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BIOLOGICAL AGENT TRANSMISSION THROUGH MUNICIPAL WATER TREATMENT SYSTEMS

An Interactive Qualifying Project Report
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by

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1. Bioterrorism
2. Drinking Water Treatment
3. Pathogen Removal

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Abstract

This study analyzes the possibility of a biological agent passing through the Worcester Water Filtration Plant by measuring the effectiveness of the current plant for removing pathogens. This project estimates the public's view on the safety of Worcester's water by analysis of survey results. The analysis of the plant's removal of pathogens determined that it is more than sufficiently effective, and surveys showed that the population of Worcester is roughly evenly divided over the topic of water safety.

Authorship

Eric Hart was the primary writer and editor of the following sections:

- Chapter 2 (Background) – History of Drinking Water Legislation, Drinking Water Treatment.
- Chapter 3 (Methods) – Water Treatment.
- Chapter 4 (Results and Analysis) – Worcester Water Filtration Plant, Worcester Water Filtration Plant Data Analysis.
- Appendix B (Removal Calculations Spread Sheet) – All calculations and analysis.

Ian Sellon wrote and revised the first version of our introduction and also revised the Goals section. In Chapter 2 (Background), he wrote and revised the History of Bioterrorism section. In the Methods chapter, he wrote the Introduction, Cost of Water and Surveys sections. In Chapter 4 (Results and Analysis) he wrote Survey Results and Implementation Effects. He also made revisions to the Conclusions section.

Benoit Steenland-Gilbert was the creator and primary distributor of the survey. He was responsible for the tabulation of the results as well as the analysis. Benoit was also responsible for the research and documentation of the Biological Agents (Chapter 3 and 4) and the subsequent reviews of that section. He also wrote the Conclusions section and reviewed The History of Bioterrorism section in Chapter 2 (Background). Benoit also made reviews to the Water Treatment section in Chapter 3 between the first and final drafts and conducted the personal interview with Mr. Bob Moylan.

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Chapter 1, Introduction

Terrorism is any use of violence that is intended to instill fear into a populace for the purpose of bringing about political or social changes that the terrorists believe could not be gained by any other means. Any use of biological agents such as bacteria, viruses and biological toxins to achieve these ends is called bioterrorism. After Operation Desert Shield/Desert Storm (January 1991-March 1991), it became clearer than ever that the threat of a biological attack against U.S. soldiers was significant. Iraq was known to possess biological weapons at this time, and the numerous cases of "Gulf War" syndrome indicate that the Iraqis may have released these weapons on U.S. troops (Spector and Tucker, 2001). Because of increased threats and terrorist attacks throughout the world like the New York City World Trade center bombing (February 26, 1993), the Tokyo subway sarin release (March 20, 1995), the Oklahoma City bombing (April 19, 1995) and the Atlanta Centennial Park bombing (July 27, 1996), civilians have now been given a reason to worry about terrorism as well. The September 11, 2001 terrorist attacks on the Pentagon and New York City Twin Towers and the anthrax strikes that followed have brought the threat of terrorism and bioterrorism into a very real fear for U.S. residents.

Bioterrorism differs largely from conventional and chemical terrorism in its duration and effects on the populace. Conventional terrorist attacks such as bombs, hijackings, and hostage situations, tend to end quickly. Conventional terrorist attacks also target a finite number of people in the same area such as a bomb's radius of detonation or the number of people on a hijacked plane. When a chemical attack occurs, the threat ends once the chemicals have exhausted themselves by reacting in the affected area. This is not necessarily the case with a biological attack. In the event that the pathogen used is contagious, an infected group can spread their disease to a portion of the remaining population if not tended to immediately. Biological agents can also infect livestock, soil and water, sometimes remaining dormant for years and thus making it extremely difficult to calculate the damage caused by a particular attack. Furthermore, many disease symptoms may mimic flu symptoms, further complicating diagnosis and treatment of an infected population. The flu-like symptoms can make people who actually have the flu believe that they have been victim to a biological attack. Conversely, victims of biological attacks may at first be misdiagnosed, delaying treatment and potentially allowing the disease to spread. This uncertainty and fear are some of the most paralyzing effects of bioterrorism.

The danger of having a disease spread rapidly is enhanced by the highly mobile nature of the United States' populace. Also, since most biological agents have an incubation period between infection and the first showing of symptoms, infected citizens may travel far from the place they were infected. Once the public has been made aware that it has been subjected to a biological attack, many people who display the slightest symptoms will flock to hospitals for treatment fearing infection. A populace of a densely populated area could potentially overwhelm medical facilities with a large number of people to be examined and treated. Since biological agents act gradually over time, can spread quickly through the populace, and come without warning as all terrorist attacks do, the threat they pose is very real and must be addressed. It is also important for citizens to know that the threat is being addressed so they can continue with their daily lives with the comfort of knowing they are at least as safe as they can possibly be. Many programs are ongoing to improve preparedness within all levels of government for the possibility of a bioterrorist attack and new countermeasures are proposed everyday (Food and Drug Administration, 2000).

Biological agents can enter the body any of three ways often causing different symptoms depending on the method of contraction. Pathogens can be inhaled, absorbed through the skin, or ingested with food or drink. For agents such as anthrax, the symptoms brought on by inhalation are far worse than the others. An aerosol distribution is one of the most likely modes of transmission for biological attacks because the disease can be spread to a large area (especially with the right wind conditions). Many pathogens that can be aerosolized will cause infection whether they are inhaled or simply come in contact with skin. Cutaneous infections, which arise from contact with the skin, can occur any time a person touches an object or another person that has been exposed to the agent. The transmission of an agent through water is a possibility that many people have become aware of recently for several reasons. Some pathogens, like *Cryptosporidium* and *Giardia*, have natural defenses that allow them to survive in the environment for long periods of time. Water transmission is also a desirable method of attack for terrorists because of the way municipal water systems are set up. If an attack were made into a public water source and the treatment system in place was insufficient to kill or remove the agent, people would be in danger of infection once the water was distributed to consumers.

Goals

This IQP assessed the effectiveness of the Worcester Water Filtration Plant's processes in killing and removing the natural pathogens in the water. The Worcester Water Filtration Plant is a direct filtration plant. Pathogens are removed in the filters and are inactivated by two disinfectants: ozone and chlorine. It was important to note that the plant was not designed to be prepared for biological attack. However, the United States Environmental Protection Agency (U.S. EPA) regulations which the plant was designed to meet do require the removal and/or inactivation of many pathogenic organisms, including viruses, bacteria, and protozoa. Since the biological agents that would be used for this kind of attack would most likely be viruses or bacteria, the processes in the plant should still work as effectively against an introduced biological agent as they would for naturally occurring pathogens.

Goal #1, Microorganism Removal through Current Plant

The project's first goal was to assess the current Worcester Water Filtration Plant using the regulations that were used to design and create the plant. Each process in the treatment plant was assigned a log removal (or percent removal) value for removal of viruses and *Giardia*. The log removals were added to obtain a total value for plant removal. This provided theoretical removal efficiency according to the U.S. EPA regulations.

The Worcester Water Filtration Plant was then assessed using actual plant data from November of 2000 to November 2001. Plant data on chlorine, filter and ozone processes were provided. Log removal values for each process of the plant were determined for each of the four seasons. Using these numbers, the removal value of the actual plant could be compared to the theoretical efficiency as determined by U.S. EPA regulations.

Goal #, Assess Benefits of Treatment Upgrade

As a means of examining the benefit of a possible upgrade, the project also determined the removal value for the plant if a settling tank was added to the treatment plant. The main purpose of this goal was to determine whether or not the additional credit gained would provide a sizable advantage in the event of a bioterrorist attack. Since the Worcester treatment plant does not currently have a settling tank in place, the calculations for this process were based on log removal values stated by the U.S. EPA.

Goal #3, Public Opinion of Water Safety

Part of the importance of this project was to understand public opinion on the safety of the water system. The reason is that terrorism is a direct attack on the public and so it is up to the people to learn how large the threat is and how strong they want safety precautions to be so that the decision can be made at the governmental level. Without raising fears about a terrorist attack, information was obtained through an opinion survey which asked Worcester citizens how safe they felt their water was.

Goal #4, Analysis of Upgrade Implementation

It was important to identify the person or group who would be responsible for implementing any changes that might be needed to the water treatment plant and the methods by which these changes would come about. The important part of this goal was to determine the process by which, having decided to upgrade the water treatment system, the city would go about getting it implemented and paid for. Such upgrades to the public water system could result in additional taxes or water bills. This information was obtained via an interview with Mr. Bob Moylan and through the Internet.

In the following chapters, we detail our study of biological agents, treatment plant processes and all the other aspects of this project. The next chapter contains the background information collected to help give us an idea of where the project would be going. Chapter three shows the methods by which we conducted each phase of the project and gives an explanation for the purpose of each step. Chapter four contains the results found after our calculations were made and gives an analysis of what each one means. In the fifth chapter, we present our conclusions and answer any lingering questions about the project.

Chapter 2, Background

Introduction

Throughout history, human dependence on drinking water in order to survive has always created a potential weakness because of the possibility that the source of water could become contaminated either accidentally, naturally or through acts of terrorism. In this section we describe the past development and usage of bioterrorism, the development of drinking water treatment, the legislation passed in the United States regarding quality standards for drinking water and the methods that are used for making water safe to drink. Before any conclusions can be made about the threat of a bioterrorist attack against a water treatment system, it is important to examine all the history and background information from nearly 3000 years ago up to current events.

History of Bioterrorism

The use of biological agents as weapons in warfare has been recorded throughout history. The Food and Drug Administration's Biological Warfare and Terrorism Medical Issues and Response Satellite Broadcast (Food and Drug Administration, 2000) has an informative background history that details some of the historical uses of biological warfare and bioterrorism. From ancient times, right up to today, aggressive parties have often noted the destructive power of using pathogens against their enemies and have taken advantage of that fact with disastrous results.

Bioterrorism through the 1700's

Even before humans had the technology to produce dangerous pathogens for warfare, other convenient sources could still be found and used by an army willing to risk infecting their own men. The Tartar army controlled by Ghengis Khan and his successors hurled the bodies of plague victims over the city walls and infected the besieged city of Kaffa, now called Feodosia, in 1346. The people living inside the city then contracted the Black Plague from the dead bodies and were eventually faced with certain death or surrendering their city. It is believed that some of the people who left Kaffa following the Mongol attack may have started the Black Death pandemic which spread throughout Europe (Food and Drug Administration, 2000).

The smallpox virus has also been used heavily as a biological weapon during the conquest of the Americas. Pizarro, the Spanish conqueror of Peru, is said to have given smallpox infected blankets to the South American natives in order to dominate the nation quickly when he landed in the 1500's. The natives, having never come into contact with European diseases before, quickly became infected and without knowing exactly the cause of the illness, they spread it to others. In a matter of weeks, hundreds of thousands of Incas were dead from the virus, allowing the Spanish an easy conquest (Cohen, 2001).

The English also used bioterrorist tactics during the French and Indian War (1754-1760). It is said that Sir Jeffery Amherst, the British field marshal and governor general responsible for British North America, provided Indians loyal to the French with smallpox laden blankets from which they quickly contracted a disease they had no defense against. The epidemic casualties suffered by the Native Americans directly contributed to the loss of Fort Carillon, NY to the English in 1759 (Food and Drug Administration, 2000).

Bioweapons and Bioterrorism in the Twentieth Century

During World War I, the French and Germans experimented with germ warfare but found the delivery systems for spreading diseases using artillery shells meant that conditions had to be ideal to allow the weapons to disperse disease properly. Without these conditions, the attack could just as likely backfire on friendly troops as do any harm to the enemy (Cohen, 2001).

In the 1930's, both Russia and Japan developed bioweapons programs. Russia's bioweapons program began in 1933 at the Scientific Research Institute of Microbiology in Perkhushkovo. Japan began a biological warfare program in 1937. They created "Unit 731", a laboratory complex that tested various biological agents on prisoners of war, 40 miles south of Harbin, Manchuria. The Japanese bioweapons program was estimated to have 400 kilograms of anthrax ready to use in a specially designed fragmentation bomb during World War II. Under Japanese General Ishii, slightly less than 1000 human experiments were carried out at Unit 731, mostly using prisoners of war. Ishii had his test subjects exposed to aerosolized anthrax for the purpose of determining its efficiency as a weapon. Following reported overhead flights by Japanese planes suspected of dropping fleas during WWII, a plague epidemic ensued in China and Manchuria. Unit 731 remained completely unknown until 1945 when it was burned down and its supply of anthrax destroyed (Food and Drug Administration, 2000).

Other nations had similar or even larger biological warfare programs. The United States started a biological weapons program in 1943, in response to a perceived German biological warfare threat, rather than a Japanese one. The U.S. conducted this research at Camp Derrick (now Fort Derrick, Maryland) and produced agents at other sites until 1969 when President Nixon stopped all offensive biological and toxin weapon research and production by executive order (Food and Drug Administration, 2000).

The United States destroyed their bioweapons stockpile between May 1971 and May 1972 in the presence of monitors representing the states of Maryland, Colorado, Arkansas and the United States Departments of Agriculture, Health, Education and Welfare. The stockpile of destroyed agents included *Bacillus athracis, Francisella tularensis, Coxiella burnetti, Bucella suis,* botulinum toxin, Venezuelan equine encephalitis virus, and Staphylococcal enterotoxin B (Food and Drug Administration, 2000).

During the late 1970's, planes and helicopters delivering aerosols of several colors attacked Laos and Kampuchea. This incident was thought to be some kind of biological weapons test, run by the Vietnamese government. After exposure, people and animals became disoriented and ill, and a small percentage of those stricken died. The clouds were thought to be trichothecene toxins. After much controversy it is still undetermined if these clouds (collectively called "yellow rain") were actually biological agents. No one has ever been able to confirm exactly who made this attack as the only evidence was the testimony of those who witnessed it (Food and Drug Administration, 2000).

In 1978, a Bulgarian exile named Georgi Markov was attacked in London with a device disguised as an umbrella. The device injected a tiny pellet filled with ricin toxin into his skin while he was waiting for a bus. He died several days later. "On autopsy, the tiny pellet was found and determined to contain the toxin. It was revealed that the Bulgarian secret service carried out the assassination and the technology to commit the crime was supplied by the former Soviet Union" (Food and Drug Administration, 2000).

In Sverdlovsk (present day Yekaterinburg), in the former Soviet Union there appeared to be an accidental release of *Bacillus anthracis* in April of 1979. The spores were released by the Soviet military microbiology laboratory called Compound 19. Residents living downwind from the facility developed high fever and experienced difficulty breathing. There were 66 fatalities of the 77 identified cases. The Soviet Ministry of Health blamed the deaths and illness on the consumption of contaminated meat and for years a controversy raged in the international community and the press over the actual cause of the outbreak. In the summer of 1992, the new Russian President Boris Yeltsin acknowledged that the Sverdlovsk incident was linked to military research and production at the microbiology facility (Inglesby *et al.*, 2000).

In 1988, Iraq began experimentation with biological agents signaling the start of a new serious threat and prompting the U.S. to begin creating new safety measures. In the next year "Juniper" was created by the Bush administration to monitor Russian bioweapon activities. In 1991, United Nations Special Commission: Team 7 (UNSCOM) was founded to verify the destruction of Iraqi biological weapons and weapons of mass destruction. Further in 1995 the Global 95 war game was used to determine the effects of North Korean biological weapons attack on American forces in the demilitarized zone (Cable News Network, 2001).

Within the United States of America, there have been very few biological attacks, until just recently. One of these few attacks was in 1984, by an Oregon based cult called the Rajneeshees. The Rajneeshees spread *Salmonella entercia* on salad bars of ten restaurants in The Dalles, Oregon as a test prior to a similar attack on the town's water source. Fortunately for the people of The Dalles, the group was caught before this second phase of their plan could be realized (Inglesby *et al.*, 2000).

Bioweapons Legislation

In 1972 the UK, USSR and United States of America signed the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological and Toxin Weapons and on Their Destruction, commonly called the Biological Weapons Convention (BWC). The treaty prohibits biological agent stockpiling for military purposes and also forbids research into offensive employment of biological agents. In 1991, it was realized that there was a need for more strength in the treaty and more ability to enforce the BWC. In September 1994 in Geneva, the countries that had already agreed to the BWC established the Ad Hoc Group of the States parties to the BWC. Their task was to find means by which the Convention could be enforced and other countries could be signed into it. The Ad Hoc Group has since continued to establish the rules by which the Convention can be enforced and their Fifth Review took place in November and December of 2001 (United Nations, 2001).

Despite this convention, research in the field of biological warfare has continued to flourish in many countries hostile to the United States. Several countries yet have not signed the convention and many of those who have are still believed to be conducting secret bio-weapons research and stockpiling. Most notable among those countries that are not part of the convention are Iraq and Israel. Syria has signed the convention but has not ratified it. Other countries that still pose major concerns with regard to bioterrorism threat are China, Egypt, Iran, Libya and North Korea. These concerns are based largely on the military nature of those countries and difficulty encountered thus far in obtaining accurate intelligence reports about their weapons programs (Henry L. Stimson Center, 2001).

Recent Bioterrorism in the United States

After the terrorist attacks of September 11th 2001 against the Twin Towers in New York and the Pentagon in Washington D.C., several people in the United States were attacked with letters containing anthrax spores. These were believed to have been produced by the same party responsible for the September 11th 2001 attacks. On October 5th 2001, Robert Stevens, a photo editor for American Media Inc., died of inhalation anthrax in Boca Raton, Florida. After an investigation by the Centers for Disease Control and Prevention, several other employees for the same publishing company were found to have been exposed to anthrax though no others actually developed the disease.

In New York, the anthrax attacks were targeted largely at persons involved in large news organizations. An assistant to NBC news anchor Tom Brokaw tested positive for cutaneous anthrax after being exposed to a letter that contained odd-looking powder. The letter was addressed to Tom Brokaw on September 18th 2001. Three more people in the NBC news office were reported to have contacted anthrax from the envelope though none developed the disease. The 7-month-old son of an ABC news producer, who was said to have visited the network's headquarters on September 28th 2001, also tested positive for cutaneous anthrax. On October 17th, anthrax spores were discovered in the office of Governor George Pataki. No staff members tested positive for the disease, however several were prescribed antibiotics as a precautionary measure. Attacks continued in the following days. An assistant to CBS anchor Dan Rather tested positive for cutaneous anthrax on October 18th and then an employee at the New York Post tested positive on October 19th. On October 26th, the U.S. Postal Service confirmed that anthrax bacteria colonies were found on four sorting machines at the Morgan processing and distribution facility, which were quickly shut down and quarantined. The most recent New York case was on October 29th when a hospital worker was treated for what was later confirmed as anthrax.

The attacks were not limited to New York, though it will never be fully clear exactly how many of the terrorist's targets were deliberate. On October 18th, a postal worker in Hamilton, New Jersey tested positive for cutaneous anthrax. An investigation done by the Centers for Disease Control and Prevention (CDC) the next day found that a second employee was exposed to the spores also and tested positive for cutaneous anthrax. On October 28th, the CDC identified a New Jersey postal worker with inhalation anthrax and this person was quickly given treatment that allowed him to recover.

In Washington D.C., the attacks made using anthrax were targeted more toward harming political leaders. Several people came into contact with anthrax spores after a letter sent to Senate Majority Leader Tom Daschle on October 15th was found to contain anthrax spores. More than 20 employees in Senator Daschle's office later tested positive for exposure to anthrax spores. On October 20th, traces of anthrax spores were found in a mail bundling machine in the House of Representatives office building, forcing all mailroom employees to undergo testing with nasal swabs for possible infection. Only one worker was actually diagnosed with inhalation anthrax.

On October 22nd, two postal workers at the Brentwood mail facility (near Washington D.C.) died from what was later confirmed to be inhalation anthrax. Another mailroom employee at the U.S. State Department was hospitalized on October 25th for inhalation anthrax and the next day anthrax spores were found in a filter at the Supreme Court's off-site mailing facility. A small amount of anthrax bacteria was also found in a Central Intelligence Agency building in Langley, Virginia on October 26th. More traces of anthrax were then found on October 29th in the U.S. Supreme Court, a Department of Health and Human Services building and the main State Department building. A new letter was found on November 16th which was quite similar to that sent to Senator Daschle. This letter was addressed to Senator Patrick Leahy and contained anthrax spores that luckily were disposed of before they could harm anyone. This letter was found due to new increased security precautions, as hundreds of large barrels of mail in and around Washington D.C. were quarantined and tested.

The threat of anthrax is still very real, though it seems the current series of attacks has come to an end. On October 31st, a postal machine sent for cleaning to a company near Indianapolis tested positive for anthrax spores. On November 1st, four mailrooms used by the Food and Drug Administration in Rockville, Maryland tested positive for anthrax in preliminary tests. Traces of anthrax have also been found in Kansas City, Missouri on garbage bags that originated from Washington D.C.'s Brentwood mail facility.

The investigation into these bio-terrorist attacks determined that the letters containing anthrax spores all seem to have originated in Trenton, New Jersey. The letters were all very similar in appearance and content and though no more cases are likely to occur in the near future, security is still tight throughout the United States as a precautionary measure. All information gained on the 2001 anthrax attacks was provided by CNN's crisis tracker website (Cable News Network, 2001).

History of Drinking Water Legislation

For over a century, people have been aware of the necessity of having clean water distributed to the public. Many laws have been put into effect during that time which helped to minimize the risk due to natural pathogens. Subsequently, these laws also helped lessen the risk of a successful bioterrorist attack since traditional water cleansing techniques would work just as well against a deliberately implanted pathogen as naturally occurring pathogens.

Legislation Concerning Drinking Water Sources

The first legislation affecting drinking water sources, the Interstate Quarantine Act, was enacted in 1893. To prevent the spread of disease, this regulation prohibited travelers from using a common drinking cup by the authority of the United States Public Health Service (U.S. PHS) (HDR Engineering Inc., 2001).

The Water Pollution Control Act, instated by the U.S. PHS in 1948, was the first regulation to provide for legal action to be taken against persons attempting to contaminate a public water source. Though it was limited in power, it provided funds for state water pollution control agencies, and provided technical assistance to states. The U.S PHS followed this act in 1958 with the Federal Water Pollution Control Act (FWPCA), which provided more funding for water pollution research and training, and established a three-stage enforcement process. The FWPCA also imposed stricter punishments on people caught attempting to pollute public water sources deliberately. In 1965, the U.S. PHS passed the Water Quality Act. This Act required states to construct and implement plans for protecting all public sources of water. Finally, in 1972, the United States Environmental Protection Agency (U.S. EPA) amended the FWPCA to be even stricter on polluters. The amendments also set effluent limitations on the concentration of toxic substances (Davis, 1998).

In 1977 the U.S. EPA established the Clean Water Act, which endorsed that toxic waterborne substances must be controlled. The Clean Water Act established requirements for best available technology for the treatment of toxic substances, and best conventional technology for the treatment of conventional pollutants. It also added to the effluent limitations put forth by the 1972 FWPCA amendments (Davis, 1998).

Legislation Concerning Drinking Water Treatment

Prior to the 1900's there were no regulations concerning the quality of drinking water. Consumers of water relied on sensory perception to determine if water was drinkable. Only qualities such as taste, odor and clarity were taken into consideration. At this time it was not known that water could contain non-visible harmful substances such as viruses and bacteria (James M. Montgomery, Consulting Engineers, Inc., 1985).

In 1845, Dr. John Snow conducted his historically significant epidemiological study on the Broad Street Well cholera epidemic in London. During that year, London's populous was suffering from a cholera epidemic. Dr. Snow concluded that a leaking sewer pipe had contaminated the Broad Street Well, from which nearly half the population of London obtained its drinking water. He determined that cholera was being spread through the water in the well. The epidemic abated only after Dr. Snow removed the pump handle from the well, preventing people from drinking the contaminated water. This was the first recorded case where a cholera outbreak was linked to a contaminated water supply. Since that time it has been known that water can serve as a medium for the spread of disease (HDR Engineering, Inc., 2001).

During the early 1900's, the U.S. PHS, a division of the Treasury Department, developed standards to protect the public from contaminated water. The U.S. PHS developed the first regulation concerning bacteriological quality of water in 1914. This regulation required sampling for bacteria in municipal water distribution systems. These regulations were expanded in 1925, 1942, and 1946. They included maximum levels for lead, fluoride, arsenic, selenium, and chromium, and became the basis for standards of water quality in the United States (HDR Engineering, Inc., 2001).

Virtually all of the 50 states adopted federal water quality standards put forth by the U.S. PHS in 1962. The Water Quality Act was passed in 1965, requiring states to set water quality regulations and develop implementation plans for protecting all public sources of water. In 1969, the U.S. PHS's bureau of Water Hygiene conducted a survey of water supply systems across the country to determine their compliance with the 1962 standards for water quality. The bureau found that less than 60% of the water systems it surveyed were adequate according to the standards. Maximum contaminant levels as well as bacterial content were not met.

In 1970, it became apparent that an organization was needed to enforce drinking water standards and protect the environment. In response to this, President Nixon instated the United States Environmental Protection Agency (U.S. EPA) (James M. Montgomery, Consulting Engineers, Inc., 1985).

Congress enacted the Safe Drinking Water Act in 1974. This gave the administrator of the U.S. EPA the authority to develop safe standards to control the quality of drinking water for the protection of public health (U.S. EPA, 2001b). In 1975, the U.S. EPA published the National Primary Interim Drinking Water Regulations. These regulations were enforced by 1977 (Sanks, 1979). By 1979, the U.S. EPA developed a secondary set of non-enforceable regulations called the National Secondary Drinking Water Regulations. The purpose of these regulations was for guidance in treating drinking water for aesthetic qualities (HDR Engineering Inc., 2001).

By 1986, satisfactory progress in the regulation of contaminants by the U.S. EPA had not been made. The required number of maximum contaminant levels had not been regulated, and existing maximum contaminant levels were not being enforced. Because of this, the Safe Drinking Water Act was amended by Congress to encourage the U.S. EPA to enforce maximum safe levels of contaminants expediently, and add more contaminants to the list. These amendments required that the original 83 contaminants be regulated by 1989, and that 25 new contaminants be regulated every 3 years thereafter. They also required that previously recommended maximum contaminant levels become mandatory, and that the best available technology be used to treat contaminants. Finally, the U.S. EPA was required to improve their enforcement policies and monitor for contaminants that had not yet been regulated.

The 1986 Safe Drinking Water Act amendments expired in 1991. Due to the U.S. EPA's failure to keep up with the 1986 requirements, they were not replaced until 1996 (HDR Engineering, Inc., 2001). The 1996 Safe Drinking Water Act Amendments placed less emphasis on the numbers of contaminants to be regulated, and focused instead on contaminants that posed the greatest risk to public health (U.S. EPA, 2001c).

Current Regulations

The National Primary Drinking Water Regulations, which were first established in 1975, serve as a basis by which municipal drinking waters are treated. The U.S. EPA has continually updated the National Primary Drinking Water Regulations. Among these current regulations are requirements for filtration and disinfection of surface waters and ground waters under direct influence of surface waters. The purpose of disinfection is to inactivate microorganisms. Filtration is used to remove particles in water that affect its aesthetic value, shield microorganisms from disinfection, and reduce the disinfectant's effectiveness. The National Primary Drinking Water Regulations also provide criteria for avoiding filtration for high quality source waters.

For surface waters, or ground waters under the direct influence of surface waters, all disinfection and physical removal systems have to meet specific requirements. The Surface Water Treatment Rule requires that treatment plants achieve at least 99.9% (3-Log) removal or inactivation of *Giardia lamblia* cysts, and at least 99.99% (4-Log) removal or inactivation of viruses (U.S. EPA, 1989a). Additionally, they must remove 99% (2-Log) of *Cryptosporidium parvum* oocysts, per the Interim Enhanced Surface Water Treatment Rule (IESWTR), which became effective January 1st, 2001 (U.S. EPA, 1998).

Log removals for plants with filtration systems are determined by a system of credits. Each filtration system is given a credit for log removal, and the remainder of the total removal or inactivation requirement for *Giardia* and viruses must be met by the disinfection system. As shown in Table 2-1, conventional treatment, direct filtration, slow-sand filtration, and diatomaceous earth (DE) filtration receive credits for *Giardia* and virus removal.

Table 2-1, Log Removal Credits

(Source: U.S. EPA, 1999 and 2002)

Filtration	***Giardia* Log Removal**	**Virus Log Removal**	***Cryptosporidium* Log Removal**
Conventional	2.5	2.0	2.0
Direct Filtration	2.0	1.0	2.0
Slow-Sand Filtration	2.0	2.0	2.0
Diatomaceous Earth	2.0	1.0	2.0

The remainder of the log inactivation of viruses and *Giardia* is achieved by disinfection. The log inactivation achieved by a disinfectant is based on a CT value. CT is the product of the concentration (C) of residual disinfectant in the system in milligrams per liter (mg/L), and the contact time (T, in minutes) of disinfection between the addition of the disinfectant and measurement of the residual chlorine concentration (U.S. EPA, 1999). The U.S. EPA published CT values for inactivation of *Giardia* and viruses by several disinfectants, including chlorine, chorine dioxide, chloramines and ozone. Example CT values for chlorine are shown in Table 2-2.

