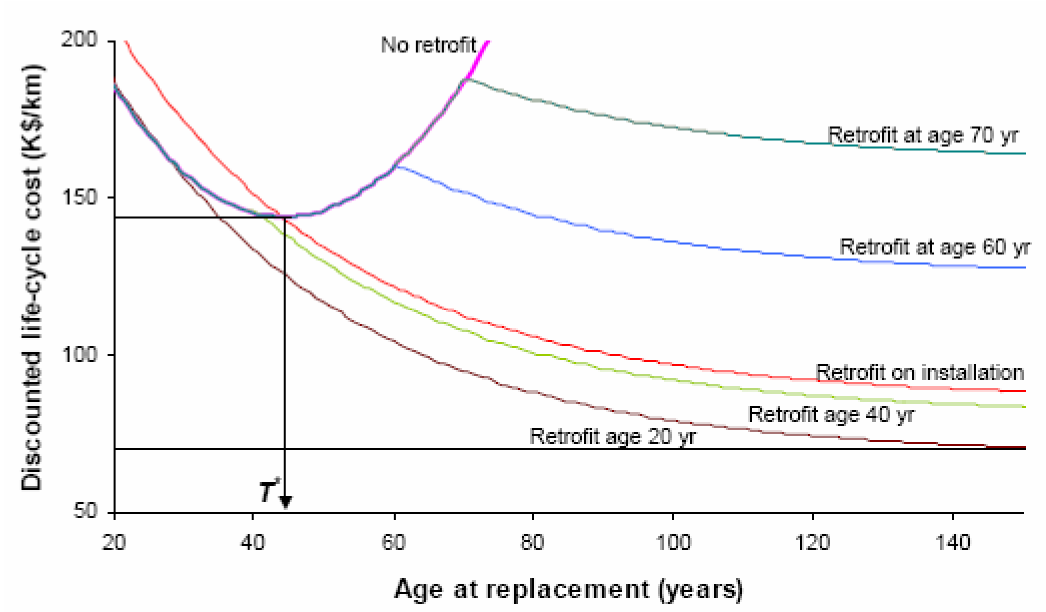


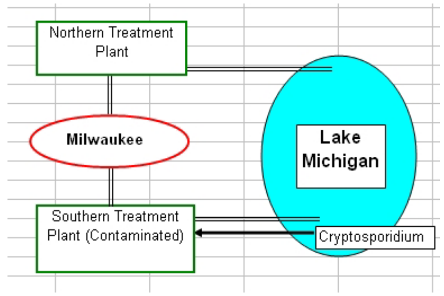
Figure 17. Effect of Retrofit Protection on Life-Cycle Costs of Water Mains
Source: Kleiner et al., 2002.

The pipe age which offered the best cost to benefit ratio is 44 years. Additionally, it would extend the life of the pipe to around 150 years. Retrofitting earlier would provide little benefit because corrosion does not have as strong an impact on pipe integrity early in the pipe age. The life of the pipe would still be extended to around 150 years. Retrofitting after the 44 year peak does have significant advantages because unlike HS fitting, this form of protection is continued indefinitely. The economic benefits of a retrofit program in Worcester are discussed in the Conclusions and Recommendations chapter.

Analysis of Emergency Response Case Studies

In the event of a chemical contamination, response time is critical to reduce the risk to public health. It is important to develop a detailed plan of action to counteract the spread of illness and panic. According to Phil Guerin Worcester's emergency response plan is private information for security reasons, and therefore cannot be directly analyzed (personal communication, November 21, 2005). However, in order to provide recommendations that a strong plan should include, we analyzed case studies to determine what typically may go wrong in an actual emergency scenario. These case studies included the cryptosporidium outbreak in Milwaukee and a more localized cryptosporidium outbreak in a small Florida community. While these were not chemical contaminations, the lessons learned from these incidents are valuable to our discussion.

Milwaukee, WI: During the spring of 1993, the previously clean reputation of Milwaukee's drinking water was shattered by an outbreak of cryptosporidium. While the protist parasite was not originally suspected, it quickly became the most likely cause within one or two days. This was due to the consumer complaints, increased absenteeism from places of work, and from greatly increased sales of diarrhea medications at drug stores and supermarkets. Unfortunately, by the time the Milwaukee Health Department was able to isolate the cause of the illness as being a parasite in the drinking water, too many people with weak immune systems had already consumed the water. As a result, over 400,000 people were infected with the parasite, contributing to the death of 100 people and loss of approximately $54 million. What is particularly disheartening about this tragedy is the fact that the response time could have been much faster with continuous turbidity monitors, which were installed after the outbreak (Blair, 1995).



Milwaukee Cryptosporidium Response Timeline - Starting on April 5, 1993

Outbreak	Data collected	Action	Shut down		Reopening		Analysis
Day 0	Day 1	Day 2	Day 3	-----	Day 10	-----	Day 14
Initially detected by phone calls, increased absenteism, and increased sales of diarrhea medications	Information was gathered and possible source was identified	Lab tests performed on infected persons; mayor issued a "boil water" order	Southern treatment plant was shut down and replaced with emergency water		One week was used to incubate and kill the cryptosp.; then plant was reopened		Engineering firm completed overhaul recommen-dations to improve treatment facility

Figure 18. Historical response timeline of Milwaukee Health Department to cryptosporidium outbreak in 1993[2]

[2] Blair, Kathleen. MS. Drinking Water and Health Newsletter, City of Milwaukee Health Department. Milwaukee, 1995.

There are several emergency response lessons that can be learned from the Milwaukee cryptosporidium outbreak. Perhaps the most important lesson is that early detection is critical to minimizing harm. Fortunately, the Worcester drinking water facility has real-time turbidity monitors that help identify cryptosporidium outbreaks. Additionally, feedback from the public is important, especially to determine if a contamination has occured if the treatment facility does not detect one itself. It is necessary to maintain open communication with both the public and pharmacies to help detect a contamination as early as possible.

In addition to the importance of rapid detection, another important lesson from the Milwaukee case is the necessity of a fast and reliable method to test infected patients. For example, if the Milwaukee lab had taken several days to isolate the cause, then possibly many more people would have consumed the contaminated water before the treatment plant was closed down. Similar to early detection, communication and availability of able workers is very important in this case. Furthermore, a reliable method to instruct water consumers is necessary in case orders such as “boil water” need to be conveyed to them. A specific type of order may be particularly important for the different types of contaminations that may have different containment procedures. Finally, a secondary emergency water source is important to provide water to citizens while the contamination is being contained. Fortunately, the entire Worcester County is under contract with the MWRA to be provided with water in the event of a drinking water emergency.

In summary, the Milwaukee cryptosporidium outbreak demonstrated the necessity for public water utilities to have the following guidelines:

- Maintain open communication with public and marketplaces that sell health medications
- Fast and accurate lab testing is important
- Have an emergency water source available

Alachua County, FL: On July 27, 1995, an outbreak of Cryptosporidium in a summer day camp was reported in the Alachua County Elementary School in Florida by the local health department (Regan et al., 1998). The cause of the outbreak was completely unknown at the time, but initial speculations led people to believe it could have originated at either source water or a cross connection in the school's plumbing. In order to pinpoint the cause and to prevent further harm, the health department notified Gainesville Regional Utilities (GRU), the public department responsible for the delivery of the school's water.

After initial meetings with public health officials and the school board, a well-planned emergency procedure was executed by GRU in order to prevent further outbreak and to locate the source of the contamination (Regan et al., 1998). This procedure was a systematic approach to deduce the actual cause of the outbreak, while at the same time assuring that the proper safety precautions were followed. The procedure can be broken into two large components: 1) decontamination and prevention and 2) communication. Below are the two flow charts for these processes.

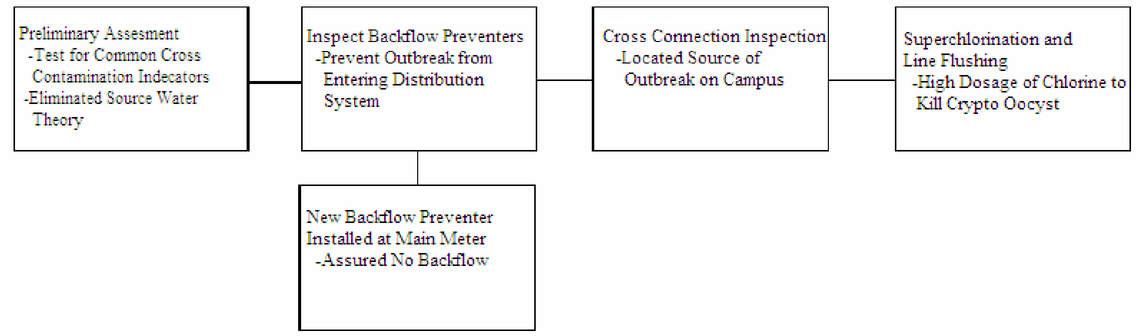


Figure 19. Decontamination and Prevention Procedure, Alachua Co., FL
Source: Regan et al., 1998.

