EFFECTIVENESS OF DISINFECTANT RESIDUALS IN DISTRIBUTION SYSTEMS

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ABSTRACT

In many drinking water systems in the United States, disinfectant is added to water as it leaves the plant to maintain a residual concentration in the distribution system. The disinfectant residual is maintained to inactivate contamination that enters the distribution system, to control biofilms, and to act as a sentinel for contamination in the distribution system. A model was developed to evaluate the potential effectiveness of the disinfectant residual at inactivating contamination. The model was used to examine contamination of a hypothetical distribution system through backpressure at a cross-connection under different operating conditions. The dilution and pathway of the hypothetical contaminant were examined as the contaminant moved through the system. Disinfection and inactivation kinetic relationships were used to model the inactivation of the contaminant in the system by the amount of disinfectant present. The model showed that both chlorine and chloramines in each decay and inactivation condition considered provided some benefit over no disinfectant at all when examining susceptible organisms. Chlorine, under medium and low decay conditions, provided the best inactivation. Where 29.8% of total node time steps received a contamination of concern in the absence of disinfectant residual, as low as 4.8% of total node time steps received a contamination of concern in the presence of disinfectant residual. Chloramines was found to persist longer in the distribution system, but resulted in much lower inactivation compared to chlorine. Disinfectant doses typical of common distribution system operation were able to reduce the impact of contamination once it entered the distribution system but, except for four cases, were unable to prevent contamination from spreading within the distribution system. Therefore, it was concluded that presence of a disinfectant residual will reduce the total number of exposure opportunities from a contamination event, but cannot be relied upon to eliminate the chance of exposure resulting from contamination.

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1.0 INTRODUCTION

1.1 Purpose

Disinfectant residuals, or secondary disinfection, are often used throughout drinking water distribution systems in the United States to protect treated water from contamination. Some systems maintain a disinfectant residual to minimize biofilm growth and other possible pathogen contamination that occurs in distribution systems. Because disinfectant residual is easy and inexpensive to measure, the absence of disinfectant residual can be used as an indicator of distribution system contamination because the available disinfectant residual is easily consumed by contamination.

Maintenance of disinfection residuals in the United States is required by the Surface Water Treatment Rule (SWTR; USEPA, 1989a) and is limited by the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR; USEPA, 1998). The SWTR requires surface water systems and systems using ground water under the direct influence of surface water to maintain a minimum detectable residual throughout the distribution system[1]. The Stage 1 DBPR established a Maximum Residual Disinfectant Level (MRDL) for chlorine or chloramines at 4.0 mg/L (measured as either free or total chlorine and calculated as a running annual average of all measurements in the distribution system) and for chlorine dioxide at 0.8 mg/L (as a monthly average of measurements in the distribution system). Concern for disinfection byproducts (DBPs) that are formed through contact between chlorine and organic matter have led water purveyors to use alternative disinfectants for secondary disinfection such as chloramines and chlorine dioxide.

Although the maintenance of a disinfectant residual is recognized as a good practice, the benefits of maintaining a residual have not been quantified. This project was designed to evaluate the effectiveness of inactivating contamination events in a hypothetical distribution system through the maintenance of a disinfectant residual. It will also compare contamination in

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[1] At least 95% of the sites must have a detectable disinfectant residual or an HPC level of < 500 CFU for the system to be in compliance with the Rule.

the absence of a disinfectant residual with contamination in the presence of a disinfectant residual. The results may be useful in determining potential risk in ground water systems that do not maintain a disinfectant residual or the vulnerability of consumers in sections of the distribution system where systems are unable to maintain a disinfectant residual. This paper will describe the development and use of a model for predicting the effectiveness of a residual during a contamination event. The model considers properties of the distribution system, disinfectants, and contamination. Such a model would be useful to water suppliers in making informed choices on how best to reduce the effects of different contamination events through residual disinfection.

The results of this project can be used as a foundation for predicting the effect of a contamination event on a distribution system, informing the decision of which disinfectant is most appropriate for a particular system, and evaluating the effectiveness of potential alternative secondary disinfectants.

1.2 Problem Identification: Outbreaks resulting from pathogen contamination in distribution systems

Outbreaks of waterborne disease are reported voluntarily every year to the Centers for Disease Control and Prevention (CDC). Between 1971 and 1998, 619 waterborne disease outbreaks were reported in community water systems (CWSs) and non-community water systems (NCWSs) (Craun and Calderon, 2001). Although most of these outbreaks occurred in systems with untreated surface waters and ground waters (29.7%) or when water treatment was inadequate or interrupted (44.1%), 18.3% of reported outbreaks were caused by chemical and microbial contaminants that either entered or formed within the distribution system (Craun and Calderon, 2001). Outbreaks due to distribution system deficiencies in CWSs accounted for 30% of CWS outbreaks (Craun and Calderon, 2001).

Distribution system deficiencies that allow for contamination can occur during normal distribution system operations. Wherever water leaks out of distribution system pipes, there is potential for contamination to enter the distribution system during negative pressure transients.

Such transients can be caused by events such as power outages, valve closure, or pump shut-offs. The process of water entering the distribution system due to low or negative pressure is called intrusion.

Kirmeyer et al. (2001) found that 10 to 32% of total water produced was attributed to unbilled water in a survey of 26 systems. Leakage greater than 10% has been identified as a common occurrence in some distribution systems (AWWA and AwwaRF, 1992). Such leakage rates present pathways for contamination to enter during low or negative pressure events. The amount of water that can enter the pipe through intrusion depends on the size of the orifice, the external pressure, and the nature of the pressure transient event, so it is difficult to assess the quantity of water and pathogens that may enter the distribution system in one of these events.

Backflow contamination can occur when a non-potable contaminant source is connected to a potable water system through a cross-connection. Backflow contamination happens when negative pressure pulls the non-potable substances into the potable system (backsiphonage), or when the pressure in the non-potable source is greater than the pressure in the potable system (backpressure). Low pressures that allow for backsiphonage can result from main breaks, flushing, pump failure, or firefighting. When connected to the drinking water distribution system, pressurized residential or industrial systems that use pumps can allow for backpressure. Common examples are water systems for irrigation, fire protection, car washes, and cooling systems. Backflow contamination was the identified cause of 50.6% of CWS outbreaks attributed to distribution system deficiencies between 1971 and 1998, corresponding to 45 events (Craun and Calderon, 2001). The USEPA has documentation of 309 events during the same time period (USEPA, 2002a), including the outbreaks reported by CDC. The EPA and the University of Southern California Foundation for Cross-connection Control and Hydraulic Research believe that this is a small subset of the total events that occurred.

Disinfectant residual present in the distribution system during deficiencies such as those identified above may inactivate some of the microbial contamination or oxidize some of the chemical contamination. However, as indicated by the outbreak data, it is also possible that the residual is not present in sufficient quantities or sufficiently effective to contain the contamination.

Of the waterborne disease outbreaks caused by distribution system deficiencies identified by the CDC between 1971 and 1998, 30% occurred in surface water systems, 47% occurred in groundwater systems, and 23% were not identified by source water type (Craun and Calderon, 2001). Examples of the deficiencies identified included contamination from backflow, corrosion, and contamination of storage. The SWTR requirement to maintain a disinfectant residual in the distribution system came into effect in 1991 for unfiltered systems, and 1993 for filtered systems (USEPA, 1989a). Only surface water systems and ground water systems under the direct influence (GWUDI) of surface water are required to disinfect and maintain a disinfectant residual in the distribution. Table 1 presents a comparison of the total number of reported waterborne disease outbreaks attributed to microorganisms as a result of distribution system deficiencies before and after 1993. GWUDI systems were not identified in the outbreak reports; all well sources were considered ground water for this analysis.

Table 1: Microbial Distribution System Outbreaks Before and After Residual Disinfection Requirements

	1981-1992	**1993-2000**
Total Outbreaks per Year		
All Surface Water Systems	0.67	0.63
All Ground Water Systems	1.08	1.25
Unidentified Source	1.17	0.00
Overall	**2.92**	**1.88**
Illnesses per Outbreak		
All Surface Water Systems	157.9	94.4
All Ground Water Systems	117.5	108.1
Unidentified Source	204.9	0
Overall	**161.7**	**103.5**

Source: 1981-2000 CDC Surveillance Reports

Table 1 shows that the total number of waterborne disease outbreaks and the number of illnesses per outbreak decreased after the SWTR was implemented. However, there was no significant change in the number of outbreaks per year for surface water systems. These data do not confirm or reject the hypothesis that disinfectant residuals prevent or reduce outbreaks due to distribution deficiencies. However, the data do show that outbreaks may still occur in the presence or an attempt to maintain a disinfectant residual.

There are several examples of outbreaks that occurred in systems despite the fact that residual disinfection was part of the treatment process. In 1994, an outbreak of 304 cases of gastrointestinal illness occurred at a Tennessee correction facility housing 1,290 inmates. *Giardia* was detected in the distribution system despite the maintenance of a chlorine residual. The probable cause of contamination was a cross-connection at the facility's wastewater pump station that contaminated the system during a loss of water pressure that occurred for three days (Craun and Calderon, 2001).

In September of 1995, an outbreak at a Wisconsin high school left 148 people with illness attributed to a small, round-structured virus (US CDC, 1998). The school received its drinking water from a community water system with a surface water supply, and the contamination occurred when water from a flooded football field was siphoned through submerged hoses. Although outbreak reports do not include disinfectant residual data, maintenance of a disinfectant residual was a requirement for this system at the time of the outbreak.

An outbreak of toxoplasmosis was identified in March 1995, in Greater Victoria, British Columbia. One hundred individuals were diagnosed with an outbreak-related case. The drinking water system maintained an average chloramines residual of 0.5 mg/L in the distribution system at the time of the outbreak (Bowie et al., 1997; Irwin, 2003).

Two backflow events were identified in 1995 that resulted in chemical related illnesses. Disinfectant residuals are not used for the purpose of controlling chemical contamination, although disinfectant could oxidize some chemicals or some chemical contaminants could consume the disinfectant residual and allow it to operate as an indicator of contamination. The following are two illustrations of how disinfectant residual does not prevent illness from all contamination events: six people in New Jersey developed acute cyanosis as a result of nitrites in boiler fluids that flowed through a faulty check valve, and three people became ill in a school in California after consuming water from a system with a malfunctioning double-check backflow prevention valve (Craun and Calderon, 2001). Both of these systems were required to maintain a residual, but the residual did not change the toxicity of the nitrite. In some cases, disinfectant residual may even increase the toxicity of some chemical contaminants.

Although not associated with distribution system deficiencies, recent *Cryptosporidium* outbreaks have shown that disinfectant residuals do not provide protection against some pathogens if there is a process failure at the water treatment plant. The Milwaukee outbreak of 1993, and an outbreak in North Battleford, Saskatchewan in 2001 (Henton, 2001), occurred after increases in finished water turbidity in both systems. Because *Cryptosprodium* is resistant to chlorine, little protection was provided by the residual present in these systems. The result in the Milwaukee outbreak was an estimated 400,000 cases of Cryptosporidiosis and over 50 deaths (Juranek, 1997). *Cryptosporidium* can also occur as a distribution system contaminant.

Distribution system deficiencies also occurred in a large number of ground water systems. As stated above, close to half of the outbreaks related to distribution system deficiencies from 1971-1998 were reported in ground water systems. From 1993-2000, 46% of distribution system deficiency outbreaks occurred in ground water systems, 39% in surface water systems, and 14% did not identify source water type (1993-2000 CDC waterborne disease outbreaks). Ground water systems are not required by any federal regulation to maintain a disinfectant residual. Consequently, it cannot be assumed that a disinfectant residual was provided at the time of the outbreak if an outbreak report does not include residual information. Therefore it is difficult to assess the effect of disinfectant residuals in these systems. Table 1 shows that the change in outbreak data after 1993 is not as pronounced as it is in surface water systems.

The information in Table 1 also has some interesting implications. First, although the number of outbreak events for both surface water and ground water did not change significantly after 1993, it is possible that reporting improvements led to better characterization of outbreaks in the latter time period. One example of this is the fact that all outbreak reports in the later time period had identified the source type.

The dramatic decrease in number of illnesses per outbreak after 1993 has several possible explanations. It is possible that improved waterborne outbreak surveillance techniques have facilitated the identification of smaller outbreaks, thus decreasing the number of illnesses per event. Another explanation could be that disinfectant residuals are providing some benefit. In this case, contamination and subsequent outbreaks could continue to occur, but disinfectant residuals are inactivating contamination earlier in the distribution system, resulting in a smaller population being affected by each outbreak. Although EPA believed that most surface water systems were providing a disinfectant residual in the distribution system prior to the SWTR (USEPA, 1987), the SWTR requirements likely resulted in greater reliability of residual maintenance and higher residual levels in the distribution system. A third explanation is that this decrease in illnesses per outbreak is due to another unidentified variable, such as increased consumption of bottled water.

Analysis of CDC outbreak surveillance data (USCDC, 1993-2000) for waterborne disease outbreaks attributed to distribution system deficiencies showed that there were 16 outbreaks that each resulted in 100 or more cases of illness between 1981 and 1992. The two outbreaks with the highest number of illnesses produced 1,272 and 750 cases. The total number of illnesses resulting from these 16 outbreaks was 5,019. Between 1993 and 2000, there were only 5 outbreaks that resulted in 100 or more cases of illness, the two highest resulting in 625 and 304 cases. Only 1,300 total illnesses resulted from these 5 outbreaks. These data show that both the number of large outbreaks and the number of illnesses per large outbreak is decreasing. This implies that the presence of a disinfectant residual may be providing some benefit by decreasing the magnitude of each outbreak.