Table 2-2, Values for Inactivation of *Giardia* Cysts by Free Chlorine at 0.5°C or Lower at pH<=6

(Source: U.S. EPA, 1999)

CHLORINE CONCENTRATION	pH<=6 Log Inactivation					
(mg/L)	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	23	46	69	91	114	137
0.6	24	47	71	94	118	141
0.8	24	48	73	97	121	145
1	25	49	74	99	123	148
1.2	25	51	76	101	127	152
1.4	26	52	78	103	129	155
1.6	26	52	79	105	131	157
1.8	27	54	81	108	135	162
2	28	55	83	110	138	165
2.2	28	56	85	113	141	169
2.4	29	57	86	115	143	172
2.6	29	58	88	117	146	175
2.8	30	59	89	119	148	178
3	30	60	91	121	151	181

After filtration, all filtration systems must meet specific requirements for turbidity. Turbidity is a measure of light passing through a sample of water and is measured in Nephelometric Turbidity Units (NTU). In conventional or direct filtration systems turbidity must measure less than or equal to 0.3 NTU in at least 95% of measurements per month. In systems using slow sand filtration or diatomaceous earth filtration, turbidity must measure less than or equal to 1 NTU in at least 95% of measurements per month. Turbidity levels in conventional and direct filtration systems must never reach a turbidity of more than 1 NTU (U.S. EPA, 2002).

Along with log removal and maximum turbidity requirements, treatment plants must also meet maximum coliform bacteria amounts according to the Total Coliform Rule (U.S. EPA, 1989b). These requirements, however, are not maximum concentration levels, but rather limits on the number of positive coliform tests allowed. In all systems serving water to the public there must be no more than 5% positive total coliform tests in a month. Every sample testing positive for total coliforms must be analyzed for fecal coliforms. In these samples there must be no fecal coliforms or *E. coli* present (U.S. EPA, 1989b). Requirements for all treatment plants are displayed below in Table 2-3.

Table 2-3, Maximum Contaminant Level Requirements for Surface Water Treatment Plants

(Source: U.S. EPA, 2001a and 2002)

Contaminant	**Regulation**
Giardia *Cryptosporidium* Viruses	3 log removal and/or inactivation 2 log removal 4 log removal and/or inactivation
Turbidity	≤ 0.3 NTU in 95% of measurements, never to exceed 1 NTU for conventional and direct filtration plants.
Coliforms	No more than 5% positive tests, containing no fecal coliforms, or *E. coli*

Along with regulations for disinfection and filtration, the U.S. EPA has provided criteria by which water sources can avoid filtration and use only disinfection. For a system to avoid filtration, at least 90% of fecal coliform tests must be negative for six months previous to operation of the system. These systems must also have fecal coliform concentrations less than or equal to 20 out of 100 ml, and total coliform concentrations less than or equal to 100 out of 100 ml. Additionally turbidity cannot exceed 5 NTU twice in 12 months.

Disinfection systems operating without filtration must meet the effluent requirements for systems with filtration, shown in Table 2-3. Additionally they must continually meet the requirements for avoiding filtration. Furthermore, these systems must meet CT values for specified log inactivations to ensure proper inactivation of protozoa and viruses. Microorganisms are not removed in these systems, they are inactivated, or killed, by the disinfectant. Systems operating without filtration are also subject to yearly on site inspections.

Drinking Water Treatment

For water to be fit to drink it must first have any disease causing microorganisms and harmful chemicals present removed by means of treatment. Currently, conventional treatment techniques and federally mandated drinking water quality standards help keep U.S. drinking water relatively safe. This causes high consumer confidence, which allows travelers and U.S. residents to drink tap water without fear of harmful chemicals or waterborne disease. This hasn't always been true. The modern world has only seen common central water treatment since the early 1800s. Before that time, treatment of water was an individual responsibility.

History of Drinking Water Treatment

It has been known for thousands of years that not all water is safe to drink, and some water must first be treated. The Old Testament warns of bitter water, and describes the desperate search for pure, life-sustaining water. Along with early Hebrew writings, Sanskrit and Greek writings described how to treat water 6000 years ago. They revealed that impure water should be treated by boiling or by filtering through sand and gravel (HDR Engineering, Inc., 2001).

By 2000 B.C., people in India were known to have filtered water through charcoal. The treated water was preserved in copper pots for later use. This practice purified water, and kept it for times when it was needed. Later, around 1500 B.C. and 1300 B.C., Egyptians were known to have purified their water. Paintings depicted men filtering water through wick siphons out of a sedimentation apparatus. Egyptians also used alum to assist in the settling of particles, which improved clarity. Between 460 B.C. and 354 B.C., Hippocrates, known as the Father of Medicine, recommended water treatment before consumption. He suggested that to maintain the public health, water be purified by boiling and straining before consumption (HDR Engineering, Inc., 2001). The first public water systems were created around the end of the 3rd century B.C. These systems were created in Rome, Greece, Carthage, and Egypt. Along with these distribution systems, storage and settling cisterns were constructed to remove silt through sedimentation. These advances in public water distribution systems led to the construction of the Roman aqueducts between 343 B.C. and 225 A.D. Very little progress in water treatment technology was made between 225 A.D. and the 16th and 17th centuries A.D. Not only did technology stop progressing during this time period, but also water treatment stopped being used throughout Europe after the fall of the Roman Empire (AWWA, 2001).

Water treatment by filtration began in Europe in the 1600's and 1700's. In 1685, the Italian physician Luc Antonio Porzio published the first illustrations of sand filters for treating water. His filters consisted of straining and sedimentation compartments followed by sand filtration with both upward and downward flow (AWWA, 2001). Later, in the mid 1700's, a Frenchman by the name of Joseph Amy was granted the first patent for a water filtration system that used sponges (HDR Engineering, Inc., 2001). These early filters filtered water through charcoal surrounded by wool and sponges. They were sold for use individual use in homes (AWWA, 2001). James Peacock, a British architect, was awarded the first British patent in 1791 for his description of a water filter using carefully placed graded layers of sand and gravel (HDR Engineering, Inc., 2001). In 1804, John Gibb built a water facility in Paisley, Scotland to supply his bleachery as well as town. Paisley was the first town in Europe to have filtered water available to the entire town. Originally, the filtered water was transported to customers by horse drawn cart, but by 1807 both Paisley and Glasgow, Scotland began piping the filtered water to customer's homes. In 1806, a large treatment plant using sand and charcoal filters was built in Paris. The plant's filters were renewed every six hours, and delivered water by horse driven pumps (AWWA, 2001). Central treatment of water by filtration was adopted all over Europe by the early 1800's (HDR Engineering, Inc., 2001).

Although water filtration was available all over Europe during the early 1800's, the link between water filtration and reduction of the spread of waterborne diseases had yet to be made. During the 1850's, the populous of the United States was plagued by typhoid fever outbreaks. These outbreaks caused many deaths. However, it was not until Louis Pasteur proposed his "germ theory" in the 1880's that the cause and spread of disease by microorganisms was understood. In 1887, the Massachusetts State Board of Health established an experiment station in Lawrence to study water filtration. Before the study was concluded the town suffered a typhoid fever outbreak. In response to this a sand filter was installed. By 1892, the correlation between water filtration and protection against disease had been provided by Dr. Robert Koch. Dr. Koch examined the German cities of Hamburg and Altona that were suffering from cholera outbreaks. The city of Altona, which filtered its water, was downstream from Hamburg, but suffered fewer cholera outbreaks. He determined that the low number of cholera related deaths were due to filtration. In 1893, Professor W.T. Sedgwick from the Massachusetts Institute of Technology examined typhoid cases before and after the installation of sand filters. He determined that the death rate due to typhoid fever dropped 79% because of filtration (HDR Engineering, Inc., 2001).

Although water distribution systems were common in Europe by the mid 1700's, public water distribution systems did not emerge in the United States until the late 1700's. Philadelphia, Pennsylvania was the first city in the United States to build a public water distribution system. This system, however, did not treat the water. A system that treated water by means of sand filtration was not constructed in the United States until 1832. This system was built in Richmond, Virginia. By the late 1800's, sand filtration was adopted widely in the United States. By 1900, there were more than 3,000 municipal water systems in the United States, and the prevention of spread of waterborne disease by sand filters had been proven. In 1906, Philadelphia adopted sand filtration, and by 1907, over 30 U.S. cities used sand filtration (HDR Engineering, Inc., 2001).

Even though sand filtration was effective at removing pathogens, it did not destroy them. Because of this outbreaks due to waterborne diseases were still common. By the 1900's, it had been determined in laboratories that chlorination kills pathogens. Chlorination had previously been used to destroy pathogens in water, but it had only been used on a temporary basis. The first permanent chlorination plant was installed in Belgium in 1902. Over the next couple of years chlorination was adopted as a standard practice all over Great Britain (HDR Engineering, Inc., 2001). The early 1900's saw the use of chlorination, as well as other methods of disinfection. Ozone was first used as a disinfectant in Nice, France in 1906. The equipment, however, was complex and costly to operate. This caused the process of ozonation to be less wide spread than chlorination (AWWA, 2001).

Chlorination in the United States did not appear until 1908. The first U.S. chlorination plant was installed in Jersey City, New Jersey in 1908. This plant caused a marked decrease in typhoid and other waterborne diseases. In 1919, Abel Wolman helped develop the concept of chlorine demand. He demonstrated that the water in different cities consumed different amounts of chlorine. By 1920, sand filtration and chlorine disinfection was considered state-of-the-art water treatment in the United States (HDR Engineering, Inc., 2001).

To this day, most municipal water systems treat their water with sand filtration and chlorine disinfection. Even though this is still considered the most effective method of water treatment, it proved to be insufficient in 1993. In Milwaukee, Wisconsin over 400,000 people suffered intestinal discomfort, and over 100 people died due to a *Cryptosporidium parvum* outbreak. Prior to the mid-1970s, it was not known that *Cryptosporidium* could be transmitted to people through water. Prior to 1993, it was not known that certain activities could cause high risk of *Cryptosporidium* run off into surface water. Because of this, surface water systems are now required to maintain the area around the reservoir where runoff from rain flows into the reservoir, known as the watershed. This area is to be protected from activities that may cause *Cryptosporidium* contamination by limiting the presence of septic systems, and recreational activities in that area. Protecting a watershed is difficult however because it is impossible to control the activities of wild animals in the area (HDR Engineering, Inc., 2001).

Current Treatment Techniques

Before surface water is distributed to customers, it must first be disinfected by killing or removing any harmful microorganisms as per the U.S. EPA's regulations. The primary purpose of water treatment is disinfection. Disinfection can be performed directly to raw water, or after the unit processes of rapid mixing, coagulation, flocculation, sedimentation, and filtration. The purpose of these unit processes is to remove microbes, and particles that may shield pathogens from disinfection, or reduce the disinfection capabilities of the disinfectant (HDR Engineering, Inc., 2001).

Rapid Mix, Coagulation, Flocculation, Sedimentation

Rapid mix, coagulation, flocculation, and sedimentation are processes that help remove particulate impurities as well as soluble organics from water. These processes are most often performed in plants treating water with high turbidity, but may also be used in plants treating water with low turbidity. They remove particles by settling, and are usually followed by filtration (HDR Engineering, Inc., 2001).

The theory that these unit processes are based on is that all particles with a density higher than water should eventually settle due to gravity. However, gravity is not the only force acting upon a particle in water. There also exist electrostatic forces acting between particles. These forces keep particles suspended in the water. To counteract this effect, something must be added to water to destabilize and agglomerate suspended particles (HDR Engineering, Inc., 2001).

Agglomeration of suspended particles is achieved by coagulation. Chemical coagulation refers to the addition of a chemical to water which bonds to many particles in suspension. This forms large flocs that can be settled out later. Chemicals that are commonly used for this process are aluminum sulfate (alum), polyaluminum chloride, ferric sulfate, and ferric chloride. This process can also be achieved by addition of synthetic organic polymers, activated silica, aluminum (III) hydroxide, iron (III) hydroxide, or certain carbonate precipitates. Selection of the most appropriate coagulant is site specific. For proper aggregation of suspended particles, the coagulant must be thoroughly mixed in the water (HDR Engineering, Inc., 2001).

Thorough mixing of the coagulant and water is performed after or during addition of the coagulant to water, by the rapid mix process. This process is performed by mechanical mixers, in-line blenders, jet injection or hydraulic mixing. These mechanisms thoroughly mix the coagulant and the water it is being added to almost instantaneously. Rapid mixing occurs for a short time to allow for dispersion of the coagulant through water. After rapid mixing, particles are mixed slowly to allow for contact between particles and coagulant (HDR Engineering, Inc., 2001).

Slow mixing of chemically treated water occurs in large flocculation basins. This aggregates destabilized particles. There are three types of flocculation: Perikinetic, orthokinetic, and differential settling. Perikinetic flocculation is driven by the thermal energy of the fluid. In this process, aggregation occurs as a result of random thermal motion of particles. Orthokinetic flocculation is caused by inducing varying velocity gradients in a fluid. In orthokinetic flocculation, suspended particles follow streamlines of varying velocities, and eventually collide. The different settling velocities of different particles cause differential settling (HDR Engineering, Inc., 2001).

Immediately after flocculation takes place the particles are settled out of the water. Particles and flocs are settled out by a process called sedimentation. Sedimentation works because particles and flocs with densities larger than water will settle due to gravity. Sedimentation usually takes place in large tanks with graded bottoms that collect settling particles. Sedimentation tanks must periodically have the layer of sludge that collects on the bottom removed. Some tanks have built in mechanical sludge removal devices that work continuously (HDR Engineering, Inc., 2001).

The processes of rapid mixing, coagulation, flocculation, and sedimentation work to remove particles that may shield microorganisms from disinfection, and reduce the potency of the disinfectant. These processes also work to remove microorganisms themselves. Chemical coagulation with alum has been noted by researchers to remove bacteria and viruses in significant percentages (Culp *et al.*, 1986). These processes are almost always followed by filtration in water plants.

Filtration

Filtration is a process that removes suspended particulate impurities from water. It usually takes place in a relatively deep granular bed, or some sort of porous medium. There are two general types of filters: gravity filtration systems (used by larger plants) and pressure filtration systems (used by smaller plants).

There are two kinds of gravity filtration systems: rapid rate gravity filtration and slow-sand filtration. Rapid rate gravity filtration is the most widely used type of filter. In these systems, water flows down through a granular bed. Solids accumulate in the voids on the top and within the bed of the filter. Over time the voids in the filter become increasingly smaller. The filter must be periodically cleaned with an upward flow, known as backwashing. Slow-sand filtration is similar to rapid rate gravity filtration, except it uses smaller pores, and the flow rate of water through the filter is slower. It also uses biological mechanisms to function (HDR Engineering, Inc., 2001). Slow-sand filtration is used because of its effectiveness in removing pathogenic organisms. Slow-sand filtration provides over 3-log removal of *Giardia* and *Cryptosporidium*, while rapid rate gravity filtration only provides a 2.5-log removal of *Giardia* and *Cryptosporidium* (AWWA, 1999).

There are four types of pressure filters: rapid rate pressure filtration, diatomaceous earth (DE) filtration, membrane filtration, and cartridge filtration. Rapid rate pressure filtration is used for small industrial water supplies. It is similar to rapid rate gravity filtration, except that flow enters and exits the vessel under pressure. Rapid rate pressure filtration is not normally permitted for use in municipal surface water treatment. Diatomaceous earth filtration is used for treatment of municipal water supplies. DE filtration can be used to directly treat surface water with low levels of turbidity. The filter consists of a layer of DE supported by a filter element. DE consists of the fossilized remains of ancient algae called diatoms that have silica in their cell walls. DE filtration is used for its ability to remove bacteria, viruses, and protozoa. DE filtration provides greater than 3-log removal of *Giardia* and *Cryptosporidium* cysts.

Membrane filtration is filtration through a membrane with uniformly sized pores. Low-pressure membranes are capable of removing very small particles. Microfiltration is capable of removing particles as small as 0.1 micron. Ultrafiltration is capable of removing particles as small as 0.01 micron. These types of membrane filtration are sometimes used because of their capability to completely remove viruses and bacteria. Cartridge filtration systems are used just prior to membrane filtration systems. They are made of fabric or string filter mediums supported by a filter element. Viruses and bacteria can pass through most of these filters. Cartridge filters sometimes pose an economical problem because when the cartridges are done being used they are thrown out instead of backwashed (HDR Engineering, Inc., 2001).

Filtration helps remove microorganisms as well as large particulate impurities that may shield microorganisms from disinfection and reduce the effectiveness of the disinfectant. Some filtration systems are capable of filtering out all microorganisms, but these systems are not commonly used due to their large operational costs. The effectiveness of filtration for removal of pathogenic organisms such as *Giardia* cysts and viruses is determined through the system of log removal credits discussed previously (HDR Engineering, Inc., 2001).

Disinfection

The goal of water treatment plants is disinfection, which inactivates pathogenic organisms and prevents them from spreading disease. Disinfection is achieved in any one of three ways. The first method is destruction of cellular structure by destroying major parts of the cell, such as the cell wall, or other semi-permeable membranes. Disinfection is also achieved by removing the energy-yielding metabolism capabilities of the organism or by destroying necessary enzymes. Finally, disinfection works by interference with growth and reproduction, by preventing the synthesis of proteins, nucleic acids, coenzymes, or cell walls (HDR Engineering, Inc., 2001).

There are several disinfectants that are regularly used in the disinfection process. Chlorine, chlorine dioxide, sodium hypochlorite, and calcium hypochlorite are all forms of chlorine. Chlorine works by oxidizing and destroying the cell wall of microorganisms. Other chemical disinfectants that are used are monochloramine, anhydrous ammonia, ammonium hydroxide, and ozone. These chemicals are also oxidants (HDR Engineering, Inc., 2001). Aside from chemical oxidants, UV light can be used for disinfection. UV light disinfects by damaging nucleoproteins necessary for operation and reproduction (Culp *et al.*, 1986).

All disinfection systems must meet CT values specified by the U.S. EPA. These values are associated with certain log removal numbers. The total log removal of 3-log for *Giardia*, 2-log removal for *Cryptosporidium,* and 4-log for viruses is required for all surface water treatment plants. The log removals for *Giardia* and viruses are achieved by a combination of credit log removal for filtration systems and CT log removal values of disinfection systems. Log removal for *Cryptosporidium* is achieved only from filtration credit log removal.

Simple addition of disinfectants is not the only way to remove pathogenic microorganisms. Treatment of water is achieved by optimizing the unit processes of coagulation, sedimentation, filtration, and disinfection. Together these systems produce water that is safe to drink.

Chapter 3, Methods

Introduction

This project began with accumulating information about bioterrorism and water treatment. This research was conducted in the library and on the Internet. Despite the large volume of information available, only a few Internet sites were deemed credible enough to be used as sources for this study. Most of these sources were produced by the United States government and by organizations for public safety and health reform. Information was needed on bioterrorism history, water treatment processes and clean water regulations.

The second phase of the project involved learning about the Worcester Water Filtration Plant. Unfortunately due to security concerns, a tour of the plant was not possible. The plant data itself was still relevant, since it allowed for calculations on log removal of microorganisms. Additionally, numerous web published newspaper articles provided a broad idea of the public's concerns and of the media's stance on the subject of bioterrorism. Personal and phone interviews as well as surveys on public opinion provided us with more insight on these topics.

Biological Agents

The first stage in researching was done primarily on the Internet and in the library. Information was gathered on the properties of biological agents, in particular their modes of infection, lethality, contagiousness and size. The information was later used to ensure that calculations for water treatment processes were applicable to biological agents that would likely be used in a terrorist attack. The Centers for Disease Control and Prevention web site and the University of Pennsylvania's Index of Biological Agents provided the necessary data on pathogens. We also noted the three primary types of biological agents: biological toxins, bacteria, and viruses.

Water Treatment

To determine if biological agents will survive a water treatment plant, it was necessary to find information on the different unit processes within a water treatment plant. This research was accomplished by studying water treatment books written for professional engineers and engineering students, such as the Handbook of Public Water Systems (Culp *et al.*, 1986; HDR Engineering, Inc, 2001). These books gave detailed information on the operations of the unit processes found in water treatment plants. They also gave detailed information on how the processes remove and inactivate microorganisms, as well as theoretical information about why they work.

Regulations

Once the unit processes of a water treatment plant were determined, it was necessary to determine regulations governing water treatment plant operations. This information was available from the U.S. Environmental Protection Agency. The U.S. EPA maintains a set of regulations for water treatment plant operations known as the National Primary Drinking Water Regulations. The U.S. EPA regularly publishes manuals for testing water quality and determining removal of viruses and protozoa through water treatment processes. These reference materials are available on the U.S. EPA's website. The information found in these references allowed the removal of viruses and *Giardia* to be determined at the Worcester Water Filtration Plant from information that the water treatment plant must document daily.

Worcester Water Filtration Plant

After a method of determining removal of viruses and *Giardia* from regularly documented data was made, information on the unit processes and the documented data from the Worcester Water Filtration Plant was needed. The unit processes that the plant uses were available on the Worcester Water Filtration Plant website. The information that the plant regularly documents to determine removal of viruses and *Giardia* was obtained directly from Robert Hoyt, the Plant Manager of the Worcester Water Filtration Plant. The information Mr. Hoyt supplied was particle counter data, ozone concentration and contact time (CT) values, and chlorine CT values. This information was used to determine the removal of viruses and *Giardia* that the plant achieved through its unit processes.

Data Analysis

In analyzing the data gathered about the Worcester Water Filtration Plant, the calculations were divided into three classifications. First, we wanted to know a static removal percent for the plant as it is today. Particle counter information and chlorine CT information was used for this task. From the particle counter information, it was possible to estimate a log removal accounting for filtration and ozone processes together. These log removal values were then added to log removals calculated from the known CT values for chlorine to determine overall removal rate for the plant. The second group of calculations also evaluated the plant as it is today; however, we used regulatory information instead of particle counter information to determine log removal credit for filters. This was added to log removals calculated from ozone and chlorine CT values, giving a total log removal for the plant. A third calculation was made using the same data as the second calculation plus the credit that would be gained by adding a settling tank to the plant, which is not strictly required by regulation. All three calculations were made for both virus and *Giardia* scenarios. Separate evaluations were made for each of the four seasons, rather than making calculations for each day of the entire year. A summary of calculation methods is shown in Table 3-1.

Table 3-1, Data Analysis Calculations Summary for Water Filtration Plant

Calculation	Scenario	Method		
		Ozone	Filter	Chlorine
1	Current plant	Particle Counter Data	Particle Counter Data	Chlorine CT Values
2	Current plant	Ozone CT Values	Regulatory Credit System	Chlorine CT Values
3	Plant with addition of settling tank	Ozone CT Values	Regulatory Credit System	Chlorine CT Values

Cost of Water

One of the initial questions for this project was whether an upgrade would be necessary to the Worcester Water Filtration Plant in order to ensure consumer safety and plant effectiveness against bioterrorist attacks. If such an upgrade were implemented, it would result in increased water rates for Worcester residents or increased property taxes. First, the current cost of water for the average Worcester resident was determined. A telephone interview was conducted with Bob Moylan, the Worcester Commissioner of Public Works in order to learn who makes decisions regarding plant upgrades. We determined that so long as the town is meeting regulations in full, they are not required to make any upgrades to their plant. In order to get an optional upgrade put in place, it would need to be desired by the people of Worcester. That was the reason we designed our survey. The surveys asked Worcester citizens how much more they would be willing to pay for their water. This information might be used at a later date by the Water Billing Department to determine whether citizens want an upgrade badly enough to pay the extra costs it would entail.

Surveys

A series of public opinion surveys were conducted to assess the feelings of the Worcester citizens about the safety of their water. Surveys were conducted on December 3rd, 5th and 6th (2001) from 11:00AM to 4:00PM and on December 8th and 16th from 2:00PM to 5:00PM. These surveys were distributed in a number of different locations throughout Worcester in order to gain a representative group of persons of different age, gender and residential status. Many were distributed at the Greendale Mall at 7 Neponset St. and Worcester Common Fashion Outlet mall at 100 Front Street, Worcester, MA. A number were also filled out near city hall at 455 Main Street, at WPI at 100 Institute Road, and in several other parts of Worcester. The survey was administered to any Worcester resident above the age of 18 and willing to participate. The survey was designed to assess whether the people of Worcester prefer tap water to bottled water, whether they feel the tap water is safe, and whether they would be willing to pay more to further ensure the safety of their water. The survey distributed is shown in Appendix A.

Chapter 4, Results and Analysis

In this chapter we reveal and assess all of the answers gathered by this study. First we establish the basis for our project by determining which biological agents would likely be used in a bioterrorist attack and why. We then analyze each of the water treatment plant's processes both by credit and by particle counters to determine their effectiveness against such an attack. Our survey data is presented and discussed in detail for the purpose of gaining a public perception about the safety of tap water. This leads up to a cost of water analysis in which we determine how a decision to upgrade the treatment plant might come.

Biological Agents Likely To Be Introduced In a Water Treatment System

Introduction

Since there were too many varieties of biological agents that could be used in an attack on the Worcester Water Filtration Plant, a list of the most likely agents was created. The Centers for Disease Control and Prevention (CDC) has classified microorganisms into 3 categories; A, B, and C. Each category consists of groups of microorganisms based on their priority. The CDC priority assessment includes an evaluation of rate of transmission, lethality, probability of transmission, probability to cause panic or riots, and special treatment requirements (Centers for Disease Control and Prevention, 2002a).

This project focused on class A category microorganisms because it was felt that if microorganisms in this category were deemed most dangerous, they would be most likely to be used in a bioterrorist attack. Category A diseases and agents are national security risks because they are easily disseminated or transmitted from person to person, result in high mortality rates and have the potential for a major public health impact, might cause a public panic or social disruption, and require special action for public health preparedness (Centers for Disease Control and Prevention, 2002b).

Research identified three modes of potential biological attack; bacterial attacks, viral attacks and the use of biological toxins. Biological toxins are harmful substances produced by living organisms. They are not chemical weapons in that biological toxins are not man made, not volatile, provide no vapor hazard, and as a group are usually not dermally active though mycotoxins are the exception (Food and Drug Administration, 2000). Table 4-1 displays the category A viruses and bacteria that could be used in a biological attack.

Table 4-1, Biological Agent Sizes and Information

(Centers for Disease Control and Prevention, 2002a, and John Hopkins, 2002)

Agent	Disease	Type	Size	Risk of Transmission	Lethality
Bacillus anthracis	Anthrax	Bacteria	0.5 µm to 1.0 µm in diameter-	Very Low	Very High
Yersinia pestis	Plague	Bacteria	0.5 µm to 0.8 µm in width and 1.0 µm to 3.0 µm long-	High	Very High
Variola virus	Smallpox	Virus	0.02 µm to 0.2 µm in diameter	Very High	Moderate
Hantavirus, Rift Valley Fever, Congo-Crimean, Lassa Fever, Marburg, Ebola, Yellow Fever, Dengue	Viral Hemorrhagic Fevers (VHF)	Virus	0.02 µm to 0.2 µm in diameter	High	Very High
Clostridium botulinum	Botulism	Bacteria	0.5 µm wide and 0.3 to 0.9 µm long	Very Low	High
Francisella tularensis	Tularemia	Bacteria	0.5 µm to 1.0 µm in diameter	Undocumented	Moderate

Bacteria used for biological attacks generally range in size between 0.5 µm to 3.0 µm in diameter. Specifically, cocci most often have a diameter of 0.5 µm to 1.0 µm whereas baccilli have a similar diameter but form a rod up to 3.0 µm in length. However, the viruses range between 0.02 µm and 0.2 µm in diameter. Since biological toxins act as molecules in the blood stream and have sizes measured in Daltons, they are too small to filter or accurately measure with regard to this IQP. Therefore, only bacteria and viruses were considered.

The Worcester Water Treatment Plant is required by U.S. EPA regulations to remove or inactivate 4-log of viruses. It does not have removal values for specific viruses, rather it receives credit for viral removal/inactivation based on the treatment process. It was important to correlate the viral agents to the viral pathogens removed by the plant by size. Since the viral biological agents discussed here are also the virus sizes used by the U.S. EPA, it is likely that the plant removal values for naturally occurring viral pathogens and viral biological agents would also be comparable. In addition it is likely that U.S. EPA regulations are based on the viral species that are most difficult to remove or inactivate (in order to provide the necessary factor of safety). Therefore plant removal values for naturally occurring viruses should provide a reasonable, even conservative estimate of viral biological agent removal. The Worcester Water Treatment Plant does not have a removal value for bacteria, but it does have a value for the protozoa *Giardia*. Bacteria are smaller and more susceptible to disinfection than *Giardia*, which can form into protective cysts. Because of this it is reasonable to assume that using removal of *Giardia* as a removal value for bacteria would give a conservative estimate of bacteria removal.

Worcester Water Filtration Plant

Introduction

The Worcester Water Filtration Plant is located in Holden, MA. This plant was chosen for its proximity to WPI, as well as the fact that it supplies Worcester's municipal water customers with all of their water. The Worcester Water Filtration Plant operates in compliance with the U.S. EPA's National Primary Drinking Water Regulations, as well as all the U.S. EPA's regulations pertinent to surface water systems. It treats approximately 25 million gallons per day (MGD) of water. This water is supplied from the Holden Reservoir, which, in turn, is supplied by a network of reservoirs stretching through the towns of Leicester, Paxton, Rutland, Holden, and Princeton, MA (Worcester Department of Public Works, 2002).