In order to determine where the contamination occurred, the GRU immediately began to run tests on potential sources. While this was happening, the entire water system was shut down within the school, and backflow preventers were inspected to ensure no water from the school's system was entering the public distribution system. A new backflow preventer was installed at the school's main meter to quarantine the school from the public drinking water system. One system located from a garbage can washing unit was found to be defective. This was also the same cooler that students had drawn water to fill their coolers. Sampling confirmed this as the sole point of contamination, and the school's water system was superchlorinated and flushed to kill all Cryptosporidium.

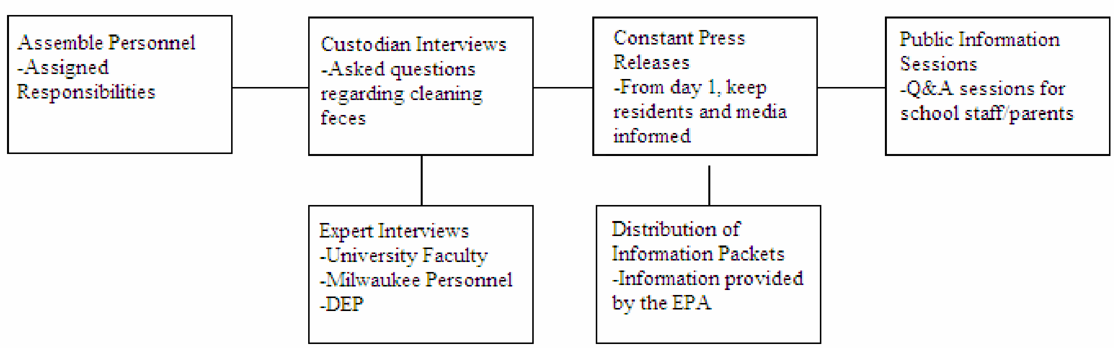


Figure 20. Communication Procedure, Alachua Co., FL
Source: Regan et al., 1998.

While the procedure was being implemented, a very strong line of communication was established. Initially, all personnel were briefed and given their responsibilities. Next, interviews with custodians were conducted to determine if they noticed anything unusual before the contamination. This would prove to be invaluable, as one of the custodians noticed the presence of feces around the garbage can washing unit. This led officials to test the area for cross contamination, finding the cause in very little time. Expert help was also consulted from nearby universities, personnel from the Milwaukee, WI incident, as well as the Department of Environmental Protection (DEP). The DEP was a valuable resource and provided ideas to clean the contamination site with the least environmental impact. Also, from the first day, the GRU issued a press release discussing what they knew, and what they were doing to fix the problem. Also, information packets were distributed to citizens in the area containing health information and advice provided by the EPA. Finally, public information workshops provided concerned parents and staff of the school with a question and answer seminar.

Due to the quick and well-planned action by Gainesville Regional Utilities, a larger scale incident and further contamination was prevented in a timely and efficient manner. Using a systematic approach with deductive reasoning and the input of groundskeepers and custodians, the root cause of the contamination was determined in short time. With the assistance of experts, the entire procedure was done in the most efficient and safest manner possible.

The entire key to GRU's operation was an excellent line of communication. For example, by opening the floor for communication with citizens in the area, a level of panic that was seen in the Milwaukee incident was completely avoided. Additionally, by keeping news and media outlets informed, GRU was able to portray a calm demeanor as well as an assuring confidence to remedy the situation. Gainesville Regional Utilities demonstrated the confidence of a previously constructed emergency procedure, providing a textbook example of how drinking water emergencies should be handled.

Worcester Department of Public Works 2005 Budget Overview

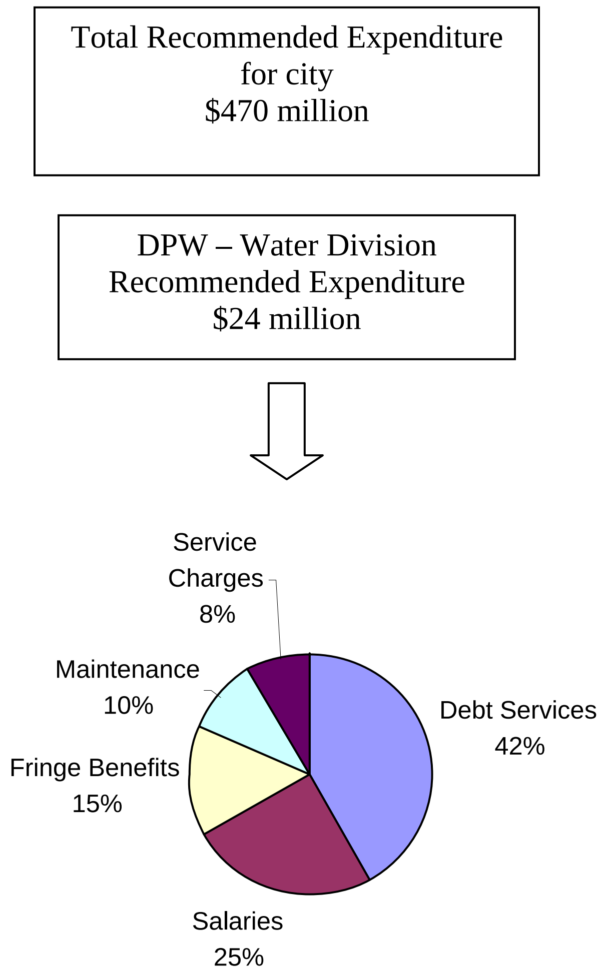


Figure 21. Budget breakdown of Worcester Department of Public Works
Source: Moylan, 2005.

Figure 21 above is a visual representation of the percentage of funds that Worcester spends on its water division each year. The total annual salary of $6 million including overtime is divided amongst 131 total positions, averaging $39,000. The 131 Water Division employees include four security guards and one senior security guard.

The three central financial strains on any water utility are compliance with the Safe Drinking Water Act and EPA regulations, the need to replace aging components, and the need to meet water demand from an increase in developmental growth (Beecher, Mann, and Stanford, 1993). To pay for this expenditure, Worcester sells its water on a per volume basis. The principle buyers of the water are Worcester citizens, with only a very small amount of water sold to outside towns. The water rate for in-city users is $0.31 per 100 gallons and $0.42 per 100 gallons for out of town users. Using a typical annual consumption of 90,000 gallons, this translates into $286 per year for Worcester citizens (Tighe & Bond, 2004).

The revenue generated from the sale of water helps pay for 99.4 percent of the expenditure costs for the water division. Due to the very high percentage of funding coming from water sales, it seems likely that Worcester bases its budget for the water department of the DPW on the amount of water sold. With respect to vulnerability of the water system, there are two main concerns with the water budget: the quantity of revenue for adequate protection and the stability of the source of that revenue.

The question of whether or not the amount of funds is adequate can be answered in multiple ways. As stated in Figure 21, the Worcester DPW's Water Division receives approximately $24 million per year for all expenses. As we have seen with the previous analysis of the amount of EPA health and monitoring violations, the Worcester DPW prevents contaminations very well. The number of health violations over the past twelve years was low in comparison to similar Massachusetts towns, and on this basis it can be concluded that the $24 million has been adequate in the past. Additionally, the same is true for the amount of monitoring and reporting violations, which were both in the low-middle bracket for similar Massachusetts towns. With respect to EPA regulations, the amount of money the Water Department spends is certainly adequate. Thus, the vulnerability of the water system to an incidental contamination due to a lack of funding is low with the current budget.

Another way to assess the effectiveness of the water budget is to analyze the accomplishments of the Water Department. In the 2004 fiscal year, the Water Department listed six accomplishments. These have been summarized below in Table 5:

Table 5. Worcester DPW Water Division Fiscal 2004 Accomplishments

Accomplishment	Description
Rehabilitation of Water Mains	Approximately 1 mile of water mains cleaned and cement lined (0.2% of total); approximately 4 miles of “older” water mains replaced; additional 1 mile of new public water mains installed
Lead Detection Survey and Water Accountability	Over ½ of the distribution system was surveyed for leaks and 65 leaks were found and repaired; this saved 373,000 gallons of water per day which equates to over $400,000 annually
Water Quality	The water complied with all state and federal (EPA) regulations
Water Quality Reports	The 2003 Consumer Confidence Report was prepared and distributed to all water consumers
Hydrant Flushing Program	Crews flushed 150 hydrants and operated 20 gates. The purpose of this is to improve water quality in the system and to provide information about the water main conditions and hydrant operations; however, “due to a lack of available staff no flushing was completed in the fall of 2003 and the program was drastically curtailed in the spring of 2004. Thus, only 12% of the goal of 1200 hydrants per year was achieved”.
Water Analysis	The filtration plant laboratory analyzed 3,776 water samples from throughout Worcester’s water system from a variety of sources, including: water from reservoirs and tributaries, treated water from taps, construction samples taken after installation of new water mains, samples in response to customer complaints and samples taken under a new water quality monitoring program instituted under heightened security.

The majority of these accomplishments in Table 5 show that the funds are being used effectively. For example, collecting and analyzing almost 4,000 water samples is certainly not a small undertaking. However, there is one program in particular that could perhaps benefit from additional funding. The “Hydrant Flushing Program” is an important component of the Water Division’s maintenance because it not only ensures that the fire hydrants are operating properly but also helps remove excess particles that line the water pipes. If too much material builds up inside the water mains, the water quality decreases. Furthermore, the pressure in the pipes increases, which may lead to a leak or burst. It is very important to continually flush the hydrants to ensure accessible water in the event of a fire and to ensure clean water to citizens.