The number of illnesses per outbreak decreased by 63.5 for surface water, 9.4 for ground water, and 58.2 overall for the time period after 1993 (Table 1). The decrease in the number of illnesses per outbreak is much smaller for ground water systems than for the other two categories (note that the overall number includes outbreaks that did not identify source water type). The number of illnesses per outbreak in ground water systems was lower in the 1981-1992 time period compared to the other two categories, which may reflect the fact that ground water systems tend to serve fewer customers than surface water systems. However, although the number of illnesses per outbreak decreased, it was actually higher for ground water systems after 1993 than the other two categories. One possible explanation is that, while some states started to require ground water disinfection and disinfectant residuals at the same time as the SWTR and led to some decrease in the number of illnesses per outbreak, the effect in ground water systems was not as dramatic as it was for surface water systems because it is not a nationwide requirement. An alternative explanation could be found in different weather patterns, or other external factors not considered in this work that do not involve presence of a disinfectant residual.

One must be cautious when interpreting these data. The data reported in the CDC Waterborne Disease Outbreak summaries should not be considered the total number of waterborne disease outbreaks that occurred during this time period. Many outbreaks go undetected and/or unreported. Two requirements must be met for an outbreak to be recorded in the CDC Surveillance for Waterborne-Disease Outbreak summaries. First, at least two individuals must experience similar illnesses after water ingestion. This criterion is waived for single cases of laboratory-confirmed primary amoebic meningoencephalitis and for single cases of chemical poisoning if water quality data indicate contamination by the chemical. Second, epidemiologic evidence must implicate water as the probable source of the illness (US CDC, 2002).

It is difficult to assess the true occurrence of waterborne disease outbreaks for several reasons. First, many events are not recognized until large numbers of customers experience symptoms. For instance, one outbreak in Saskatchewan, Canada was identified when a local pharmacy was unable to keep anti-diarrheal medications in stock (Henton, 2001). The number of cases necessary to make an outbreak identifiable probably results in many small outbreaks going unnoticed. Second, most reported distribution system outbreaks are caused by significant or continuing contamination. Contamination was still present during the investigation in many of the outbreaks described above (Craun and Calderon, 2001). Small events that do not cause large numbers of illnesses or ongoing contamination can easily go undetected or unreported. Third, surveillance activities, laboratory testing capabilities, requirements for reporting particular diseases, and follow-up investigations are handled differently by State, territorial, and local health agencies. Inconsistencies in local policies may easily lead to under-reporting. Fourth, reporting of outbreaks is voluntary and may not reflect the number of known events. Liability concerns regarding outbreaks may also lead to non-reporting. It has been estimated that only 10-30% of US waterborne disease outbreaks are actually reported (Craun and Calderon, 2001).

An illustration of the difficulty of identifying a waterborne disease outbreak may be made using the Milwaukee *Cryptosporidium* outbreak in 1993. Of the 285,000 people who reported symptoms of watery diarrhea, only 17,100 sought health care. Out of this group, 971 were tested for parasites. From this subset, 42 were tested for *Cryptosporidium*. Only twelve of those tested positive for *Cryptosporidium*, leaving 99.996% of those with symptoms undiagnosed (Juranek, 1997). When the largest outbreak in the United States in recent history resulted in only twelve diagnosed cases of Cryptosporidiosis, it is easy to see how small waterborne disease outbreaks go undetected and unreported.

It is also difficult to assess the number of outbreaks associated with distribution system deficiencies that occurred while a disinfectant residual was maintained in the distribution system. In addition to the difficulties described above, waterborne disease reports do not always include complete information on water treatment practice and presence of a disinfectant residual. Even if a system was expected to maintain a disinfectant residual in the distribution system, there may not be data available to determine whether the equipment was working properly during the contamination event, whether the residual was consumed by the contamination event, or whether a measurable residual was present during the entire event.

Although it is difficult to assess the overall occurrence of waterborne disease outbreaks in the presence of a disinfectant residual, outbreaks continue to occur in the presence of a residual. This analysis substantiates that pathogens and chemicals that enter distribution systems as a result of a distribution system deficiencies are capable of causing waterborne disease outbreaks, even when those systems are taking steps to maintain disinfectant residuals. Given that maintenance of a disinfectant residual does not necessarily prevent outbreaks, it is desirable to evaluate more quantitatively the level of protection provided by disinfectant residuals so that better outbreak protection can be provided. Consequently, the development of a mathematical model was undertaken for this project so that the performance of residual disinfectants in inactivation of contamination entering distribution systems could be examined in more detail.

2.0 REVIEW OF LITERATURE

2.1 Role of primary versus secondary disinfection

Disinfection is employed to destroy harmful organisms. Primary disinfection is the term used to describe destruction or inactivation of pathogens at the treatment works (Grayman et al., 2000). Primary disinfection can be achieved through use of chlorine, chloramines, ozone, chlorine dioxide, or ultra-violet radiation (UV). Although not part of the disinfection process, filtration technologies also remove organisms from drinking water. Use of a disinfection barrier is an important part of primary treatment of drinking water. Where disinfection employs oxidation processes, the addition of a chemical disinfectant may also provide the added benefit of controlling other chemical constituents such as taste and odor compounds (LeChevallier, 1999).

Secondary disinfection involves maintaining a disinfectant residual in the distribution system. This disinfectant is added downstream of the water plant. It has been standard practice in the United States to use chlorine for both primary and secondary disinfection, but it is becoming more common for two different disinfectants to be used for primary and secondary disinfection (Trussell, 1999).

There are three basic reasons for adding a chemical disinfectant following primary treatment: 1) to prevent or limit growth of microorganisms in the distribution system, 2) to inactivate any microorganisms that may enter the system through contamination (LeChevallier, 1999), and 3) to indicate (through absence of a residual) the presence of contamination into the distribution system.

The USEPA first required surface water systems and systems using GWUDI to maintain a disinfectant residual under the SWTR (USEPA, 1989a). The reasons cited for requiring the residual were to limit growth of heterotrophic bacteria and *Legionella* in distribution systems, reduce waterborne disease cases as a result of contamination events, and to serve as an indicator of contamination (Shaw and Regli, 1999). The Stage 1 DBPR (USEPA, 1998) later established an upper limit on residual levels to protect customers from health effects associated with disinfection byproducts.

There is an ongoing debate over whether residuals are necessary to provide safe drinking water in distribution systems. Some European countries, such as the Netherlands, insist they can provide safe drinking water without maintaining a residual in the distribution system. The USEPA believes that residuals do provide a necessary protection from microbial growth within the distribution system and from contamination originating outside the system (USEPA, 1989a). The USEPA is currently reevaluating this requirement as part of the six-year review of the Total Coliform Rule (USEPA, 2003).

Some researchers encourage the use of residuals because backflow contamination events are possible, even in ideally maintained systems. Also, even well maintained systems may lose as much as 10% of delivered water (AWWA and AwwaRF, 1992), and intrusion may occur during pressure drops in such systems. Another argument for maintaining disinfectant residuals is related to the age of distribution system pipes. In 1999, the average age of the oldest section of distribution system pipe in the United States approached 100 years (Haas, 1999a). As pipes become more vulnerable at the end of their useful life, disinfectant residuals offer some protection against contaminants entering the system during main breaks and leaks, which are more likely in aging systems. Also, because primary disinfection does not result in complete sterilization, the presence of a disinfectant residual may prevent otherwise inevitable microbial growth in the distribution system (Haas, 1999a).

Some researchers have asserted that growth control without disinfectant residuals would require extraordinary measures (Trussell, 1999). Disinfectant residuals may also protect against reinoculation from biofilms, another growth problem that some believe cannot be solved in the absence of a residual (Trussell, 1999). There is continuing debate over which disinfectant is better at controlling growth and biofilms. Free chlorine can inactivate relatively quickly, but because of its high reactivity, in many cases it may be consumed before it can penetrate biofilms. On the other hand, chloramines can penetrate biofilms. However they are less effective disinfectants, so they are expected to achieve limited inactivation of contaminants that enter the distribution system (AWWA, 1991).

Those who oppose the use of disinfectant residuals argue that maintaining better system pressure, backflow protection, and system maintenance including replacement of old mains are more effective at improving contamination problems. Additional flushing, more conservative design, better water treatment, and selection of more protected water sources are additional protections that do not require maintenance of a residual. It is possible that some such practices may be more important than maintaining a residual, especially given the concern that only a small amount of contamination is likely to be oxidized by the residual itself (Trussell, 1999).

Another argument against relying on disinfectant residuals for maintaining safe water throughout the distribution system involves the decrease in the disinfectant residual with increasing residence time resulting from reactions with pipe materials, sediments, and water components. Because the residual decreases over time, it is not possible to provide adequate protection against microbial contamination throughout the distribution system, although booster chlorination can be used to address this problem. The effectiveness of the disinfectant residual is also limited by the travel time of water between the point of contamination entry into the distribution system and the next customer. This is the only contact time available for the disinfectant to inactivate the contamination. In this sense, provision of a disinfectant residual can provide a false sense of security about the quality of the water being delivered in the distribution system (Payment, 1999).

2.2 Secondary Disinfectants

2.2.1 Free Chlorine

Free chlorine is the most commonly used water disinfectant in the United States. Most surface water and ground water systems that practice primary disinfection use chlorine, according to the *2000 Community Water Systems Survey* (USEPA, 2002b). Eighty-three percent of large surface water systems and 85 percent of disinfecting ground water systems that participated in the Information Collection Rule study used free chlorine for primary disinfection during the time period of the study (Chen and Regli, 2002).

Chlorine is used frequently because it is simple to apply, economical, efficient, and measurable. Three forms of chlorine are commonly used for disinfection: chlorine gas (Cl_2), sodium hypochlorite (liquid) (NaOCl), and calcium hypochlorite (tablet, granular, or powdered) ($Ca(OCl)_2$). Free chlorine, the concentration of residual chlorine present in water as dissolved gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl-), participates in a variety of aquatic chemical reactions. With regard to commonly occurring constituents in drinking water sources, it may be seen to oxidize reduced iron, manganese, and sulfide.

Free chlorine also oxidizes ammonia to form chloramines, nitrate, and nitrogen gas (White, 1999). Free chlorine is also known to react with natural organic matter and bromide to form halogenated organic compounds such as trihalomethanes (THMs), haloacetic acids (HAAs), and chlorophenols. Chlorine also oxidizes organic matter to form smaller organic compounds that do not contain a halogen. The oxidized organic matter can serve as food for microorganisms growing in the distribution system.

Chlorine decay (reduction) in water initially occurs at a rapid rate followed by a slower long-term rate. The initial rapid rate, commonly termed “chlorine demand,” is due to the presence of reactive substances in the water. A more persistent residual is established with a slower decay rate once this initial demand has been met. If free chlorine is used as the primary disinfectant in the treatment process, the residual decay in the distribution system occurs at the slower, long-term rate (AWWA, 1991) in the absence of contamination.

2.2.2 Chloramines

Chloramines were first used to control taste and odor problems in drinking water. Over time, they were found to be more stable than free chlorine in distribution systems and also effective in controlling bacterial growth in distribution systems (LeChevallier et al., 1996a). Chloramines were used regularly for secondary disinfection during the 1930s and 1940s, but an ammonia shortage during World War II caused the popularity of chloramination to decline.

Chloramines react differently with natural organic matter (NOM) than chlorine and produce lower concentrations of DBPs (Symons et al., 1998). Interest in chloramines has increased recently as a result of concerns over halogenated DBPs that form in water treatment processes and in distribution systems. Because chloramines are not as reactive as chlorine, higher concentrations or contact times are necessary to achieve comparable levels of microbial inactivation. However, chloramines may be more effective than chlorine at controlling biofilms. Chloramines are used primarily as a secondary disinfectant for this reason and are typically added after primary disinfection with chlorine, although chloramines can be used after ozone, chlorine dioxide, or UV disinfection. Prior to implementation of the Stage 1 DBPR, about one third of all large surface water systems used chloramines for secondary disinfection based on data collected during the ICR (Chen and Regli, 2002). Use of chloramines is expected to increase as the water supply industry makes treatment changes to comply with the Stage 1 and Stage 2 DBPRs.

Chloramines are formed by adding chlorine and ammonia to water. They can be added simultaneously, or either can be added first. Adding chlorine first is more likely to contribute to DBP formation, but additional chlorine inactivation of pathogens encourages use of this practice. Aqueous ammonia (ammonium hydroxide), anhydrous ammonia (gas) and ammonium sulfate are used to form chloramines (White, 1999). Chorine-to-ammonia ratios of 3:1 or 4:1 are commonly used (Haas, 1999b).

Hypochlorous acid from the chlorine reacts with ammonia to form inorganic chloramines in a series of competing reactions in aqueous solutions. Monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and nitrogen trichloride (NCl_3) are the species potentially formed in these reactions. These competing reactions depend primarily on pH and are controlled to a large extent by the chlorine:ammonia nitrogen ratio (Cl_2:NH_3-N), temperature, and contact time. Both ammonia and chlorine can be converted to other molecules that do not act as disinfectants and are not detected when chlorine residual is measured. Although dichloramine is a more effective disinfectant, monochloramine is the most commonly maintained species due to odor problems, pH, and ratio sensitivities of the other species.