Worcester Water Filtration Plant Specifications

The Worcester Water Filtration Plant is a direct filtration plant. Direct filtration means that the plant does not include sedimentation. Particle removal occurs through the filters. The present treatment plant unit processes are ozonation, rapid mix, coagulation, flocculation, filtration and chlorination (see Figure 4-1).

The Worcester Water Filtration Plant uses ozonation as primary disinfection. The ozonation process of the Worcester Water Filtration Plant uses two ozone contactors, supplied by four ozone generators. This system adds ozone to the water to achieve an average concentration of 1 mg/L. The average detention time of these ozone contactors is 4 minutes per contactor. After the process of ozonation the water is sent to the rapid mix process (Worcester Department of Public Works, 2002).

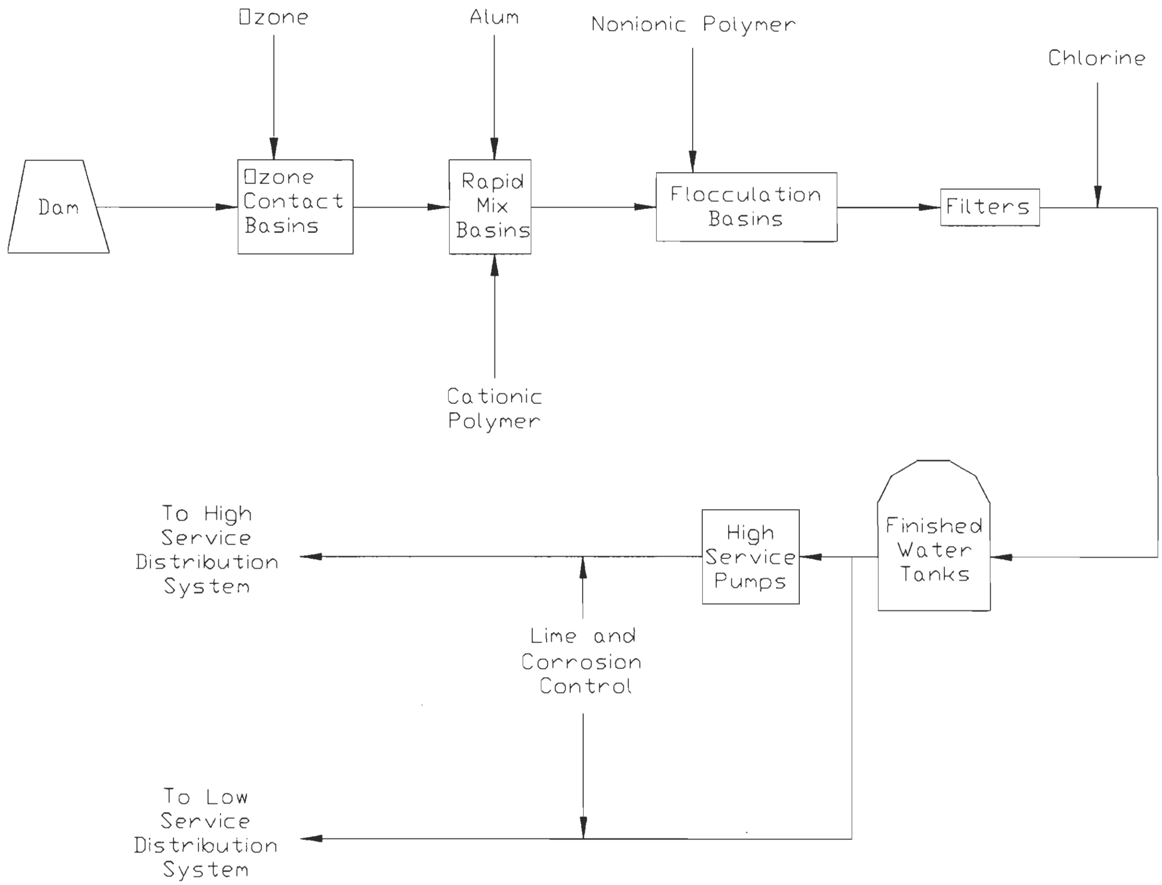

Figure 4-1, Worcester Water Filtration Plant Schematic

This plant's rapid mix systems are vertical shaft radial turbine mixers having two stages. Alum (aluminum sulfate) and a cationic polymer are used as coagulation agents. The alum concentration added to the water is 10 parts per million (ppm), and the cationic polymer concentration is 2.5 ppm. These coagulants are mixed in the four mechanical mixers for 30 seconds before moving on to the flocculation unit process (Worcester Department of Public Works, 2002).

Water is detained in the Worcester Water Filtration Plant's twelve flocculators for a total of 15 min. During flocculation, a nonionic polymer is added as a filtration aid. The plant uses vertical shaft axial flow flocculators. After flocculation, the water is filtered (Worcester Department of Public Works, 2002).

There are eight filters in the Worcester Water Filtration Plant. They each contain 60 inches of anthracite coal over 12 inches of sand. The filters are designed to operate at 8 gallons per minute per square foot. Filter surface area is 20 feet by 40 feet, giving the filters an individual rate of 6,400 gallons per minute, and a combined rate of 51,200 gallons per minute. These filters are also designed to accept an activated carbon media in case more thorough filtration is required in the future. Water is disinfected after filtration (Worcester Department of Public Works, 2002).

Disinfection in the Worcester Water Filtration Plant is also achieved by chlorine. Chlorine is typically added at a concentration of 3.0 mg/L, which results in residual concentration at the start of the distribution system of about 1.5 mg/L. Chlorine is not directly added to the water. Instead chlorine gas is mixed with a small amount of water in a high concentration before being added to the water being treated. After chlorine is added to the water, the water passes into large storage tanks (clear wells) to provide sufficient contact time with the chlorine disinfectant. Average contact time of chlorine used to determine CT values is about 35 minutes. As per federal regulations, the time of contact with chlorine and the residual concentration are multiplied to determine a CT value. These CT values correspond with charts provided by the U.S. EPA to determine log disinfection of microorganisms.

After the above unit processes are performed on the water drawn from the Holden Reservoir, the water is pumped through a distribution system to the city of Worcester, MA. This water supplies roughly 200,000 of Worcester's population with water for residential and commercial uses.

Worcester Water Filtration Plant Data

All data from the Worcester Water Filtration Plant was obtained through Robert Hoyt, the Plant Manager. This data included particle count information, monthly chlorine CT reports and chemical treatment reports, and daily ozone system reports. This data, combined with the U.S. EPA's regulatory credit system for filtration systems, was used to determine microorganism removals for each of the four seasons for the Worcester Water Filtration Plant.

The particle count data was provided in the form of line graphs (see Appendix C). These graphs measure removal of particles by the ozonation and filtration systems. The particle counters count particles in the raw influent water to the plant, as well as in the effluent of the filters. The machines then calculate the log removal by comparison of the two counts. An example of this calculation is provided in Figure 4-2.

If initial = 50000 particles per ml and final concentration = 2 particles per ml, and:

$$100\% - \left(\frac{final\ concentration}{initial\ concentration}\right) * 100\% = \%\ removal$$

$$Log\ removal = Log\left(\frac{100}{100 - \%\ removal}\right)$$

Then % removal = 99.996%, and Log removal = 4.398.

Figure 4-2, Log Removal Calculation

After the removal is determined it is plotted by the particle counters. The y-axis of the graphs represented log removal of all particles larger than 2 μm. The x-axis of the graphs represented time. Each graph shows particle removal data over 24 hours. A single day of particle counter data was chosen to represent each season. An average log removal was determined for each season by averaging the log removal values of incremental periods, of roughly four hours each, along the graph of the representative day. Microorganism removal calculated from these particle counter graphs is limited to the removal of *Giardia*, and excludes viruses because of size detection limitations.

Monthly chlorine CT reports provided CT values, pH, temperature, and residual chlorine concentration achieved by the plant for every day of the month (see Appendix C). Months were divided into four seasons, and an average value of the above data was calculated for each season. This data was then used to determine microorganism log inactivation for *Giardia* and viruses for each of the four seasons. This log inactivation is attributed solely to the chlorine disinfection system, and not the plant as a whole.

A single daily ozone system report was chosen to represent each of the four seasons (see Appendix C). These reports provided log inactivation of *Giardia* and viruses achieved by the ozonation system. These log inactivation values are a result of only the ozonation system, and not the entire plant.

Finally, the U.S. EPA's regulatory credit system for filtration systems was used to determine the log inactivation of the rapid mix, coagulation, flocculation, and filtration systems combined. The U.S. EPA assigns log removals for filtration systems based on the type of filter (filter rate and media), and whether the filter is preceded by a settling tank. These removals were added to CT calculated log removal values from plant disinfectant systems in determination of total log removal of *Giardia* and viruses according to U.S. EPA regulations.

Water Treatment Plant Microorganism Removals

Introduction

This section contains the complete set of removal information calculated from the data gathered from the Worcester Water Filtration Plant. The calculated information is presented in log removal form for the individual models, and is presented in log and percent removal form for the total summary of removals. All calculations were performed using Microsoft® Excel 2000. Calculations were made for three models. The first model was based on the current plant. Microorganism removal was determined by combining particle counter data with chlorine CT value data. The second model is also of the current plant; however, microorganism removal was determined by combining regulatory credits for filtration with ozone and chlorine CT value data. The third model examines an upgraded treatment plant with the addition of a sedimentation tank. As with the second model, microorganism removal was calculated by combining regulatory credits for filtration with ozone and chlorine CT.

Model 1: Microorganism Removal Through Current Plant Using Particle Counter and Cl_2 CT Data

Removal by particle counter data and calculated removal from chlorine CT can be seen in Table 4-2. These numbers were determined by adding removal from particle counter data (which incorporates both ozone and filtration removal) to the calculated log removal of chlorine CT. It was assumed that *Giardia* was removed to the same extent as particles in general. These calculations only determined log removal of *Giardia*. Log removal of viruses could not be determined using particle counter data because the particle counters cannot detect particles as small as viruses. Average log removal of all the seasons was 4.23. The lowest log removal occurred in winter at 3.81-log, and highest occurred in summer at 4.92-log. The ozonation and filtration systems provided greater than 2.4-log removal for all seasons, while chlorine disinfection provided an additional log removal of 0.92 to 2.18. Ozone and filtration removal was highest in the spring for this model, while chlorine removal was highest in the summer. This is because, at the same dosage, chlorine disinfection is more effective at a higher temperature.

Table 4-2, Removal of *Giardia* using Particle Counter Data and Chlorine CT

***Giardia* Removal**	**Winter**	**Spring**	**Summer**	**Fall**
Particle Counter Removal (log)	2.89	3.34	2.74	2.46
Chlorine CT Removal (log)	0.92	1.11	2.18	2.00
Total Log Removal (log)	3.81	4.45	4.92	4.46

Model 2: Microorganism Removal Through Current Plant Using Regulatory Credit System

Log removal of *Giardia* and viruses was determined by regulations in this model. The log removals for this model are shown in Table 4-3. Log removal credits given for filtration systems were added to log removals calculated from ozone and chlorine CT values. Using this model, average log removal was 4.56 for *Giardia* and 6.72 for viruses. Removal of *Giardia* ranged between 4.23-log and 8.66-log, and log removal of viruses ranged between 6.44 and 8.51. Ozone removal was highest in the fall, due to dosage variations, while chlorine removal was highest in the summer due to temperature differences between seasons.

Table 4-3, Removal of *Giardia* and Viruses Using Regulatory Credit System – Existing Direct Filtration Plant

Removal	Type	Winter	Spring	Summer	Fall
Ozone CT Removal (log)	*Giardia*	1.37	1.12	1.74	4.66
	Viruses	1.61	1.44	1.84	3.51
Direct Filtration Credit (log)	*Giardia*	2.00	2.00	2.00	2.00
	Viruses	1.00	1.00	1.00	1.00
Chlorine	*Giardia*	0.92	1.11	2.18	2.00
	Viruses	4.00	4.00	4.00	4.00
Total	*Giardia*	4.29	4.23	5.92	8.66
	Viruses	6.61	6.44	6.84	8.51

Model 3: Microorganism Removal Upgraded Treatment Plant Using Regulatory Credit System

Removals using this model were almost identical to the current plant analyzed by the regulatory credit framework. The only difference was the credit given to the filtration system by the regulations. The current treatment (direct filtration) plant was given a log removal credit of 2 for *Giardia*, and 1 for viruses. This model (conventional treatment plant due to additional settling tank) is given log removal credit of 2.5 for *Giardia*, and 2 for viruses. This extra log removal credit is because this model uses a settling tank before filtration. These numbers and the credit log removal numbers for a system with a settling tank are shown in Table 4-4. The individual log removals from chlorine and ozone CT were shown previously in Table 4-3. Average log removal for *Giardia* in this model was 5.06, and was 7.72 for viruses. Removals ranged between 4.73-log and 9.16-log for *Giardia*, and between 7.44-log and 9.51-log for viruses.

Table 4-4, Removal of *Giardia* and Viruses using Regulatory Credit System – Upgraded Plant With a Settling Tank

Removals	**Winter**	**Spring**	**Summer**	**Fall**
Conventional Filtration Credit for *Giardia* (log)	2.5	2.5	2.5	2.5
Conventional Filtration Credit for Virus (log)	2	2	2	2
Total *Giardia* Removal (log)	4.79	4.73	6.42	9.16
Total Virus Removal (log)	7.61	7.44	7.84	9.51

Total Microorganism Removal: Summary of All Models

Log removals were determined using three methods. First the current plant log removal for *Giardia* was calculated using particle counter information, and calculated CT values for chlorine disinfection. These log removals were added to determine the total log removal of *Giardia* of the plant. The second method of determining log removal of *Giardia* and viruses was to add credited log removal for direct filtration to credited log removal from ozone and chlorine CT. This gave a total log removal for the current plant based on the U.S. EPA's regulations for determination of *Giardia* and virus removal. Finally, a theoretical model of an upgraded plant using credited log removal for conventional treatment, and log removal calculated from ozone and chlorine CT was used. The credit for log removal due to conventional treatment assumes that the plant adds a settling tank to the existing treatment train. The results for total log removal using the three different methods can be seen in Table 4-5.

Table 4-5, Log and Percent Removals For All Scenarios

Particle Counter and CT Removal (Current Plant)	**Winter**	**Spring**	**Summer**	**Fall**
Giardia Log	3.18	4.45	4.92	4.45
Giardia %	99.9845	99.9965	99.9988	99.9965
Regulations, Direct Filtration (Current Plant)	**Winter**	**Spring**	**Summer**	**Fall**
Giardia Log	4.29	4.23	5.92	8.66
Giardia %	99.9949	99.9941	99.9999	>99.9999
Virus Log	6.61	6.44	6.84	8.51
Virus %	>99.9999	>99.9999	>99.9999	>99.9999
Regulations, Conventional Treatment (Plant With Settling Tank)	**Winter**	**Spring**	**Summer**	**Fall**
Giardia Log	4.79	4.73	6.42	9.16
Giardia %	99.9984	99.9981	>99.9999	>99.9999
Virus Log	7.61	7.44	7.84	9.51
Virus %	>99.9999	>99.9999	>99.9999	>99.9999

These results were also put into graphical form along with the U.S. EPA's standards for log removal for ease of comparison. The comparisons for *Giardia* removal are shown in Figure 4-3, and the comparisons for viruses are shown in Figure 4-4.

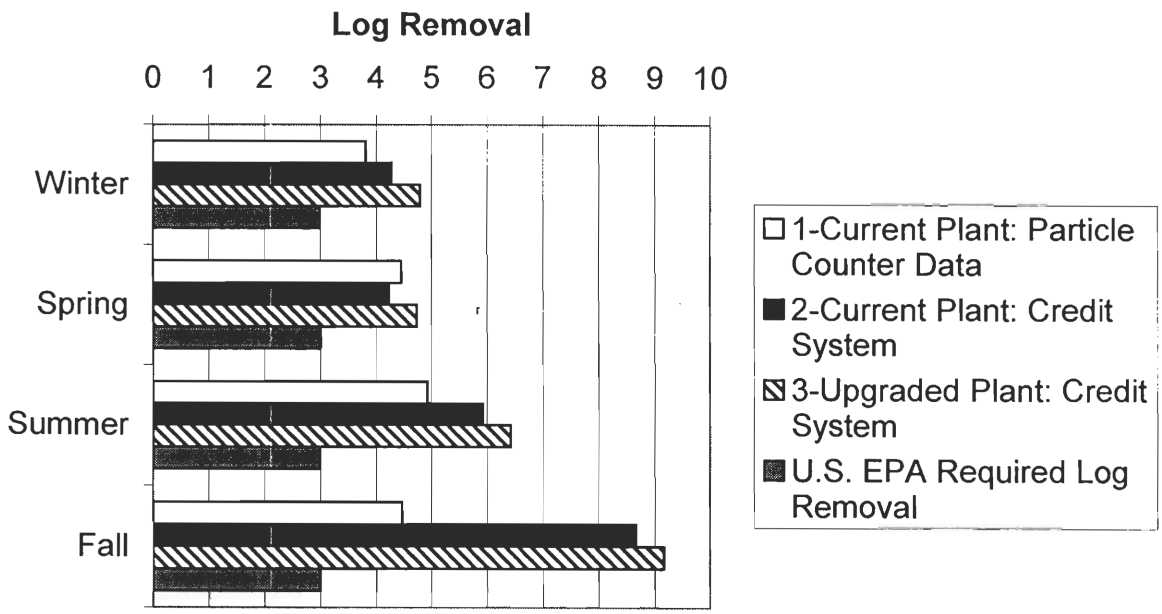

Figure 4-3, *Giardia* Log Removal Comparisons

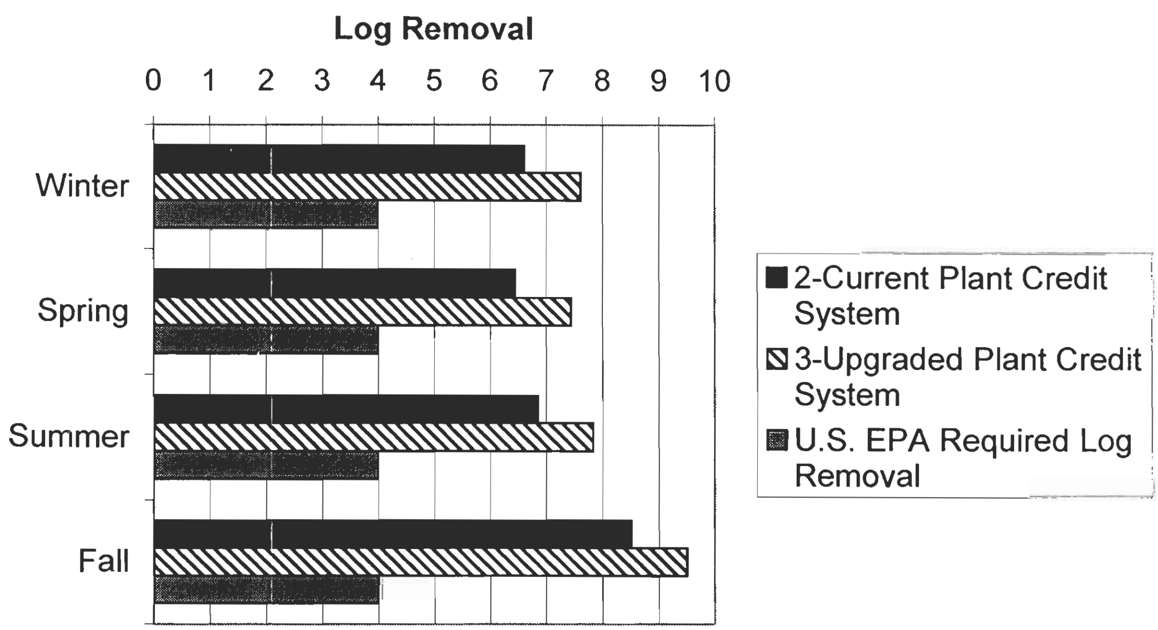

Figure 4-4, Virus Log Removal Comparisons

As can be seen in the above table and figures, the log removals calculated with all the models for both viruses and *Giardia* well exceeded the U.S. EPA's standards for removal. The U.S. EPA's standard for the removal of *Giardia* is 3-log, and the standard for the removal of viruses is 4-log. These standards were exceeded in all four seasons.

Worcester Water Filtration Plant Data Analysis

Introduction

The purpose of this section is to explain what the calculated log removals from each model mean, as well as to explain why each model's removals are accurate or inaccurate with regard to removal of various pathogens, including biological agents. The models calculated log removals in two different ways. One of these ways was to use particle counter data from the plant to account for the ozonation, rapid mix, coagulation, flocculation, and filtration systems. The other was to use ozone system data gathered from the plant to account for the ozonation system, and the U.S. EPA's regulatory credit system to account for rapid mix, coagulation, flocculation, and filtration systems. This section will also explain the difference between these two methods of determining log removal, as well as the validity of the model's results.

Model 1: Microorganism Removal Through Current Plant Using Particle Counter and Cl_2 CT Data Analysis

This model of the current plant determined removal through particle counter data and chlorine CT data. This model can be used to determine the removal of *Giardia*, but not viruses or bacteria due mainly to size restrictions. The particle counters can only determine the removal of particles bigger than 2 μm, such as *Giardia*, which has an approximate size of 7 to 12 μm. Research has shown that the removal of particles through conventional and direct filtration plants is statistically related to the removal of *Giardia* (LeChevallier and Norton, 1992).

However, because this model is restricted to determining removal of particles larger than 2 μm, it has significant limitations with regard to prediction of biological agent removal. Because of this not only can the model not determine the removal of viruses, such as plague or small pox, but it also is a poor gauge of removal of bacteria, such as anthrax and brucellosis. Most bacteria are smaller than 2 μm. In addition, because the placement of particle counters, this model takes ozone disinfection into account as well as removal from filtration systems, without the ability to differentiate between the two.

Though this project assumes that the Worcester Water Treatment Plant removes or inactivates viral agents as easily as naturally occurring viruses, it can only be assumed that bacteria are removed with an efficiency between that of *Giardia* inactivation and virus inactivation.

Model 2: Microorganism Removal Through Current Plant Using Regulatory Credit System

This model of the current Worcester Water Filtration Plant used a combination of ozone log removal, filtration system credits mandated by the U.S. EPA, and chlorine log removal. Unlike the model utilizing particle counter data, this model is able to determine the removal of viruses as well as *Giardia*. This is because ozone CT log removal and chlorine CT log removal are easily determined for viruses. The U.S. EPA's regulatory credit system also assigns log removal credit for viruses to filtration systems.

This model provides a good gauge of all virus removal because of the ability to determine it through existing regulations. It also is a good measure of bacteria removal because of its use of disinfectant data. Disinfection will destroy bacteria more easily than *Giardia*. Due to its ability to form cysts, *Giardia* is more resistant to disinfection, making this model's estimate of bacteria removals conservative (James M. Montgomery, Consulting, Engineers, Inc, 1985).

As was shown in Table 4-5 and Figures 4-2 and 4-3, the U.S. EPA's standards for log removal of *Giardia* and viruses were well exceeded by this model. In the summer and fall these *Giardia* standards were nearly doubled. The removal of viruses using this model also well exceeded the U.S. EPA's regulations: over 7-log removal achieved in all seasons compared to 4-log required. This means that any water treated with this system has an exceptionally small amount of microorganisms. This model is considered to be more accurate than model 1 that used particle counter data to determine log removal, not only because it can determine log removal of viruses, but also because it considers the ozone disinfection system separately.

Model 3: Microorganism Removal Through Upgraded Treatment Plant Using Regulatory Credit System

This model is almost identical to the model of the current plant using the U.S. EPA's regulatory filtration credit system, ozone CT data, and chlorine CT data, except that it assumed the plant has an added settling tank. This would allow more particles to be removed during treatment. The difference in removals between this model and the prior one comes in the credit system for the filter type. More credit is assigned for the removal of *Giardia* and viruses in a system that uses conventional treatment, or a system with a settling tank, than a system with direct filtration, or a system without a settling tank.

In this model, as in the previous model, removal for viruses and *Giardia* are well exceeded in all seasons. This is expected because the only difference between this model and the previous model is that it is assigned more credit for its filtration system. This extra credited removal is unnecessary because the plant without a settling tank well exceeded the required removals. Any biological agents placed in the water being treated by this system would be significantly removed and destroyed by its treatment processes.

Microorganism Input Required for Infection

To help show the effectiveness of these models in removing microorganisms, calculations were made to determine the number of microorganisms that must be introduced to a reservoir to cause infection in the populous. However, since there was no data researched on exactly how many microorganisms must be ingested to cause illness, this cannot be determined exactly. Infection from a microorganism is dependent on the individual's level of immune system functioning and general health as well as the type of organism that is ingested. For this reason the numbers of 1, 10, and 100 microorganisms per liter were chosen as amounts of a microorganism that may cause infection.

The number of microorganisms required for infection was first calculated as a concentration existing in the reservoir, and then as a number of microorganisms required for the determined concentration in the Holden 1 reservoir. The concentration was chosen as number of microorganisms per liter for ease of calculations. It was estimated that a single person will ingest at least a liter of water every day. This makes the number of microorganisms per liter tap water the number of microorganisms that a person would ingest in a day.

Another important factor taken into consideration is the percent mixing that would occur with any amount of biological agents placed into the reservoir. A sample introduced next to the reservoir's inlet for the water filtration plant would experience minimal mixing, assumed to be 10% of the reservoir's volume. A sample placed on the opposite end of the reservoir would experience a much greater mixing of close to 100% of the reservoir's volume. For this reason calculations were made for both 10% and 100% mixing. The results of these calculations can be seen in Table 4-6. Calculations were also made for 50% mixing, but are shown only in Appendix B.

Table 4-6, Required Microorganism Input

	Organisms Required in Reservoir for Infection (10%)	**Organisms Required in Reservoir for Infection (100%)**	**Organism Concentration in Reservoir (Org/L)**	**Average Log Removal (log)**	**Organisms in Tap (Org/L)**
Model 1					
Giardia	$4.66*10^{12}$	$4.66*10^{13}$	$1.69*10^{04}$	4.23	1
	$4.66*10^{13}$	$4.66*10^{14}$	$1.69*10^{05}$	4.23	10
	$4.66*10^{14}$	$4.66*10^{15}$	$1.69*10^{06}$	4.23	100
Model 2					
Giardia	$9.93*10^{12}$	$9.93*10^{13}$	$3.59*10^{04}$	4.56	1
	$9.93*10^{13}$	$9.93*10^{14}$	$3.59*10^{05}$	4.56	10
	$9.93*10^{14}$	$9.93*10^{15}$	$3.59*10^{06}$	4.56	100
Viruses	$1.46*10^{15}$	$1.46*10^{16}$	$5.29*10^{06}$	6.72	1
	$1.46*10^{16}$	$1.46*10^{17}$	$5.29*10^{07}$	6.72	10
	$1.46*10^{17}$	$1.46*10^{18}$	$5.29*10^{08}$	6.72	100
Model 3					
Giardia	$3.14*10^{13}$	$3.14*10^{14}$	$1.14*10^{05}$	5.06	1
	$3.14*10^{14}$	$3.14*10^{15}$	$1.14*10^{06}$	5.06	10
	$3.14*10^{15}$	$3.14*10^{16}$	$1.14*10^{07}$	5.06	100
Viruses	$1.46*10^{16}$	$1.46*10^{17}$	$5.29*10^{07}$	7.72	1
	$1.46*10^{17}$	$1.46*10^{18}$	$5.29*10^{08}$	7.72	10
	$1.46*10^{18}$	$1.46*10^{19}$	$5.29*10^{09}$	7.72	100

As can be seen in Table 4-6, an enormous concentration of microorganisms is required in a reservoir to cause a small concentration of microorganisms to show up in tap water. The likelihood that this amount of microorganism could be produced and covertly delivered to a reservoir is very low.

An important point to take into consideration when reading the table is that, instead of bacteria, the table lists *Giardia*. This is because the log removals calculated for each model were for *Giardia* and viruses. It is important to take this into consideration because *Giardia*, because of its ability to form cysts, is more resistant to disinfection than bacteria. Bacteria introduced into this system may require a greater number and concentration in the reservoir to produce the chosen concentrations in tap water than is indicated in the tables. It is also important to note that the removal for values for bacteria may differ from those of *Giardia* due to a smaller size, as well as the inability to form cysts. The spores produced by anthrax may also behave differently than both the bacteria and *Giardia*. The virus removal values for naturally occurring viral pathogens should be comparable to expected viral removal for viral biological agents due to their comparable sizes.

Survey Results

During the months of November and December 2001, 287 surveys were distributed into various public areas in the city of Worcester (Appendix A). These surveys were intended to assess the opinion of the people regarding the safety of their water. Information was gathered about each person filling out the survey so that they could later be segregated into groups by age, gender and living situation. Each of these distinctions would allow for a different analysis because each group might have had different concerns and interests. The end goal was to determine whether Worcester citizens would be willing to pay more for their water, a fact which might be different based on what group a person falls into. Because this project examined the possibility of an upgrade to the Worcester Water Filtration Plant, it was necessary to know whether the people would be willing to pay for this upgrade which would amount to an added monthly charge to water bills or property taxes. Since it would likely have caused a large problem to ask Worcester citizens directly about the threat of bioterrorism against their water system, the survey was designed to elicit opinions about water safety without directly asking about bioterrorism.