Unfortunately, the Water Division was only able to flush 12 percent of the target 1200 hydrants during the 2004 fiscal year. The reasoning for this was due to a lack of available staff. There seem to be two likely causes of this: either no extra staff or contractors were called for, or no extra money could be spared to hire extra contractors to do the work. On the whole, the amount of funds to the Water Division allows them complete most of their maintenance objectives. They have been able to keep the number of EPA health and monitoring violations low and have been able to complete special requirements such as water analysis, leak detection, and rehabilitation of water mains. Therefore, the vulnerability of the water system to a contamination from a lack of funding is low.

The other main concern with the water budget is stability. The above analysis of the vulnerability of the water system from a budgeting perspective assumes that the source of the funding remains constant. As stated earlier, 99.4 percent of Water Division’s budget comes from consumer fees for water. While it may seem that this is a very secure method of obtaining funds at first, it is important to establish the stability of these methods. Without a consistent source of funds, the Water Division would either have to borrow funds from another source or would be significantly impaired.

The fees that the Water Division charges for water services are on a per-volume basis and not based on a one time annual fee. This method of service makes sense, particularly in a large city such as Worcester that may have commercial or industrial users drawing more water than a homeowner. Therefore, the two variables that determine how much revenue the Water Division obtains are the number of water consumers and the amount of water that the consumers use.

Since Worcester is a heavily college affiliated town, much of its revenue comes from the water use from these schools. In an interview with the Water Division's head Phil Guerin, he described how the summer tends to strain the Water Division's budget due to the large decrease in students (personal communication, November 21, 2005). However, this decrease is well calculated in advance and the fees to consumers include this expected drop in revenue. The other zones in Worcester, the residential, commercial, and industrial areas, also decrease somewhat in the summer, but do not contribute nearly as much as the impact from the decrease in college students.

Another possible threat to the revenue of the Water Division is a particularly "wet" summer with a large amount of precipitation. This is damaging to the water budget because consumers will use less water on things such as watering their lawns. Unfortunately, the most accurate way to avoid losing money is to refer to past precipitation data and to predict the amount of rain for the next year. As long as Worcester's budget planners err on the side of too much rain instead of too little, this should not be a large problem. Therefore, while an excess of rain may reduce the amount of total funds, it is possible to appropriately compensate in advance. This avoids the need for loans that would drive the Water Division further into debt.

With this in mind, it is possible to conclude that the amount of funds is adequate to run the water system well and the source of the funds is stable. Therefore, the vulnerability that an incidental contamination will occur due to budgeting problems is low. Since the Worcester Water Division is self contained, utilizes a modern treatment facility, and does not rely on outside sources, the likelihood that the Water Division to fall into debt is remote (Wirick, Borrows, and Goldberg, 1997). Even more remote is the possibility that the Water Division will end up bankrupt from not being able to pay off these debts, especially when there are a large number of emergency funds available (1997). However, this does not mean that the Water Division will not benefit from additional funding to help pay for new programs that will further reduce the risk of a contamination.

In addition to analyzing the vulnerability of the water budget, we also investigated methods to help pay for the additional expenses of our recommendations. One method to increase the water division's revenue is to simply increase the water price. This is not an uncommon practice for the Worcester water division; between fiscal 2004 and 2005, the price of water increased by 8 percent (Moylan, 2005). This should be considered the least desirable option, because ideally changes should be made without increasing costs to existing consumers. Additionally, increasing the water price may have political resistance and may not be an option at all.

Instead, the method that we recommend to fund new projects is to use water efficiently. In short, water efficiency saves money because a lower water demand costs less to treat, costs less to distribute, and helps to avoid costly infrastructure upgrades (Gleick, 1998; EPAa, 2003). Maximizing this effect takes efforts from both the public and from the utility. Studies have shown that water efficiency can be increased by implementing the following two low-cost ideas: offer very low cost water-efficient shower heads to consumers, and develop a water efficiency education program. Specific information about these programs is provided below.

An effective method to reduce the water demand by Worcester consumers is to offer an inexpensive and easy way to minimize residential water use. This can be accomplished by providing water efficient shower heads to consumers at no cost to them. New low-flow shower heads are easy to install, and it is estimated that the average American household could save up to 20,000 gallons per year by switching to low-flow showerheads (EPAa, 2003).

As an example of the cost-benefit properties of installing efficient showerheads, consider the following three case studies. An apartment building in New England was completely refurbished with low-flow shower heads for an initial cost of $1,074. As a result, 1,750,000 gallons of water, $8,500 for energy, and $980 for water were saved in one year (EPAb, 2003). A similar program was implemented in Marble Falls, Texas, where public houses were retrofitted with new low-flow shower heads. This resulted in an 11 percent decrease in water use per capita (EPAb, 2003). Furthermore, a residential water conservation study in Seattle, Washington, found that the use of new water-efficient appliances including shower heads reduced average water consumption per capita by 43 percent (DeOreo, 2001). These studies show that shower heads are very effective in reducing water use in a residential setting.

If low-flow shower head use becomes widespread, not only would consumers save money, but Worcester's water department could as well. Over time, this will occur due to increasing water efficiency in the city, leading to the reduction of cost to treat water, implement new infrastructure, and repair old infrastructure.

Another low-cost method to conserve water is to develop a water-efficiency education program. The program should provide consumers with information about water efficiency and should promote the use of water-efficient appliances, like water aerators and low-water washing machines. Additionally, it should promote water-saving practices, like covering pools and not letting the water run when it is not necessary. To do this, the Worcester DPW could have water efficiency programs in the city schools (similar to the D.A.R.E. program), could use displays encouraging water conservation, and could have periodic public speaking programs about the importance of water conservation. A similar education program was implemented in Houston, where for every dollar invested in the program, $3.70 was saved from smarter water use (EPAa, 2003).

This education program must not be done haphazardly, however. An attempt to educate the public in Nova Scotia on the benefits of water use was largely unsuccessful, in part due to the low funding for the project (Machat, 1996). They offered different water-saving appliances to consumers at one-third of their normal cost, but were initially largely rejected by the public because of unwillingness to upgrade (1996). Through education about the benefits of water conservation to both consumers and the water utilities, the discounted water appliances were eventually sold. The budget used for their education program was $30,000, but more money may be necessary to ensure success.

The above two programs will save money in the long term, but require initial investments. Fortunately, there are very-low to zero interest loans available for these types of water conservation projects. The Drinking Water State Revolving Fund (DWSRF) may be used for the distribution of water-efficient appliances like low-flow shower heads, and the Clean Water State Revolving Fund (CWSRF) may be used to fund water efficiency education programs (EPAa, 2003). Therefore, there is an opportunity to implement these conservation ideas without impacting the current water budget.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Based on data collected throughout the course of this project, Figure 22 is a representation of the overall urgency in which each area of vulnerability should be improved upon:

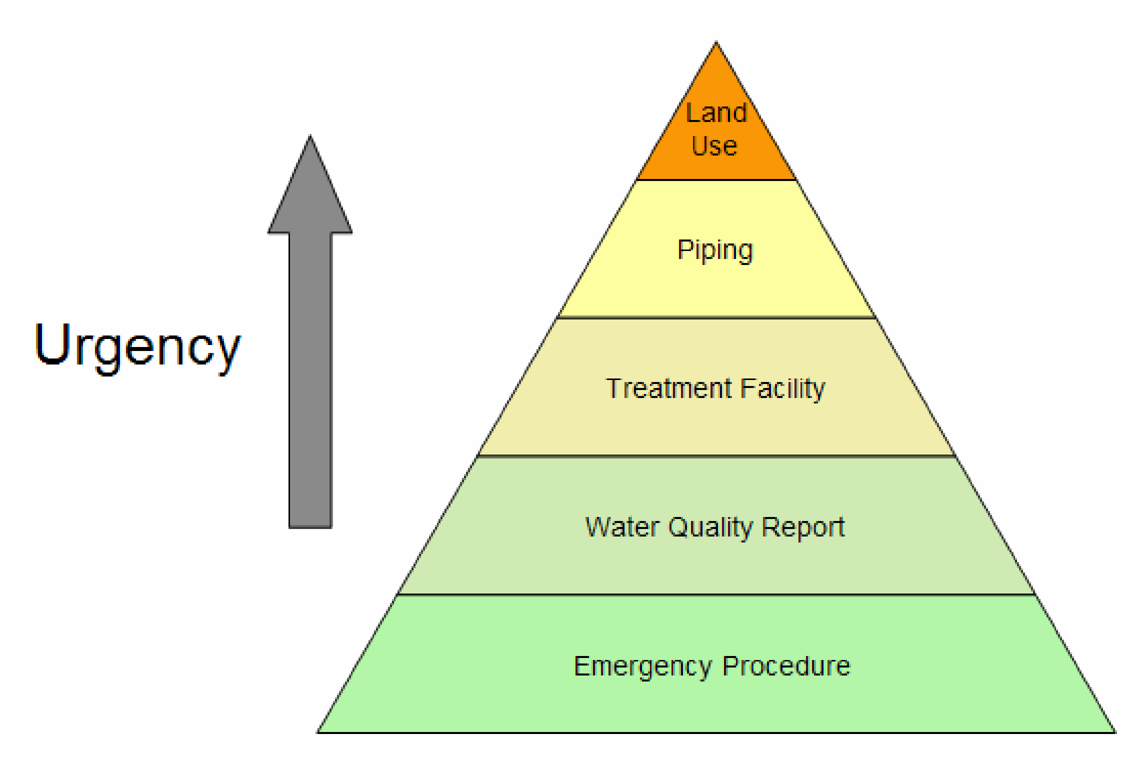


Figure 22. Recommended areas of improvement ranked from most to least urgent

The direct exposure of open water sources to their surroundings coupled with a questionable land use policy gave land use and protection the highest level of vulnerability in our findings. This however should not undermine the importance of the other areas, and is only a ranking of priority. Based on this hierarchy of urgency as well as a realistic understanding of budget and financial concerns, we have made recommendations for Worcester city officials to consider to improve the overall state of the City of Worcester's public water system.