2.3 Distribution System effects on disinfectant residual decay

Although many studies are available which discuss the decay of disinfectants in the bulk water, the factors that influence decay in pipes or distribution systems are not necessarily the same. According to Vasconselos et al. (1996), the three most frequently cited sources of chlorine consumption are:

- Organic and inorganic substances in the bulk aqueous phase
- Biofilms
- Corrosion

Hallam et al. (2002) found that the majority of previously conducted research showed that pipe material and diameter, initial chlorine concentration, corrosion, and biofilm presence influenced the process of disinfectant decay at the pipe wall, otherwise known as wall decay. Relationships were also observed between wall decay and total organic carbon (TOC), and temperature. Powell et al. (2000a) found bulk chlorine decay to be most related to initial concentration, temperature, and either absorbance of ultraviolet light at a wavelength of 254 nm or TOC as measures of organic matter.

Temperature is an important variable in determining disinfectant residual effectiveness because both chemical and biochemical reaction rates increase with increasing temperature.

Affected reactions include those responsible for disinfection byproduct formation, chlorine decay, pipe corrosion, inactivation, and microbiological growth (APHA et al., 1994; Tchobanoglous and Schroeder, 1985). Information of effects on the overall availability of a disinfectant residual is important, because temperature control in distribution systems is not feasible. Temperature may increase in the pipe due to friction (Vasconselos et al., 1996). While an increase in temperature increases disinfection effectiveness (Snead et al., 1980), it also increases the decay rate. Both Hallam et al. (2002) and Powell et al. (2000a) identified temperature as a significant source of disinfectant decay.

Maier et al. (2000) found no relationships between single decay coefficients and temperature using monochloramine as the disinfectant. However, Valentine et al. (1998) did determine that a relationship existed between monochloramine decay rates and temperature. As with chlorine, an increase in temperature was found to increase the decay rate of monochloramine.

Corrosion is an oxidative process that occurs at the surface of a metal, resulting in dissolution of the metal. Linear chlorine decay has been identified in the presence of corrosion, indicating that the reaction may be zero order (Kiene et al., 1998). Kiene et al. (1998) also found that corrosion plays a major role in the decay of chlorine. Corrosion increases with high flow velocity, high temperature, low pH, low alkalinity, high dissolved oxygen concentration in water, high total dissolved solids, hardness, and biofilms attached to pipe walls (Grayman et al., 2000; Schock, 1999). Free chlorine occurring at concentrations greater than 0.4 mg/L was found to increase the rate of steel corrosion (Schock 1999). Corrosion contributes so much to chlorine decay that even low corrosion levels are known to interfere with chlorine disinfection. This is because corrosion products react with disinfectant residuals, preventing disinfectants from acting as a biocide (LeChevallier et al. 1993). In iron pipes, chlorine preferentially reacts with Fe^{2+} over oxygen (Vasconselos et al., 1996). Chemicals added for corrosion control can slow the rate of chlorine decay, thereby enhancing disinfection and reducing biofilm growth.

Low corrosion levels do not interfere with disinfection by monochloramine (Clement et al., 2003; LeChevallier et al., 1993). Monochloramine did not decay as rapidly as chlorine in metal pipe (Clement et al., 2003). Likewise, monochloramine was less corrosive to copper and steel compared to free chlorine (Reiber, 1991).

In iron pipe, chlorine is principally consumed by reactions with iron deposits, TOC, and biofilms, while the rate is most affected by the temperature of the bulk water (Kiene et al., 1998). However, pipe wall reactions related to corrosion of ferrous pipe materials can consume significantly more chlorine than those related to biofilm (Vasconselos et al., 1996). The different effect of corrosion on chlorine and chloramines results in better biofilm control using chloramines compared to free chlorine in systems using iron pipes (LeChevallier et al., 1990).

In contrast to metal pipe, studies of high-density polyethylene (HDPE), polyvinyl chloride (PVC), glass reinforced polyester (GRP), and polypropylene pipes found that the plastic material did not have a significant effect on the disinfectant decay constant (Vasconselos et al., 1996). Hallam et al. (2002) characterized these materials as nonreactive, and concluded that the material itself did not exert a significant disinfectant demand.

Biofilm growth is common in drinking water distribution systems. The extent of biofilm accumulation is affected by the disinfectant concentration in the distribution system (Characklis, 1988; Holden et al., 1995), with lower concentrations of disinfectant resulting in larger quantities of biofilm. Excessive biofilm growth has been observed after the loss of disinfectant residual (Crozes and Cushing, 2000). Likewise, presence of biofilm consumes disinfectant as described by Kiene et al. (1998). Corrosion is considered one of the primary factors affecting biofilm growth (Volk, 2000). Metal pipes have consistently been reported to have higher biofilm formation potential than plastic pipes (Block et al., 1991; Camper et al., 1996; Niquette et al., 2000; Holden et al., 1995). Corrosion has been identified as the cause for increased biofilms on metal pipes. Attached growths of this nature have been found to interfere with disinfection (Clement et al., 2003; LeChevallier 1990; Crozes and Cushing, 2000). Volk and LeChevallier (1999) found that selection of pipe material might be more influential than the level of organic matter in the system in determining biofilm growth.

As with temperature, many important biological and chemical reactions depend on pH, including disinfection, biofilm formation, and corrosion (APHA et al., 1994). Both temperature and pH influence the distribution of free chlorine between hypochlorous acid and hypochlorite ion. Lower pH accelerates corrosion, thus increasing the rate of disinfectant decay. However, lower pH also increases the effectiveness of chlorine as a disinfectant. Lower pH has also been found to increase the rate of monochloramine decay (Valentine et al., 1998).

Following the influence of pipe material on disinfectant decay, the rate of reaction at the pipe wall is inversely related to pipe diameter. The rate of disinfectant decay has been reported to be primarily limited by the rate of mass transfer of chlorine to the wall (Hallam et al., 2002; Vasconselos et al., 1996). When pipe diameters are greater than 80 mm, the chlorine consumed by biofilms was found to be equal to or less than that consumed by the water itself (Vasconselos et al., 1996). A significant positive relationship was identified between flow velocity and chlorine wall decay for all pipe sections surveyed by Hallam et al. (2002). Low flow velocities can also result in stagnant water, allowing sufficient time for the disinfectant to be consumed by materials in the bulk water. However, Maier et al. (2000) did not identify a relationship between flow and chloramines decay.

Water treatment processes target removal of fine particulates (generally measured as turbidity) because they can support microbial growth, consume chlorine, and reduce disinfection efficiency (APHA et al. 1994). The chlorine decay constant has been found to increase with increased TOC due to increased disinfectant demand (Vasconselos et al., 1996; Clement et al., 2003). Valentine et al. (1998) found that the monochloramine decay rate increases with presence of dissolved organic carbon (DOC). Clark et al. (2001) found that demand caused by inorganic or microbial demand in the bulk phase was much less than the demand associated with natural organic matter (NOM).

Some studies have indicated that decay constants decrease with increased initial chlorine concentration (Vasconselos et al., 1996). Maier et al. (2000) found no relationship for monochloramine, but Valentine et al. (1998) did determine that higher initial monochloramine concentration resulted in a lower decay rate. Another less important factor in the decay of chlorine is the presence of ammonia, which may reduce disinfectant residual through nitrification. On the other hand, Valentine et al. (1998) indicated that monochloramine decay increases during a decrease in ammonia. Bromide concentrations greater than 0.5 mg/L have been reported to act as a catalyst to accelerate monochloramine decay, and the presence of bicarbonate may have a similar effect (Valentine et al., 1998).

Overall, it appears that some conditions that increase chlorine decay may also influence chloramines decay, however to a smaller degree. Valentine et al. (1998) also indicated that monochloramine demand of water may not be noticeable at higher concentrations of monochloramine whereas this has not been the case with chlorine demand.

Table 2 summarizes the previous discussion of factors influencing free and combined chlorine decay by listing the conditions that are likely to increase chlorine decay and those that are less likely to have an effect. Each condition is known individually to affect disinfectant decay. The conditions listed may or may not occur simultaneously, but their additive effects have not been described in the literature.

Table 2: Factors influencing disinfectant decay in distribution systems

High Chlorine Decay	Low Chlorine Decay	Contribution To Monochloramine Decay
High TOC	Low TOC	High DOC
Low pH In Metal Pipes– High Corrosion	Plastic Pipe Or Corrosion Control	Low pH
High Biofilms	Low Biofilms	Low Initial Concentration
High Temperature	Low Temperature	High Temperature
Small Pipe Diameter	Large Pipe Diameter	Bromide > 0.5 mg/L
Very High Or Very Low Velocities	High Initial Disinfectant Concentration	Bicarbonate
Ammonia		

Sources same as those identified in text

Many studies have determined that a first order assumption does a satisfactory job of modeling disinfectant decay (Powell et al., 2000b; Wable et al., 1991). Some more advanced models, such as nth order and second order, provided more accurate models, but these require more information to derive necessary decay parameters, thereby restricting the ease of use (Powell et al., 2000b). Several studies have attempted to develop a universal bulk decay model that correlates chlorine and chloramines decay with water quality parameters that are known to affect decay, but to date none have produced a reliable model (Koechling et al., 1998; Isabel et al., 2000; Summers et al., 2001; Valentine et al., 1998). The author is unaware of any attempts to develop a universal pipe decay model.

The major weaknesses of using first order decay models identified in the literature are the inability to reproduce the high rate that typically follows chlorination (Haas and Karra, 1984; Zhang et al., 1992; Jadas-Hecart et al., 1992), and the inability to predict decay after rechlorination (Clark and Sivaganesan, 1998; Shang et al., 2002). These two problems appear to be caused by two separate phenomena. The first is a result of fast reacting substances during initial disinfection that lead to rapid consumption of disinfectant (Haas and Karra, 1984). The second occurs when reacting material, such as TOC, is no longer available in excess so the reaction is rate limited by both the disinfectant concentration and the reacting material concentration (Clark and Sivaganesan, 1998; Powell et al., 2000a; Boccelli et al., 2003).

The first weakness is primarily a problem when predicting decay during primary disinfection in the clearwell prior to distribution. The initial drop-off in chlorine concentration is not as important in the distribution system because the water is usually distributed after it has had sufficient CT in the clearwell to meet required disinfection standards. The initial rapid drop-off should have already occurred before water is released to the distribution system, and the disinfectant concentration in the finished water would serve as C_0 in calculations of CT to estimate inactivation in the distribution system. However, this initial decay may occur during booster disinfection or when disinfectant is added just prior to entry in the distribution system. The second weakness may be a significant factor in the distribution system. As a result, the trend in the literature is moving towards the development and use of second order decay models

(Clark and Sivaganesan, 1998; Boccelli et al., 2003; Shang et al., 2002), which better accommodate blending of different sources and water qualities, tanks, and booster disinfectant.

2.4 Presence and inactivation of pathogens in distribution systems

Distribution system conditions that are favorable to the growth and presence of microorganisms are likely to result in microbial presence when those conditions occur in actual systems. These conditions are important to consider because, if contamination enters the distribution system when favorable conditions for growth exist, pathogen inactivation through the presence of a disinfectant residual is necessary. In addition, this section discusses conditions that increase or decrease inactivation of pathogens.

Temperature is one of the most important factors affecting microbial growth, because reaction rates, including growth rates, increase with temperature. Temperatures greater than 15°C have been associated with increased growth in the distribution system (Fransolet et al., 1985; Donlan et al., 1988; LeChevallier et al., 1991; Donlan et al., 1994). Effectiveness of chemical inactivation also increases with temperature, which is reflected in published CT values that require greater CTs at lower temperatures (e.g., Chandrakanth et al., 2001).

Because organisms require nutrients to grow, the availability of essential nutrients in source water and contaminated water entering the distribution system will have an effect on the growth of organisms and therefore the ability of disinfectants to inactivate those organisms. To achieve optimal growth, coliforms and other heterotrophic bacteria require organic carbon, nitrogen, and phosphorus in a ratio that is approximately 100:10:1 (C:N:P). Due to this ratio, organic carbon is often the growth-limiting nutrient. It must be noted that complete removal of nutrients is not practical, and it is not likely to eliminate all bacteriological concerns (LeChevallier et al., 1996b). Organism growth may increase in the distribution system if higher concentrations of organic carbon are available following treatment. A range of biodegradable dissolved organic carbon (BDOC) concentrations from 0.15 to 0.3 mg/L have been identified as limits above which growth in the distribution system increases, or where growth below the limit is unlikely (Niquette et al., 2001; Camper et al., 2000; Servais et al., 1992; Laurent et al., 1999; and Prevost et al., 1997).

Assimilable organic carbon (AOC) concentrations have also been reported to have positive effects on bacterial growth (van der Kooij, 1992). This is of particular interest in distribution systems because AOC concentrations may increase with time due to chlorine oxidation, while bacteria activity decreases these concentrations. However, LeChevallier et al. (1987 and 1991) and van der Kooij et al. (1992) found that AOC concentrations decreased with travel time in the distribution system. This finding may decrease the concern of an AOC contribution towards microbial growth or occurrence in the distribution system.