The survey was only distributed to persons 18 years old or above because persons younger than 18 years old are not allowed to vote and thus could note express their opinion in such a manner. Improvements and upgrades to the water plant caused by failure to meet regulations are not voted upon, however an optional upgrade would be decided by a town vote. A voted upgrade could only be voted on by persons of 18 years or older, thus setting the age limit for our survey.

The survey data were first sorted by gender. 49.2% of participants were male, while 50.8% were female. This information was gathered so that it might be possible to determine whether men or women are more concerned about safety and also which are more worried about increased cost. Of the 146 surveyed, 61 (41.8%) of females felt that that their water was safe. Similarly 59 out of 141 (41.8%) of males felt that their water was safe. A certain percentage of males (9.2%), and females (9.5%) did not know whether their water was safe or not safe. Overall 41.8% of the surveyed group felt that their water was safe, 48.7% felt that the water was not safe, and 9.1% did not know if their water was safe (see Figure 4-5).

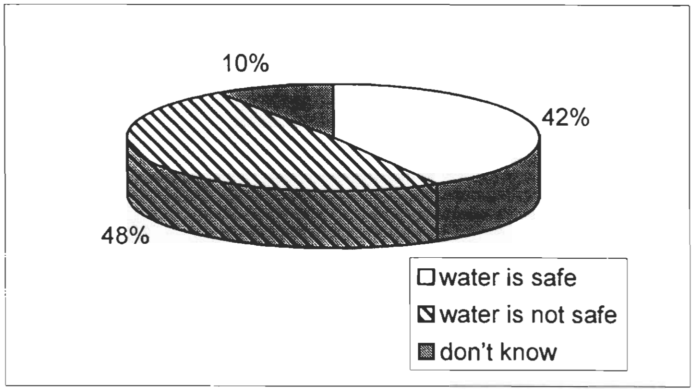

Figure 4-5, Percent of Surveyed Population Considering Their Water Safe

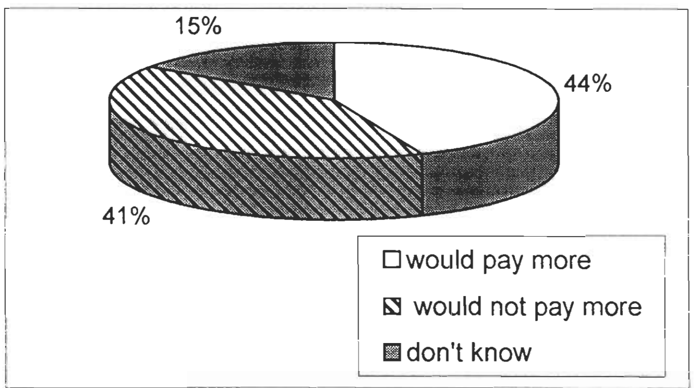

Figure 4-6, Percent of Population Surveyed Willing To Pay More for Increased Water Safety

For an answer to the financial question, it was made very simple so that any citizen could clearly determine what was being asked. The unit price of $50 per billing period per person was put before them and they were then asked how reasonable a 10%, 25% and 50% increase in water rates would be. 43.6% of people said they would pay some increased amount to increase the safety of their water. 15.3% of participants did not know if they would pay any more for safer water, and 41.1% said they would not pay any amount more for their water. Of the 125 people who said they would pay more for their water, 51 were male and 74 were female. Statistically, more females claimed that they would pay more for their water than males. Of the group that said they would pay more for their water to increase its safety, 69 (55.2%) would not pay more than a 10% increase. 24% of the paying group would pay up to 25% more for their water and only 20.8% of this group would pay a 50% increase in their water bill for safer water.

Implementation Effects on Water Costs

Acquiring information about the actual cost of water in Worcester was essential to this project. When the city makes any kind of change or upgrade to its water system, particularly one that has an implied maintenance cost, the overall cost of water for each citizen must be increased to compensate. Since part of this project was to determine whether an upgrade to the treatment plant would be necessary to ensure safety against a bioterrorist attack, we had surveys to learn whether people felt the risk was important enough to warrant paying higher bills.

A phone conversation with Mr. Bob Moylan at the town billing department was what provided the base cost of water used in the surveys. This department is essentially where the cost of water is determined and so decisions about an increase or decrease are made here. If such a decision were ever to be made, it would follow such a process:

1. Billing department becomes aware that people feel water is unsafe
2. A feasibility plan is proposed for making water safer
3. The cost of this plan is weighed
4. The upgrade is made using tax money if the cost is reasonable
5. The price of water increases to pay for the upgrade and for new maintenance costs

While the surveys were being distributed, a few of the people taking it became confused because another issue regarding the addition of fluoride to the water was being considered by the city at that time as well. This brings up the important question of what forces an ordinance to be voted on. Essentially any proposed upgrade, which is not directly required by government regulations in order to meet water quality standards, must be voted on. If the people of Worcester could show that they wanted more security and that they were willing to accept an increase in water bills to pay for it, they city would have to devise a plan to appease their needs.

Chapter 5, Conclusions

The project makes educated conclusions from plant data with regard to the Worcester Water Filtration Plant's current effectiveness and its potential effectiveness at stopping a biological attack. Furthermore, conclusions have been drawn from the distributed surveys concerning the public's opinion on the safety of its water. Finally, personal interviews determined who would bring about changes in the treatment system if necessary and how this would be accomplished.

After the removal data for the three models was made and analyzed it is clear that the present Worcester Water Filtration Plant is doing a more than adequate job removing any microorganisms present in the water supply. This was determined based on the fact that both the models of the current plant showed more than adequate removal of *Giardia* and viruses. When the settling tank was added to the model of the current plant the log removals of viruses became so high that in some seasons the removal climbed as high as 9.51-log. Even the current plant, assessed by the regulatory credit system, provided 6.72-log removal of viruses on average, and 4.56-log removal of *Giardia* on average. Because of this it can be concluded that the current plant does not need any additional unit processes to treat its water. Furthermore it is concluded that the Worcester Water Treatment Plant adequately removes or disables natural viral pathogens and would likely adequately remove viral biological agents. The plant is also adequately removes *Giardia* from the water supply. Since it adequately removes particles and microorganisms both larger and smaller than bacteria, it is logical to conclude that the Worcester Water Treatment Plant also removes bacteria from the water supply. In addition, some bacteria are more susceptible to disinfection than *Giardia*, making the use of *Giardia* removal a conservative estimate of bacteria removal. This IQP has concluded that the Worcester Water Treatment Plant should also be able to withstand a bioterrorist attack of its source water. Any attack of source water would need to be in a very high concentration to result in a significant infection rate in consumers.

Though these calculations show a very wide safety margin for the plant under normal operations, it is difficult to predict exactly how a plant would react to extremely large numbers of organisms that would be introduced during a bioterrorist attack. It is also important to note that calculations used in this project assume that a bioterrorist attack is made on the water source prior to entry to the plant. Any biological agents placed into the system at any point after the treatment processes would only be affected by residual chlorine and would not go through any ozone or removal process. Furthermore, the residual chlorine would be much lower after the water had left the storage tanks and would have a much lower kill rate due to its decreased concentration. It is likely that many biological organisms could survive if introduced after the water treatment plant.

The survey distributed in November and December of 2001 shows that there is no significant majority within the 287 people in the survey group that felt their water was either safe or unsafe. 48.7% of the surveyed group felt that their water was unsafe but 41.8% of the group felt that their water was safe. Since 9.1% of the surveyed group did not know if their water was safe or unsafe, their decision could change which category was the majority.

Since 41.1% of the surveyed group said that they would not pay more money to make their water safe and 15.3% of participants did not know if they would pay any amount more for safer water, it seems likely that a settling tank upgrade or any other proposed plant upgrade would fail if voted on by the citizens of Worcester. Since the Worcester Water Filtration Plant is significantly surpassing its operational requirements imposed by federal regulations, it is likely to stop a biological attack in the water source without difficulty. Thus a vote to increase the cost of water for reasons of increased safety is unneeded.

It is the conclusion of this IQP that the Worcester Water Filtration Plant is more than adequate in its current operation. The plant data supplied for the year 2001 indicates that a biological attack on the water supply would have a negligible chance of succeeding so long as the plant maintains its current mode of operation. Furthermore this IQP has concluded that the people of Worcester are divided on the issue of their water's safety, but would be unlikely to accept a motion to raise the cost of water to pay for an additional process in the treatment system.

Further research as to the effects of a biological attack on a public water supply should be conducted. Specifically, scenarios in which biological agents are introduced at different points of the water distribution system after the water leaves the treatment plant should be evaluated. The effectiveness of residual chlorine on specific biological agents should be studied.

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Appendix A, Survey

General Info
Gender
Male____Female____ Age:____
Residence
House:____ Apt:____ Other:____

	Tap	Bottle	No Pref
Do you prefer to drink bottled water or municipal tap water?			
Do you drink tap water or bottle water most often?			

	Yes	No	Don't Know
Do you use a home filter to filter your tap water?			

Does your water have a chlorine after taste?

	Yes	No	Don't Know
Bottled			
Tap			
Filtered			

Do you feel that your water is clean and safe to drink?

	Yes	No	Don't Know
Bottled			
Tap			
Filtered			

	Yes	No	Don't Know
Do you feel that bottled water companies adequately remove harmful particles from bottled water?			
Do you feel that treatment plants adequately remove harmful particles from municipal tap water?			
Do you feel that home filters adequately remove harmful particles from municipal tap water?			

In Worcester water costs approximately $50 per person per billing period. How much more would you be willing to pay for water knowing that the extra cost would insure its purity and safety?

	Yes	No	Don't Know
10%=$55			
25%=$63			
50%=$75			

Survey Results

total surveys	male	%men	female	% women	total	%total	
287	141	49.20%	146	50.80%	287		
safe water							
yes	59	41.80%	61	41.80%	120	41.80%	
no	70	49%	71	48.70%	141	48.70%	
don't know	12	9.20%	14	9.50%	26	9.10%	
pay more?							
yes	51	36.20%	74	50.70%	125	43.60%	
no	58	41.10%	60	41.10%	118	41.10%	
don't know	32	22.70%	12	8.20%	44	15.30%	
how much more							% of the 125
DK/0%	79	56%	83	56.80%	162	56.40%	0%
10%	33	23.40%	36	24.70%	69	24%	55.20%
25%	15	10.60%	15	10%	30	10.50%	24%
50%	14	9.90%	12	8.20%	26	9.10%	20.80%

Appendix B, Removal Calculations Spread Sheet

Particle Counter Log Removal

Winter	2.89
Spring	3.34
Summer	2.74
Fall	2.46

Ozone Log Removal

	Giardia	Viruses
Winter	1.37	1.61
Spring	1.12	1.44
Summer	1.74	1.84
Fall	4.66	3.51

Log Removal Credits

	Giardia	Viruses
Direct Filtration	2	1
Conventional	2.5	2

Chlorine CT Removal

	Winter	Spring	Summer	Fall
Avg. Temp	3.988889	8.619565	23.55435	15.67033
Avg. pH	7.420111	7.52163	7.504674	7.43967
Avg. Conc	1.485489	1.58	1.577196	1.932747
	58.99222	61.23337	54.18337	66.8167
Giardia Log Removal	0.92	1.11	2.18	2
Virus Log Removal	4	4	4	4

Winter

	December				January				February			
Day	Temp	pH	Cl Conc		Temp	pH	Cl Conc		Temp	pH	Cl Conc	
1	5	7.52	1.46	54.16	4	7.47	1.65	65.07	4	7.5	1.38	58.27
2	4	7.55	1.48	58.91	4	7.54	1.5	66.08	4	7.5	1.4	52.81
3	3	7.14	1.65	61.88	4	7.35	1.54	70.35	4	7.3	1.36	52.26
4	4	7.4	1.39	54.96	4	7.53	1.48	59.5	4	7.43	1.45	59.1
5	4	7.39	1.42	58.9	4	7.46	1.65	64.77	4	7.44	1.44	56.64
6	3	7.25	1.5	57.02	4	7.6	1.58	67.19	4	7.49	1.48	60.41
7	4	7.54	1.36	53.79	4	7.34	1.56	58.54	4	7.51	1.51	61.22
8	4	7.25	1.5	61.62	4	7.48	1.38	51.7	4	7.38	1.61	63.59
9	4	7.32	1.66	60.07	4	7.6	1.28	52.78	4	7.44	1.36	71.27
10	4	7.17	1.35	50.83	4	7.25	1.38	54.82	4	7.6	1.45	57.62
11	4	7.3	1.31	50.08	4	7.47	1.48	60.93	4	7.42	1.554	61.27
12	4	7.32	1.4	52.17	4	7.44	1.43	55.07	4	7.49	1.35	52.65
13	4	7.3	1.68	62.75	4	7.08	1.64	58.5	4	7.57	1.24	55.79
14	4	7.47	1.53	61.67	4	7.42	1.62	63.57	4	7.41	1.35	56.09
15	4	7.36	1.45	61.29	4	7.58	1.59	58.31	4	7.61	1.5	71.63
16	4	7.45	1.53	59.51	4	7.44	1.39	58.71	4	7.52	1.56	60.31
17	4	7.4	1.53	60.12	4	7.36	1.41	52.45	4	7.53	1.56	58.26
18	4	7.44	1.45	56.94	4	7.38	1.31	50.4	4	7.48	1.62	62.27
19	4	7.36	1.51	60.78	4	7.45	1.46	62.75	4	7.52	1.63	62.31
20	4	7.36	1.47	60.31	4	7.25	1.45	54.26	4	7.61	1.65	61.86
21	4	7.53	1.46	57.48	4	7.25	1.46	53.53	4	7.43	1.43	61.7
22	4	7.36	1.48	66.62	4	7.52	1.33	53.82	4	7.51	1.61	62.5
23	4	7.3	1.6	57.76	4	7.36	1.51	59.02	4	7.48	1.53	58.6
24	4	7.3	1.73	64.55	4	7.58	1.38	57.48	4	7.27	1.61	59.32
25	4	7.34	1.66	68.74	4	7.41	1.3	53.55	4	7.34	1.6	65.11
26	4	7.26	1.76	64.92	4	7.44	1.29	54.24	4	7.47	1.46	54.73
27	4	7.55	1.48	60.24	4	7.26	1.29	54.22	4	7.48	1.47	56.47
28	4	7.35	1.44	53.88	4	7.38	1.33	50.2	4	7.58	1.44	58.03
29	4	7.44	1.51	62.87	4	7.42	1.5	58.31				
30	4	7.41	1.7	64.6	4	7.55	1.39	59.21				
31	4	7.43	1.61	59.78	4	7.28	1.47	58.68				

Avg. Temp	3.988889
Avg. pH	7.420111
Avg. Conc	1.485489
	58.99222

Spring

Day	March Temp	pH	Cl Conc		April Temp	pH	Cl Conc		May Temp	pH	Cl Conc	
1	4	7.57	1.52	62.9	4	7.52	1.61	69.85	12	7.57	1.41	48.73
2	4	7.59	1.45	76.55	4	7.54	1.74	69.72	13	7.32	1.89	63.55
3	4	7.43	1.59	61	4	7.58	1.53	66.81	14	7.44	1.6	52.85
4	4	7.22	1.62	68.4	4	7.51	1.5	60.85	14	7.3	1.58	54.3
5	4	7.51	1.5	62.05	4	7.49	1.48	61.14	14	7.21	1.49	50.14
6	4	7.46	1.46	79.2	4	7.43	1.52	64.41	14	7.28	1.63	56.19
7	4	7.48	1.57	64.6	4	7.34	1.45	54.96	14	7.75	1.53	53.45
8	4	7.54	1.53	67.77	4	7.36	1.54	64.64	14	7.57	1.52	52.32
9	4	7.49	1.58	63.77	4	7.54	1.32	55.17	15	7.53	1.71	58.33
10	4	7.39	1.56	61.2	4	7.44	1.47	67.46	15	7.58	1.56	51.7
11	4	7.37	1.56	68.8	4	7.5	1.44	59.18	16	7.53	1.54	51.66
12	4	7.43	1.49	58.43	4	7.49	1.51	60.26	16	7.33	1.6	49.23
13	4	7.49	1.49	61.44	4	7.52	1.63	60.28	17	7.67	1.59	53.84
14	4	7.52	1.5	68.73	4	7.33	1.69	59.09	16	7.72	1.6	54.9
15	4	7.4	1.51	64.07	5	7.39	1.75	64.36	16	7.32	1.65	58.72
16	4	7.59	1.5	61.6	5	7.36	1.59	56.12	16	7.58	1.74	62.42
17	4	7.46	1.49	59.42	6	7.4	1.56	65.14	16	7.55	1.69	60.57
18	4	7.49	1.56	68.07	5	7.45	1.54	56.57	16	7.82	1.55	53.43
19	4	7.56	1.46	57.67	6	7.42	1.54	64.19	16	7.7	1.62	52.24
20	4	7.54	1.52	62.32	6	7.44	1.68	61.5	16	7.54	1.66	54.35
21	4	7.42	1.64	64.08	6	7.44	1.73	64.75	16	7.65	1.7	59.34
22	4	7.55	1.62	65.76	7	7.44	1.68	57.47	17	7.53	1.75	63.25
23	4	7.42	1.46	60.71	8	7.55	1.13	42.43	16	8.6	1.53	57.94
24	4	7.55	1.52	57.72	9	7.46	1.62	58.91	16	7.63	1.75	64.48
25	4	7.42	1.61	63.41	12	7.41	1.55	59.9	16	7.93	1.6	60.15
26	4	7.51	1.68	68.13	10	7.39	1.58	59.12	16	7.44	1.68	66.82
27	4	7.62	1.6	65.55	11	7.55	1.53	57.43	17	7.61	1.7	85
28	4	7.87	1.5	65.5	12	7.61	1.57	57.53	16	7.66	1.73	67.93
29	4	7.45	1.73	72.89	12	7.44	1.56	57.16	17	7.98	1.49	54.65
30	4	7.59	1.55	63.18	11	7.58	1.78	64.14	18	7.65	1.89	74.68
31	4	7.46	1.58	61.8					17	7.69	1.61	59.05

Avg. Temp	8.619565
Avg. pH	7.52163
Avg. Conc.	1.58
	61.23337

Summer

Day	June Temp	pH	Cl Conc		July Temp	pH	Cl Conc		August Temp	pH	Cl Conc	
1	17	7.67	1.6	56.59	24	7.51	1.52	53.22	25	7.59	1.68	55.2
2	17	7.67	1.74	61.87	25	7.34	1.45	52.13	25	7.25	1.7	55.48
3	17	7.56	1.79	63.29	23	7.44	1.54	53.64	25	7.36	1.42	46.08
4	18	8.06	1.62	61.68	23	7.52	1.43	51.13	25	7.65	1.32	46.44
5	18	7.72	1.63	61.39	24	7.69	1.3	45.9	26	7.37	1.38	47.79
6	18	7.75	1.54	57.77	24	7.52	1.61	58.92	26	7.6	1.51	50.15
7	18	7.6	1.53	53.68	24	7.59	1.68	59.63	26	7.64	1.58	52.51
8	18	7.59	1.49	50.84	23	7.24	1.67	68.07	26	7.27	1.62	54.11
9	18	7.68	1.59	51.43	24	7.8	1.48	53.79	27	7.28	1.45	43.27
10	19	7.41	1.63	52.65	24	7.42	1.6	55.06	27	7.28	1.59	50.25
11	19	7.96	1.49	50.75	24	7.5	1.79	53.79	27	7.36	1.76	58.13
12	20	7.71	1.61	60.85	24	7.44	1.74	59.05	27	7.42	1.68	59.68
13	19	7.68	1.49	51.81	24	7.86	1.46	51.68	26	7.55	1.71	57.77
14	20	7.82	1.28	43.94	24	7.5	1.71	57.77	26	7.37	1.43	51.29
15	21	7.33	1.63	56.94	24	7.52	1.66	58.26	26	7.38	1.67	59.68
16	21	7.71	1.42	46.62	24	7.54	1.65	55.09	26	7.61	1.45	44.15
17	21	7.53	1.4	53.15	24	7.5	1.6	58.68	26	7.42	1.62	55.42
18	21	7.67	1.18	41.54	24	7.5	1.61	56.87	26	7.39	1.55	54.53
19	21	7.56	1.32	44.97	24	7.39	1.47	51.96	26	7.33	1.56	55.32
20	21	7.6	1.43	48.45	24	7.2	1.722	58.57	26	7.28	1.43	49.64
21	22	7.67	1.51	55.57	24	7.38	1.7	56.38	26	7.49	1.54	54.95
22	21	7.99	1.41	49.74	24	7.57	1.74	59.05	26	7.31	1.73	59.15
23	21	7.58	1.37	46.09	25	7.54	1.73	53.19	26	7.42	1.77	50.65
24	23	7.67	1.4	50.01	25	7.27	1.91	62.62	26	7.59	1.66	57.11
25	23	7.56	1.38	46.65	26	7.4	1.61	53.05	26	7.51	1.72	58.06
26	23	7.55	1.31	44.43	26	7.15	1.8	64.3	26	7.34	1.72	58.24
27	23	7.44	1.45	47.88	25	7.3	1.69	58.49	26	7.44	1.72	57.61
28	24	7.65	1.45	47.52	24	7.69	1.64	55.47	26	7.34	1.67	57.06
29	24	7.35	1.44	48.7	25	7.22	1.85	62.77	26	7.35	1.74	60.22
30	24	7.75	1.37	43.92	25	7.32	1.84	64.39	26	7.27	1.62	55.26
31					25	7.38	1.71	57.77	25	7.24	1.69	58.26

Avg. Temp	23.55435
Avg. pH	7.504674
Avg. Conc.	1.577196
	54.18337

Fall

	September				October				November			
Day	Temp	pH	Cl Conc		Temp	pH	Cl Conc		Temp	pH	Cl Conc	
1	25	7.46	1.54	51.43	19	7.49	2.43	88.47	12	7.5	2.02	72.27
2	25	7.58	1.76	60.48	18	7.39	1.65	57.71	12	7.42	1.81	66.16
3	25	7.28	1.72	56.12	18	7.35	2.27	79.16	12	7.58	7.08	72.73
4	24	7.36	1.71	59.12	18	7.45	2.12	75.09	12	7.47	1.84	62.92
5	24	7.33	1.73	58.89	18	7.49	1.9	64.64	12	7.67	1.9	72.08
6	23	7.3	1.67	57.74	18	7.6	1.62	57.43	11	7.44	1.82	66.42
7	24	7.27	1.57	52.94	18	7.59	1.92	68.25	10	7.49	1.56	56.25
8	24	7.68	1.56	50.54	16	7.47	1.98	71.78	10	7.54	1.41	50.77
9	24	7.37	1.62	52.34	16	7.37	2.22	86.41	10	7.24	1.74	63.33
10	24	7.22	1.58	52.45	15	7.37	2.48	89.56	10	7.29	1.89	64.51
11	24	7.38	1.88	64.59	15	7.37	2.19	77.34	9	7.39	1.82	67.6
12	24	7.64	1.57	52.83	16	7.63	2.43	87.12	9	7.25	1.86	62.94
13	23	7.46	0.95	33.05	16	7.49	2.67	93.44	8	7.35	1.79	68.08
14	23	7.39	1.49	53.36	16	7.59	2.5	88.42	8	7.42	1.73	64.27
15	22	7.46	1.52	50.85	16	7.47	2.29	82.3	8	7.35	1.58	57.89
16	22	7.48	1.84	62.23	16	7.39	2.26	81.86	8	7.33	1.66	60.49
17	22	8.05	1.64	54.88	16	7.57	2.21	77.02	8	7.35	1.8	61.07
18	21	7.23	1.84	63.39	15	7.38	1.91	69.86	8	7.21	2.01	68.76
19	22	7.7	1.87	64.1	14	7.48	2.02	73.79	8	7.31	1.83	66.36
20	21	7.48	2.15	74.93	14	7.42	2.23	76.07	8	7.41	1.81	64.03
21	21	7.53	2.15	77.04	14	7.51	2.19	80.56	8	7.27	1.79	64.6
22	21	7.71	1.92	66.4	14	7.47	2.06	75.83	8	7.26	1.73	58.12
23	22	7.74	1.6	58.63	14	7.37	1.93	71.68	8	7.32	1.77	66.11
24	22	7.5	1.6	57.57	14	7.47	2.06	75.41	8	7.38	1.85	68.31
25	21	7.45	1.59	59.81	14	7.3	2.05	75.6	8	7.34	1.82	67.22
26	21	7.36	1.76	66	14	7.47	1.75	62.04	8	7.32	1.74	64.58
27	21	7.56	1.99	71.5	14	7.42	1.93	68.36	8	7.27	1.85	68.16
28	20	7.37	1.7	61.3	14	7.39	2.21	73.67	8	7.68	1.51	56.38
29	20	7.43	2.28	76.51	13	7.47	2.17	80.67	9	7.46	1.57	59.54
30	19	7.39	2.2	78.25	13	7.31	2.14	78.94	8	7.44	1.64	62.24
31					12	7.56	1.86	68.38				

Avg. Temp	15.67033
Avg. pH	7.43967
Avg. Conc	1.932747
	66.8167

Total Log and Percent Removals

Plant by Particle Counters and CT Log Removal

	Winter	Spring	Summer	Fall	Avg.
Giardia	3.81	4.45	4.92	4.46	4.227203

Plant by Regulations Log Removal

	Winter	Spring	Summer	Fall	Avg.
Giardia	4.29	4.23	5.92	8.66	4.555272
Viruses	6.61	6.44	6.84	8.51	6.723433

Plant by Regulations with Settling Tank Log Removal

	Winter	Spring	Summer	Fall	Avg.
Giardia	4.79	4.73	6.42	9.16	5.055272
Viruses	7.61	7.44	7.84	9.51	7.723433

EPA Required Log Removal

	Winter	Spring	Summer	Fall	Avg.
Giardia	3	3	3	3	3
Viruses	4	4	4	4	4

Plant by Particle Counters and CT Percent Removal

	Winter	Spring	Summer	Fall	Avg.
Giardia	99.98451	99.99645	99.9988	99.99653	99.99407

Plant by Regulations Percent Removal

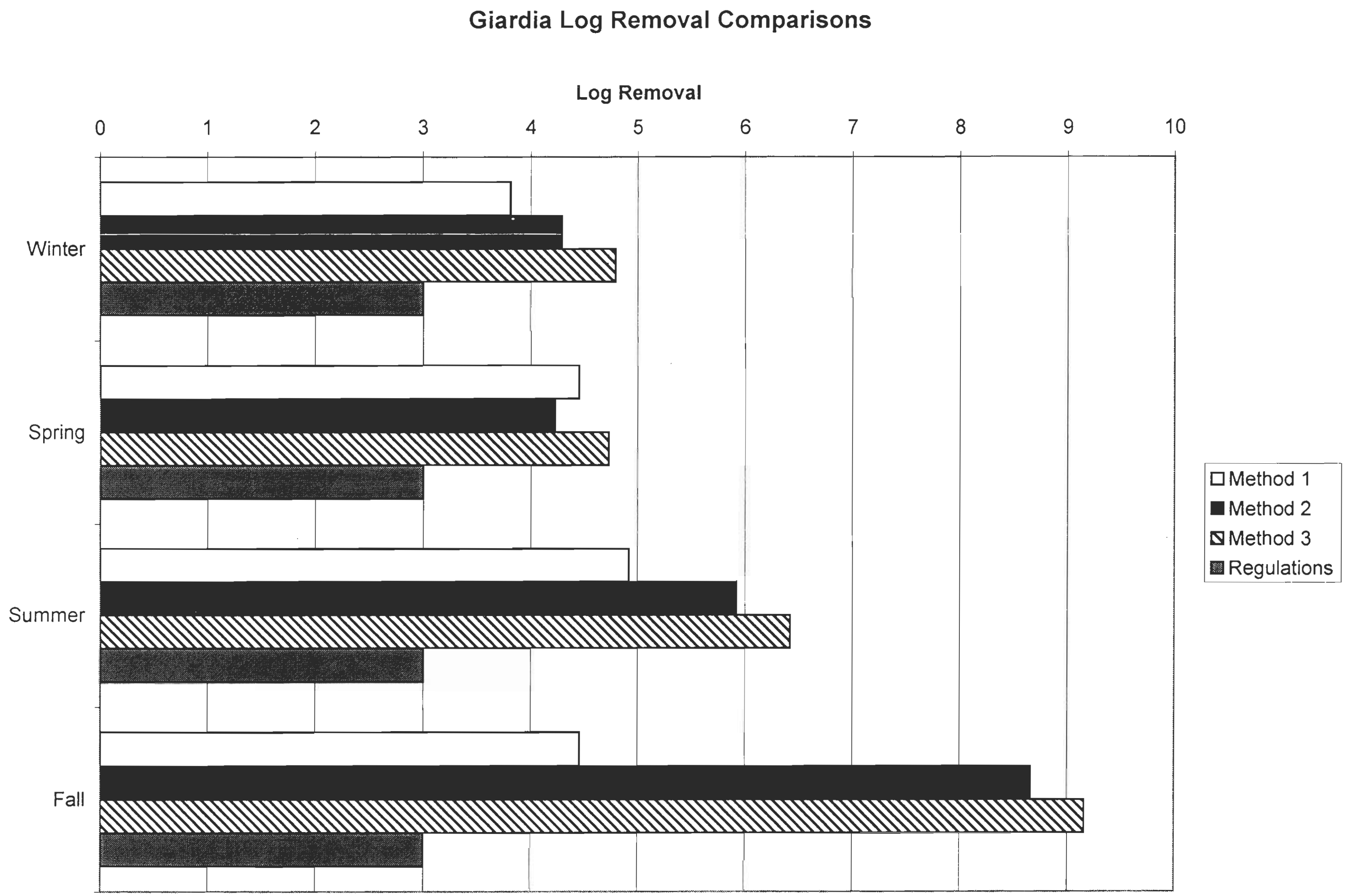
	Winter	Spring	Summer	Fall	Avg.
Giardia	99.99487	99.99411	99.99988	100	99.99722
Viruses	99.99998	99.99996	99.99999	100	99.99998