Recommendations for Land Protection

According to the City of Worcester's annual Consumer Confidence Report (2004), the first barrier to having clean drinking water is clean source water that is well protected. While Worcester owns much land within the watershed, gaining control of land is an ongoing battle. In order to maintain clean source water, the City of Worcester must continue in its pursuit to control the land around all ten of its reservoirs, as well as any streams that may feed into them, in order to prevent development in these areas. Unfortunately, purchasing such vast amounts of land is extremely expensive, and will increase the Water Department's debt. In order to continue purchasing new land, recommendations will be made in a later section regarding budget.

While buying land may be the best way to protect a reservoir, based on our results, there are other ways to ensure that our tap water is safe to drink. For example, one of the major weaknesses found in our land protection assessment was the absence of proper signage. Currently, there is little to no need for any vehicles to travel Reservoir St. by the Holden Reservoir. However, access to this road is not restricted or limited. While removing all traffic from this road will most certainly cause public backlash, access should be limited strictly to passenger vehicles on all roads with direct contact with a reservoir. This would prevent larger trucks such as chemical and oil tankers from using the road, thus eliminating the fear of a chemical spill along the reservoir's shores. According to Richard C. Moeur, Professional Traffic Engineer (2006), the cost of the proper signage is slightly over $400 per sign, including labor. The placement of these signs at the few areas described above is a simple and affordable solution to one of the greatest concerns posed by our land protection assessment.

Another improvement that could be made around Worcester's reservoirs is upgrading certain lengths of guardrails. Currently, outdated guardrails made of concrete and cables do little to protect drivers or the reservoir from danger. Therefore, for these sections, replacing cables will not only protect travelers along these roads, but anyone who drinks Worcester's city water as well. Similarly, there are a few sections of roadway that offer no barrier between the road and reservoir, including open stretches of roadway and stream crossovers described in the land protection assessment. In order to promote proper public safety and health, guardrails must also be placed in these locations. According to Margaret Rys and Eugene Russell of Kansas State (1997), the estimated cost of replacing these guardrails would be $82.50 per meter, labor included.

Even though the watershed around the Holden Reservoir was fairly protected from residential neighborhoods and farmland, areas that are not currently owned by the City of Worcester and roads along the reservoir pose particular concern to the threat of contamination. While it is apparent Worcester has a plan for the purchase of such key areas, there are innovative methods to act as a "barrier" for potential contaminants. One of such barriers that we recommend Worcester investigates is biofiltration for stormwater runoff.

Filter strips are areas of land designed to slow the flow of water with the use of densely planted vegetation (Ad Hoc Committee Members, 2002). The major advantage to this system is its ability to remove pollutants from stormwater due to the deep root structure of the grasses used in filter strips (Shaw et al., 2003). The deep roots slow the flow of stormwater, allowing for natural microbial degradation of contaminants to occur. In addition, the mechanism of adsorption within the root structure has been proven to intercept and trap chemicals such as pesticides, preventing them from entering a river, lake, or stream (Ad Hoc Committee Members, 2002).

The use of filter strips is growing throughout the United States, recently used by private farms in Wisconsin to prevent fertilizers and livestock waste from entering environmentally sensitive areas (Ad Hoc Committee Members, 2002). In addition, studies of filter strips on highway edges have shown that after less than five meters of strip length, total suspended solids (which includes toxic and harmful contaminants to any water source) were reduced from dangerous levels of 119 mg/L to a mere 20 mg/L (California Stormwater Quality Association, 2003). The cost of filter strips is almost exclusively the cost of seed or sod for the grass material, ranging from \$0.30/ft^2 for seed to \$0.75/ft^2 for sod, and a \$350/acre-year maintenance cost for mowing and trash removal (California Stormwater Quality Association, 2003). If seed was used for planting, a ten foot length filter strip would cost approximately \$16,000/perimeter mile. If this cost is of concern to the Worcester Water Department, filter strips could be installed only in areas where a high amount of suspended solids have the potential for entering the reservoirs, including areas running parallel to roadways.

Recommendations for Pipe Breakage Prediction

Since a large portion of the water department budget devoted to pipe replacement and repair, any effort to reduce that cost would be extremely beneficial. Water main breaks also pose the greatest public health risk in the water distribution system because there is no further filtering after the water leaves the treatment plant and also because they occur unexpectedly and frequently. Probabilistic predictions of water main breaks and therefore contamination of water would be both important to public health and the water department budget. By predicting pipe breakage rates, the public can be better informed about the likelihood of contamination for a given season or for a specific neighborhood. Additionally, the water department can more easily ready themselves for a season of more numerous or fewer water main breaks. The anticipation of breaks can allow for more accurate budgeting of the water department and as a result, a smaller deficit.

According to Dr. Kleiner, currently the statistical model used for these three cities is being applied to software that can calculate breakage rates in real time (personal communication, January 16, 2006). The data used for calculating this model is readily available from the water department and simple climatological instruments. A system can be devloped with a small overhead and maintained at virtually no cost.

The correlation between predicted and observed water main breakage rates using the multi-variable exponential model (Kleiner et al., 2002) is strong enough to qualify that the model produces very accurate predictions of the quantity of water main breaks for a given season. Due to the low cost in implementing the model and ease through which data to compute the model is collected, we recommend that the Worcester Department of Public Works research and implement this model.

Recommendations for Pipe Remediation and Protection

The city of Worcester has a water main infrastructure composed of Cast Iron and Ductile Iron pipe, with several lengths installed long ago as 130 years. A distribution of pipe ages is given in Figure 23:

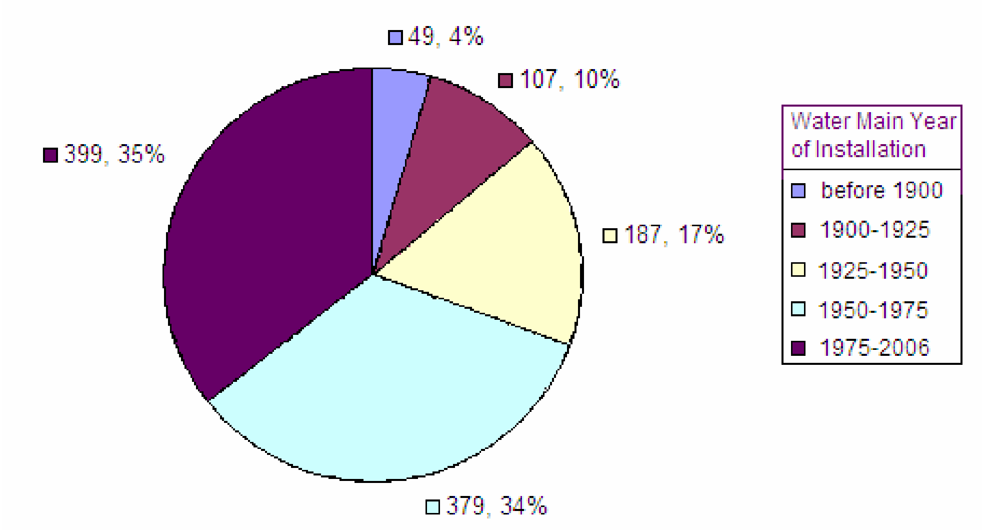


Figure 23. Number of Water Mains Installed in District Five by Year

District Five was chosen because according to Phil Guerin it shares features that are representative of the city at large (personal communication, December 13, 2005) but may not be as evident in the newer residential districts. The distribution of piping ages describes the number of pipes of varying length installed for a given range of years. Unfortunately we did not have the capability to produce a chart of the total length of pipe installed in a given range of years.

We recommend the water division performs an analysis of predicted breakage rates to assess the need for either a Hot Spot (HS) Cathodic protection program or a Retrofit Cathodic Protection program. The peak age for maximum benefit to cost is 40-60 years, which is where a significant percentage of Worcester's pipes lie.