As illustrated in the cellular mass ratio presented above, it is clear that both nitrogen and phosphorus are necessary for microbial growth. Nitrogen, in at least one of its forms, is typically available in distribution systems. LeChevallier et al. (1988) found that microbe resistance to monochloramine was not affected by nutrient concentration. However, the same study found that resistance to chlorine increased with biofilm age and existence of low nutrient concentrations. Phosphorus is frequently added as a polyphosphate for corrosion inhibition. This form is not readily available for bacterial growth due to the slow rate of hydrolysis. Rosenzeig et al. (1987) found that these inhibitors did not significantly influence the growth of several strains of bacteria, and some orthophosphates actually showed inhibitory effects. A study investigating the proportion of multiple antibiotic resistant bacteria in drinking water found an increase with increased copper concentrations resulting from corrosion (Armstrong, 1981). One study found that bacteria acclimatized to low nutrient concentrations were more resistant to disinfectants than those grown at higher nutrient concentrations (Olson and Stewart, 1990). However, Watters and McFeters (1990) found that higher nutrient concentrations may facilitate the recovery of disinfectant-stressed microbes.

Turbidity is used to characterize the fine particulates in water, including clays, silts, plankton, and microorganisms. Turbidity presence has been associated with microorganism colony counts in some studies (LeChevallier et al., 1987; Goshko et al., 1983; Hass et al., 1983) but other investigators have found no association (McCoy et al., 1986). A study by LeChevallier et al., (1981) found that disinfection effectiveness was negatively correlated with turbidity. Turbidity may also be related to the accumulation of organic and inorganic sediments in low flow areas of distribution systems, and may enhance microbial activity by providing protection against disinfectant contact, and by providing a nutrient source (USEPA, 1992).

The effectiveness of free chlorine as a disinfectant is strongly affected by pH; inactivation increases as pH decreases (Haas et al., 1980). This property was used in the development of the CT tables for determining log removal of pathogens. Carter (2000) found that higher bacterial growth was observed under conditions of increased pH.

As previously mentioned, some studies have demonstrated a relationship between iron corrosion and microbial densities (Clement et al. 2003). As a result of reactions between corrosion byproducts and chlorine residuals, microorganisms present in corrosion tubercles can be sheltered from disinfectants (LeChevallier et al., 1990 and 1993).

As with disinfectant decay, pipe diameter may play an important role in the inactivation of pathogens in distribution systems. Studies have demonstrated that, as the ratio of accumulated surface area (S) to accumulated water volume (V) increases, the inner surface contact time with chlorine also increases (Servais et al., 1992). According to Prevost et al. (1997), the S/V ratio is one of the factors that significantly affect growth in warm waters in distribution systems.

Table 3 presented below summarizes how the factors considered in this section affect pathogen inactivation. The conditions described below each individually increase or decrease inactivation. These conditions are not necessarily expected to occur simultaneously, nor have their additive effects been described in the literature.

Table 3: Factors influencing pathogen inactivation in distribution systems

Increases chlorine inactivation	Decreases chlorine inactivation	Increases Chloramines inactivation	Decreases Chloramines inactivation
High Temperature	Low Temperature	High Temperature	Low Temperature
Low pH	High pH	No relationship to nutrients	
Low turbidity	Low nutrient levels		
Low corrosion	High Turbidity		
	High corrosion		

Sources same as identified in text

2.5 Use of models to measure effectiveness of disinfectant residuals

There are few published studies that have investigated the effectiveness of disinfectant residuals in distribution systems. Snead et al. (1980) conducted the first study of this type with an investigation of the effectiveness of chlorine residuals in a laboratory system with a simulated cross-connection. Different concentrations of sterilized sewage were seeded with microorganisms and added to the water. The comparative survivals of the microorganisms were evaluated. It was determined that initial free chlorine residual was more effective than an equivalent initial combined chlorine residual.

Payment (1999) evaluated chlorine inactivation of microorganisms added to drinking water samples taken from different points in a distribution system. Payment concluded that maintenance of a free residual concentration in a distribution system does not provide significant inactivation of pathogens.

Propato and Uber (2004) investigated the ability of chlorine and chloramines to inactivate deliberate pathogen contamination of distribution systems using an EPANET model of a constant contaminant concentration input into the distribution system. This study did not consider the effect of the distribution system and water quality on disinfectant decay.

The present study attempts to quantify the effectiveness of disinfectant residuals on inactivating pathogens during commonly occurring contamination events by taking some disinfectant, pathogen, and distribution system variables into consideration.

3.0 METHODS

Several aspects of disinfectants, contaminants, distribution systems, and contamination events must be considered to develop a comprehensive model for examining disinfectant residual effectiveness in the distribution system. Table 4 provides an overview of these factors. Many of these factors were discussed previously in the literature review. Each of these factors was considered to determine whether they were appropriate to include in developing this model.

Table 4: Factors influencing effectiveness of disinfectant residuals in distribution systems

Disinfectant Properties	Type: Chlorine, Chloramines, Chlorine Dioxide Decay Characteristics Dose
Microorganism Properties	Type: Virus, Bacteria, Protozoa Number of organisms (concentration) Matrix (associated particles, free floating, etc) Form (spore, cyst, cell, vegetative) Microbial interactions (competitive, symbiotic) Growth Die-off
Contamination Event Properties	Mixing Behavior Disinfectant Demand Volume Number of contamination entry points Spatial distribution of contamination entry points Proximity to consumers
Distribution System and Distributed Water Properties	System Demand on disinfectant Pipe/Reservoir Volume Available contact time Corrosion Corrosion Control Degree of looping Demand properties of materials (nutrient providing) Temperature pH Turbidity Nutrients in source water

While section 2.2 discussed properties of individual disinfectants, section 2.3 discussed water quality and distribution system parameters that determine decay of disinfectants in the distribution system. Disinfectant dose is frequently determined by the amount of decay in the distribution system, and dose is calculated such that a detectable residual can be maintained throughout the distribution system to comply with the SWTR. This is a system specific parameter that was determined for use in this model, but it was compared to typical values used nationwide.

Viruses, bacteria, and protozoa are known distribution system contaminants. *Giardia*, a protozoon, was selected as the indicator organism for this model because it has been detected in distribution systems, it is more resistant to chemical disinfection than other common organisms such as *E. coli*, and it was the most commonly identified microbe in backflow events collected by EPA between 1970 and 2001 (USEPA, 2002a). The control case, with no disinfectant residual present, also represents the case of an organism that is extremely resistant to disinfection, such as *Cryptosporidium*. The control scenario is also representative of ground water systems that do not maintain a disinfectant residual in the distribution system. The number of organisms in contamination slugs selected for this model is discussed below. Matrix, form, and microbial interactions affect disinfectant effectiveness against pathogens. However the specific effect is not well understood. A range of inactivation rates is used in this model to reflect varying degrees of resistance to disinfection. Die-off after contamination enters the distribution system is also reflected in the inactivation rate.

Contamination properties are highly event specific. Turbidity or TOC associated with contamination can be a significant source of disinfectant decay. Selection of these factors for the current model is discussed below with the development of the model. Likewise, distribution system characteristics are system specific. Some of these are set by the distribution system selected for the study, including pipe and reservoir volume, degree of looping, and available contact time. Other parameters were varied in this study to reflect different distribution system conditions. System demand on disinfectant, corrosion, corrosion control, and demand properties of materials were reflected through a range of disinfectant decay constants used to represent high or low demand/decay scenarios. The variety of both decay constants and inactivation rates represent the effects of temperature, pH, presence of nutrients, and turbidity on inactivation in the distribution system.

As discussed in the literature review, the effect of distribution system and water quality parameters on disinfectant decay and pathogen inactivation is poorly understood. At best, researchers have identified the relative importance of different parameters but have not been able to quantify their effect. For this reason, a range of values was selected from the literature that may represent high, medium, and low disinfectant decay conditions as described in the literature review. Likewise, a range of inactivation rates was selected from the literature to represent varying degrees of resistance to disinfection that may be brought about by the distribution system and organism characteristics discussed above.

3.1 The Model

Figure 1 provides an illustration of the concept supporting this model. First, disinfectant residual is provided in a distribution system, and it decays as it moves throughout the distribution system. For this study, it was assumed that the decay rate is constant throughout the distribution system. The decay rate is affected by distribution system and disinfectant conditions. Although decay rates are known to vary locally, this study used one rate to represent the entire system. In the model, microbial contamination enters the distribution system triggered by a pressure drop, and the contamination may or may not be inactivated by the disinfectant that is available at the time of contamination. The degree of inactivation depends on disinfectant properties, contaminant and event properties, and distribution system properties.

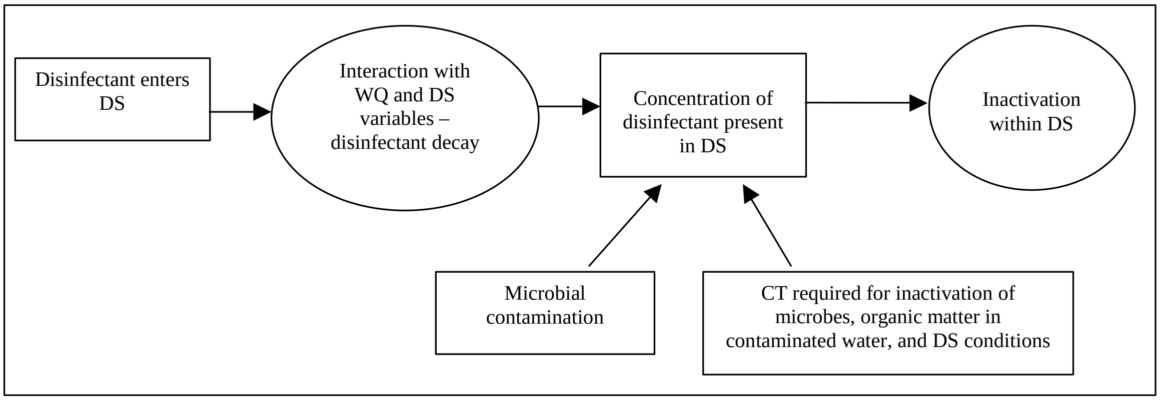

Figure 1: Model Inputs (rectangles) and Calculations (ovals)

The model starts with a small, hypothetical distribution system (Figure 2). This system is example network 2 that is provided with EPANET software. This system includes one storage tank, one pump station, and 36 nodes including the storage tank. The network consists entirely of 8- and 12-inch diameter pipes, covering a total of 36,000 feet or 6.8 pipe miles. Elevations in the network range from 50 to 230 feet. A 24-hour demand pattern was applied to the network, and the first 24 hours of the EPANET pump station pattern was retained for this model. There is a large fluctuation in water age due to tank operation. Some nodes experience significant fluctuations in water age. For instance, one node had water age ranging between 5 and 120 hours. Water age in the entire system ranges from 0 to 150 hours. Disinfectant is added to the network at the pump station, node 1.

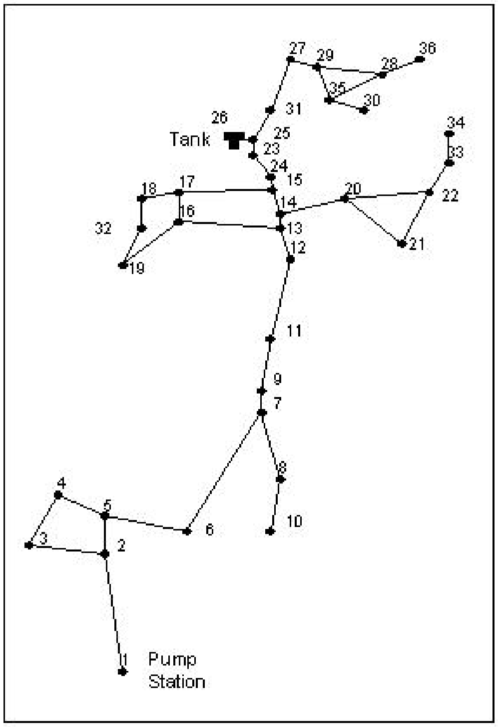

Figure 2: Model Network

Low pressures in distribution systems can create a pathway for contamination to enter the distribution system. This is known to happen through unprotected cross-connections between a nonpotable line and the potable water line when the pressure in the nonpotable system is higher than the pressure in the potable system. Low distribution system pressure, such as during water main breaks, can allow contamination to enter the distribution system through backflow. Backpressure can also result in contaminant entry to the system when pressure in the nonpotable system is higher than the pressure in the potable system even in the absence of low pressure in the distribution system. Some dilution will occur as the contaminated water travels through the distribution system.

One case of distribution system contamination is investigated through the use of this model: an unprotected cross-connection to a pressurized nonpotable water system, such as a recycled water line. Contamination is entered into the model at two nodes (Nodes 23 and 31) one at a time, and disinfectant is added at the entrance to the distribution system (Node 1). This approach first examines the path of contamination, taking a preliminary look at how far the microbial contamination travels and the effect of dilution on the pathway of the contamination. Next, several model runs were completed using different decay constants and different inactivation rates to represent different distribution system conditions, different disinfectants, and different microbial resistance to disinfection. Contaminant matrix was not considered in this study, but may be added in further investigations. The following sections describe how the model inputs were selected for this project and are summarized in Table 11 at the end of this section.

Pressure transients are not modeled in this project, because the software used is not capable of modeling them. Backpressure contamination is added at a specified node, and the effectiveness of the disinfectant residual for inactivating that contamination is modeled. The dilution in the system once it has entered, the concentration of disinfectant available in the distribution system, the inactivation of the pathogen by the disinfectant, and the travel time within the system are the factors that the model calculates to determine the concentration of pathogens that reach downstream nodes. The results of this investigation are specific to the hypothetical distribution system studied and are not necessarily representative of distribution systems nationwide. However, the trends identified here may be similar to many distribution systems. Distribution systems are very location specific, and there is no standard distribution system configuration. Depending on system configuration such as looping, pipe diameter, flow, and velocity, different travel times within the distribution system may result in a large difference in inactivation. Therefore, the inactivation achieved through CT values in these simulations cannot be assumed to be relevant for all distribution systems.