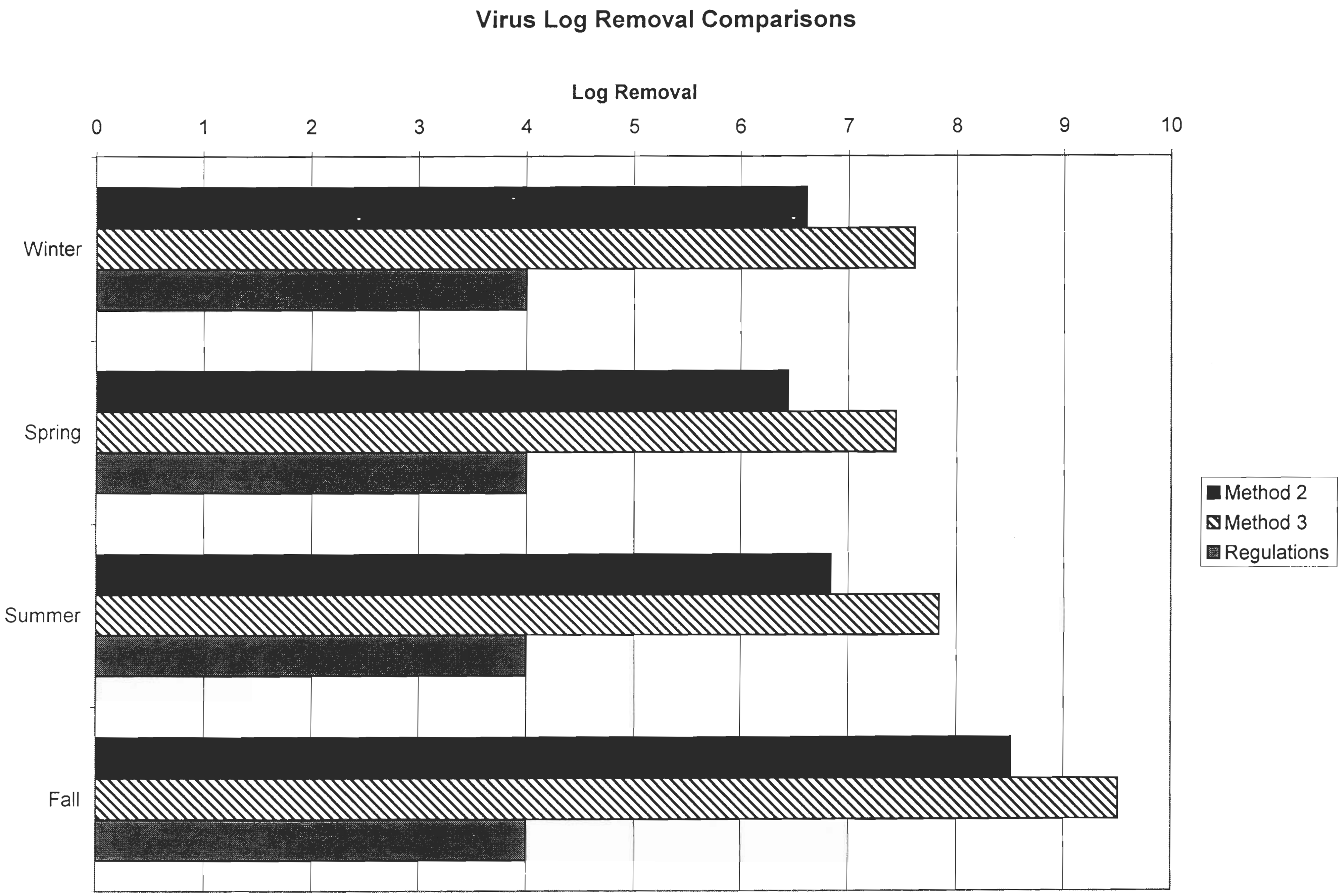
Plant by Regulations with Settling Tank Percent Removal

	Winter	Spring	Summer	Fall	Avg.
Giardia	99.99838	99.99814	99.99996	100	99.99912
Viruses	100	100	100	100	100

EPA Required Percent Removal

	Winter	Spring	Summer	Fall	Avg.
Giardia	99.9	99.9	99.9	99.9	99.9
Viruses	99.99	99.99	99.99	99.99	99.99


Giardia Log Removal Comparisons
Log Removal
0
1
2
3
4
5
6
7
8
9
10
Winter
Spring
Summer
Fall
Method 1
Method 2
Method 3
Regulations


Virus Log Removal Comparisons
Log Removal
0
1
2
3
4
5
6
7
8
9
10
Winter
Spring
Summer
Fall
Method 2
Method 3
Regulations

Model 1

Giardia

Org. Conc. Tap (Org/L)	% Mixed	Res. Volume (L)	Avg. Rem. (log)	Avg. Rem. (%)	Org Conc. F	Total Organisms
1	100	2764047000	4.227202938	99.99407352	1.69E+04	4.66E+13
10	100	2764047000	4.227202938	99.99407352	1.69E+05	4.66E+14
100	100	2764047000	4.227202938	99.99407352	1.69E+06	4.66E+15
1000	100	2764047000	4.227202938	99.99407352	1.69E+07	4.66E+16
1	50	1382023500	4.227202938	99.99407352	1.69E+04	2.33E+13
10	50	1382023500	4.227202938	99.99407352	1.69E+05	2.33E+14
100	50	1382023500	4.227202938	99.99407352	1.69E+06	2.33E+15
1000	50	1382023500	4.227202938	99.99407352	1.69E+07	2.33E+16
1	10	276404700	4.227202938	99.99407352	1.69E+04	4.66E+12
10	10	276404700	4.227202938	99.99407352	1.69E+05	4.66E+13
100	10	276404700	4.227202938	99.99407352	1.69E+06	4.66E+14
1000	10	276404700	4.227202938	99.99407352	1.69E+07	4.66E+15

Model 2

Giardia

Org. Conc. Tap (Org/L)	% Mixed	Res. Volume (L)	Avg. Rem. (log)	Avg. Rem. (%)	Org Conc. F	Total Organisms
1	100	2764047000	4.555272445	99.99721563	3.59E+04	9.93E+13
10	100	2764047000	4.555272445	99.99721563	3.59E+05	9.93E+14
100	100	2764047000	4.555272445	99.99721563	3.59E+06	9.93E+15
1000	100	2764047000	4.555272445	99.99721563	3.59E+07	9.93E+16
1	50	1382023500	4.555272445	99.99721563	3.59E+04	4.96E+13
10	50	1382023500	4.555272445	99.99721563	3.59E+05	4.96E+14
100	50	1382023500	4.555272445	99.99721563	3.59E+06	4.96E+15
1000	50	1382023500	4.555272445	99.99721563	3.59E+07	4.96E+16
1	10	276404700	4.555272445	99.99721563	3.59E+04	9.93E+12
10	10	276404700	4.555272445	99.99721563	3.59E+05	9.93E+13
100	10	276404700	4.555272445	99.99721563	3.59E+06	9.93E+14
1000	10	276404700	4.555272445	99.99721563	3.59E+07	9.93E+15

Viruses

Org. Conc. Tap (Org/L)	% Mixed	Res. Volume (L)	Avg. Rem. (log)	Avg. Rem. (%)	Org Conc. F	Total Organisms
1	100	2764047000	6.723432956	99.9999811	5.29E+06	1.46E+16
10	100	2764047000	6.723432956	99.9999811	5.29E+07	1.46E+17
100	100	2764047000	6.723432956	99.9999811	5.29E+08	1.46E+18
1000	100	2764047000	6.723432956	99.9999811	5.29E+09	1.46E+19
1	50	1382023500	6.723432956	99.9999811	5.29E+06	7.31E+15
10	50	1382023500	6.723432956	99.9999811	5.29E+07	7.31E+16
100	50	1382023500	6.723432956	99.9999811	5.29E+08	7.31E+17
1000	50	1382023500	6.723432956	99.9999811	5.29E+09	7.31E+18
1	10	276404700	6.723432956	99.9999811	5.29E+06	1.46E+15
10	10	276404700	6.723432956	99.9999811	5.29E+07	1.46E+16
100	10	276404700	6.723432956	99.9999811	5.29E+08	1.46E+17
1000	10	276404700	6.723432956	99.9999811	5.29E+09	1.46E+18

Model 3

Giardia

Org. Conc. Tap (Org/L)	% Mixed	Res. Volume (L)	Avg. Rem. (log)	Avg. Rem. (%)	Org Conc. F	Total Organisms
1	100	2764047000	5.055272445	99.9991195	1.14E+05	3.14E+14
10	100	2764047000	5.055272445	99.9991195	1.14E+06	3.14E+15
100	100	2764047000	5.055272445	99.9991195	1.14E+07	3.14E+16
1000	100	2764047000	5.055272445	99.9991195	1.14E+08	3.14E+17
1	50	1382023500	5.055272445	99.9991195	1.14E+05	1.57E+14
10	50	1382023500	5.055272445	99.9991195	1.14E+06	1.57E+15
100	50	1382023500	5.055272445	99.9991195	1.14E+07	1.57E+16
1000	50	1382023500	5.055272445	99.9991195	1.14E+08	1.57E+17
1	10	276404700	5.055272445	99.9991195	1.14E+05	3.14E+13
10	10	276404700	5.055272445	99.9991195	1.14E+06	3.14E+14
100	10	276404700	5.055272445	99.9991195	1.14E+07	3.14E+15
1000	10	276404700	5.055272445	99.9991195	1.14E+08	3.14E+16

Viruses

Org. Conc. Tap (Org/L)	% Mixed	Res. Volume (L)	Avg. Rem. (log)	Avg. Rem. (%)	Org Conc. F	Total Organisms
1	100	2764047000	7.723432958	99.99999811	5.29E+07	1.46E+17
10	100	2764047000	7.723432958	99.99999811	5.29E+08	1.46E+18
100	100	2764047000	7.723432958	99.99999811	5.29E+09	1.46E+19
1000	100	2764047000	7.723432958	99.99999811	5.29E+10	1.46E+20
1	50	1382023500	7.723432958	99.99999811	5.29E+07	7.31E+16
10	50	1382023500	7.723432958	99.99999811	5.29E+08	7.31E+17
100	50	1382023500	7.723432958	99.99999811	5.29E+09	7.31E+18
1000	50	1382023500	7.723432958	99.99999811	5.29E+10	7.31E+19
1	10	276404700	7.723432958	99.99999811	5.29E+07	1.46E+16
10	10	276404700	7.723432958	99.99999811	5.29E+08	1.46E+17
100	10	276404700	7.723432958	99.99999811	5.29E+09	1.46E+18
1000	10	276404700	7.723432958	99.99999811	5.29E+10	1.46E+19

Appendix C, Worcester Water Filtration Plant Data

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month January Town City of Worcester PWS Name Worcester Department of Public Works
Year 2001 System/Treatment Plant Worcester Water Filtration Plant PWSID 2348000
Disinfectant / Sequence of Application Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.65	39.43	65.07	7.47	4	64	1.02
2	1.50	44.05	66.08	7.54	4	76	0.87
3	1.54	45.68	70.35	7.35	4	62	1.13
4	1.48	40.20	59.50	7.53	4	76	0.78
5	1.65	39.25	64.77	7.46	4	64	1.01
6	1.58	42.52	67.19	7.60	4	76	0.88
7	1.56	37.52	58.54	7.34	4	62	0.94
8	1.38	37.46	51.70	7.48	4	61	0.85
9	1.28	41.24	52.78	7.60	4	74	0.71
10	1.38	39.72	54.82	7.25	4	61	0.90
11	1.48	41.17	60.93	7.47	4	62	0.98
12	1.43	38.51	55.07	7.44	4	62	0.89
13	1.64	35.67	58.50	7.08	4	64	0.91
14	1.62	39.24	63.57	7.42	4	64	0.99
15	1.59	36.67	58.31	7.58	4	76	0.77
16	1.39	42.24	58.71	7.44	4	61	0.96
17	1.41	37.20	52.45	7.36	4	62	0.85
18	1.31	38.47	50.40	7.38	4	61	0.83
19	1.46	42.98	62.75	7.45	4	62	1.01
20	1.45	37.42	54.26	7.25	4	62	0.88
21	1.46	36.66	53.53	7.25	4	62	0.86
22	1.33	40.50	53.86	7.52	4	74	0.73
23	1.51	39.09	59.02	7.36	4	62	0.95
24	1.38	41.65	57.48	7.58	4	74	0.78
25	1.30	41.19	53.55	7.41	4	61	0.88
26	1.29	42.05	54.24	7.44	4	61	0.89
27	1.29	42.03	54.22	7.26	4	61	0.89
28	1.33	37.75	50.20	7.38	4	61	0.82
29	1.50	38.87	58.31	7.42	4	62	0.94
30	1.39	42.60	59.21	7.55	4	74	0.80
31	1.47	39.92	58.68	7.28	4	62	0.95

Prepared by Robert Hoyt
Title Water Filtration Plant Manager
Date 2/5/2001

Signature ____________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

Water

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month: Febryary Town: City of Worcester PWS Name: Worcester Department of Public Works

Year: 2001 System/Treatment Plant: Worcester Water Filtration Plant PWSID: 2348000

Disinfectant / Sequence of Application: Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)			Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1		1.38		42.22	58.27	7.50	4	61	0.96
2		1.40		37.72	52.81	7.50	4	62	0.85
3		1.36		38.42	52.26	7.30	4	61	0.86
4		1.45		40.76	59.10	7.43	4	62	0.95
5		1.44		39.33	56.64	7.44	4	62	0.91
6		1.48		40.82	60.41	7.49	4	62	0.97
7		1.51		40.54	61.22	7.51	4	76	0.81
8		1.61		39.50	63.59	7.38	4	64	0.99
9		1.36		52.40	71.27	7.44	4	61	1.17
10		1.45		39.74	57.62	7.60	4	76	0.76
11		1.54		39.79	61.27	7.42	4	62	0.99
12		1.35		39.00	52.65	7.49	4	61	0.86
13		1.24		44.99	55.79	7.57	4	74	0.75
14		1.35		41.55	56.09	7.41	4	61	0.92
15		1.50		47.75	71.63	7.61	4	76	0.94
16		1.56		38.66	60.31	7.52	4	76	0.79
17		1.56		37.35	58.26	7.53	4	76	0.77
18		1.62		38.44	62.27	7.48	4	64	0.97
19		1.63		38.23	62.31	7.52	4	77	0.81
20		1.65		37.49	61.86	7.61	4	77	0.80
21		1.43		43.15	61.70	7.43	4	62	1.00
22		1.61		38.82	62.50	7.51	4	77	0.81
23		1.53		38.30	58.60	7.48	4	62	0.95
24		1.61		36.84	59.32	7.27	4	64	0.93
25		1.60		40.69	65.11	7.34	4	64	1.02
26		1.46		37.49	54.73	7.47	4	62	0.88
27		1.47		38.41	56.47	7.48	4	62	0.91
28		1.44		40.30	58.03	7.58	4	76	0.76
29									
30									
31									

Prepared by: Robert Hoyt

Title: Water Filtration Plant Manager

Date: 3/5/2001

Signature: ____________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month: March | Town: City of Worcester | PWS Name: Worcester Department of Public Works

Year: 2001 | System/Treatment Plant: Worcester Water Filtration Plant | PWSID: 2348000

Disinfectant / Sequence of Application: Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.52	41.38	62.90	7.57	4	76	0.83
2	1.45	52.79	76.55	7.59	4	76	1.01
3	1.59	38.36	61.00	7.43	4	62	0.98
4	1.62	42.00	68.04	7.22	4	64	1.06
5	1.50	41.37	62.05	7.51	4	76	0.82
6	1.46	54.25	79.20	7.46	4	62	1.28
7	1.57	41.34	64.90	7.48	4	62	1.05
8	1.53	44.30	67.77	7.54	4	76	0.89
9	1.58	40.36	63.77	7.49	4	62	1.03
10	1.56	39.23	61.20	7.39	4	62	0.99
11	1.56	44.10	68.80	7.37	4	62	1.11
12	1.49	39.22	58.43	7.43	4	62	0.94
13	1.49	41.24	61.44	7.49	4	62	0.99
14	1.50	45.82	68.73	7.52	4	76	0.90
15	1.51	42.43	64.07	7.40	4	62	1.03
16	1.50	41.07	61.60	7.59	4	76	0.81
17	1.49	39.88	59.42	7.46	4	62	0.96
18	1.56	43.64	68.07	7.49	4	62	1.10
19	1.46	39.50	57.67	7.56	4	76	0.76
20	1.52	41.00	62.32	7.54	4	76	0.82
21	1.64	39.08	64.08	7.42	4	64	1.00
22	1.62	40.60	65.76	7.55	4	77	0.85
23	1.46	41.58	60.71	7.42	4	62	0.98
24	1.52	37.97	57.72	7.51	4	76	0.76
25	1.61	39.38	63.41	7.58	4	77	0.82
26	1.68	40.55	68.13	7.47	4	64	1.06
27	1.60	40.97	65.55	7.62	4	77	0.85
28	1.50	43.67	65.50	7.87	4	76	0.86
29	1.73	42.13	72.89	7.45	4	64	1.14
30	1.55	40.76	63.18	7.59	4	76	0.83
31	1.58	39.11	61.80	7.46	4	62	1.00

Prepared by: Robert Hoyt

Title: Water Filtration Plant Manager

Date: 4/5/2001

Signature: ____________________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month April Town City of Worcester PWS Name Worcester Department of Public Works
Year 2001 System/Treatment Plant Worcester Water Filtration Plant PWSID 2348000
Disinfectant / Sequence of Application Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.61	43.38	69.85	7.52	4	77	0.91
2	1.74	40.07	69.72	7.54	4	77	0.91
3	1.53	43.67	66.81	7.58	4	76	0.88
4	1.50	40.57	60.85	7.51	4	76	0.80
5	1.48	41.31	61.14	7.49	4	62	0.99
6	1.52	42.37	64.41	7.43	4	62	1.04
7	1.45	37.90	54.96	7.34	4	62	0.89
8	1.54	41.97	64.64	7.36	4	62	1.04
9	1.32	41.80	55.17	7.54	4	74	0.75
10	1.47	45.89	67.46	7.44	4	62	1.09
11	1.44	41.10	59.18	7.50	4	62	0.95
12	1.51	39.91	60.26	7.49	4	62	0.97
13	1.63	36.98	60.28	7.52	4	77	0.78
14	1.69	34.97	59.09	7.33	4	64	0.92
15	1.75	36.78	64.36	7.39	5	64	1.01
16	1.59	35.29	56.12	7.36	5	47	1.19
17	1.56	41.75	65.14	7.40	6	47	1.39
18	1.54	36.73	56.57	7.45	5	47	1.20
19	1.54	41.68	64.19	7.42	6	47	1.37
20	1.68	36.61	61.50	7.44	6	48	1.28
21	1.73	37.43	64.75	7.44	6	48	1.35
22	1.68	34.21	57.47	7.44	7	48	1.20
23	1.13	37.55	42.43	7.55	8	54	0.79
24	1.62	36.36	58.91	7.46	9	48	1.23
25	1.55	38.65	59.90	7.41	12	31	1.93
26	1.58	37.42	59.12	7.39	10	31	1.91
27	1.53	37.54	57.43	7.55	11	38	1.51
28	1.57	36.64	57.53	7.61	12	38	1.51
29	1.56	36.64	57.16	7.44	12	31	1.84
30	1.78	36.04	64.14	7.58	11	39	1.64
31							

Prepared by Robert Hoyt
Title Water Filtration Plant Manager
Date 5/5/2001

Signature ____________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month: May Town: City of Worcester PWS Name: Worcester Department of Public Works

Year: 2001 System/Treatment Plant: Worcester Water Filtration Plant PWSID: 2348000

Disinfectant / Sequence of Application: Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.41	34.56	48.73	7.57	12	38	1.28
2	1.89	33.62	63.55	7.32	13	33	1.93
3	1.60	33.03	52.85	7.44	14	32	1.65
4	1.58	34.36	54.30	7.30	14	31	1.75
5	1.49	33.65	50.14	7.21	14	31	1.62
6	1.63	34.47	56.19	7.28	14	32	1.76
7	1.53	34.93	53.45	7.75	14	38	1.41
8	1.52	34.42	52.32	7.57	14	38	1.38
9	1.71	34.11	58.33	7.53	15	39	1.50
10	1.56	33.14	51.70	7.58	15	28	1.85
11	1.54	33.55	51.66	7.53	16	28	1.85
12	1.60	30.77	49.23	7.33	16	24	2.05
13	1.59	33.86	53.84	7.67	17	28	1.92
14	1.60	34.32	54.90	7.72	16	29	1.89
15	1.65	35.59	58.72	7.32	16	24	2.45
16	1.74	35.87	62.42	7.58	16	29	2.15
17	1.69	35.84	60.57	7.55	16	29	2.09
18	1.55	34.47	53.43	7.82	16	28	1.91
19	1.62	32.25	52.24	7.70	16	29	1.80
20	1.66	32.74	54.35	7.54	16	29	1.87
21	1.70	34.90	59.34	7.65	16	29	2.05
22	1.75	36.14	63.25	7.53	17	29	2.18
23	1.53	37.87	57.94	8.60	16	41	1.41
24	1.75	36.84	64.48	7.63	16	29	2.22
25	1.60	37.59	60.15	7.93	16	29	2.07
26	1.68	39.77	66.82	7.44	16	24	2.78
27	1.70	50.00	85.00	7.61	17	29	2.93
28	1.73	39.27	67.93	7.66	16	29	2.34
29	1.49	36.67	54.65	7.98	17	28	1.95
30	1.89	39.51	74.68	7.65	18	30	2.49
31	1.61	36.67	59.05	7.69	17	29	2.04

Prepared by: Robert Hoyt

Title: Water Filtration Plant Manager

Date: 6/5/2001

Signature: ____________________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month June Town City of Worcester PWS Name Worcester Department of Public Works

Year 2001 System/Treatment Plant Worcester Water Filtration Plant PWSID 2348000

Disinfectant / Sequence of Application Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.60	35.37	56.59	7.67	17	29	1.95
2	1.74	35.56	61.87	7.67	17	29	2.13
3	1.79	35.36	63.29	7.56	17	29	2.18
4	1.62	38.07	61.68	8.06	18	35	1.76
5	1.63	37.66	61.39	7.72	18	29	2.12
6	1.54	37.51	57.77	7.75	18	28	2.06
7	1.53	35.09	53.68	7.60	18	28	1.92
8	1.49	34.12	50.84	7.59	18	28	1.82
9	1.59	32.35	51.43	7.68	18	28	1.84
10	1.63	32.30	52.65	7.41	19	24	2.19
11	1.49	34.06	50.75	7.96	19	28	1.81
12	1.61	37.80	60.85	7.71	20	29	2.10
13	1.49	34.77	51.81	7.68	19	28	1.85
14	1.28	34.32	43.94	7.82	20	28	1.57
15	1.63	34.93	56.94	7.33	21	16	3.56
16	1.42	32.83	46.62	7.71	21	19	2.45
17	1.40	37.96	53.15	7.53	21	19	2.80
18	1.18	35.20	41.54	7.67	21	18	2.31
19	1.32	34.07	44.97	7.56	21	18	2.50
20	1.43	33.88	48.45	7.60	21	19	2.55
21	1.51	36.80	55.57	7.67	22	19	2.92
22	1.41	35.27	49.74	7.99	21	19	2.62
23	1.37	33.64	46.09	7.58	21	18	2.56
24	1.40	35.72	50.01	7.67	23	19	2.63
25	1.38	33.80	46.65	7.56	23	18	2.59
26	1.31	33.92	44.43	7.55	23	18	2.47
27	1.45	33.02	47.88	7.44	23	16	2.99
28	1.45	32.77	47.52	7.65	24	19	2.50
29	1.44	33.82	48.70	7.35	24	16	3.04
30	1.37	32.06	43.92	7.75	24	18	2.44
31							

Prepared by Robert Hoyt

Title Water Filtration Plant Manager

Date 7/5/2001

Signature

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month July Town City of Worcester PWS Name Worcester Department of Public Works

Year 2001 System/Treatment Plant Worcester Water Filtration Plant PWSID 2348000

Disinfectant / Sequence of Application Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.52	35.02	53.22	7.51	24	19	2.80
2	1.45	35.95	52.13	7.34	25	16	3.26
3	1.54	34.83	53.64	7.44	23	16	3.35
4	1.43	35.76	51.13	7.52	23	19	2.69
5	1.30	35.30	45.90	7.69	24	18	2.55
6	1.61	36.60	58.92	7.52	24	19	3.10
7	1.68	35.49	59.63	7.59	24	19	3.14
8	1.67	40.76	68.07	7.24	23	16	4.25
9	1.48	36.34	53.79	7.80	24	19	2.83
10	1.60	34.41	55.06	7.42	24	16	3.44
11	1.79	36.50	65.33	7.50	24	16	4.08
12	1.74	33.94	59.05	7.44	24	16	3.69
13	1.46	35.40	51.68	7.86	24	19	2.72
14	1.71	33.78	57.77	7.50	24	16	3.61
15	1.66	35.10	58.26	7.52	24	19	3.07
16	1.65	33.39	55.09	7.54	24	19	2.90
17	1.60	36.67	58.68	7.50	24	16	3.67
18	1.61	35.33	56.87	7.50	24	16	3.55
19	1.47	35.35	51.96	7.39	24	16	3.25
20	1.72	34.05	58.57	7.20	24	16	3.66
21	1.70	33.17	56.38	7.38	24	16	3.52
22	1.74	33.94	59.05	7.57	24	19	3.11
23	1.73	30.75	53.19	7.54	25	19	2.80
24	1.91	32.79	62.62	7.27	25	16	3.91
25	1.61	32.95	53.05	7.40	26	16	3.32
26	1.80	35.72	64.30	7.15	26	16	4.02
27	1.69	34.61	58.49	7.30	25	16	3.66
28	1.64	33.82	55.47	7.69	24	19	2.92
29	1.85	33.93	62.77	7.22	25	16	3.92
30	1.84	35.00	64.39	7.32	25	16	4.02
31	1.71	33.78	57.77	7.38	25	16	3.61

Prepared by Robert Hoyt

Title Water Filtration Plant Manager

Date 8/6/2001

Signature

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

Summer

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month: August Town: City of Worcester PWS Name: Worcester Department of Public Works

Year: 2001 System/Treatment Plant: Worcester Water Filtration Plant PWSID: 2348000

Disinfectant / Sequence of Application: Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.68	32.86	55.20	7.59	25	19	2.65
2	1.70	32.64	55.48	7.25	25	16	2.96
3	1.42	32.45	46.08	7.36	25	16	2.81
4	1.32	35.18	46.44	7.65	25	18	2.56
5	1.38	34.63	47.79	7.37	26	15	2.96
6	1.51	33.21	50.15	7.60	26	19	2.36
7	1.58	33.23	52.51	7.64	26	19	2.50
8	1.62	33.40	54.11	7.27	26	16	3.05
9	1.45	29.84	43.27	7.28	27	16	2.61
10	1.59	31.60	50.25	7.28	27	16	2.34
11	1.76	33.03	58.13	7.36	27	16	3.20
12	1.68	35.52	59.68	7.42	27	16	3.64
13	1.71	33.78	57.77	7.55	26	19	1.25
14	1.43	35.86	51.29	7.37	26	16	3.16
15	1.67	35.44	59.18	7.38	26	16	3.46
16	1.45	30.45	44.15	7.61	26	19	2.28
17	1.62	34.21	55.42	7.42	26	16	3.42
18	1.55	35.18	54.53	7.39	26	16	3.36
19	1.56	35.46	55.32	7.33	26	16	3.30
20	1.43	34.71	49.64	7.28	26	16	3.05
21	1.54	35.68	54.95	7.49	26	16	3.16
22	1.73	34.19	59.15	7.31	26	16	2.99
23	1.77	34.27	60.65	7.42	26	16	3.56
24	1.66	34.40	57.11	7.59	26	19	3.01
25	1.72	33.76	58.06	7.51	26	19	3.00
26	1.72	33.86	58.24	7.34	26	16	3.53
27	1.72	33.49	57.61	7.44	26	16	3.41
28	1.67	34.17	57.06	7.34	26	16	3.57
29	1.74	34.61	60.22	7.35	26	16	3.68
30	1.62	34.11	55.26	7.27	26	16	3.43
31	1.69	34.47	58.26	7.24	25	16	3.49