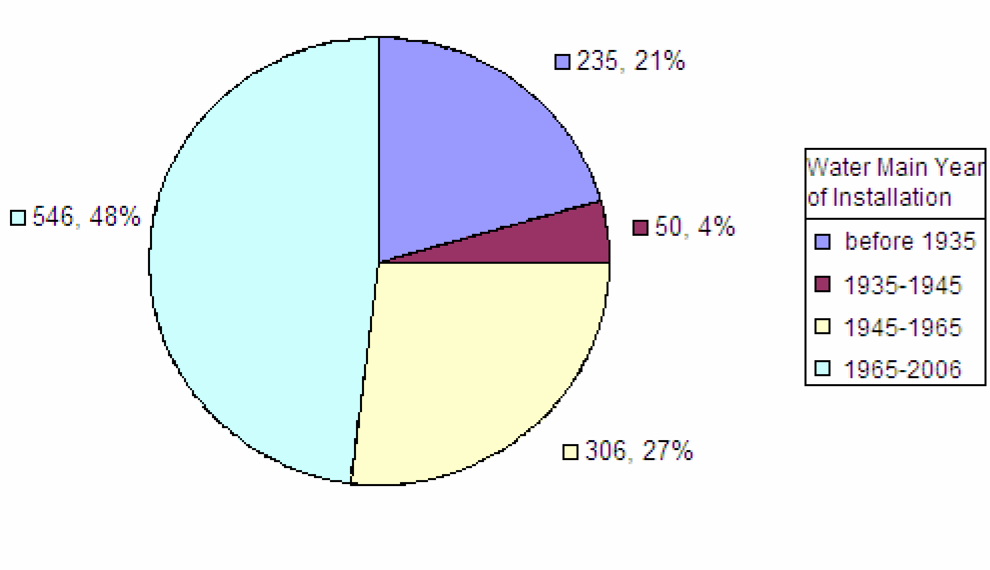


Figure 24. Number of Water Mains Installed in District Five, Grouped Homogenously

Figure 24 is a distribution of piping age that gives details regarding main composition and defines the boundaries of a retrofit program if one were to be implemented. Pipes installed prior to World War II (1935) had thicker walls then the pipes installed during World War II (1935-1945), which according to Phil Guerin contributes to the weakening of newer pipes that are in greater need of protection (personal communication, January 24, 2006). The period of time after World War II until 1965 represents a range of years where Retrofit protection would offer the greatest savings and life extension. The period after 1965 represents piping that would not benefit from cathodic protection. There are two reasons for this: first because those water mains are relatively new and also because after 1965, a majority of new pipes were composed of ductile iron which cathodic protection has not been verified against.

The HS protection program offers a number of benefits over the Retrofit protection program. First, it is easier to implement because the locations for anodes are readily known. In addition, the area adjacent to the pipe has already been unearthed for repairs, so additional costs are minimized to welding of the electrode and cost of the anode. However, the Retrofit program is more versatile than the HS program. Anode costs are regulated by the budget and not by the frequency of pipe breaks. Also, it will save more money in the long term by delaying a water main break rather then treating and then delaying a break, which is the case with HS protection. Both programs offer significant savings by delaying the occurrence of pipe breakage.

The costs for HS protection are calculated based on the $250 cost to install an anode (Kliener et al., 2004) and that there are approximately 150 water main breaks per year according to statistics provided by Phil Guerin (personal communication, January 24, 2006). The total cost for HS protection is approximately $37,500/per year.

The cost to implement a Retrofit program would vary depending on the extent of protection. Given that the water mains most in need of a retrofit are the ones installed during World War II, that there is an approximately equal number of similarly cast water mains in each of the five districts and the cost for implementation is $250, the estimated cost for a basic Retrofit program would be approximately $62,500 per 15 year replacement (Kleiner et al., 2004). This is the minimum cost if a Retrofit program were established because of the limited number of pipes receiving a retrofit. Additionally, this cost is not as accurate as the HS cost estimate because the length of the pipe was not accounted for. Extended lengths of pipe needing numerous anodes may increase the cost several fold. Finally, the cost per retrofit will be greater than $250 because the cost to unearth the pipe and repave the road above it was not taken into account.

Recommendations for Monitoring and the Treatment Facility

The previous chapter provided data supporting Worcester's chlorine disinfection process to minimize trihalomethane byproducts. While the treatment process is optimized to reduce THM production, the risk of THM contamination still exists. It is important to regulate this group of chlorine byproducts because of their known carcinogenic properties in animals and likely similar properties in humans (Nazir & Khan, 2005). The EPA defined the maximum contaminant level (MCL) for THMs to be 80 ppb (EPAc, 2003). In 2004, Worcester's samples of THMs from around the city ranged from 11-82 ppb, with an annual average of 37 ppb (Worcester CCR, 2004). In order to ensure that the levels of THMs remain safe, we recommend increasing the frequency of testing from four to six times per year. We feel that the current period of three months between testing is too long to adequately detect a rise in THMs.

If Worcester's lab is unable to process an additional two sample sets per year, there are other options. Assuming that the current eight water samples per set are still taken, a total of sixteen additional samples per year would need to be tested. Pricing was found to be $105 per sample from Saskatchewan Research Council (SRC) Analytical Laboratories (SRC Analytical, 2005) in Canada. Including an extra $45 for shipping and labor per sample, this brings the total cost for the extra recommend sampling to $2400 per year.

In addition, the previous chapter provided evidence to support the use of spectrophotometric in-line sensors at the treatment facility. Recent studies have shown them to be useful in detecting many different inorganic and organic contaminants, accurate up to 2nM concentrations, and capable of handling high-flow rates (Pyrzynska et.

al, 2003; Zhang, 2006). We found one German-American company named Optek who may be able to provide effective sensors to Worcester's treatment facility. Optek has been designing photometric sensors for industrial applications for 20 years. Among other things, their sensors can detect in real time water features such as color, total suspended solids, aromatic contaminations, filter membrane breakdowns, total organic carbon, and chlorine and ozone residuals (Optek, 2006). Due to the very high cost of these devices, we feel that this option should remain optional, especially because of the low amounts of MCL violations over the past twelve years (Rao, 1998). We recommend that the water division contacts Optek for a quote to install their real-time sensors to reduce the vulnerability of a contamination from entering the treatment facility undetected. We suggest contacting Tom Schmitt, an Optek Industrial Product Specialist who has been helpful in answering our questions about their company.

Recommendations for Annual Water Quality Report

As a whole, the current Customer Confidence Report for Worcester's drinking water is a fairly informative and easy to understand document. As seen in the adequacy assessment of this document, there are certain recommendations provided by the EPA and AWWA that have not been well-documented in past reports. While ideally all recommendations should be met in thorough detail, a report of such great detail is beyond what most citizens are concerned with seeing. This reasoning is exactly why old reports were very extensive while current reports are simplified compared to earlier versions.

While a simplified version of the report is acceptable according to citizens' feedback, there are still ways to improve the quality of the report while maintaining a straightforward design. For example, by simply referring concerned individuals to the

EPA's drinking water health risk website, detailed information involving health risks of contaminants tested for in the report would be available at the consumer's discretion. This website educates readers on everything regarding a contaminant, from health effects to how they are formed and are potentially introduced to water sources.

Another way to improve the document would be a standard for presenting test results. Currently, different classifications of contaminants have different methods of displaying results from sample testing. Such inconsistencies in reporting can be misleading to the consumer. According to the 1996 amendments to the Safe Drinking Water Act, every customer has the right to know what is in their water, as well as any possible risks associated with drinking their water. Therefore, we recommend that the water division creates a more standardized reporting method for test results. These recommendations aim to further the public's awareness to exactly what is in their drinking water, and also allow them to make an educated decision whether or not to drink Worcester city water to remain healthy and safe.

Recommendations for Emergency Contamination Procedures

There are only a few cases of widespread illness due to drinking water in the United States. As a result, our perception of safety associated with drinking water is very high. Even those in positions of authority may not have the risk of illness as a high priority because they feel they have done everything in their power to prevent it. However, the most dangerous aspect of these situations is that they can catch the public off guard. Treating a contamination is not difficult if we use previous incidents as a guide, as seen in the case concerning contamination within Alachua County Elementary School.

As shown earlier, a solid line of communication between the water consumer and the water utility is essential to a good response. According to Phil Guerin, Worcester already has a reverse 911 system which can be used to contact every single telephone in the city simultaneously (personal communication, November 21, 2005). In addition, there should be a forum for discussion for the public to voice concerns and to allow the water department to explain the steps they are taking to treat the contamination and to prevent another contamination. Honesty on the part of the utility is critical because the public is completely dependent on their water, unlike gas or electric utilities, which people can cope without for a while.

Communication should not be limited to only water customers. Communication with the health department and emergency rooms would give the first warning sign that the public is becoming sick. Communication with local stores provides early detection information because if there is an increased sale of medication to minimize gastrointestinal distress or if there is an increase in the sale of bottled water which may mean a contamination has occured. Communication between cities with past contamination experience assisted in the treatment of outbreak in Florida. We recommend that steps involving water emergencies include an open forum with the public and contact with the health department, emergency rooms and specific cities that have dealt with water emergencies before.