3.2 Model Inputs

3.2.1 Selection of Contamination Nodes

A preliminary extended period simulation was completed on the distribution system to identify nodes with low pressures. The model was allowed to run until a consistent water age pattern developed, which took 336 hours. It was confirmed that the network hydraulics produced a regular diurnal cycle. The pressures were analyzed looking for pressures below 20 psi, because

Kirmeyer et al. (2001) identified this as a recommended minimum operating pressure to prevent intrusion and backflow into the distribution system. An additional example to support this minimum operating pressure is the requirement of 30-50 feet of head for sewage ejectors to remove wastewater from a basement (Schwartz, 2004). Because 1 foot of head equates to 0.433 psi, the required head would result in a pressure up to 21.7 psi, which is enough to result in backpressure if the cross-connected potable system pressure drops below 20 psi. To create a scenario in which pressures occurred below this operating parameter, some elevations in the system were adjusted to produce lower pressures. The resulting elevations were checked to make sure they would be reasonable in a real life situation, and a contour map showing the elevations is provided in Figure 3.

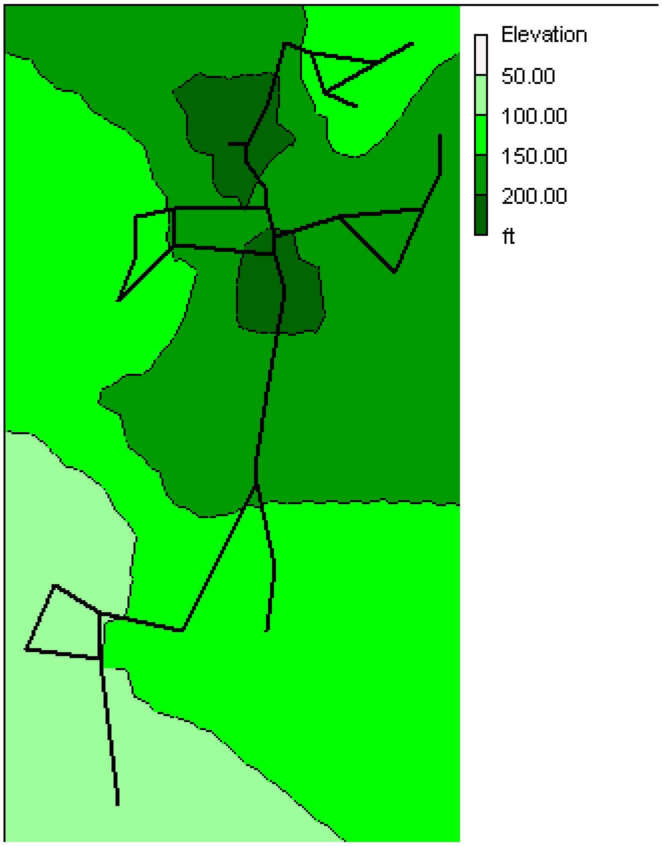

Figure 3: Distribution System elevation contour map

Two nodes that experienced pressure below 20 psi were selected for locations of the unprotected cross-connection. Reduced pressure in the system is primarily due to the elevation of the two nodes experiencing low pressure. The first node is in a location that would result in a small number of nodes exposed to contamination (node 31 in Figure 2). The second node is in a location that would result in a large number of nodes potentially exposed to contamination due to tank operation (node 23 in Figure 2). Only one node at a time was used to represent the unprotected cross-connection during model runs. Figures 4 and 5 show the pressure variation at nodes 31 and 23, respectively, during a 24-hour cycle starting at midnight.

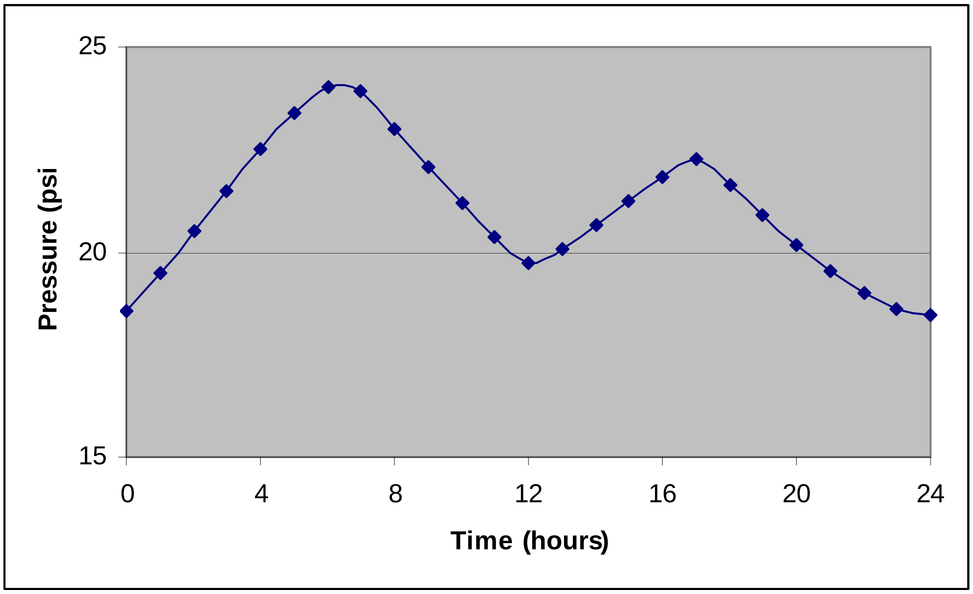

Figure 4: Twenty-four hour pressure cycle at node 31

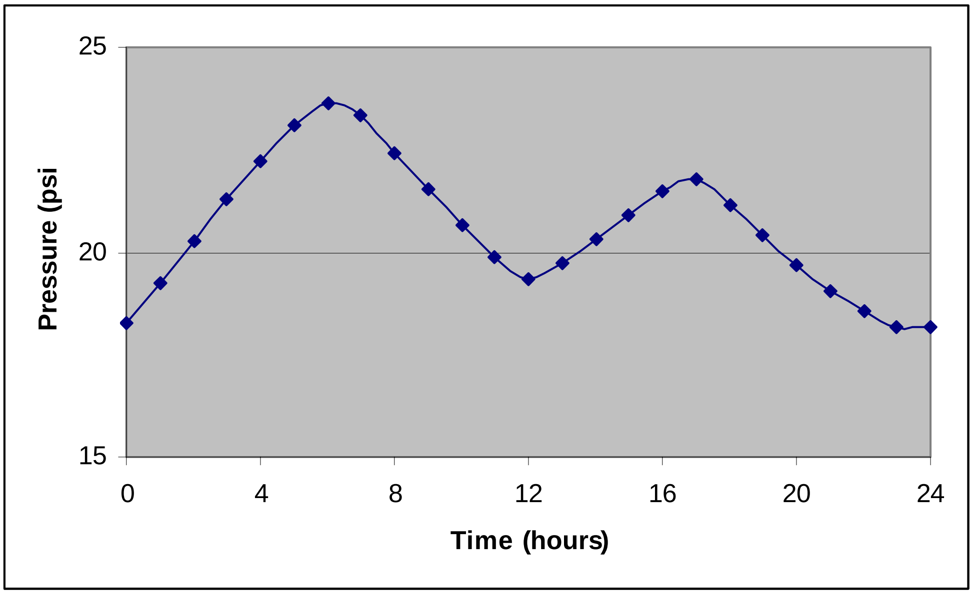

Figure 5: Twenty-four hour pressure cycle at node 23

Figure 6 provides the pressure curve at the pumping station. Although these pressures are above the recommended operating parameter of 100 psi, these pressures are comparable to the pressures in the unadjusted example provided with EPANET, which is based on a real system and is a calibrated model. This demonstrates the variation in pressure throughout the modeled distribution system.

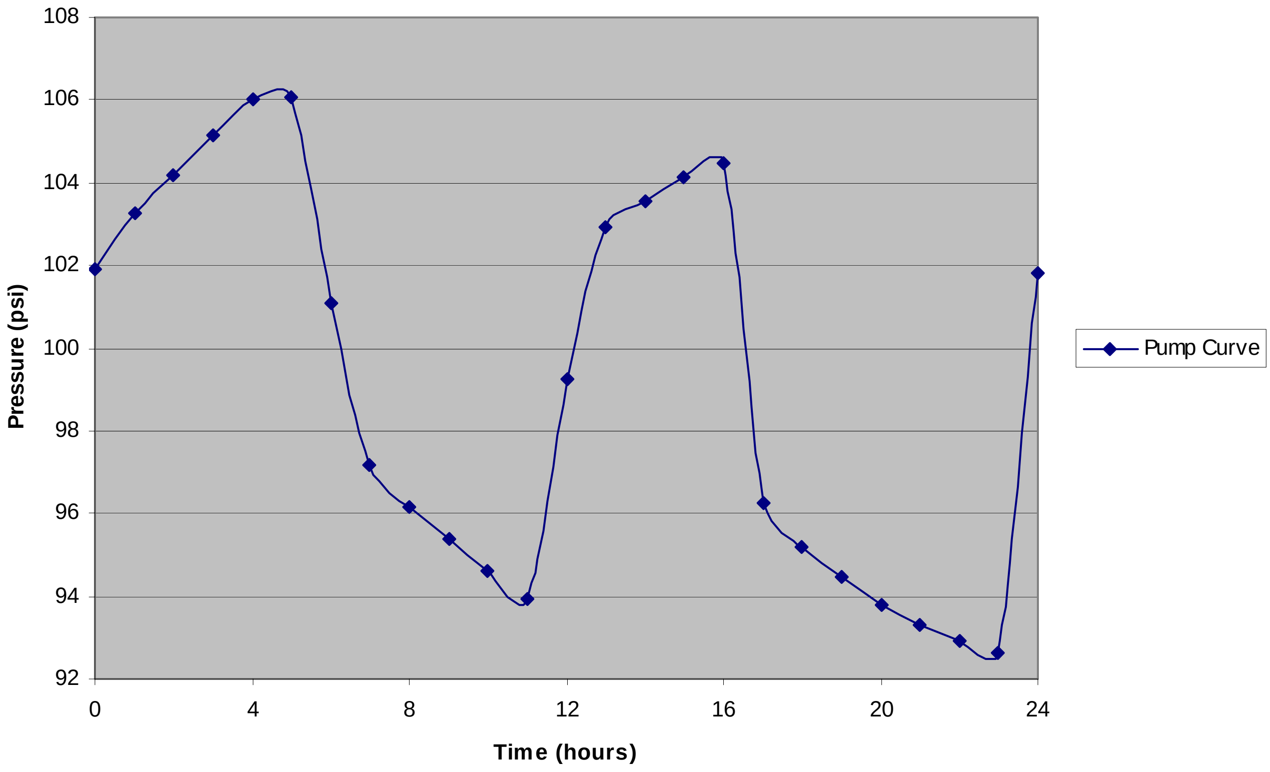

Figure 6: Pump Station Curve

3.2.2 Selection of Contaminant Concentration

Three different concentrations of contamination were used with the model. Because the cross-connection is to a recycled water line, the three concentrations were based on sewage and wastewater treatment pathogen concentrations. As stated previously, *Giardia* was selected as the indicator organism for this model because it has been detected in distribution systems, it is more resistant to chemical disinfection than some common indicator organisms such as *E. coli*, and it was the most commonly identified microbe in backflow events collected by EPA between 1970 and 2001 (12 out 58 reported microbial incidents; 32 events were not identified) (USEPA, 2002a). The worst-case scenario selected is a G*iardia* concentration equivalent to the typical concentration in raw sewage, 10^3-10^4 MPN/100 mL (Metcalf and Eddy, 2003). A best-case scenario was taken from the typical range of effluent quality after secondary biological nutrient removal plus disinfection, which for protozoa was 5-10/ 100 mL (Metcalf and Eddy, 2003). A value of 10^2/100 mL between these two ranges was selected as an intermediate value. Table 5 summarizes these selections.

Table 5: Selected Contamination Concentrations

Scenario represented by model	**Giardia Concentration (MPN)**
Worst Case Scenario: Raw Sewage	10^4/100 mL
Moderate Scenario	10^2 /100 mL
Best Case Scenario: Secondary Biological Nutrient Removal plus Disinfection	5/100 mL

To model contamination entry into the distribution system, a mass booster input was used at the selected contamination node. This input type is in units of mass per time. Therefore an estimate of flow, in addition to concentration, was required so that an input of organisms per minute could be used. For simplicity, a flow rate of 1 L/min was selected and the model inputs listed in Table 6 were used. However, these model inputs can be interpreted in several different ways. For example, the input of 100,000 organisms/min can be interpreted as 100,000 organisms/L entered at a rate of 1 L/min; 10,000 organisms/L entered at a rate of 10 L/min; or 1,000 organisms/L entered at a rate of 100 L/min. Therefore, the three model inputs selected for these simulations simultaneously represent both a range of concentrations and a range of flows of contaminated water into the potable water distribution system.