Prepared by: Robert Hoyt

Title: Water Filtration Plant Manager

Date: 9/6/2001

Signature: __________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

 Summer

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month: September Town: City of Worcester PWS Name: Worcester Department of Public Works
Year: 2001 System/Treatment Plant: Worcester Water Filtration Plant PWSID: 2348000
Disinfectant / Sequence of Application: Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.54	33.40	51.43	7.46	25	16	3.21
2	1.76	34.36	60.48	7.58	25	19	3.18
3	1.72	32.63	56.12	7.28	25	16	3.51
4	1.71	34.57	59.12	7.36	24	16	3.69
5	1.73	34.04	58.89	7.33	24	16	3.68
6	1.67	34.57	57.74	7.30	23	16	3.61
7	1.57	33.72	52.94	7.27	24	16	3.31
8	1.56	32.40	50.54	7.68	24	19	2.66
9	1.62	32.31	52.34	7.37	24	16	3.27
10	1.58	33.20	52.45	7.22	24	16	3.28
11	1.88	34.35	64.59	7.38	24	16	4.04
12	1.57	33.65	52.83	7.64	24	19	2.78
13	0.95	34.79	33.05	7.46	23	15	2.20
14	1.49	35.81	53.36	7.39	23	16	3.33
15	1.52	33.45	50.85	7.46	22	16	3.18
16	1.84	33.82	62.23	7.48	22	16	3.89
17	1.64	33.46	54.88	8.05	22	23	2.39
18	1.84	34.45	63.39	7.23	21	16	3.96
19	1.87	34.28	64.10	7.70	22	20	3.20
20	2.15	34.85	74.93	7.48	21	17	4.41
21	2.15	35.83	77.04	7.53	21	20	3.85
22	1.92	34.58	66.40	7.71	21	20	3.32
23	1.60	36.64	58.63	7.74	22	19	3.09
24	1.60	35.98	57.57	7.50	22	16	3.60
25	1.59	37.62	59.81	7.45	21	16	3.74
26	1.76	37.50	66.00	7.36	21	16	4.13
27	1.99	35.93	71.50	7.56	21	20	3.57
28	1.70	36.06	61.30	7.37	20	16	3.83
29	2.28	33.56	76.51	7.43	20	26	2.94
30	2.20	35.57	78.25	7.39	19	26	3.01
31							

Prepared by: Robert Hoyt
Title: Water Filtration Plant Manager
Date: 10/3/2001

Signature: ____________________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month: October   Town: City of Worcester   PWS Name: Worcester Department of Public Works

Year: 2001   System/Treatment Plant: Worcester Water Filtration Plant   PWSID: 2348000

Disinfectant / Sequence of Application: Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	2.43	36.41	88.47	7.49	19	26	3.40
2	1.65	34.98	57.71	7.39	18	24	2.40
3	2.27	34.87	79.16	7.35	18	26	3.04
4	2.12	35.42	75.09	7.45	18	25	3.00
5	1.90	34.02	64.64	7.49	18	25	2.59
6	1.62	35.45	57.43	7.60	18	29	1.98
7	1.92	35.55	68.25	7.59	18	30	2.27
8	1.98	36.25	71.78	7.47	16	25	2.87
9	2.22	38.92	86.41	7.37	16	26	3.32
10	2.48	36.11	89.56	7.37	15	26	3.44
11	2.19	35.31	77.34	7.37	15	25	3.09
12	2.43	35.85	87.12	7.63	16	32	2.72
13	2.67	35.00	93.44	7.49	16	27	3.46
14	2.50	35.37	88.42	7.59	16	32	2.76
15	2.29	35.94	82.30	7.47	16	26	3.17
16	2.26	36.22	81.86	7.39	16	26	3.15
17	2.12	36.33	77.02	7.57	16	30	2.57
18	1.91	36.57	69.86	7.38	15	33	2.12
19	2.02	36.53	73.79	7.48	14	33	2.24
20	2.23	34.11	76.07	7.42	14	34	2.24
21	2.19	36.79	80.56	7.51	14	41	1.96
22	2.06	36.81	75.83	7.47	14	33	2.30
23	1.93	37.14	71.68	7.37	14	33	2.17
24	2.06	36.61	75.41	7.47	14	33	2.29
25	2.05	36.88	75.60	7.30	14	33	2.29
26	1.75	35.45	62.04	7.47	14	32	1.94
27	1.93	35.42	68.36	7.42	14	33	2.07
28	2.21	33.33	73.67	7.39	14	34	2.17
29	2.17	37.17	80.67	7.47	13	33	2.44
30	2.14	36.89	78.94	7.31	13	33	2.39
31	1.86	36.76	68.38	7.56	12	40	1.71

Prepared by: Robert Hoyt
Title: Water Filtration Plant Manager
Date: 11/5/2001

Signature: ____________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month November Town City of Worcester PWS Name Worcester Department of Public Work

Year 2001 System/Treatment Plant Worcester Water Filtration Plant PWSID 2348000

Disinfectant / Sequence of Application Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	2.02	35.78	72.27	7.50	12	33	2.19
2	1.81	36.55	66.16	7.42	12	33	2.00
3	2.08	34.97	72.73	7.58	12	41	1.77
4	1.84	34.20	62.92	7.47	12	33	1.91
5	1.90	37.94	72.08	7.67	12	40	1.80
6	1.82	36.50	66.42	7.44	11	33	2.01
7	1.56	36.06	56.25	7.49	10	31	1.81
8	1.41	36.00	50.77	7.54	10	57	0.89
9	1.74	36.40	63.33	7.24	10	48	1.32
10	1.89	34.13	64.51	7.29	10	49	1.32
11	1.82	37.14	67.60	7.39	9	49	1.38
12	1.86	33.84	62.94	7.25	9	49	1.28
13	1.79	38.03	68.08	7.35	8	48	1.42
14	1.73	37.15	64.27	7.42	8	48	1.34
15	1.58	36.64	57.89	7.35	8	47	1.23
16	1.66	36.44	60.49	7.33	8	48	1.26
17	1.80	33.93	61.07	7.35	8	49	1.25
18	2.01	34.21	68.76	7.21	8	50	1.38
19	1.83	36.26	66.36	7.31	8	49	1.35
20	1.81	35.38	64.03	7.41	8	49	1.31
21	1.79	36.09	64.60	7.27	8	48	1.35
22	1.73	33.59	58.12	7.26	8	48	1.21
23	1.77	37.35	66.11	7.32	8	48	1.38
24	1.85	36.92	68.31	7.38	8	49	1.39
25	1.82	36.93	67.22	7.34	8	49	1.37
26	1.74	37.12	64.58	7.32	8	48	1.35
27	1.85	36.84	68.16	7.27	8	49	1.39
28	1.51	37.34	56.38	7.68	8	57	0.99
29	1.57	37.93	59.54	7.46	9	47	1.27
30	1.64	37.95	62.24	7.44	8	48	1.30
31							

Prepared by Robert Hoyt

Title Water Filtration Plant Manager

Date 12/5/2001

Signature ____________________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

FORM I

CT DETERMINATION FOR FILTERED SYSTEMS - MONTHLY REPORT TO DEP [1]

Month: December | Town: City of Worcester | PWS Name: Worcester Department of Public Works

Year: 2000 | System/Treatment Plant: Worcester Water Filtration Plant | PWSID: 2348000

Disinfectant / Sequence of Application: Chlorine / Finished Water

Date	Disinfectant[2] Concentration, C(mg/l)	Disinfectant[2] Contact Time T(min.)	CT calc[3] (=C*T)	2,4 pH	Water[2] Temp (deg. C)	CT99.9[5]	(CTcalc/CT99.9)
1	1.46	37.09	54.16	7.52	5	76	0.71
2	1.48	39.80	58.91	7.55	4	76	0.78
3	1.65	37.50	61.88	7.14	3	64	0.97
4	1.39	39.54	54.96	7.40	4	61	0.90
5	1.42	41.48	58.90	7.39	4	62	0.95
6	1.50	38.01	57.02	7.25	3	62	0.92
7	1.36	39.55	53.79	7.54	4	74	0.73
8	1.50	41.08	61.62	7.25	4	62	0.99
9	1.66	36.19	60.07	7.32	4	64	0.94
10	1.35	37.65	50.83	7.17	4	61	0.83
11	1.31	38.23	50.08	7.30	4	61	0.82
12	1.40	37.27	52.17	7.32	4	62	0.84
13	1.68	37.35	62.75	7.30	4	64	0.98
14	1.53	40.31	61.67	7.47	4	62	0.99
15	1.45	42.27	61.29	7.36	4	62	0.99
16	1.53	38.90	59.51	7.45	4	62	0.96
17	1.53	39.29	60.12	7.40	4	62	0.97
18	1.45	39.27	56.94	7.44	4	62	0.92
19	1.51	40.25	60.78	7.36	4	62	0.98
20	1.47	41.03	60.31	7.36	4	62	0.97
21	1.46	39.37	57.48	7.53	4	76	0.76
22	1.48	45.01	66.62	7.36	4	62	1.07
23	1.60	36.10	57.76	7.30	4	64	0.90
24	1.73	37.31	64.55	7.30	4	64	1.01
25	1.66	41.41	68.74	7.34	4	64	1.07
26	1.76	36.89	64.92	7.26	4	64	1.01
27	1.48	40.71	60.24	7.55	4	76	0.79
28	1.44	37.42	53.88	7.35	4	62	0.87
29	1.51	41.64	62.87	7.44	4	62	1.01
30	1.70	38.00	64.60	7.41	4	64	1.01
31	1.61	37.13	59.78	7.43	4	64	0.93

Prepared by: Robert Hoyt

Title: Water Filtration Plant Manager

Date: 1/5/2001

Signature: ____________

1. Use a separate form for each disinfectant/sampling site. Enter disinfectant and sequence position, e.g., "ozone/1st" or C102/3rd."
2. Measurement taken at peak hourly flow.
3. CTcalc = C (mg/l) x T (min.).
4. Only required if the disinfectant is free chlorine.
5. Number is obtained from CT Charts in 310 CMR 22.20 A Tables 1.1 - 1.6, 2.1, 3.1

RETURN TO DEP/DWS REGIONAL OFFICE WITHIN 10 DAYS AFTER THE REPORTING MONTH

Daily Report

Worcester WFP Ozone System Daily Report

Parameter	Units	Data	Tue	October 16, 01
Date	m/d/y	10/16/01	Test #	
No. Air Compressors	(1,2,3,4)	2	Time	0:10
No. Refrigerant Dryers	(0,1,2)	1		
No. Desiccant Dryers	(1,2)	1		
No. Off-Gas Blowers	(1,2,3,4)	2		

	Gen. No.	1	2	3	4
Generator Air Flow Rate	cfm	126			125.6
Inlet Pressure	psig	15			15
Inlet Temperature	F	64			65
O_3 Concentration	%wt	1.4			1.4
Power Demand	kW	59			61
Barometric Pressure	psia	14.3			
Dew Point	F	-137			
Dosage Setpoint	mg/L	1.7			

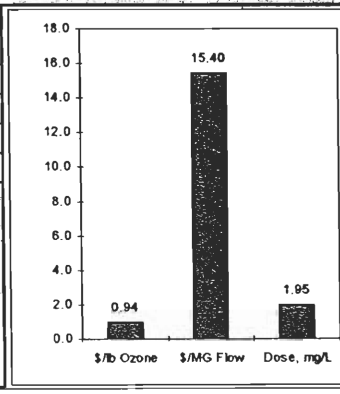
Parameter	Train #	1		2	
Gas Flow to Train	cfm	122.3		120.9	
Gas Flow to A	%	100		100	
Gas Flow to B	%				
		Rosemt.	Lab	Rosemt.	Lab
Ozone Residual A	mg/L	0.306		0.291	
Ozone Residual B	mg/L	0.001		0.001	
Ozone Residual C	mg/L	0.001		0.001	
Off-Gas Conc.	%wt	0.4908		0.4416	

Parameter	Units	Value
No. Trains in Service	(1,2)	2
Plant Water Flow	MGD	23.4
Water Temperature	F	61
Water pH		6.73
Giardia Ozone Target	Log I	1
Virus Ozone Target	Log I	3

OZONE GENERATOR INFORMATION

		1	2	3	4	Average/Total
Ozone Concentration	%wt	1.400			1.400	1.400
Feed-Gas Flow Rate	scfm	126			125	251
Ozone Production	lb/day	191			190	381
Meas. Generator Power	kW	59			61	120
Meas. Specific Energy	kWh/lb	7.41			7.69	
Ref. Specific Engery	kWh/lb	7.248			7.248	
Percent Difference	%	2.2			6.1	
Air Compressor Power	kW	44				
Other Equip. Power	kW	23.6				
Total System Power	kW	188				
System Specific Energy	kWh/lb	11.81				

$/lb =	0.94
$/MG =	15.40



GENERAL OZONE CONTACTOR INFORMATION

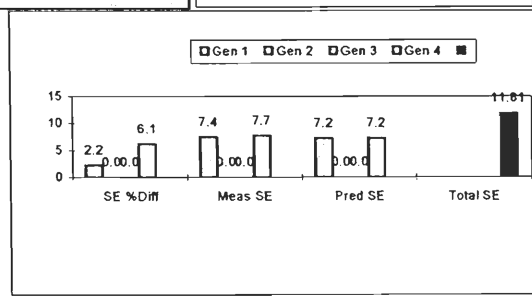
	stage	A	B	C
Cummulative HDT at end of stage	min	4.77	9.54	15.35
Total System Ozone Dosage	mg/L	1.95		

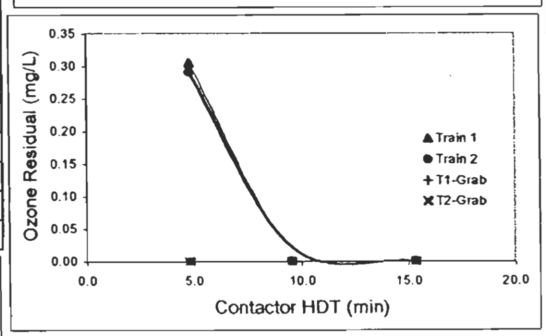
OZONE CONTACTOR TRAIN NO. 1

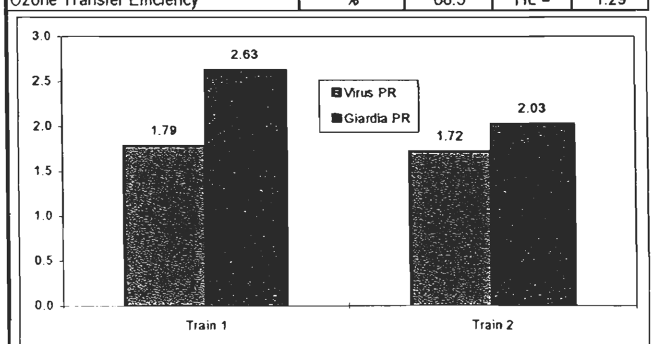
Applied Ozone Dose	mg/L	1.97		
Measured Ozone Residual	mg/L	0.306	0.001	0.001
Projected Ozone Residual	mg/L	0.306	0.023	0.001
Virus Peformance Info	LogI =	5.36	PR =	1.79
Giardia Performance Info	LogI =	2.63	PR =	2.63
Ozone Transfer Efficiency	%	64.9	HL =	1.28

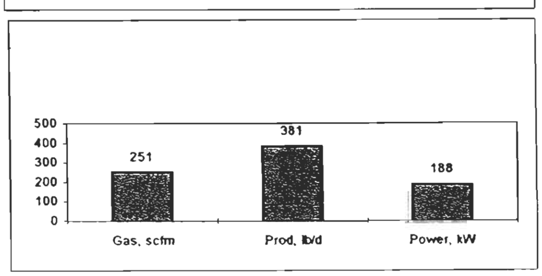
OZONE CONTACTOR TRAIN NO. 2

Applied Ozone Dose	mg/L	1.94		
Measured Ozone Residual	mg/L	0.291	0.001	0.001
Projected Ozone Residual	mg/L	0.291	0.023	0.001
Virus Peformance Info	LogI =	5.17	PR =	1.72
Giardia Performance Info	LogI =	2.03	PR =	2.03
Ozone Transfer Efficiency	%	68.5	HL =	1.29









Daily Report

Worcester WFP Ozone System Daily Report

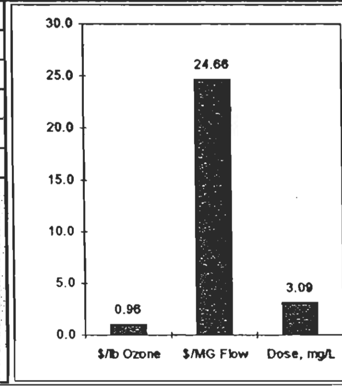
Parameter	Units	Data	Mon	July 16, 01	
Date	m/d/y	7/16/01	Test #		
No. Air Compressors	(1,2,3,4)	3	Time	0:01	
No. Refrigerant Dryers	(0,1,2)	1			
No. Desiccant Dryers	(1,2)	1			
No. Off-Gas Blowers	(1,2,3,4)	4			
	Gen. No.	1	2	3	4
Generator Air Flow Rate	cfm		126.7	123.8	125.9
Inlet Pressure	psig		14.9	14.9	14.9
Inlet Temperature	F		74	74	73
O_3 Concentration	%wt		1.538	1.538	1.538
Power Demand	kW		70	70	73
Barometric Pressure	psia	14.27			
Dew Point	F	-160			
Dosage Setpoint	mg/L	2.95			

Parameter	Train #	1		2	
Gas Flow to Train	cfm	177.72		194.44	
Gas Flow to A	%	83		85	
Gas Flow to B	%	17		15	
		Rosemt.	Lab	Rosemt.	Lab
Ozone Residual A	mg/L	0.138		0.16	
Ozone Residual B	mg/L	0.002		0.002	
Ozone Residual C	mg/L	0.001		0.001	
Off-Gas Conc.	%wt	0.6029		0.3423	
No. Trains in Service	(1,2)	2			
Plant Water Flow	MGD	24.03			
Water Temperature	F	74.33			
Water pH		6.54			
Giardia Ozone Target	Log I	1			
Virus Ozone Target	Log I	3			

OZONE GENERATOR INFORMATION

		1	2	3	4	Average/Total
Ozone Concentration	%wt		1.538	1.538	1.538	1.538
Feed-Gas Flow Rate	scfm		125	122	124	372
Ozone Production	lb/day		209	204	208	620
Meas. Generator Power	kW		70	70	73	213
Meas. Specific Energy	kWh/lb		8.05	8.24	8.44	
Ref. Specific Engery	kWh/lb		7.405	7.405	7.405	
Percent Difference	%		8.7	11.3	14.0	
Air Compressor Power	kW	66				
Other Equip. Power	kW	29.6				
Total System Power	kW	309				
System Specific Energy	kWh/lb	11.95				

$/lb =	0.96
$/MG =	24.66



GENERAL OZONE CONTACTOR INFORMATION

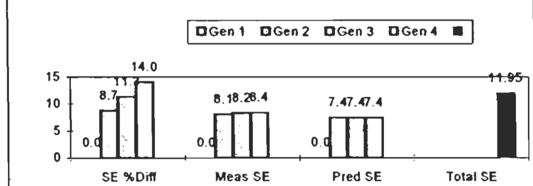
	stage	A	B	C
Cummulative HDT at end of stage	min	4.64	9.29	14.95
Total System Ozone Dosage	mg/L	3.09		

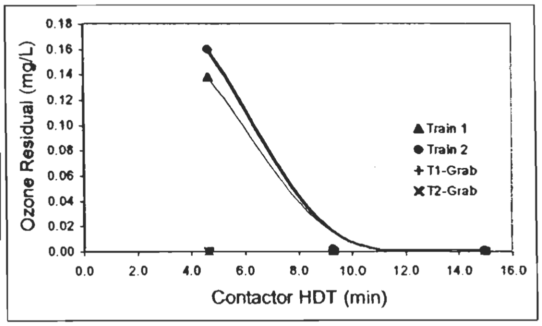
OZONE CONTACTOR TRAIN NO. 1

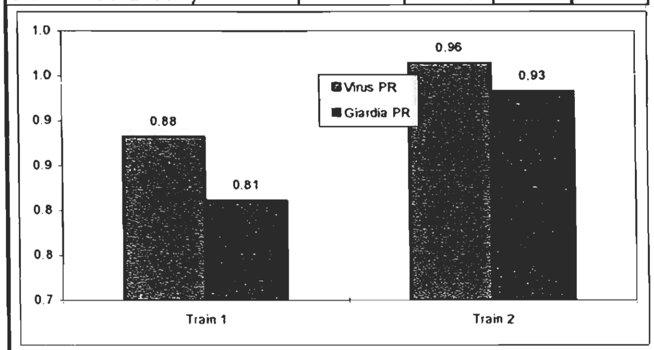
Applied Ozone Dose	mg/L	2.45	0.50	
Measured Ozone Residual	mg/L	0.138	0.002	0.001
Projected Ozone Residual	mg/L	0.138	0.015	0.001
Virus Peformance Info	LogI =	2.65	PR =	0.88
Giardia Performance Info	LogI =	0.81	PR =	0.81
Ozone Transfer Efficiency	%	60.8	HL =	1.45

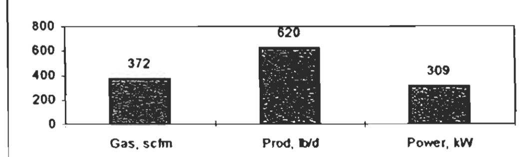
OZONE CONTACTOR TRAIN NO. 2

Applied Ozone Dose	mg/L	2.75	0.48	
Measured Ozone Residual	mg/L	0.16	0.002	0.001
Projected Ozone Residual	mg/L	0.16	0.016	0.001
Virus Peformance Info	LogI =	2.89	PR =	0.96
Giardia Performance Info	LogI =	0.93	PR =	0.93
Ozone Transfer Efficiency	%	77.7	HL =	1.41









Daily Report

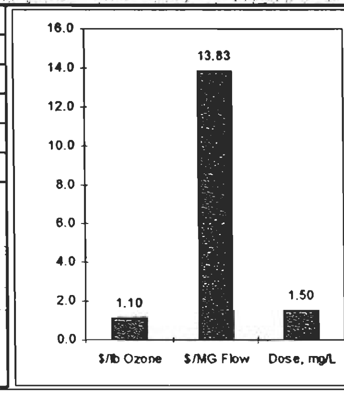
Worcester WFP Ozone System Daily Report

Parameter	Units	Data	Wed	April 4, 01	
Date	m/d/y	4/4/01	Test #		
No. Air Compressors	(1,2,3,4)	2	Time	16:45	
No. Refrigerant Dryers	(0,1,2)	1			
No. Desiccant Dryers	(1,2)	1			
No. Off-Gas Blowers	(1,2,3,4)	2			
	Gen. No.	1	2	3	4
Generator Air Flow Rate	cfm	118.2			124.6
Inlet Pressure	psig	14.5			15
Inlet Temperature	F	60			60
O_3 Concentration	%wt	1.031			1.065
Power Demand	kW	42			49
Barometric Pressure	psia	14.4			
Dew Point	F	-166			
Dosage Setpoint	mg/L	1.4			

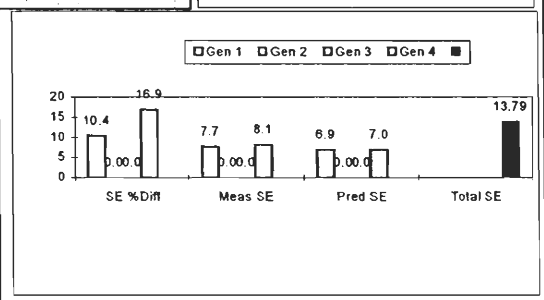
Parameter	Train #	1		2	
Gas Flow to Train	cfm	122.22		126.33	
Gas Flow to A	%	100		100	
Gas Flow to B	%				
		Rosemt.	Lab	Rosemt.	Lab
Ozone Residual A	mg/L	0.199		0.149	
Ozone Residual B	mg/L	0.001		0.001	
Ozone Residual C	mg/L	0.001		0.001	
Off-Gas Conc.	%wt	0.3076		0.3064	
No. Trains in Service	(1,2)	2			
Plant Water Flow	MGD	22.03			
Water Temperature	F	38.93			
Water pH		6.39			
Giardia Ozone Target	Log I	1			
Virus Ozone Target	Log I	3			

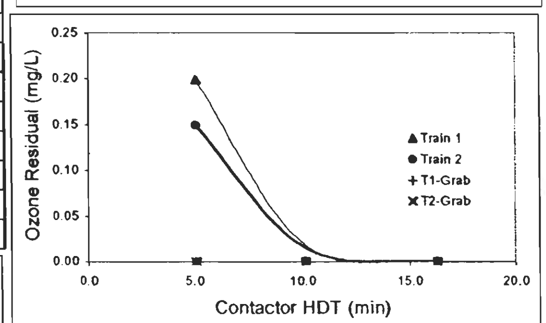
OZONE GENERATOR INFORMATION						
		1	2	3	4	Average/Total
Ozone Concentration	%wt	1.031			1.065	1.049
Feed-Gas Flow Rate	scfm	118			125	243
Ozone Production	lb/day	132			145	276
Meas. Generator Power	kW	42			49	91
Meas. Specific Energy	kWh/lb	7.66			8.14	
Ref. Specific Engery	kWh/lb	6.938			6.960	
Percent Difference	%	10.4			16.9	
Air Compressor Power	kW	44				
Other Equip. Power	kW	23.6				
Total System Power	kW	159				
System Specific Energy	kWh/lb	13.79				

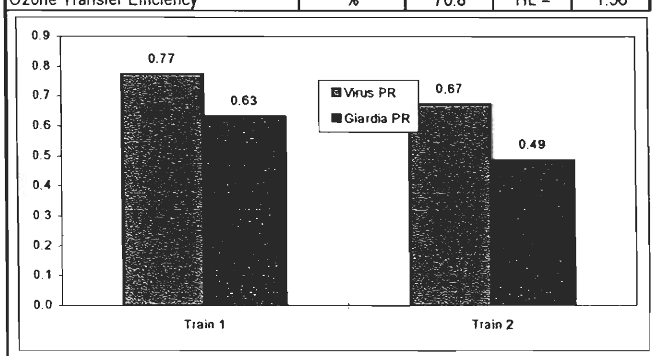
$/lb =	1.10
$/MG =	13.83

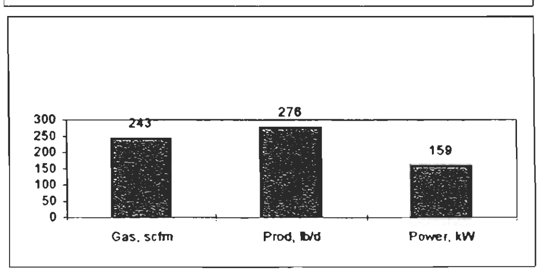


GENERAL OZONE CONTACTOR INFORMATION				
	stage	A	B	C
Cummulative HDT at end of stage	min	5.07	10.13	16.31
Total System Ozone Dosage	mg/L	1.50		
OZONE CONTACTOR TRAIN NO. 1				
Applied Ozone Dose	mg/L	1.48		
Measured Ozone Residual	mg/L	0.199	0.001	0.001
Projected Ozone Residual	mg/L	0.199	0.018	0.001
Virus Peformance Info	LogI =	2.32	PR =	0.77
Giardia Performance Info	LogI =	0.63	PR =	0.63
Ozone Transfer Efficiency	%	70.7	HL =	1.47
OZONE CONTACTOR TRAIN NO. 2				
Applied Ozone Dose	mg/L	1.53		
Measured Ozone Residual	mg/L	0.149	0.001	0.001
Projected Ozone Residual	mg/L	0.149	0.016	0.001
Virus Peformance Info	LogI =	2.02	PR =	0.67
Giardia Performance Info	LogI =	0.49	PR =	0.49
Ozone Transfer Efficiency	%	70.8	HL =	1.56









Daily Report

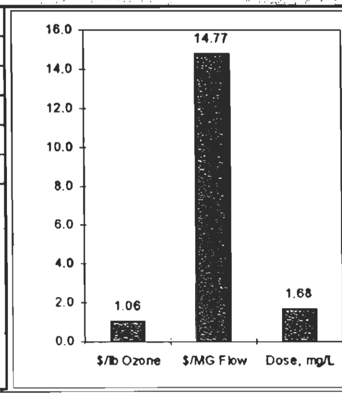
Worcester WFP Ozone System Daily Report

Parameter	Units	Data	Sun	January 14, 01	
Date	m/d/y	1/14/01	Test #		
No. Air Compressors	(1,2,3,4)	2	Time	16:15	
No. Refrigerant Dryers	(0,1,2)	1			
No. Desiccant Dryers	(1,2)	1			
No. Off-Gas Blowers	(1,2,3,4)	2			
	Gen. No.	1	2	3	4
Generator Air Flow Rate	cfm	123.21			124.17
Inlet Pressure	psig	14.21			14.3
Inlet Temperature	F	62			61
O_3 Concentration	%wt	1.344			1.279
Power Demand	kW	61			63
Barometric Pressure	psia	14.41			
Dew Point	F	-160			
Dosage Setpoint	mg/L	1.6			