Cost for Implementation of Recommendations

The above recommendations were created to be implemented by Worcester in a cost-effective manner. Due to existing debt, it was critical to minimize costs while still providing either protection or remediation. The following graphs are a summary of the relative costs for our recommendations:

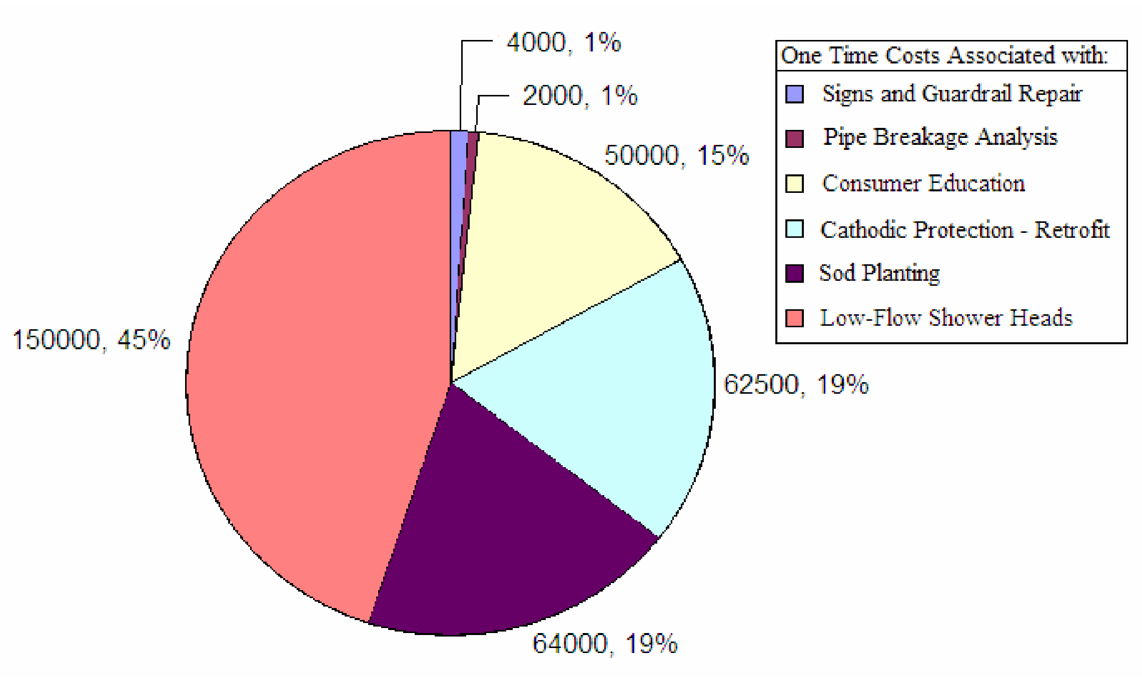


Figure 25. Recommended Cost Distribution in Dollars with One Time Execution

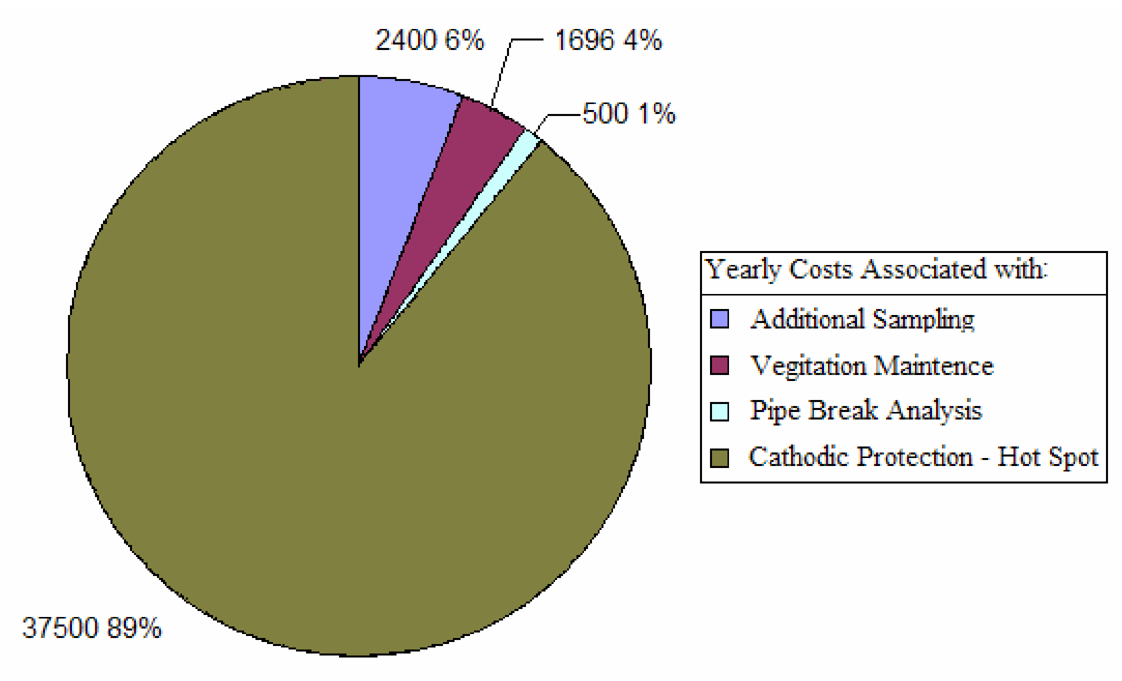


Figure 26. Recommended Cost Distribution in Dollars with Yearly Execution

The comparison of costs associated with our recommendations are provided in Figures 25 and 26. The one program that did not have an established cost was the implementation of inline sensors to detect contamination post-treatment, which was considered optional. The cost for signs and guardrail repair was based on the cost of two signs and 40 meters of guardrail repair around Holden Reservoir. Programs such as improving emergency response and the consumer quality report did not have costs associated with them and were excluded from the charts. Programs that had flexible budgets based on the extent to which they are implemented are the Retrofit Cathodic Protection program and the planting of vegetation as a biofilter. Although not a recommendation to decrease contamination, water conservation efforts such as low flow showerheads and consumer education were included in figure 25. These funding methods will be described in the following section.

The two Cathodic Protection programs make up a large portion of each chart. It is important to note that Retrofit Cathodic Protection must be updated every 15 years as the anodes are deteriorated. If all recommended programs are implemented, the initial cost would be $332,500, with the cost after ten years totaling $752,500 from a maintenance cost of $42,000 per year.

Recommended Funding Methods

The Worcester Water Division is composed of elements that require large amounts of funds to acquire and maintain. These include employees, contractors, equipment, land purchases, and past debt. Due to the limited nature of the budget, it is very important to implement cost-effective programs to minimize additional debt. Currently, there are areas in the water division that can benefit from new programs to decrease the risks of a contamination. A method to produce revenue to pay for these programs that does not require an increase in water price is to implement an active water conservation plan.

The first half of the water conservation plan is an education program. The purpose of this program is to inform water consumers about the benefits of water conservation, while emphasizing methods to reduce water consumption. Our findings demonstrate the effectiveness of such a plan, provided that enough funds are allocated to it. Based on the conservation program in Nova Scotia, we are recommending that the Worcester Water Division uses $50,000 to fund a water conservation program. This cost will cover salaries, printed papers and banners, advertising, and other expenses. The program may have the most success during a drought, because citizens may already be conscience of their water use.

The second half of the water conservation plan is to provide low-flow shower heads to consumers at no cost to them. The purpose of this program is to capitalize on the increased awareness from the education program by providing citizens with an easy to use method to decrease their water consumption. Our findings support their use and have shown that low-flow shower heads save up to nine times their initial investment and up to 11 percent water consumption per capita. Therefore, we are recommending that the Water Division uses $150,000 to purchase and distribute 5,000 low-flow shower heads to Worcester citizens free of charge. The cost is based on a total cost of $30 per low-flow shower head. The EPA notes that these shower heads only cost $5 each, but this figure does not take into account the costs to ship, assemble, and distribute the shower heads.

Additionally, to insure that they are used, extra money should be spent to ensure that high quality and aesthetic shower heads are distributed.

These two facets of the water conservation plan may be paid for by the DWSRF and CWSRF funds. Over time, the savings from these water conservation efforts will pay for the initial investments required to start them. Then the money saved could be translated into extra efforts for decreasing the vulnerability of the water system, without increasing the price of water. As outlined earlier, these include stricter protection barriers for the reservoirs, decreased detection times for contaminations in the treatment facility, more responsive water emergency protocols, and a more reliable distribution system. By implementing these recommendations, the Worcester city councilors and Worcester Water Division can reduce the risk of a contamination in the drinking water supply.

APPENDIX A

Interview - Philip Guerin
Water Resource Coordinator at Worcester Department of Public Works
November 21, 2005
2:00 pm

The interview began with introductions and asking a little about Philip Guerin's titles and history of public service. Prior to working as the Water Resource Coordinator, he held a position in the Worcester Health Department from 1984 till 1991 when he became involved in the Water Department.

Formal questioning began with discussing what single source of contamination would be the largest threat to Worcester Reservoirs. Transportation was given as the largest single threat, although there were no past instances of that sort of contamination. Specifically, tanker trucks used to transport chemicals potentially running into the reservoirs where the road is adjacent to the reservoir. The railroad running near one of the reservoirs was brought up but the threat of contamination was low from that source (that reservoir's location has a quick response time). Runoff from roads and the railroad were then mentioned but because it is constantly occurring, the department of public works addresses it in other ways then contamination.

The next questioned concerned unprotected water sources running into reservoirs. Eagle Lake was mentioned but is downstream from the reservoirs. Streeter Pond in Paxton was the only single source mentioned along with a number of unnamed streams and tributaries. However, Streeter Pond is small and remote, no transportation corridors located nearby. Most surface water supplies are connected and are treated once at the plant (lowest gradient).