Table 6: Mass Booster Model Inputs

Scenario represented by model	***Giardia* Concentration**
Worst Case Scenario: Raw Sewage	100,000 organisms/min
Moderate Scenario	1,000 organisms/min
Best Case Scenario: Secondary Biological Nutrient Removal plus Disinfection	50 organisms/min

3.2.3 Selection of Decay Constants

For the current model, a first order assumption was made to model disinfectant decay in the distribution system. Several studies have determined first order is adequate for studying disinfectant decay (see section 2.2), and many studies have published experimentally determined decay constants for first order decay. This reaction can be expressed as:

$$dC/dt = -k_c C$$

where k_c is the disinfectant decay constant. A survey of published first order decay constants for chlorine found a range of experimentally determined values. Decay constants are displayed here in units of 1/day. Vasconselos et al. (1996) published a range of decay constants between 0.082 and 17.7 1/day. Powell et al. (2000a) published several different experimental chlorine bulk decay rates, and the frequency of the experimentally determined values. There is much overlap between these two published ranges. Bulk decay is typically determined in the laboratory and does not account for wall effects on decay. Hallam et al., 2002, found wall decay rates ranging from 0 to 39.36 1/day, and decay constants for cast iron pipes were between 0.72 and 39.96. Although wall decay rates were not used in the current model, this study shows that the potential for very high decay rates does exist. For this reason, the 99th percentile of these published first order decay coefficient values, rather than the 95th percentile, was selected to represent high chlorine decay that is known to occur in the presence of corrosion at the pipe wall. The 50th percentile, and 10th percentile were selected to represent medium and low decay. These values are summarized in Table 7, and the study data are provided in Appendix D.

Table 7: Chlorine decay constants selected for the model

Scenario represented by model	**First Order Decay constant (1/day)**
High decay: Iron pipe corrosion, high TOC, high temperature, large biofilm presence	10.1
Medium decay: No/very low corrosion, medium TOC, moderate temperature, some biofilm	0.96
Low decay: Plastic pipe, low TOC, low temperature, minimal biofilm	0.27

For chloramines decay, Maier et al., 2000, published a range of 0.42 to 2.33 1/day. A total of 40 experimentally determined decay coefficients were published in this study. Table 8 contains the 95th, 50th, and 10th percentile decay coefficients published in Maier et al. The 99th percentile was not used for chloramines because wall decay effects are less significant for chloramines than for chlorine. The data for this determination are available in Appendix D.

Table 8: Chloramines decay constants selected for the model

Scenario represented by model (Conditions under which chloramines decays are not as clearly understood as for chlorine)	**First Order Decay constant (1/day)**
High decay	1.8
Medium decay	1.0
Low decay	0.68

3.2.4 Selection of Disinfectant Input

The concentration of disinfectant added at the entrance to the distribution system was determined through the use of the EPANET toolkit to calculate the minimum disinfectant residual required at the entrance of the system to maintain a minimum of 0.1 mg/L disinfectant at all points in the distribution system. As a reality check, the calculated disinfectant dose was compared to the national average of disinfectant concentrations entering the distribution system from the data received from the Information Collection Rule (Chen and Regli, 2002). The national median concentration in finished water for systems participating in the Information Collection Rule was 2.6 mg/L as Cl_2 for chlorine-only plants and 5.0 mg/L as Cl_2 for chloramines plants. The disinfectant input was calculated for each decay scenario modeled. The results of these simulations are summarized in Table 9.

Table 9: Calculated Disinfectant Required Dose

Chlorine Decay Constant (1/day)	Chlorine Dose (mg/L)	Chloramines Decay Constant (1/day)	Chloramines Dose (mg/L)
10.1	Over 50	1.8	25.7
0.96	3.41	1.0	3.78
0.27	0.49	0.68	0.63

Compared to the national medians, these disinfectant doses are not representative of typical plant operation, particularly the upper and lower ranges. The upper range of the ICR data is reigned in by the MRDL of chlorine, 4.0 mg/L, and taste and odor concerns rather than determined by the minimum dose for detection throughout the distribution system. Lower disinfectant inputs that do not maintain a disinfectant residual at all points in the distribution system are likely in a system of this description for several reasons. For example, in this simulation, all nodes were checked, or sampled, every ten minutes to determine whether or not a detectable disinfectant residual was present. Systems do not sample at all points in the distribution system, and they are only required to sample once a month in each location they do sample. A system of this size would be required to sample at only 4 sites per month according to the SWTR and Total Coliform Rule (TCR) requirements. If disinfectant is not detected at a TCR monitoring location the system can still be in compliance through use of HPC testing. Some systems with high decay provide booster disinfection if they have a problem maintaining a disinfectant residual. On the other hand, chlorine doses greater than 4.0 mg/L are possible because the MRDL requirement is measured as a running annual average throughout the distribution system.

To select more representative disinfectant input concentrations, 10th, 50th, and 99th percentile chlorine doses were selected from Information Collection Rule data for chlorine only plants, and 10th, 50th, and 95th percentile chlorine doses were selected from chloramines plants to correspond with the high, medium, and low decay scenarios (Chen and Regli, 2002). These values are presented in Table 10. The 99th percentile was selected for chlorine rather than the 95th because some published wall decay constants indicate the potential range of chlorine decay might be much greater than expressed in the studies quoted in Appendix D.

Table 10: Chlorine Doses from Chen and Regli, 2002

Chlorine Decay Constant (1/day)	Chlorine Dose (mg/L)	Chloramines Decay Constant (1/day)	Chloramines Dose (mg/L)
10.1	10.0	1.8	9.0
0.96	2.5	1.0	5.0
0.27	1.2	0.68	3.0

Table 11 is a summary of disinfectant presence in the distribution system during the simulations for this investigation. This table shows the number of node timesteps (NT) during different disinfectant conditions that have a disinfectant concentration less than 0.1 mg/L to determine how frequently disinfectant residual is absent in the distribution system. Table 11 represents disinfectant conditions during both node contamination scenarios.

Table 11: Disinfectant concentrations during simulations

Chlorine Decay Constant (1/day)	NT with disinfectant concentration <0.1 mg/L (% of total NT)	Chloramines Decay Constant (1/day)	NT with disinfectant concentration <0.1 mg/L (% of total NT)
10.1	2781 (55%)	1.8	245 (4.9%)
0.96	89 (1.8%)	1.0	0
0.27	0	0.68	0

Chlorine with high decay has a high percentage of NT with a disinfectant concentration less than 0.1 mg/L. While the model runs using high chlorine decay do not represent optimal disinfection conditions, they are representative of systems in compliance with the SWTR.

Although the SWTR requires a detectable disinfectant residual throughout the distribution system, the samples are collected only at TCR monitoring locations. The TCR requires sampling at sites that are representative of water quality throughout the distribution system (USEPA, 1989b). Nodes 28, 30, 33, 34, and 36 receive a chlorine concentration less than 0.01 mg/L during all time steps in the high chlorine decay simulation. These nodes are all located at or near dead ends and are not representative of water quality throughout the distribution system. Therefore it is unlikely that these sites would be selected for TCR sampling. In addition, a system of this size is required to sample once at only 4 sites per month. Figure 7 shows a time series plot of chlorine concentration in the distribution system during the high decay simulation. It is clear from this figure that it would be easy to sample at 4 sites representative of water quality throughout the distribution system and find a detectable disinfectant residual during most time steps during this 24-hour simulation. Given that this system would have an entire month during which it would take these samples, this system is very likely to be in compliance with the disinfectant residual requirements of the TCR and SWTR.

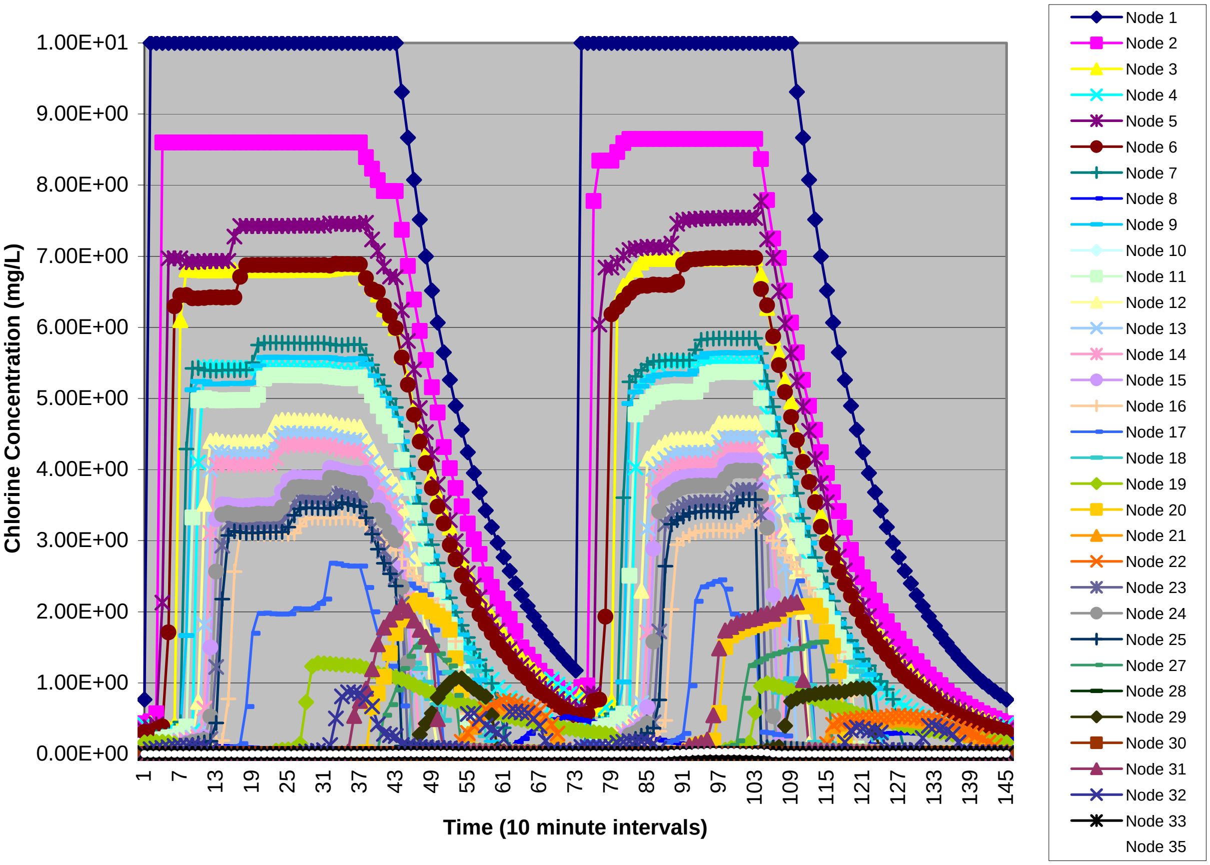

Figure 7: High Chlorine Decay Concentrations

3.2.5 Selection of Inactivation Constants

Chick (1908) and Watson (1908) described classical disinfection theory, and their work is still used today. They expressed the inactivation of microorganisms as a pseudo first-order law:

$$dP/dt = -k_pPC^n$$

Where dP/dt is the rate of inactivation, P is the number concentration of viable pathogens in individuals/L, C is the concentration of disinfectant in mg/L, n is the reaction order with respect to disinfectant, and k_p is the pathogen kinetic decay constant. The SWTR (USEPA, 1989a) included concentration and contact time (CT) values for chlorine and chloramines disinfection. These are the most frequently used inactivation data available in the literature. EPANET requires an inactivation constant to calculate the change in pathogen concentration as it moves through the distribution system. The pathogen kinetic decay constant can be derived from CT values. As a result, the pathogen decay constant can be calculated from:

$$k_p = -\ln (P_t/P_o)/(CT)$$

Based on EPA's published CT values (AWWA, 1991), Martin (1993) derived the following equation for *Giardia* inactivation due to chlorine for temperature between 0.5 and 5°C:

$$CT = 0.36\ (pH\text{^}2.69)\ (C\text{^}0.15)\ (\text{Inactivation}\text{^}1)\ (t^{-0.15})$$

Where C is the free chlorine concentration (mg/L as Cl_2) multiplied by the contact time t (min) (min·mg/L), inactivation is the logarithmic reduction in *Giardia* cyst concentration (dimensionless), and t is the temperature (ºC). Martin derived a second equation for temperatures above 5°C:

$$CT = 0.2828\ (pH\text{^}2.69)\ (C\text{^}0.15)\ (\text{Inactivation}\text{^}1)\ (0.933\text{^}(t-5))$$

In both of these cases, the reaction order, n, is 0.85. The chlorine CT values include a safety factor of 3.

Chloramines CT values published with the SWTR are dependant only on temperature. Table 12 summarizes CT values for *Giardia* using chlorine and chloramines under three different conditions, and the corresponding k_p values. The *Giardia* CTs for chloramines do not include a safety factor because it was assumed that chlorine would be added prior to ammonia in the treatment plant such that a significant portion of inactivation is attributed to chlorine alone. These values were not calculated to be representative of inactivation in the distribution system. As a result, these CTs represent a best-case scenario for chloramines and may not be representative of conditions within the distribution system.