Parameter	Train #	1		2	
Gas Flow to Train	cfm	120.47		122.8	
Gas Flow to A	%	100		100	
Gas Flow to B	%				
		Rosemt.	Lab	Rosemt.	Lab
Ozone Residual A	mg/L	0.221		0.263	
Ozone Residual B	mg/L	0.001		0.001	
Ozone Residual C	mg/L	0.001		0.001	
Off-Gas Conc.	%wt	0.2568		0.2676	
No. Trains in Service	(1,2)	2			
Plant Water Flow	MGD	24.91			
Water Temperature	F	39.51			
Water pH		6.43			
Giardia Ozone Target	Log I	1			
Virus Ozone Target	Log I	3			

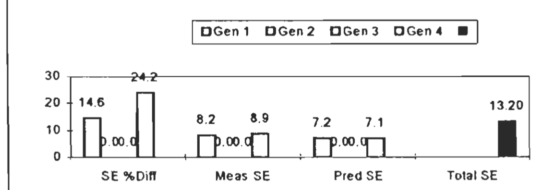
OZONE GENERATOR INFORMATION

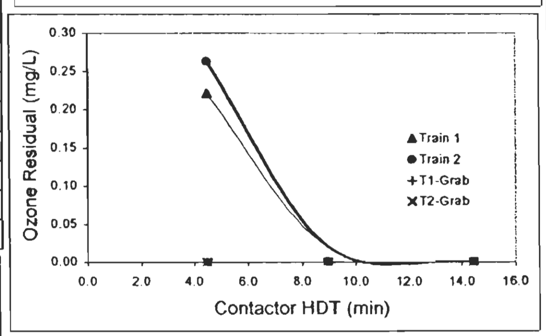
		1	2	3	4	Average/Total
Ozone Concentration	%wt	1.344			1.279	1.311
Feed-Gas Flow Rate	scfm	122			123	245
Ozone Production	lb/day	178			171	348
Meas. Generator Power	kW	61			63	124
Meas. Specific Energy	kWh/lb	8.24			8.85	
Ref. Specific Engery	kWh/lb	7.190			7.129	
Percent Difference	%	14.6			24.2	
Air Compressor Power	kW	44				
Other Equip. Power	kW	23.6	$/lb = 1.06			
Total System Power	kW	192	$/MG = 14.77			
System Specific Energy	kWh/lb	13.20				

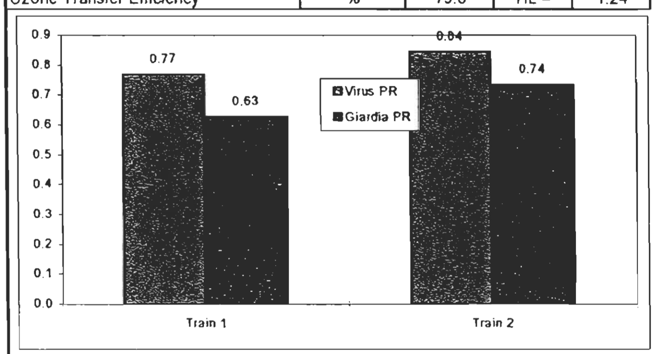


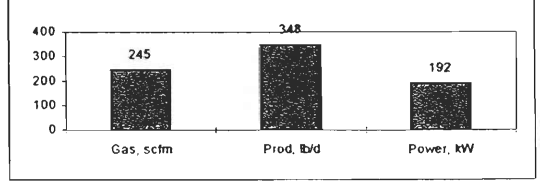
GENERAL OZONE CONTACTOR INFORMATION

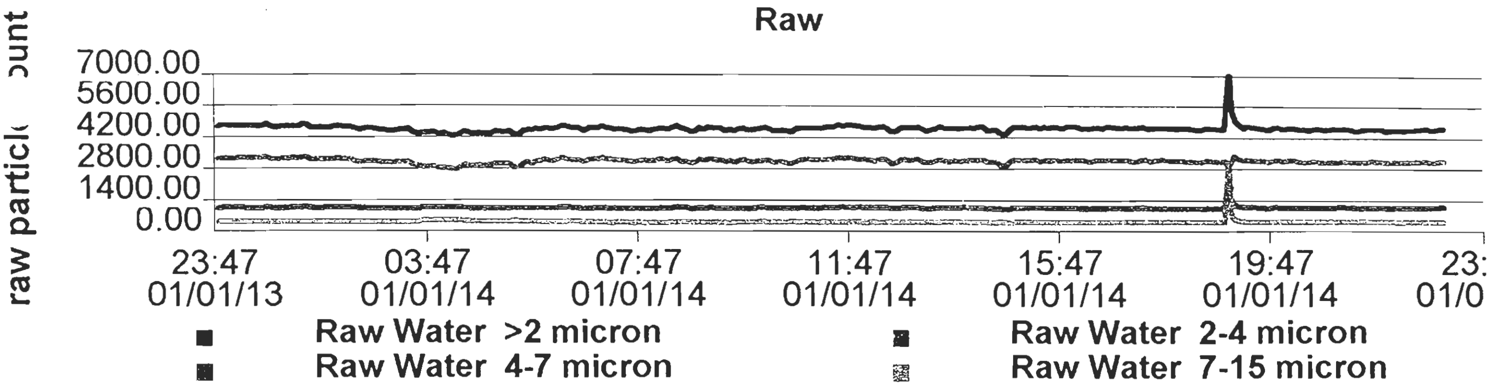
	stage	A	B	C
Cummulative HDT at end of stage	min	4.48	8.96	14.42
Total System Ozone Dosage	mg/L	1.68		
OZONE CONTACTOR TRAIN NO. 1				
Applied Ozone Dose	mg/L	1.66		
Measured Ozone Residual	mg/L	0.221	0.001	0.001
Projected Ozone Residual	mg/L	0.221	0.019	0.001
Virus Peformance Info	LogI =	2.31	PR =	0.77
Giardia Performance Info	LogI =	0.63	PR =	0.63
Ozone Transfer Efficiency	%	80.4	HL =	1.28
OZONE CONTACTOR TRAIN NO. 2				
Applied Ozone Dose	mg/L	1.69		
Measured Ozone Residual	mg/L	0.263	0.001	0.001
Projected Ozone Residual	mg/L	0.263	0.021	0.001
Virus Peformance Info	LogI =	2.53	PR =	0.84
Giardia Performance Info	LogI =	0.74	PR =	0.74
Ozone Transfer Efficiency	%	79.6	HL =	1.24

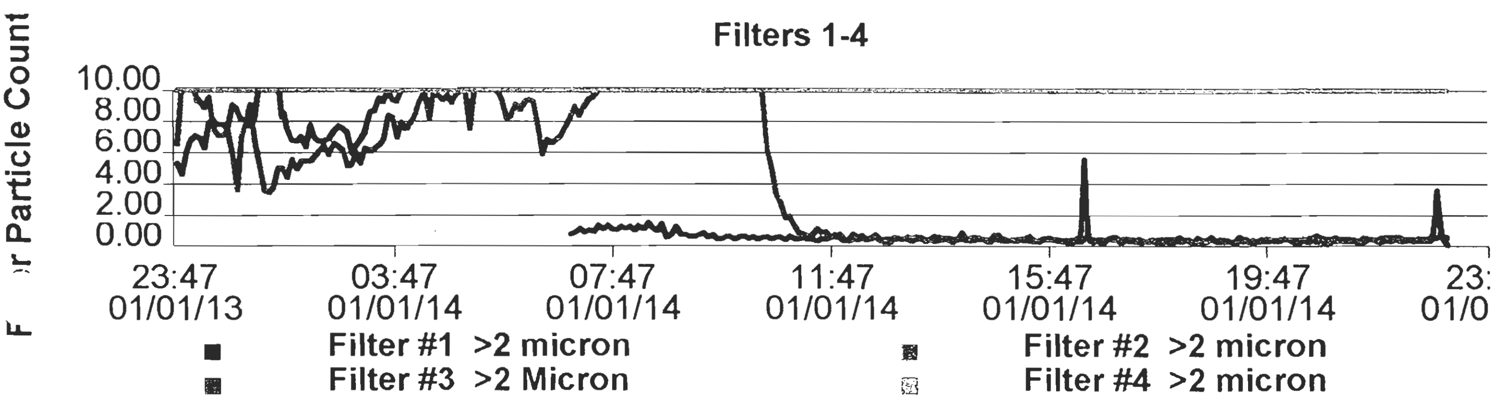


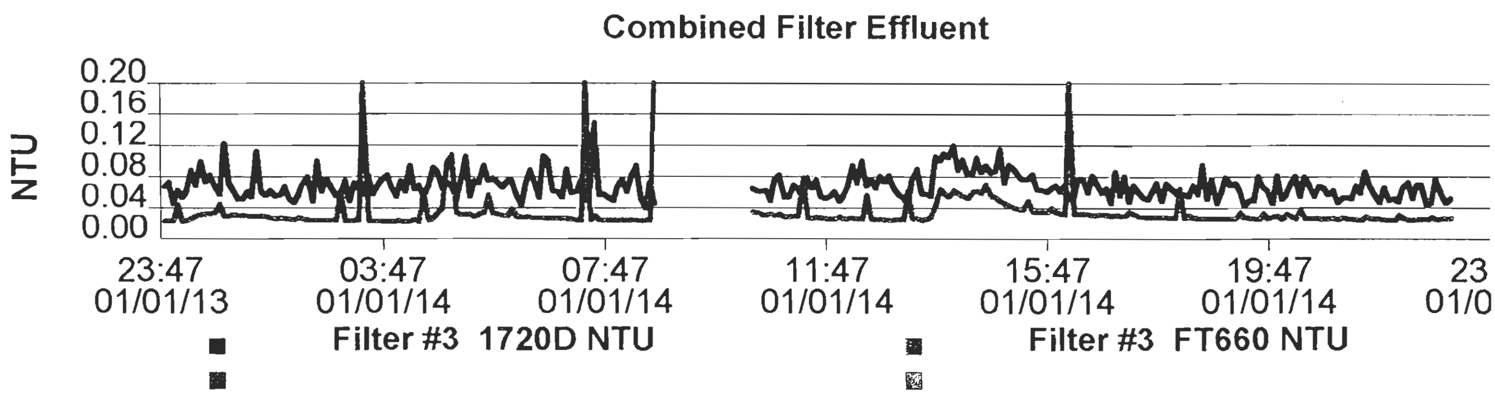


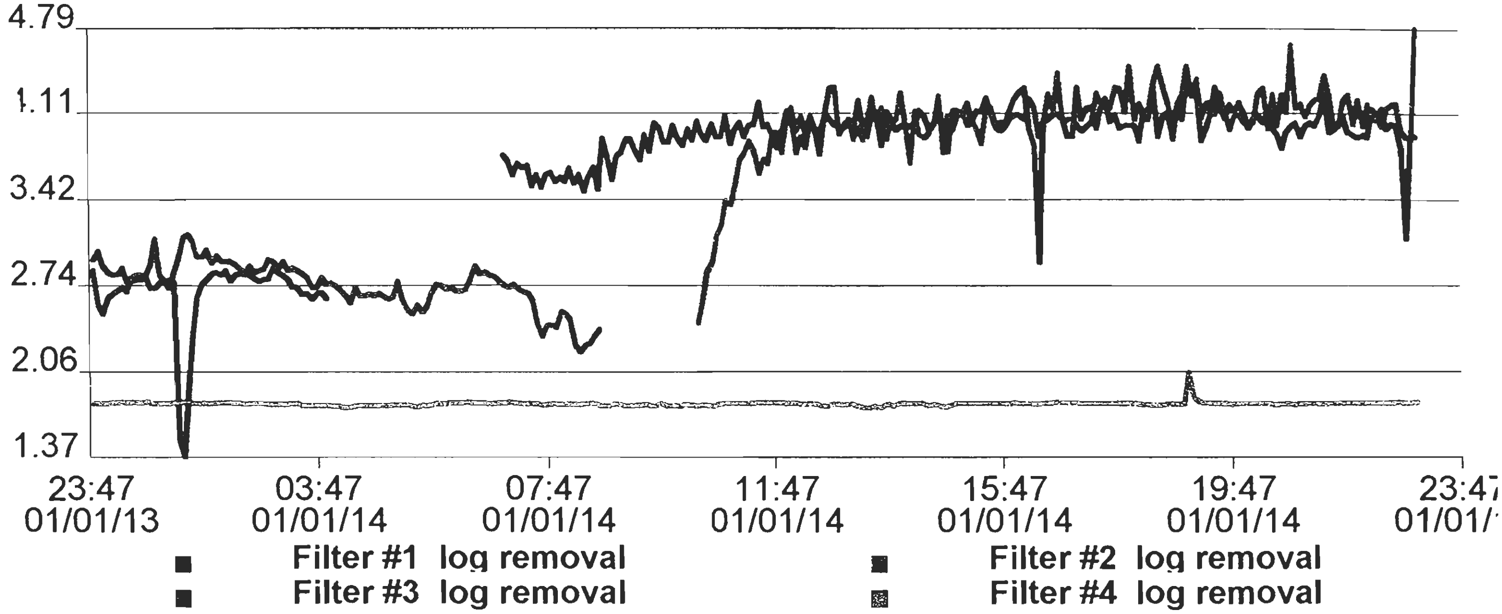


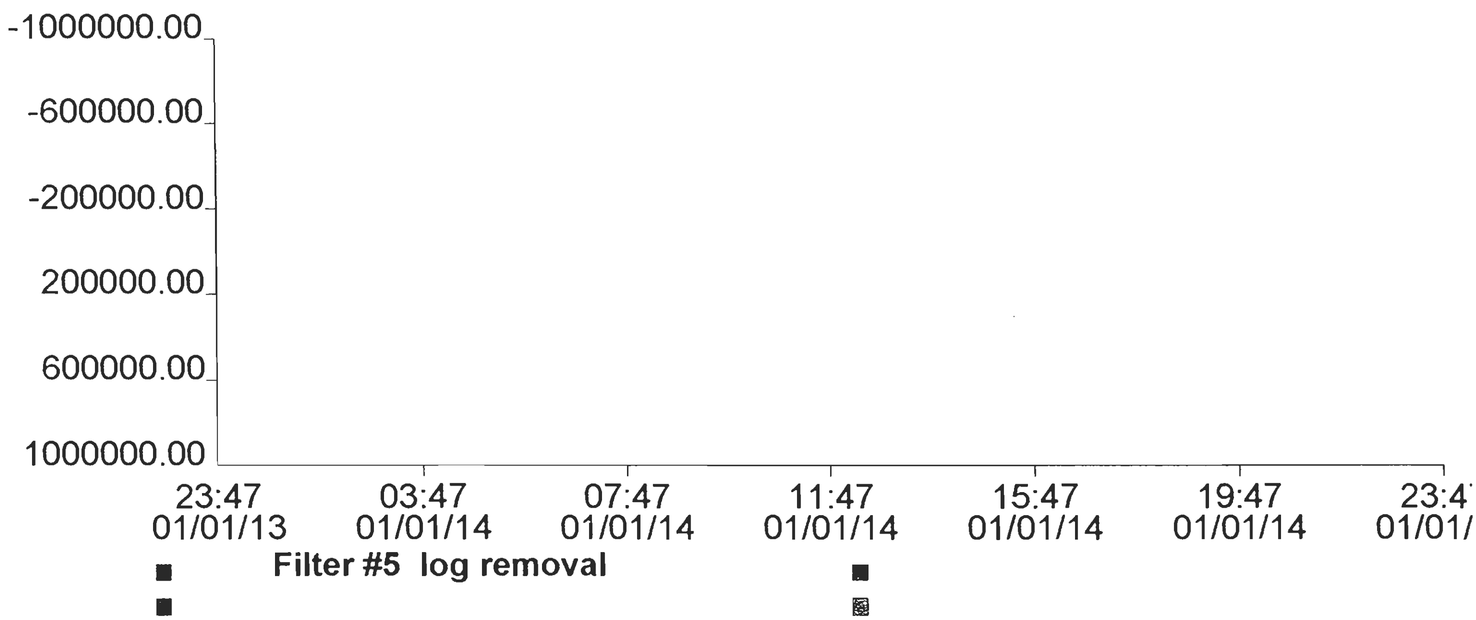


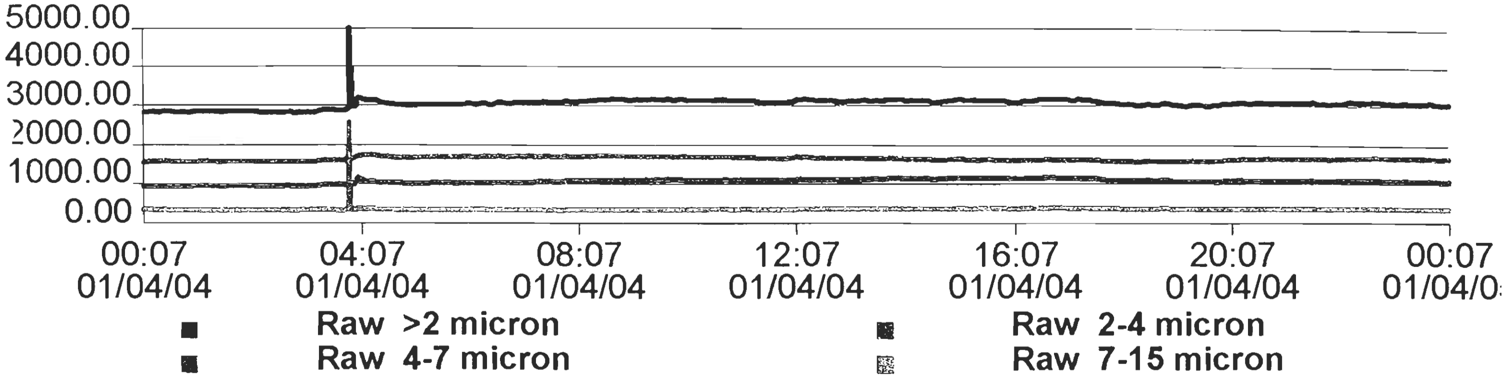

Raw
raw particle count
7000.00
5600.00
4200.00
2800.00
1400.00
0.00
23:47 01/01/13
03:47 01/01/14
07:47 01/01/14
11:47 01/01/14
15:47 01/01/14
19:47 01/01/14
23: 01/0
Raw Water >2 micron
Raw Water 2-4 micron
Raw Water 4-7 micron
Raw Water 7-15 micron

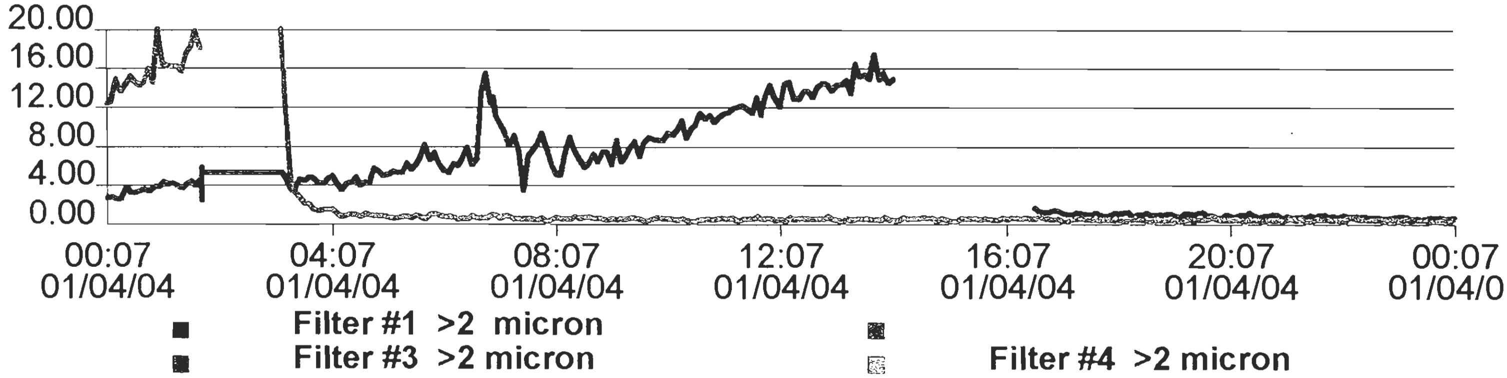

Filters 1-4
Particle Count
10.00
8.00
6.00
4.00
2.00
0.00
23:47 01/01/13
03:47 01/01/14
07:47 01/01/14
11:47 01/01/14
15:47 01/01/14
19:47 01/01/14
23: 01/0
Filter #1 >2 micron
Filter #2 >2 micron
Filter #3 >2 Micron
Filter #4 >2 micron

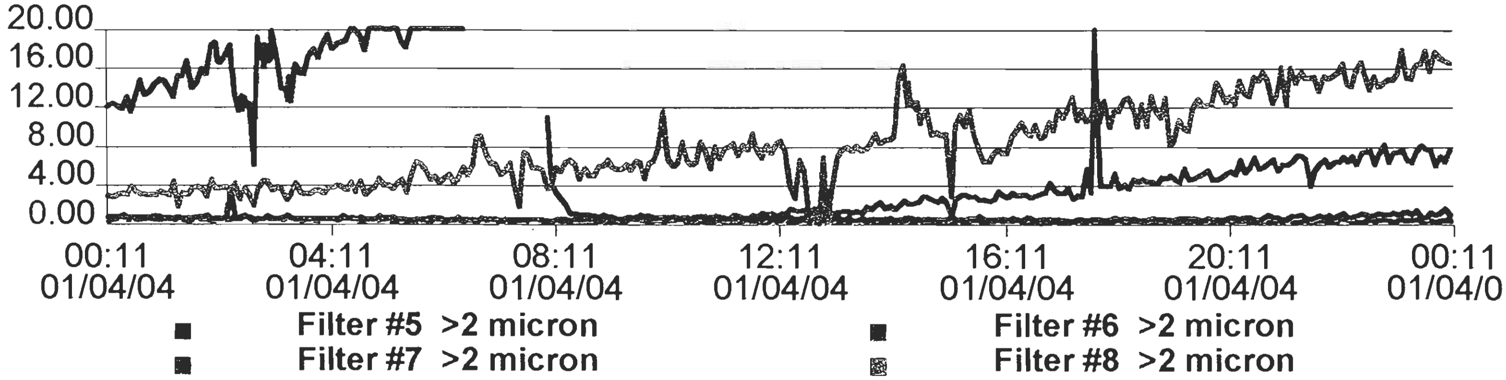

Combined Filter Effluent
NTU
0.20
0.16
0.12
0.08
0.04
0.00
23:47 01/01/13
03:47 01/01/14
07:47 01/01/14
11:47 01/01/14
15:47 01/01/14
19:47 01/01/14
23 01/0
Filter #3 1720D NTU
Filter #3 FT660 NTU

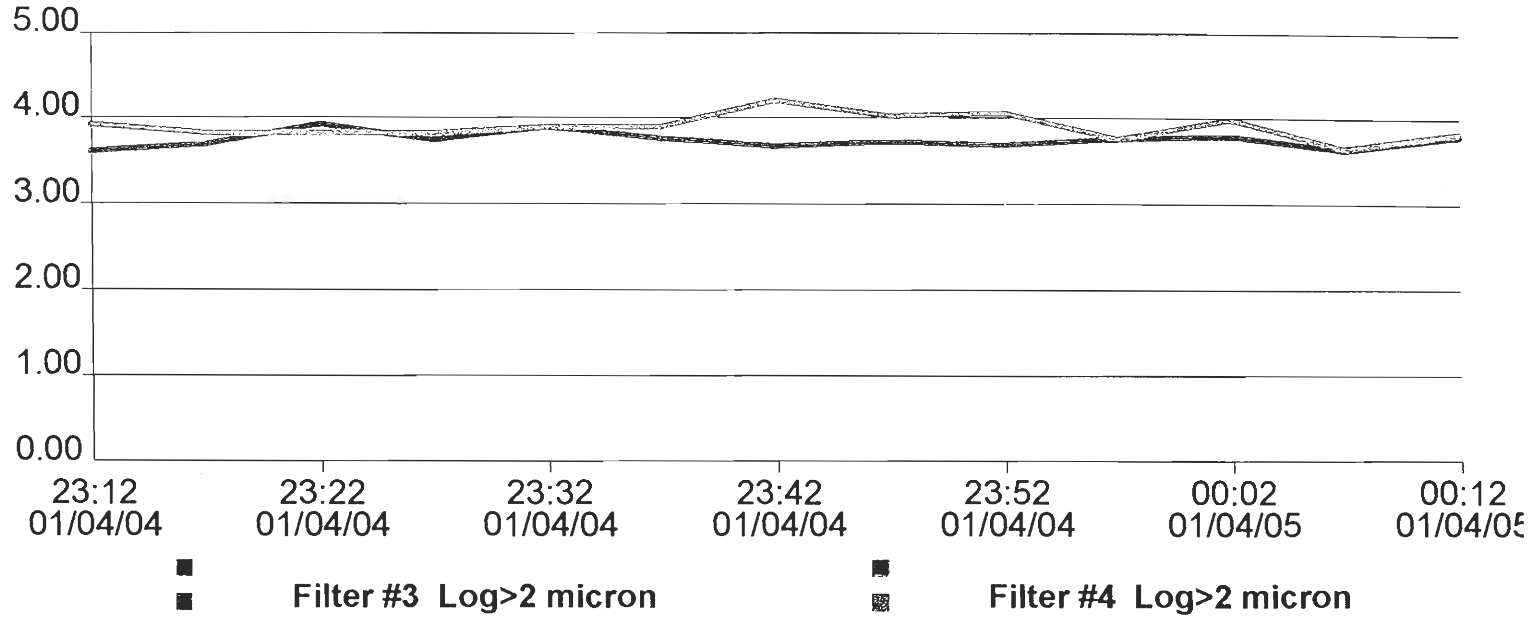

4.79
4.11
3.42
2.74
2.06
1.37
23:47 01/01/13
03:47 01/01/14
07:47 01/01/14
11:47 01/01/14
15:47 01/01/14
19:47 01/01/14
Filter #1 log removal
Filter #2 log removal
Filter #3 log removal
Filter #4 log removal

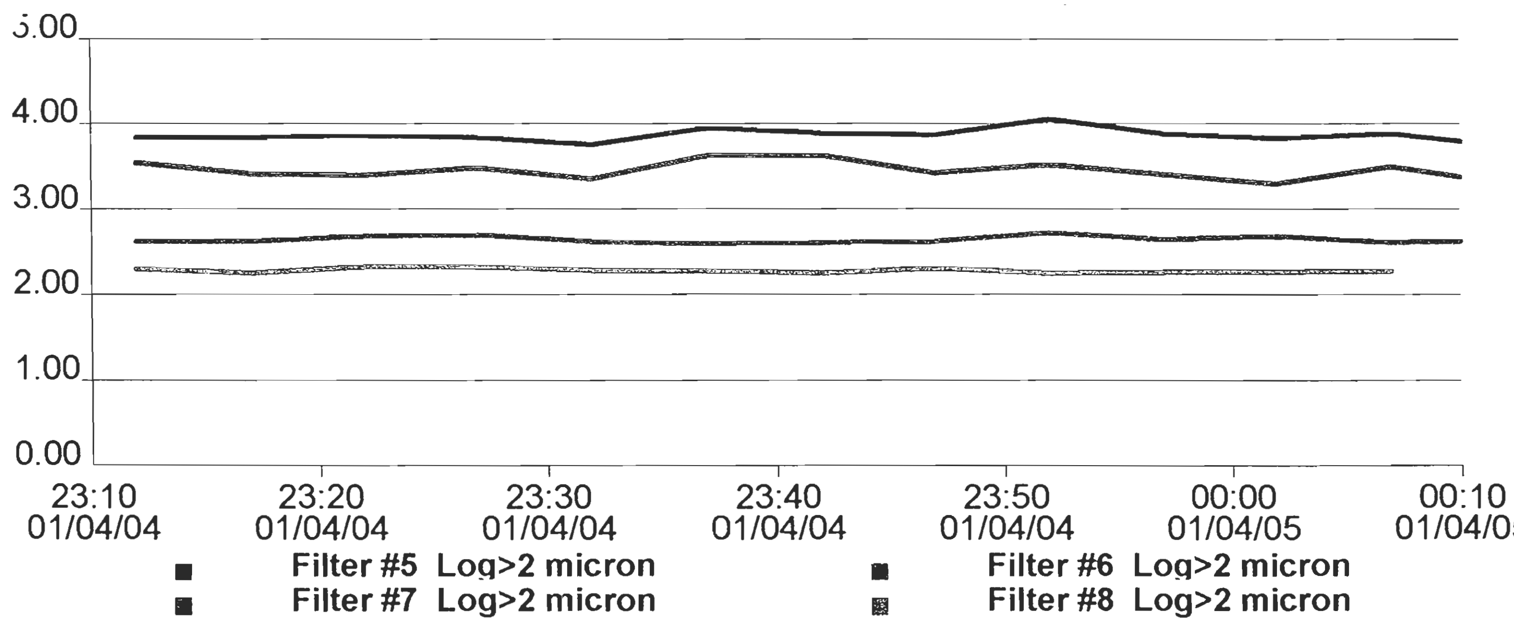

-1000000.00
-600000.00
-200000.00
200000.00
600000.00
1000000.00
23:47 01/01/13
03:47 01/01/14
07:47 01/01/14
11:47 01/01/14
15:47 01/01/14
19:47 01/01/14
Filter #5 log removal