Testing was then discussed. Indicators given are the required ones by law. There are also general chemistry techniques used to determine if there is a change in water which would lead to more in depth testing.. Health indicators are discussed but involved communication between the health department and water department. Following Milwaukee's contamination of Cryptospordium, the department acknowledged value of health indicators. No incidents yet to test health indicators. Frequency of testing varies from multiple times per day to semi-annually and annually. The Consumer Confidence Report (CCR) was given as a resource for frequency of testing by law. General indicators are continually running with alarms attached to indicate any significant changes.

The interview then moved to Emergency Response. A tanker spill was given as an example. Methods varied with different reservoirs (several can be taken out of line with the rest of the sources). Monitoring for the known contaminant from the tanker is also a common procedure. Long term procedures were then questioned. Phil Guerin mentioned that several emergency connections with other systems were available but no specific sources were given. The Massachusetts Water Resource Authority also assisted in providing water. In the event of an emergency with respect to notification; radio broadcasts, door to door notification if specific to a neighborhood and press conference were given. However, the primary source is a reverse 911 system which contacts any number of areas within the city in the event of a contamination. The response is incorporated into emergency response plans which are not available to the public.

Treatment facility was then discussed. For contamination, MTBE given as an example, the response was not publicly available. Use of activated carbon was then questioned. It is not used because there is no need, the cost is too high and it needs to be regenerated very often. If regulations changed then there is the capability to put in activated carbon. Significant watershed changes also may result in installing an activated carbon system.

Land development and purchase generated the most discussion. Financial tightening is the biggest roadblock in land purchase. Only 25 percent of the land around reservoirs is publicly owned, most purchased during the turn of the century. Recent land purchases didn't begin until the treatment plant was finished in 1997 due to plant costs. Over the past few months, 2.5 million dollars worth of land was purchased, primarily around tributaries feeding the reservoirs. There is a list of land the department is interested in purchasing and the department has the ability to take land if necessary. If private land owners wish to sell their land to the water department then they are given priority on the list of land to be purchased. Competition with developers who have much more capitol available has made it especially difficult for the acquisition of land.

The chunk of budget devoted to land purchase is typically \$100,000 to 300,000 per year which is saved for larger purchases. The rest is borrowed, which is a mix of state, local and rarely federal funds. The one federal program mentioned was the Forest Legacy program which gives grants for forest protection purchase which may assist in protecting water sources although water sources are not considered when granting money. A state grant of \$1 million dollars was made available for this year which was issued to the local government which the department of water is now indebt to. The state grants are fairly infrequent and there may be years where no grants are available. The primary source of funding are the city rate payers which makes the department privatized to a degree. The sale of water to towns outside Worcester was also noted but was not a large portion of their income.

The stability of that source was moderate. Summers with large amounts of rain and large consumers (universities, factories) leaving the city put a strain on the water budget. Most of the income primarily goes to debt services as well as worker salaries and benefits. Other costs include maintaince fees, chemical treatment costs and testing costs. The water rates are also influenced by local politics. Rates are voted on by the city council and customers primarily influence the council rather then the department of water directly.

The final topic of discussion was the CCR. The report is written by Phil Guerin and is distributed to bill payers as required by law. The department has initiated distribution to tenements of apartments with some success. Copies are also distributed to the city clerk and neighborhood centers. The budget for the CCR is approximately $15,000 which primarily goes to printing. The report is modeled after a report issued by Portland Oregon. The public response to the report is both positive and minimal. The recent changes in the report were due to negative public response. The department desired to make the report optional to those who read it which is a very small percent of the total consumer body.

The interview ended on that note and we mentioned a follow up interview at a later date which Mr. Guerin would have no problem in following through with.

APPENDIX B

Interview – Philip Guerin
Water Resource Coordinator at Worcester Department of Public Works
December 13, 2005
10:20 AM

The first point of discussion in this interview was if there were any sections of the city's piping infrastructure that were problematic. Phil Guerin stated there were no sections in particular that were problematic, just an even distribution throughout the city. He stated some isolated streets had repeated problems and at higher elevations there is typically are borderline pressure issues which are enviable.

The next question was which sections of the city had the newest laid pipes. He responded anywhere developers were active, typically residential neighborhoods. He then pointed out a few examples such as Indian Hill and Barry Road. As a follow up, I asked what portions of the city contained the oldest piping. He first stated that there were still pipes running through the city that were installed in 1870. Streets adjacent to upper Lincoln Street and Main Street south near Cambridge were areas of significantly older piping which may have been replaced recently, although he wasn't certain. Most of the oldest pipes however were evenly distributed throughout the city, the one exception being newer residential neighborhoods. He also stated that there might be a slightly higher concentration of older piping near the very center of the city but not significantly higher.

The interview then shifted focus to district 3, the area south of Hamilton Street and east of Rout 290. I first asked if district 3 was a good representation of the diversity of pressures throughout the city. He responded that pressures were high near Lake Quinsigamond and low in the hilly areas near Hamilton Street but only due to elevation. He then stated that the pressures in district 3 were typical of the city at large. Age of piping was the next area of discussion with respect to district 3. Guerin stated that he could not make a qualified statement without looking at maps and I replied that there were pipes installed in the 1870s and covered a broad range of years. I then asked if there might be a higher concentration of newer piping due to new residential areas. He replied that near Hamilton Street there would be a few newer residential neighborhoods. He then stated it is very likely that district 3 is a good representation of pipe ages for the city at large due to the mix of old city and the inclusion of a few newer residential neighborhoods.

I then asked if there were any problematic areas in district 3 or any unique features to that area with respect to piping infrastructure. He stated that there was nothing he was aware of that would be unique; the occasional main breaks are common for all areas of the city.

The discussion then shifted to the center of the city where there is a higher concentration of streets and therefore pipes and also the location of the water tower which maintains pressure for the high pressure system. He replied that there wasn't a higher rate of breakage but that breakage is caused by contractors who are working in the vicinity of water mains 80 to 90 percent of the time. In the areas with many utilities there is a higher rate of breakage due to constant work done in the vicinity the pipes. Drainage, gas and electric utilities cause a majority of the pipe breaks. Guerin then moved to address seasonal breakage where summer pipe breaks are due to contractors digging by pipes. Additionally repairs to sewer and gas mains may cause breaks in older piping due to loose compacting of sediment around the mains after the repair is complete which causes as settling of the dirt and gravel and put strain on the water mains. Summer repairs can also put strain on a pipe during the winter when the soil shifts due to the formation of ice.

The interview ended with a discussion of cleaning and lining procedures. The cost of cleaning and lining a pipe which includes diverting water while the process is taking place is 75 dollars per foot for a 12 inch pipe and about the same price for smaller diameter pipes. As a point of comparison, the cost of replacing a 12 inch pipe is 110-115 dollars per foot which does not include repaving which isn't necessary with cleaning and lining. The cost of replacing smaller pipes is almost the same as cleaning and lining the same pipes and replacement is usually preferred for pipes 8 inches and smaller. Finally he stated that all replacement and relining of piping is handled by private contractors.

APPENDIX C

Interview – Philip Guerin
Water Resource Coordinator at Worcester Department of Public Works
January 24, 2006
1:00 PM

The interview began by inquiring if Worcester used any sort of measures to physically protect water mains from breakage. The city primarily relies on a rehabilitation program which 2-3 million dollars per year is budgeted to. The program involves replacing existing water mains with pipes consisting of more resilient material (ductile iron) than older pipes, which are primarily cast iron (CI). Additionally, all pipes in the city are iron, whether CI or ductile iron (DI). There are no asbestos-cement water mains. Another protective measure used is when contractors apply for a permit to dig in the street; the water mains are marked with spray paint in the vicinity of the work being done.

The city does not use cathodic protection to prevent degradation of water mains. The department is aware of its implementation but have reservations about its effectiveness. Because of this, the DPW has not looked into it in great detail. Mr. Guerin did state that there have been occasions where pipe breaks were very likely attributed to stray currents ie, an electrical line or grounding rod in close proximity to a water main.

Pipe repairs are dealt with separately from pipe rehabilitation. The average cost for repair is variable enough that an estimate of it would be difficult to construct. The repairs are budgeted separately and based on previous yearly costs while the replacement program is standardized per month. Repairs are always dealt with by the DPW while pipe replacement is a concern of private contractors.

Another question addressed if the number of pipe breaks per year is increasing as the pipes age. While Mr. Guerin expressed interest in if there is an increasing trend in breaks, he stated that he was not sure if the number of breaks was increasing. The records are available of breakage numbers per year but controlling for years with increased road work would be difficult.

The discussion shifted to the resilience of piping materials used. Prior to 1950, nearly all pipes installed were CI. After 1950, most pipes were DI, which is more flexible. A majority of the breaks occur with the CI water mains, although there are incidents involving DI mains breaking. CI resilience varies with what years it was installed. For example, during World War 2, the pipes were significantly less thick then they were prior to the war due to the shortage of iron available. This can contribute to CI pipes much older outlasting pipes installed during the late 30s and early 40s.