Table 12: *Giardia* CT and Kp values

Chlorine *Giardia* inactivation (Martin, 1993; SWTR)			
pH	Temperature (°C)	3 log CT (min·mg/L)	k_p = -Ln(10^-3)/CT (L/min·mg)
9.00	20	36.9	0.1874*C^0.85
8.00	5	76.0	0.0909*C^0.85
9.00	5	104.3	0.0662*C^0.85
Chloramines *Giardia* inactivation (SWTR)			
	Temperature	3 log CT (min·mg/L)	k_p = -Ln(10^-3)/CT (L/ min·mg)
	20	1100	0.00628
	10	1850	0.00373
	5	2200	0.00314

3.3 Selection of EPANET for the model software and modifications for this project

EPANET is a computer program that performs extended period simulations of hydraulic and water quality behavior within pressurized pipe networks, developed by the United States Environmental Protection Agency (Rossman, 2000). EPANET tracks the flow of water in each pipe, the pressure at each node, and the height of water in each tank by computing friction headloss with the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas. This is what is termed a hydraulic solution for a distribution system. EPANET uses the flows and velocities in this model output to track the concentration of a chemical species throughout the network in what is termed a quality solution.

The program code for EPANET is available in the public domain, and the EPANET Toolkit provides a series of functions that allow distribution system modelers to access the functionalities of EPANET through independent programming. EPANET first calculates a hydraulic solution for the distribution system and uses the flow and time results to determine water quality throughout the system. EPANET is capable of calculating decay both in the bulk water and at the pipe wall. EPANET is the distribution system modeling standard in the field of drinking water, being either the preferred model or the basis of about 90% of the modeling software available (Grayman and Clark, 2004). EPANET was selected for this project because it has the functionalities required for the completion of this project, has a long history of use, is well accepted in the field, and is relevant to the many systems that use its capabilities to examine their distribution systems.

Recent enhancements to the EPANET modeler's toolkit provide the opportunity to model multiple species, either chemical or microbiological, simultaneously in the distribution system. These enhancements are described in Shang et al. (2003). For this project, a program was written in Microsoft Visual C++ 6.0 that accesses the EPANET Toolkit and multiple species code through a dynamic link library (DLL). The user can define reaction coefficients for multiple species within this DLL file. EPANET first calculates a hydraulic solution for a system and uses this output to calculate the quality solution. This created a challenge for the present project because the hydraulic solution does not run simultaneously with the quality solution, and the contamination scenario used for this model needs to use a hydraulic trigger to determine contaminant (quality) input.

To start, hydraulic simulations were completed on the selected model network using the EPANET graphic user interface, and nodes experiencing low pressures were selected as contaminant entry points. The standard EPANET toolkit code for completing an extended period hydraulic simulation was used. A model run time of 336 hours was selected such that a consistent water age pattern occurred, and disinfectant residual was detected throughout the distribution system. The time period of 336 hours was verified through the graphic user interface. A function was added that checks the pressure at the selected contaminant entry point node during each time step after 336 hours passed. A 10 minute time step was used for all simulations. Because the hydraulic solution is completed before the quality solution begins, an array of type float was created to contain the contaminant concentration at the contaminant entry point node during each time step of the hydraulic simulation.

Using the pressure check function, the program entered the previously selected contaminant value in the array if the pressure was below 20 psi. If the pressure was above this level, the program entered a contaminant concentration of zero into the array. This sequence lasted for a 24-hour period.

After the hydraulic simulation completed, the quality simulation began and ran for 336 hours. The quality simulation calculated disinfectant decay throughout the distribution system as it progressed through each time step. After 336 hours, a function set the water quality input at the contaminant node to the value stored in the contaminant concentration array during each time step. At this point, EPANET calculated the concentration of both species (*Giardia* and disinfectant) simultaneously as they moved through the distribution system using the hydraulic solution and the decay and inactivation constants previously defined in the DLL. Output files were created in the program code such that each model run produced two output spreadsheets, each containing all the values of one species during all time steps during the 24-hour sequence for all nodes. The code is provided in Appendix B.

Table 13 summarizes each of the individual model inputs selected for the model runs for this project. A comprehensive list of the simulations completed is available in Appendix E.

Table 13: Model Conditions

Node	**Contamination Strength: *Giardia***	**Disinfectant Decay Conditions: First order decay constants (1/day)**		**Inactivation Conditions: k_p (L/min·mg)**	
		Chlorine	**Chloramines**	**Chlorine**	**Chloramines**
23	100,000/min	10.1	1.8	$0.1874*C^\wedge{}^{0.85}$	0.00628
31	1000/min	0.96	1.0	$0.0909*C^\wedge{}^{0.85}$	0.00373
	50/min	0.27	0.68	$0.0662*C^\wedge{}^{0.85}$	0.00314

4.0 RESULTS AND DISCUSSION

The output files for each model run contained the pathogen concentration and disinfectant concentration at 10-minute intervals during the 24-hour simulation period. Each model output point represents the water quality present during 10 consecutive minutes of the simulation at one node. The pathogen concentrations at each node during all time steps were analyzed to determine the effects of disinfection under the different conditions used in the model. The following discussion focuses on the node water quality outputs. It does not include discussion of tank water quality because tank dynamics were not a focus of this study. There were a total of 144 time periods recorded during the simulation for each of 35 nodes (not including the tank), resulting in 5040 node timesteps (NT) that could experience contamination. Each NT with a present concentration of pathogen can be considered an opportunity for exposure. The data files were examined to determine the total number of NT experiencing presence of a pathogen concentration of concern, and the number of NT that experienced a 3-log reduction from the input concentration.

In most situations, the model outputs for simulations using the same decay and inactivation constants but different pathogen input concentrations had the same number of NT with 3-log reduction. While the log inactivation was the same for each set of results, the difference in these files was the actual concentration of pathogen at each node. Due to the consistency of model output, the medium contaminant concentration input files (1000 organisms/min) were examined for each of the decay and inactivation conditions. A summary of all the results can be found in Appendix E, and a sample output file can be found in Appendix F.

Regli et al. (1991) published a 10^{-4} risk level for *Giardia* as 6.75×10^{-6} organisms/L as an annual average concentration. This risk level assumes 6.75×10^{-6} organisms/L as typical daily exposure. This concentration was used to determine how many NT have a risk of *Giardia* exposure in simulations with and without disinfectant. Although the annual exposure is not known in this scenario, this is a reasonable starting point for determining a concentration of concern.

4.1 Analysis of Contamination at Node 31

For the simulation in the absence of disinfectant, contamination at node 31 resulted in pathogen presence at 5 different nodes. These nodes are identified in red in figure 8 below. Only 3 nodes had pathogen presence in the best performing disinfectant simulation.

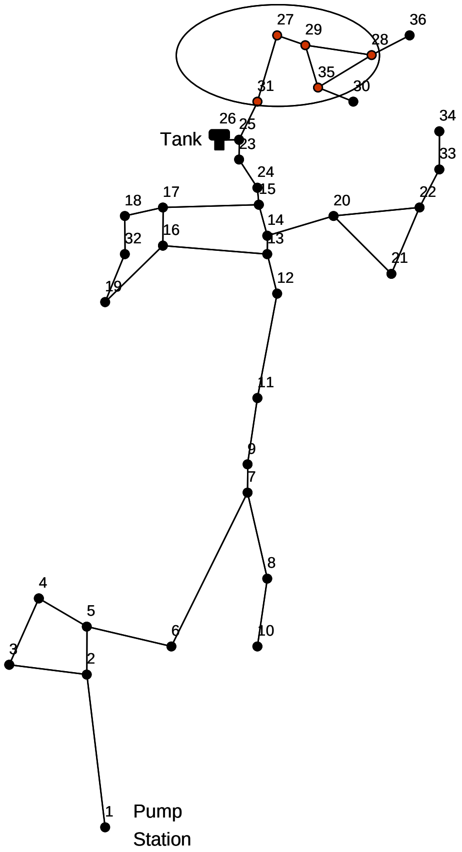

Figure 8: Node 31 Contamination - Contaminated Nodes

Figure 9 shows the pathogen concentration at the affected nodes in a time series plot during the 144 time steps. A total of 118 NT experienced a pathogen concentration during the simulation with no disinfectant. The actual contamination occurred during 39 of these NT, so there was a maximum of 79 contaminated nodes that could be inactivated, or 1.6% of total NT during the 24 hour period. The number of NT with pathogen presence decreased during some model conditions using disinfectant, but the pathogen concentration at every NT in simulations using disinfectant was lower than in the case of no disinfectant.

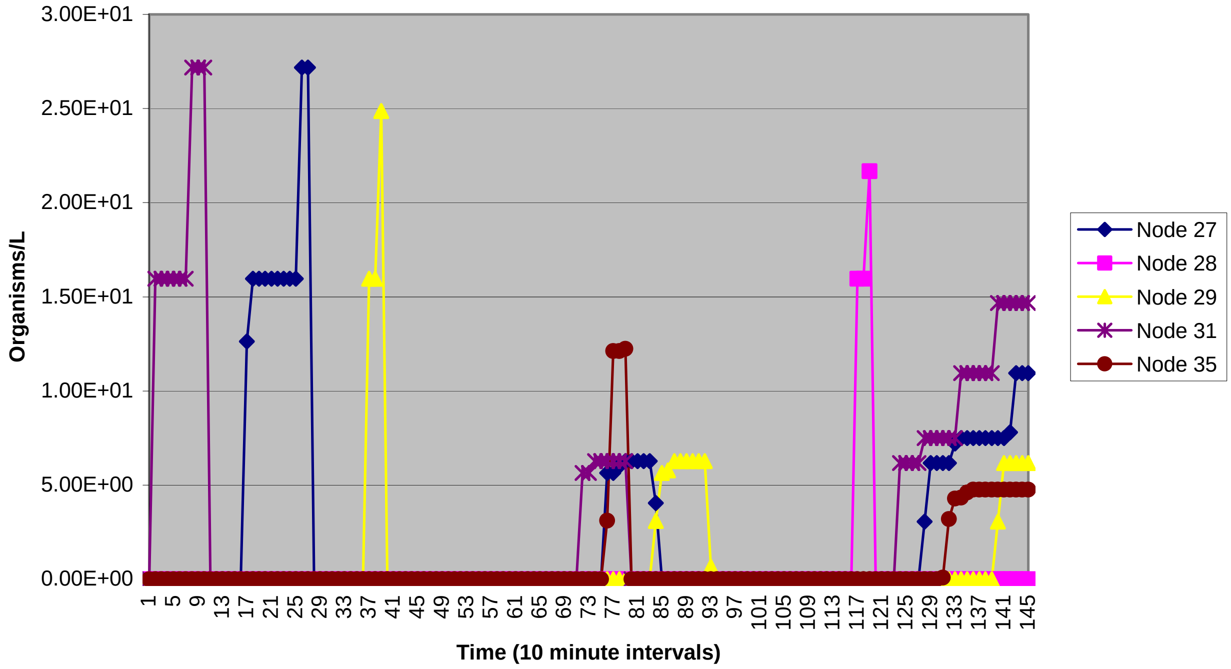

Figure 9: Node 31 Contamination with No Disinfectant

Figures 10 and 11 show the simulations using disinfectant that resulted in the lowest and highest number of NT achieving a 3-log reduction respectively, for the reader to get a better picture of the model output.

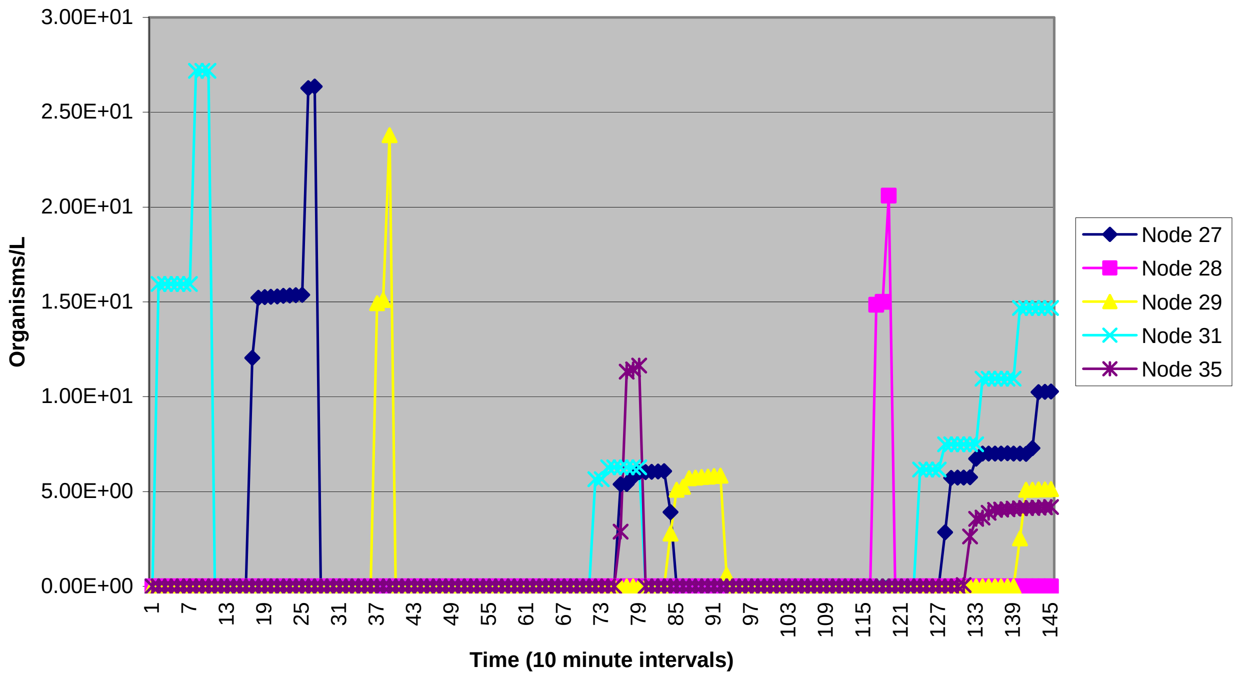

Figure 10: Chlorine, High Decay and Low Inactivation

Figure 10 demonstrates very minor, probably insignificant, improvements over the case with no disinfectant. Figure 11 shows how the greatest pathogen concentrations are present only at the contamination node itself. Although *Giardia* is present at 3 nodes, the concentration is less than 1 organism/L at all NT not including the time steps during which actual contamination occurs.