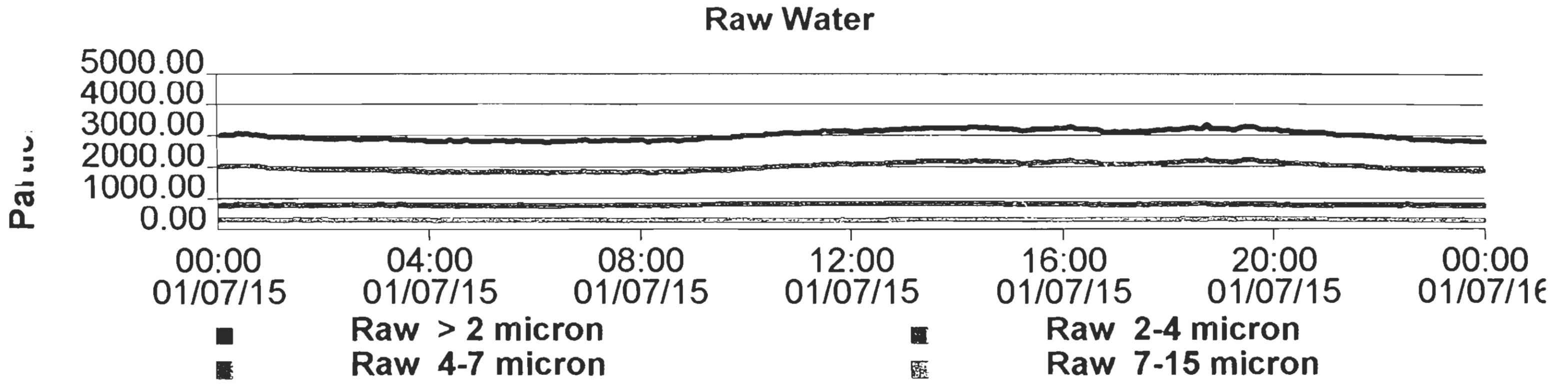

5000.00
4000.00
3000.00
2000.00
1000.00
0.00
00:07 01/04/04
04:07 01/04/04
08:07 01/04/04
12:07 01/04/04
16:07 01/04/04
20:07 01/04/04
00:07 01/04/0
Raw >2 micron
Raw 2-4 micron
Raw 4-7 micron
Raw 7-15 micron

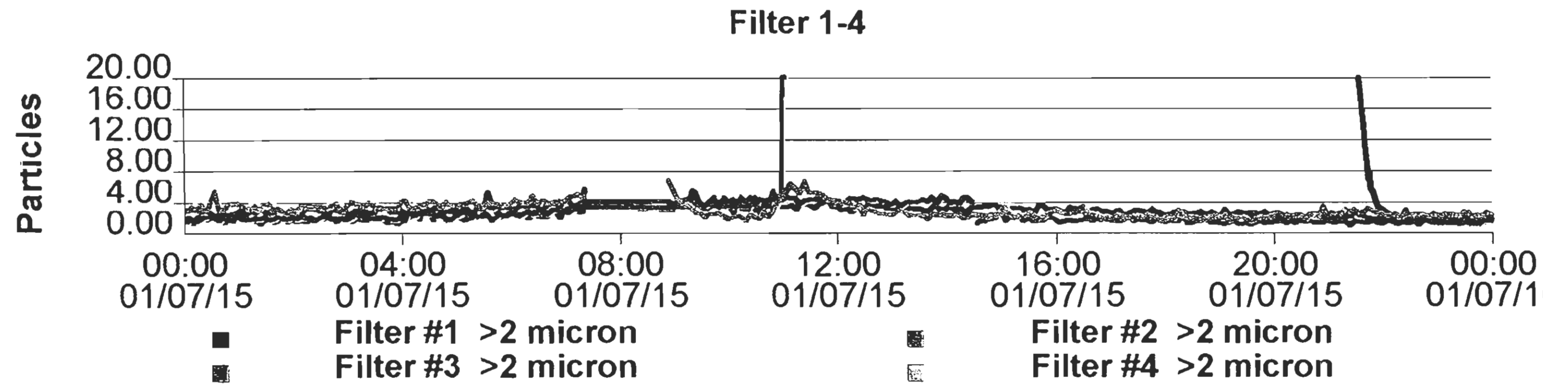

20.00
16.00
12.00
8.00
4.00
0.00
00:07 01/04/04
04:07 01/04/04
08:07 01/04/04
12:07 01/04/04
16:07 01/04/04
20:07 01/04/04
00:07 01/04/0
Filter #1 >2 micron
Filter #3 >2 micron
Filter #4 >2 micron

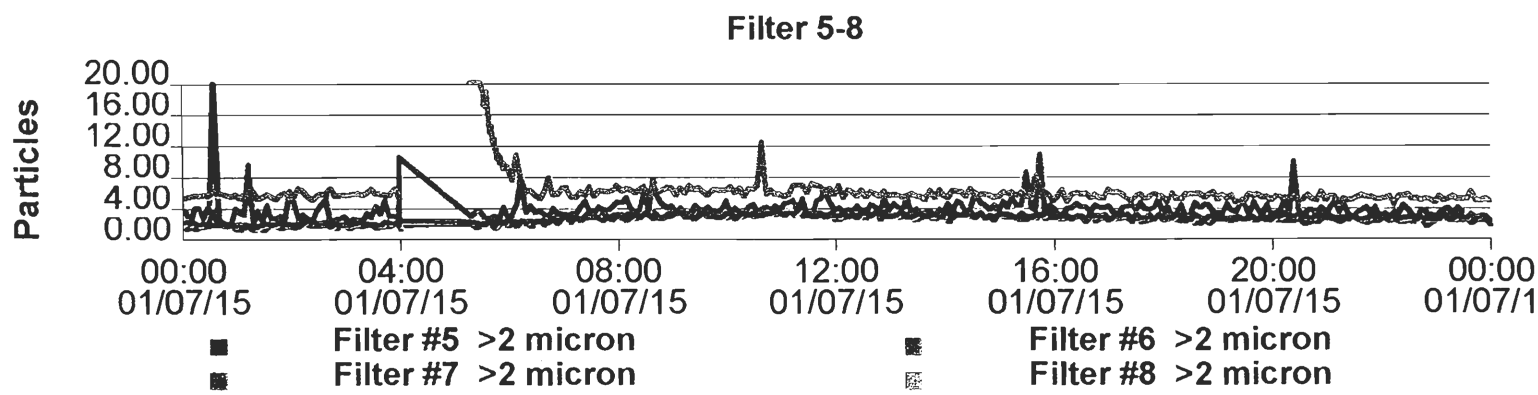

20.00
16.00
12.00
8.00
4.00
0.00
00:11 01/04/04
04:11 01/04/04
08:11 01/04/04
12:11 01/04/04
16:11 01/04/04
20:11 01/04/04
00:11 01/04/0
Filter #5 >2 micron
Filter #6 >2 micron
Filter #7 >2 micron
Filter #8 >2 micron

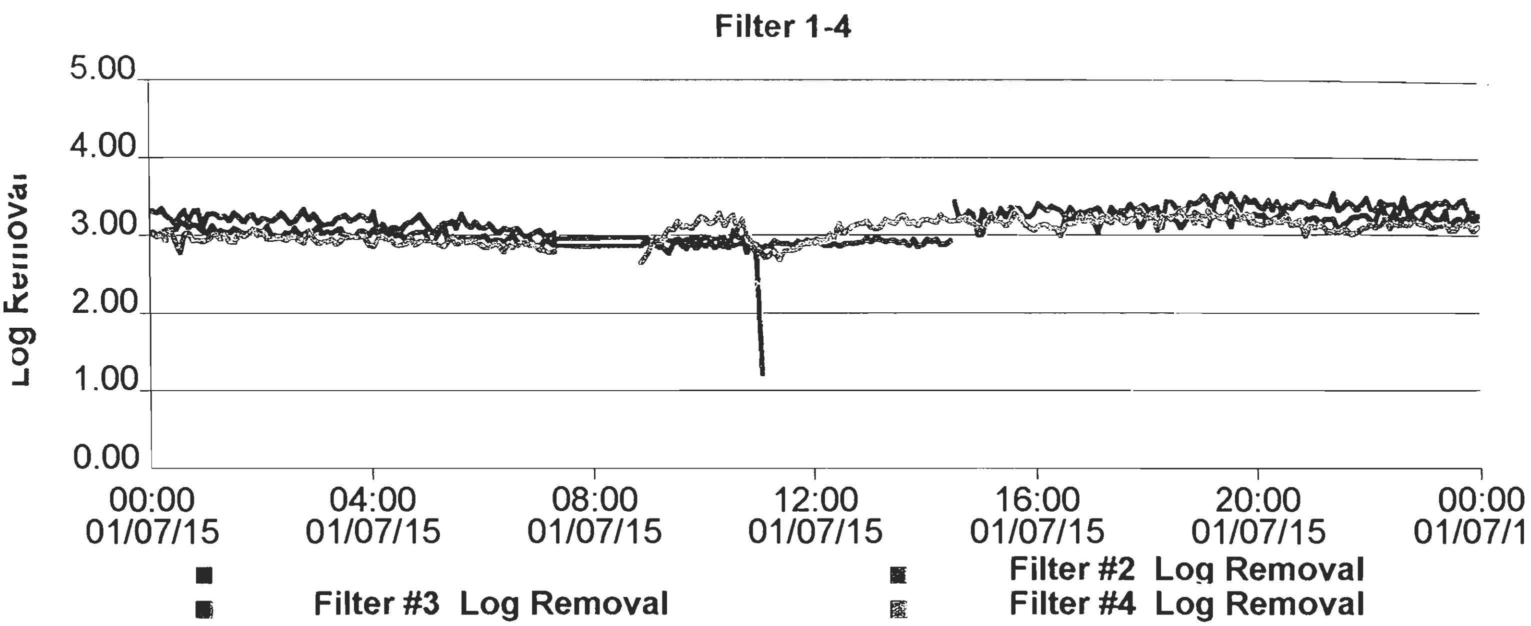

5.00
4.00
3.00
2.00
1.00
0.00
23:12 01/04/04
23:22 01/04/04
23:32 01/04/04
23:42 01/04/04
23:52 01/04/04
00:02 01/04/05
00:12 01/04/05
Filter #3 Log>2 micron
Filter #4 Log>2 micron

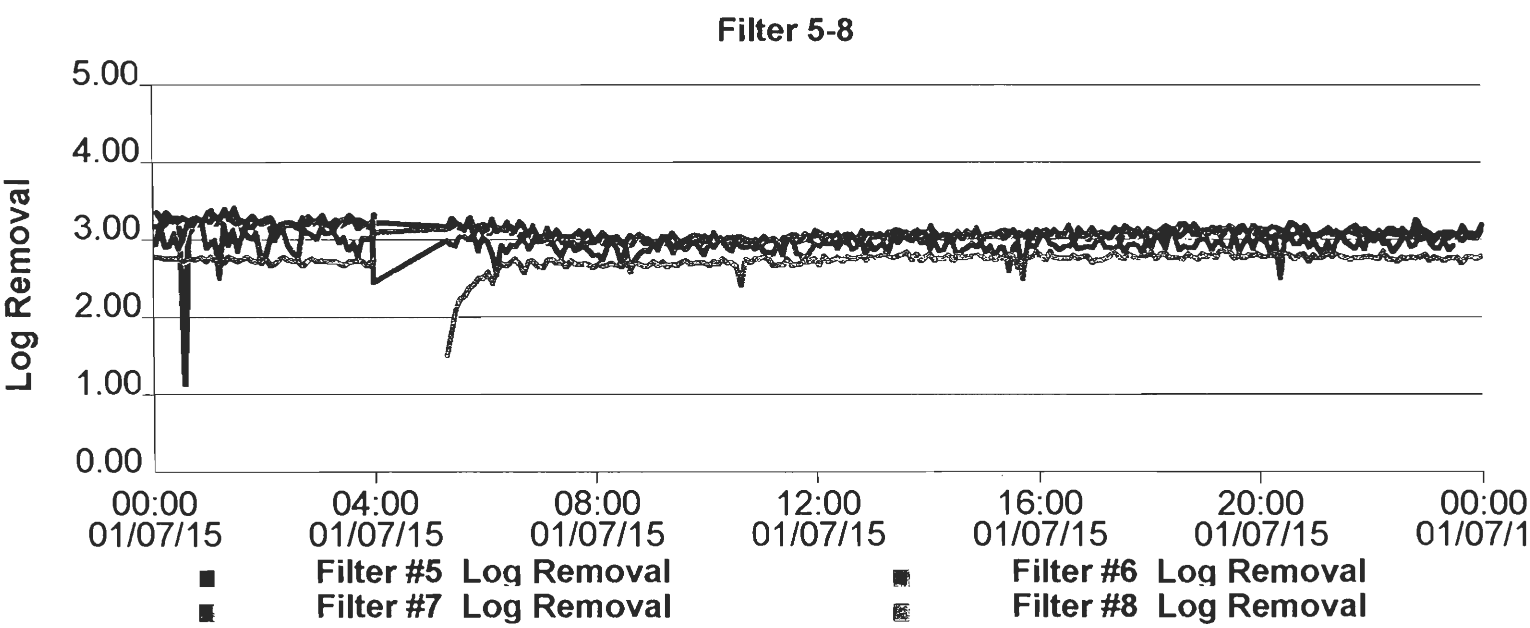

5.00
4.00
3.00
2.00
1.00
0.00
23:10 01/04/04
23:20 01/04/04
23:30 01/04/04
23:40 01/04/04
23:50 01/04/04
00:00 01/04/05
00:10 01/04/05
Filter #5 Log>2 micron
Filter #6 Log>2 micron
Filter #7 Log>2 micron
Filter #8 Log>2 micron

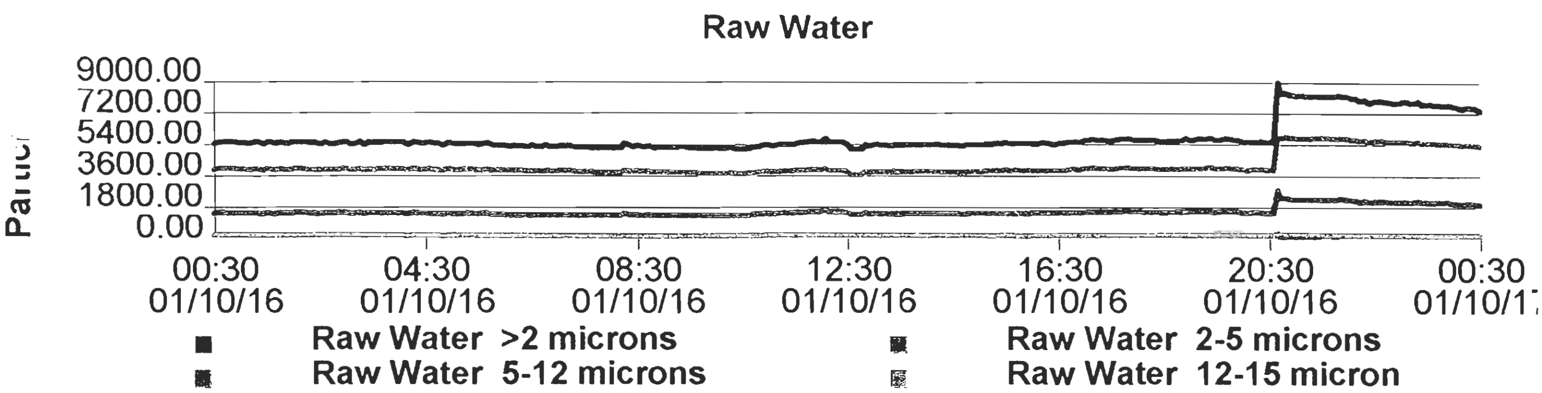

Raw Water
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
00:00 01/07/15
04:00 01/07/15
08:00 01/07/15
12:00 01/07/15
16:00 01/07/15
20:00 01/07/15
00:00 01/07/16
Raw > 2 micron
Raw 2-4 micron
Raw 4-7 micron
Raw 7-15 micron

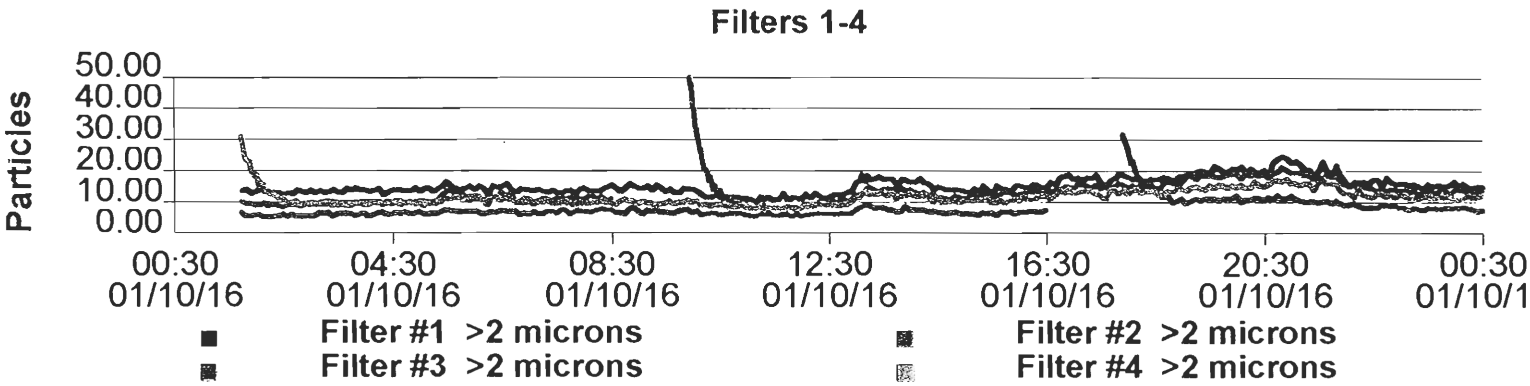

Filter 1-4
Particles
20.00
16.00
12.00
8.00
4.00
0.00
00:00 01/07/15
04:00 01/07/15
08:00 01/07/15
12:00 01/07/15
16:00 01/07/15
20:00 01/07/15
00:00
Filter #1 >2 micron
Filter #2 >2 micron
Filter #3 >2 micron
Filter #4 >2 micron

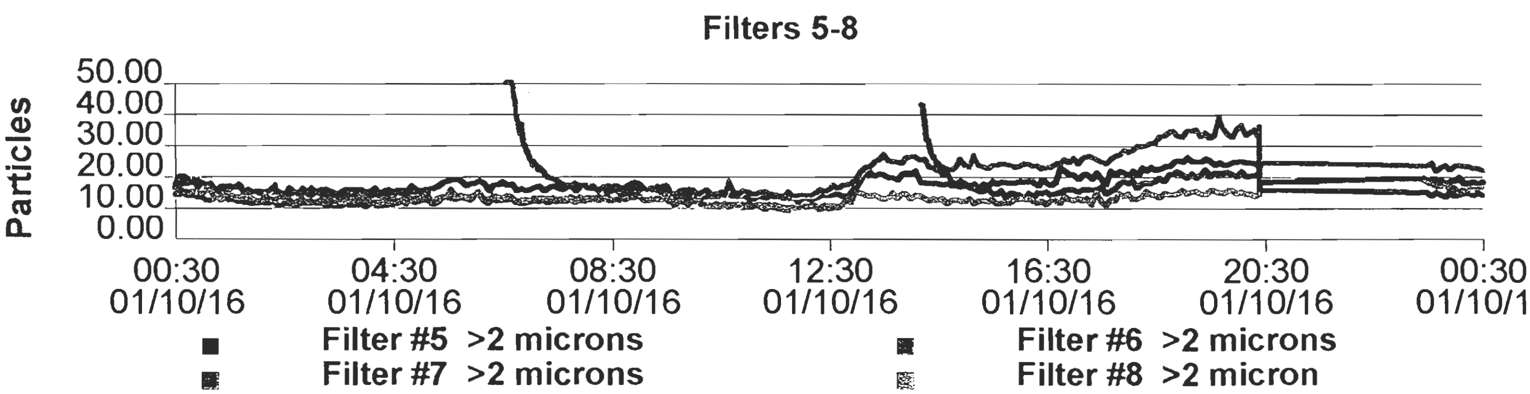

Filter 5-8
Particles
20.00
16.00
12.00
8.00
4.00
0.00
00:00 01/07/15
04:00 01/07/15
08:00 01/07/15
12:00 01/07/15
16:00 01/07/15
20:00 01/07/15
00:00
Filter #5 >2 micron
Filter #6 >2 micron
Filter #7 >2 micron
Filter #8 >2 micron

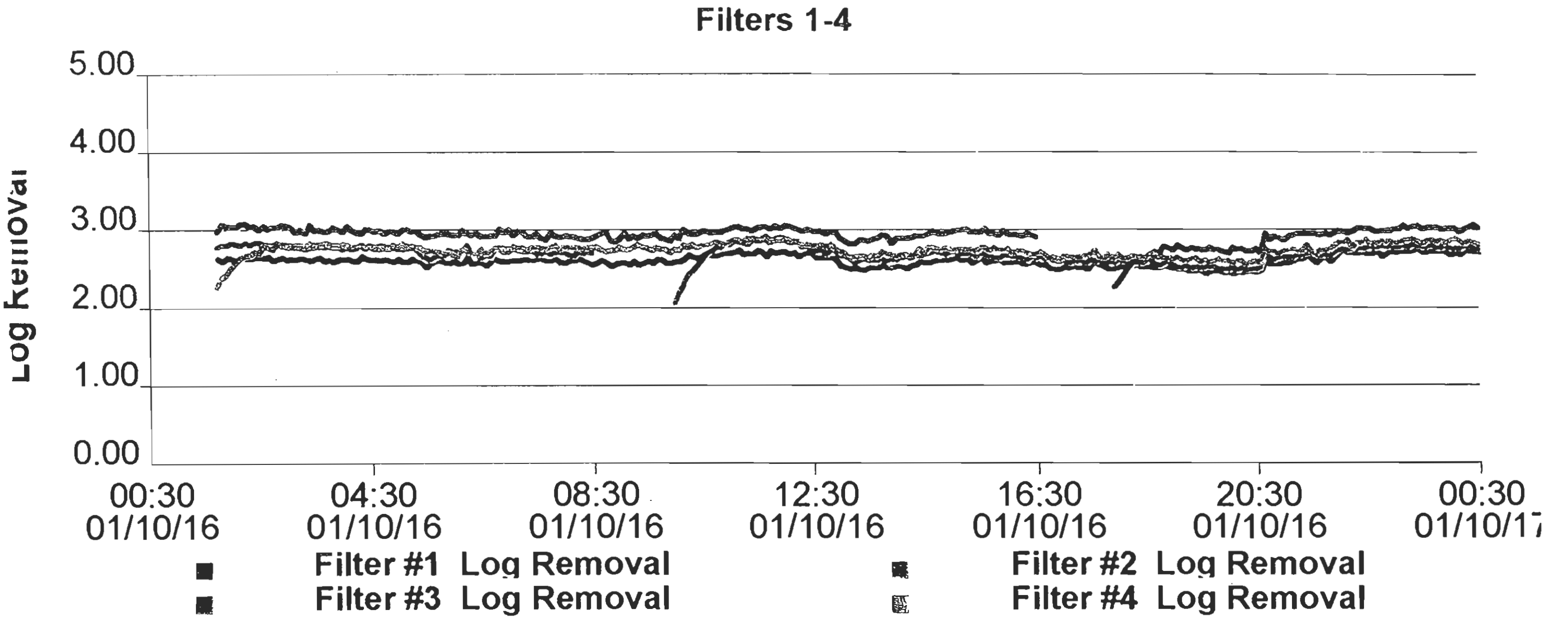

Filter 1-4
5.00
4.00
3.00
2.00
1.00
0.00
00:00 01/07/15
04:00 01/07/15
08:00 01/07/15
12:00 01/07/15
16:00 01/07/15
20:00 01/07/15
Filter #2 Log Removal
Filter #3 Log Removal
Filter #4 Log Removal

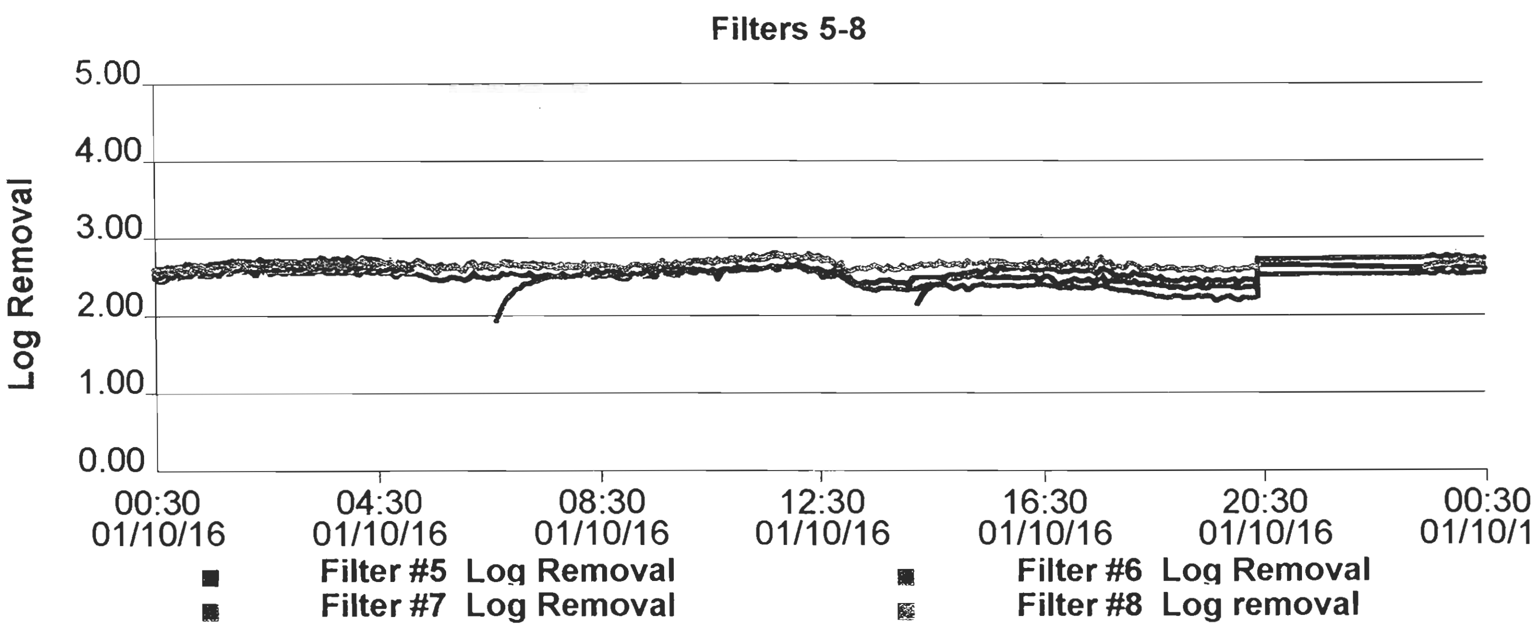

Filter 5-8
5.00
4.00
3.00
2.00
1.00
0.00
Log Removal
00:00 01/07/15
04:00 01/07/15
08:00 01/07/15
12:00 01/07/15
16:00 01/07/15
20:00 01/07/15
Filter #5 Log Removal
Filter #6 Log Removal
Filter #7 Log Removal
Filter #8 Log Removal


Raw Water
9000.00
7200.00
5400.00
3600.00
1800.00
0.00
Partic
00:30 01/10/16
04:30 01/10/16
08:30 01/10/16
12:30 01/10/16
16:30 01/10/16
20:30 01/10/16
00:30 01/10/17
Raw Water >2 microns
Raw Water 2-5 microns
Raw Water 5-12 microns
Raw Water 12-15 micron


Filters 1-4
50.00
40.00
30.00
20.00
10.00
0.00
Particles
00:30 01/10/16
04:30 01/10/16
08:30 01/10/16
12:30 01/10/16
16:30 01/10/16
20:30 01/10/16
00:30 01/10/1
Filter #1 >2 microns
Filter #2 >2 microns
Filter #3 >2 microns
Filter #4 >2 microns


Filters 5-8
50.00
40.00
30.00
20.00
10.00
0.00
Particles
00:30 01/10/16
04:30 01/10/16
08:30 01/10/16
12:30 01/10/16
16:30 01/10/16
20:30 01/10/16
00:30 01/10/1
Filter #5 >2 microns
Filter #6 >2 microns
Filter #7 >2 microns
Filter #8 >2 micron


Filters 1-4
5.00
4.00
3.00
2.00
1.00
0.00
Log Removal
00:30 01/10/16
04:30 01/10/16
08:30 01/10/16
12:30 01/10/16
16:30 01/10/16
20:30 01/10/16
00:30 01/10/17
Filter #1 Log Removal
Filter #2 Log Removal
Filter #3 Log Removal
Filter #4 Log Removal


Filters 5-8
5.00
4.00
3.00
2.00
1.00
0.00
Log Removal
00:30 01/10/16
04:30 01/10/16
08:30 01/10/16
12:30 01/10/16
16:30 01/10/16
20:30 01/10/16
00:30 01/10/17
Filter #5 Log Removal
Filter #6 Log Removal
Filter #7 Log Removal
Filter #8 Log removal