The interview questions then shifted to more general follow up questions related to sections of the project outside the pipe maintence and protection. First, which pipes are the largest diameters in the distribution network and where are they located? The largest pipes are 48 inches in diameter and are located near Chandler Street. They are lower service pipes. The largest pipes overall are 54” and are located at the intake of the treatment plant.

The next question concerned the rate structure of Worcester water pricing. All public schools and municipal facilities receive water for free. Private schools, businesses and individuals pay a flat rate for water regardless of their intake. There are no reduced consumption discounts given anywhere for customers of Worcester water. The interview ended with that set of questioning.

APPENDIX D

Interview – James Hauri
Professor of Environmental Engineering at Assumption College, Worcester
January 20, 2006
1:00 pm

The interview began with introductions and asking a little about James Hauri's education and career. Professor Hauri earned his doctorate at Berkley College in Environmental Engineering with a focus on metals. Afterwards, he worked at the CH2M Hill Consulting Firm for several years. He has been working for the past 5 years in the Chemistry department at Assumption College with research focused towards the presence of Ibuprofen in stream water and Wastewater Treatment Plants.

Formal questioning began with what were the most and least critical components of a drinking water treatment plant. He began by distinguishing primary treatment and secondary treatment. He stressed secondary treatment, which is required by law, although there are a number of towns that do not use secondary treatment. The secondary treatment is critical because of the removal of carbon which if allowed to pass would provide sustenance to bacteria post treatment. That would lead to formation of dissolved oxygen sacks in pipelines.

Additionally, we asked Professor Hauri what would be the amount of time to process a quantity of water through a treatment plant. He stated that it would be difficult to give a good estimate but stated several hours, very likely less than a day.

At that point we had realized that the discussion was about wastewater treatment rather than drinking water treatment and made Professor Hauri aware that our project focused on drinking water treatment. He then stated that he was not too familiar with drinking water treatment but rephrased his previous statements to be more applicable to drinking water treatment.

He stressed that disinfection would be the most critical aspect of drinking water treatment. Methods of disinfection he mentioned were ultraviolet light exposure and ozonation. He mentioned that chlorination is becoming less popular a method to disinfect water because it is ineffective on certain organic compounds.

The next topic was what would be the most vulnerable aspect of a treatment operation that uses ozonation, coagulation and flocculation mixers, direct filtration without settling and chlorine disinfection. He stated that filtration clogging and limits on the rate of flow would pose a serious problem. In terms of the most fragile aspect of treatment, he stated that pH levels have a serious effect on the effectiveness of flocculation. This is due to the reduced effectiveness of Alum, a catalyst in flocculation, at extreme pH levels.

In addition, chlorination is difficult to assess effectiveness given that a reduced contact time would reduce its effectiveness to a large degree. Chlorine in contact with a number of compounds with the formation of trihalomethanes (THM) also poses a serious health risk. He stated research he was aware of concerning the dangerous compounds formed with contact between Acetaminophen, a common pain reliever, and Chlorine.

The discussion then focused on the formation of THM compounds and their threat to water quality. He stated that reducing carbon residuals in water treatment cuts down tremendously on THM formation. In a process with Ozonation prior to Chlorination, the availability of carbon to react with chlorine is minimized and there is no serious risk. He ended by stating that THM level data is available from numerous municipal sources.

The next subject was if there were any problems with pumping water from the bottom of a reservoir. Water is not typically just pumped from the bottom, usually there are several feeds for the treatment plant. He stated that, in the southern states, there are problems with formation of Ammonia and Hydrogen Sulfate in water that is pumped from the bottom of reservoirs. Algae concentrations also pose risks due to the number of byproducts they produce.

The final interview question was what situation would justify the use of activated carbon filtration. Professor Hauri began by stating drinking water threats such as microbial species that are dangerous to a person’s health and carcinogenic compounds. What isn’t usually a threat is surface water contamination such as pharmaceuticals and other organic compounds as well as metals. These are not threatening because reservoirs and ground water sources are physically protected them. Metals usually don’t appear until water is exposed to the distribution network. However, while activated carbon can filter a number of organic compounds and metals, it does a poor job of filtering microbial species. His advice was that a personal filter at the tap in a household would be much more effective than activated carbon filtering prior to distribution. The household filter could remove the metals from piping networks and stray organic compounds from treatment such as THMs.

After the final question there was a discussion about current dangers in drinking water. He stated that a number of his colleagues were involved in research in detecting biological agents placed in drinking water to produce a deliberate public health risk. There are currently a number of projects concerning detection of specific agents which are known to be dangerous. These project involved gas chromatography in real time, copper ion probes and life forms such as bacteria, algae and fish which can become ill in the presence of these biological agents. The discussion ended there.

APPENDIX E

Table - The Mettler Valley Mutual drinking water facility in Los Angeles County developed this chart to analyze the risk of groundwater contamination. This chart considers the harm and probability of a contamination (PCA Risk), the subject's proximity to the wellhead (Zone) and the effectiveness of physical barriers (PBE). These criteria were quantified and their sum was the total vulnerability score.

Table 6. Possible Contaminating Activities Risk Ratings of the Mettler Valley Mutual Wellhead in Los Angeles

Zone	PCA (Risk Ranking)	PCA Risk Points	Zone Points	PBE Points	Total Vulnerability Score
A	Septic Systems – low density	5	5	3	13
A	Wells – Agricultural/Irrigation	5	5	3	13
A	Above ground storage tanks	3	5	3	11
A	Transportation corridors (Freeways/state highways)	3	5	3	11
A	Wells – Water supply	3	5	3	11
B5	Transportation corridors (Freeways/state highways)	3	3	3	9
B5	Wells – Water supply	3	3	3	9
B10	Wells – Agricultural/Irrigation	5	1	3	9
	Explanation of point ranking system:				
	PCA risk ranking	Very high=7	High=5	Moderate=3	Low=1
	Zone (Groundwater)	A=5	B5=3	B10=1	
	Physical Barrier Effectiveness	Low=5	Moderate=3	High=1	

Source: Mettler Valley Mutual Los Angeles County Drinking Water Source Assessment, California Department of Health Services, http://swap.ice.ucdavis.edu/TSinfo/output/ps1900100-001.pdf, 2002.

APPENDIX F

Summary of Zoning Areas Around a Class A Reservoir:

Zone A: the land between the surface water source and upper boundary bank and 400 foot lateral distance from the upper boundary bank, it has the most restrictive access

Zone B: the land within one-half mile of the upper boundary of a Class A public reservoir that includes Zone A

Zone C: the land within the watershed of a Class A public reservoir that does not include zones A and B

The restrictions in these zones are to protect the water supply from contamination and must be routinely checked by the Department of Environmental Protection. The restrictions of land use around an existing Class A public reservoir are outlined in 310 CMR 22 for the state of Massachusetts. They have been summarized below in Figure F.1:

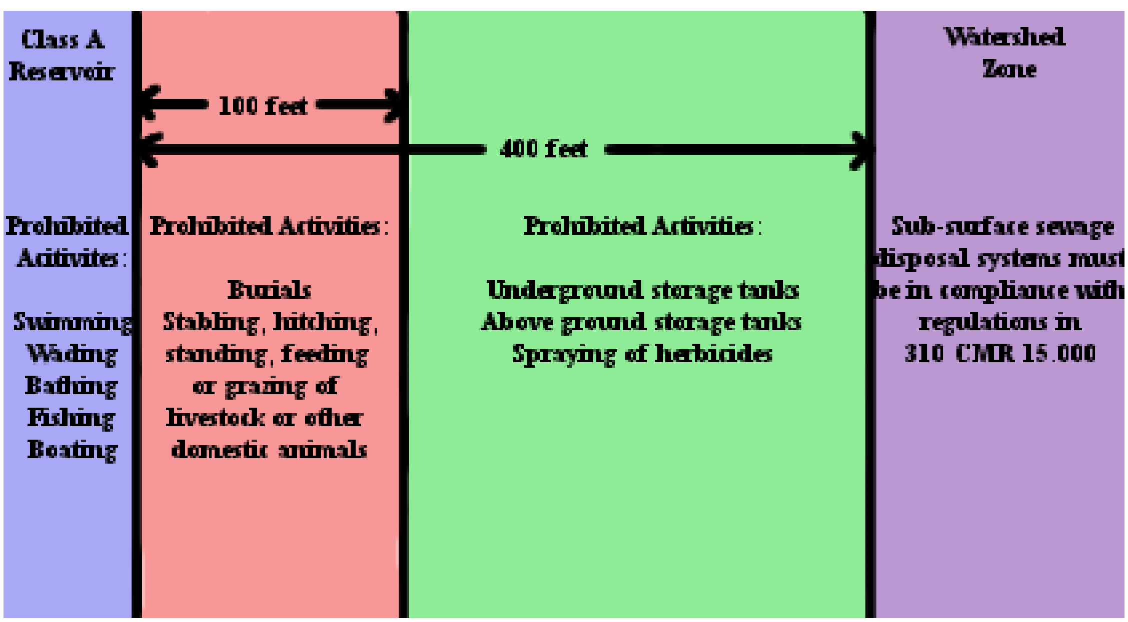


Figure 27. Distance from reservoirs and prohibited activities in Massachusetts
Source: Massachusetts DEP, 2004.

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