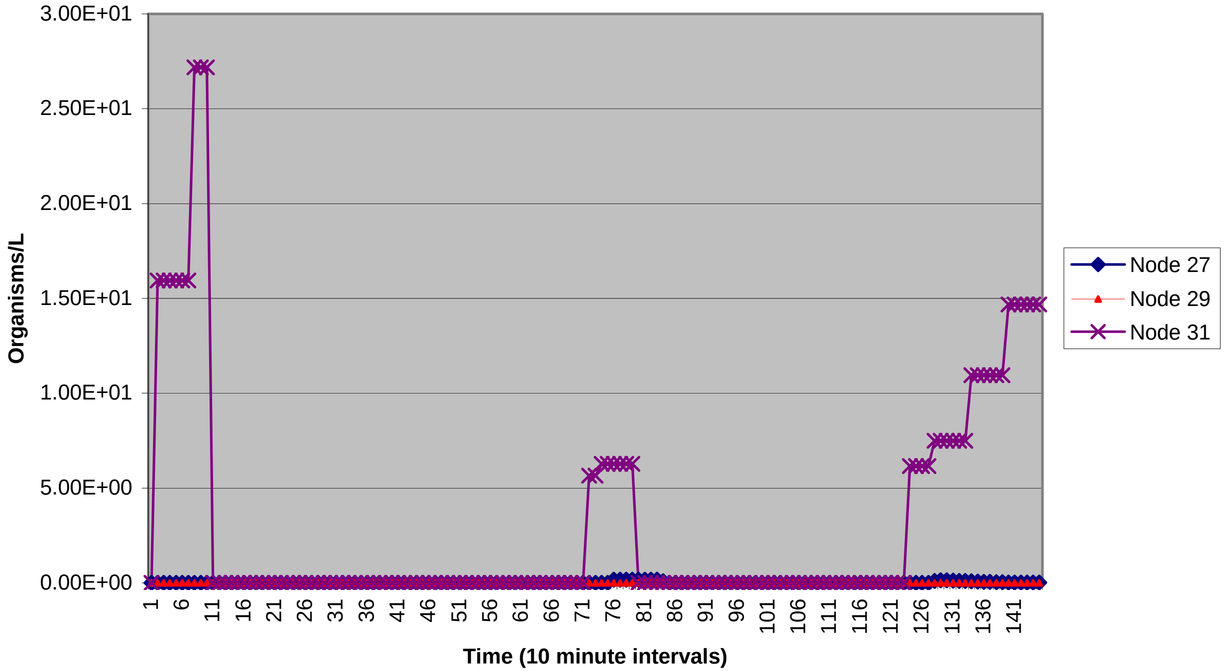

Figure 11: Chlorine, Low Decay and High Inactivation

Figure 12 summarizes the model conditions for both chlorine and chloramines, and the percentage of NT that achieved 3-log inactivation. Several relationships can be easily seen on this figure. To keep this data in perspective, the case with no disinfection results in 2.53% of NT with pathogen presence achieving a 3-log reduction through dilution alone.

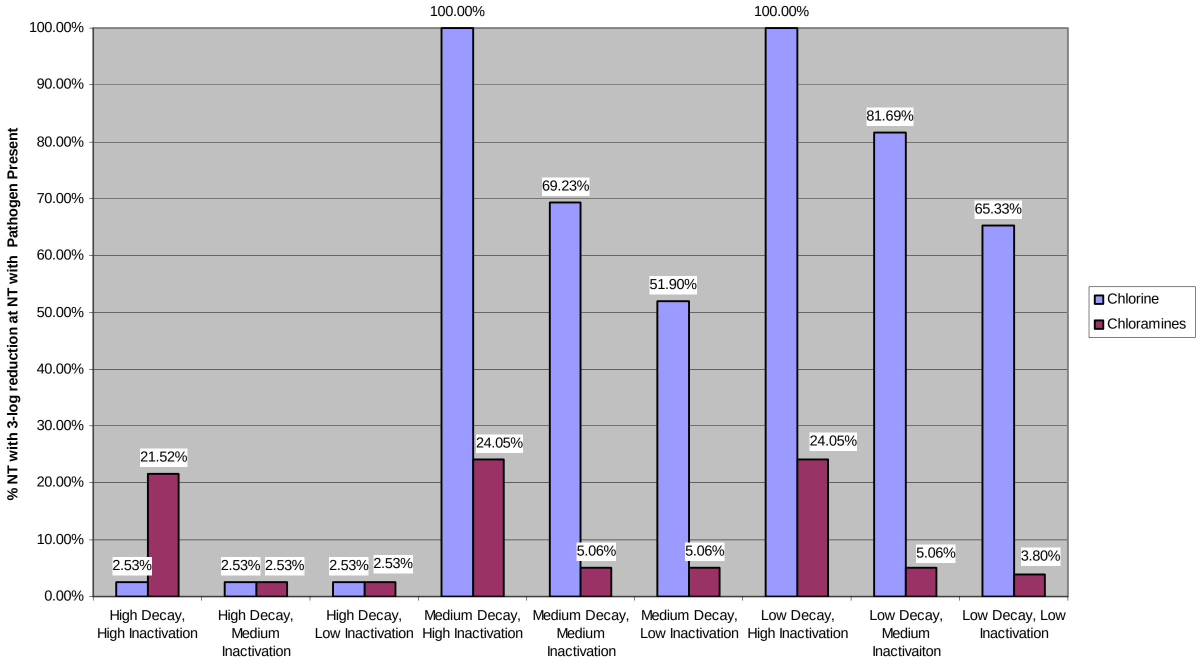

Figure 12: Node 31 Contamination, Chlorine vs. Chloramines

First, figure 12 confirms disinfection and decay theory. The trends in this chart show how, under constant decay conditions, the higher inactivation constants resulted in increased inactivation. This is true for both chlorine and chloramines. This chart also shows how, as the disinfectant decay constant decreases, the percentage of NT with 3-log inactivation increases. This trend was less pronounced for chloramines due to the small range of decay constants.

Second, figure 12 shows that for chlorine, the decay constant appears to control the inactivation results more than the inactivation rate because it determines available disinfectant at each NT. The high chlorine decay, at all inactivation rates, results in almost no 3-log inactivation, whereas medium and low decay results in much higher percentages of 3-log inactivation at all inactivation rates. For chloramines, the inactivation constant seems to control more than decay. Only the high inactivation rate results in a significant amount of 3-log inactivation, but this holds for all three decay scenarios. Third, figure 12 demonstrates that under a majority of conditions, disinfectant presence results in some level of inactivation greater than the case with no disinfectant. However, this benefit may be minimal under certain conditions.

An additional analysis was conducted using the 10^{-4} risk level for *Giardia* of $6.75x10^{-6}$ organisms/L from Regli et al. (1991). This number was used to determine the how many NT were still receiving a concentration of concern after disinfection. This analysis showed that 51 to 79 NT still received an unacceptable concentration after disinfection depending on the model conditions. It is also worthwhile to compare the number of NT affected with the total NT in the simulation. The percentage of NT with a concentration of concern in simulations with disinfectant compared to total NT in the simulation gives an idea of the risk reduction provided by disinfectant throughout the distribution system. Table 14 is a summary of this data, including the model conditions, the number and percent of NT achieving 3-log inactivation, and the NT still receiving an unacceptable dose after disinfection. The percentages displayed do not include the NT during which actual contamination occurred in the distribution system.

Table 14: Summary of Node 31 Contamination Model Conditions and Results

Disinfectant and Dose	Decay	Inactivation	NT with 3-log	% NT affected with 3-log	#NT with unacceptable concentration	% Total NT with unacceptable concentration
1.2 Cl	Low	High	54	100.00%	51	1.02%
1.2 Cl	Low	Medium	58	81.69%	57	1.14%
1.2 Cl	Low	Low	49	65.33%	57	1.14%
2.5 Cl	Medium	High	63	100.00%	60	1.20%
2.5 Cl	Medium	Medium	54	69.23%	60	1.20%
2.5 Cl	Medium	Low	41	51.90%	78	1.56%
5.0 NH2Cl	Medium	High	19	24.05%	79	1.58%
3.0 NH2Cl	Low	High	19	24.05%	79	1.58%
9.0 NH2Cl	High	High	17	21.52%	79	1.58%
5.0 NH2Cl	Medium	Medium	4	5.06%	79	1.58%
5.0 NH2Cl	Medium	Low	4	5.06%	79	1.58%
3.0 NH2Cl	Low	Medium	4	5.06%	79	1.58%
3.0 NH2Cl	Low	Low	3	3.80%	79	1.58%
10.0 Cl	High	High	2	2.53%	79	1.58%
10.0 Cl	High	Medium	2	2.53%	79	1.58%
10.0 Cl	High	Low	2	2.53%	79	1.58%
9.0 NH2Cl	High	Medium	2	2.53%	79	1.58%
9.0 NH2Cl	High	Low	2	2.53%	79	1.58%
No Disinfectant			2	2.53%	79	1.58%

Table 14 shows that in the simulation with no disinfectant, 1.58% of NT receive a *Giardia* concentration of concern. This number is only reduced to 1.02% for the best performing disinfection scenario, for a 0.56% reduction through disinfection. This number will be discussed further in comparison to the other contamination scenario at node 23.

Figure 13 is an additional illustration of these trends in inactivation of node 31 contamination.

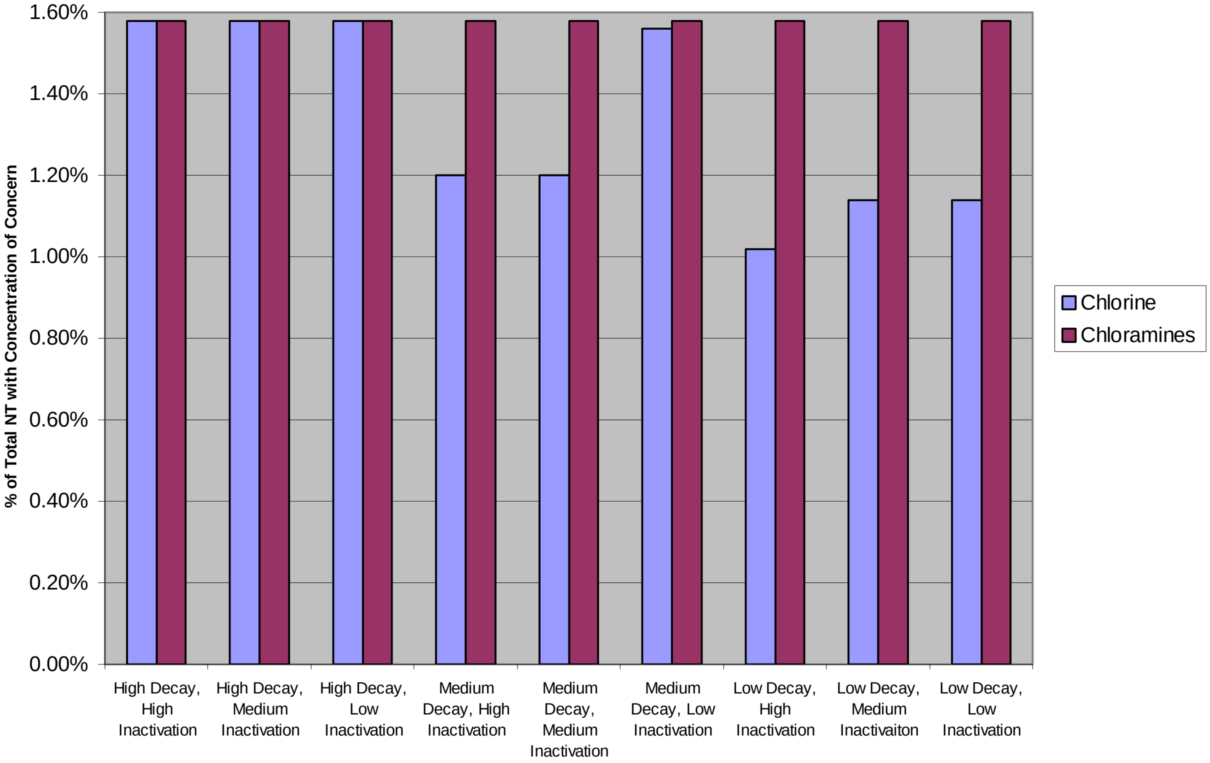

Figure 13: Node 31 Contamination - Percentage of Total NT with Concentration of Concern

Figure 13 shows that none of the chloramines model runs reduced the number of NT with a concentration of concern below the number present in the simulation with no disinfectant. The results also show that chlorine performed better than chloramines, except for the case of high chlorine decay, which had the same results as for chloramines. Figure 14 further examines the effect of disinfectant on inactivation compared to the case with no disinfectant. Figure 14 plots pathogen concentrations at Node 27 during five model runs. Figure 14 shows how the poorest performing disinfectant conditions show some reduction in concentration over the case with no disinfectant, even though they show no difference in the number of NT receiving a concentration of concern. Figure 14 also shows that chloramines even under high decay and low inactivation conditions can outperform chlorine at high decay and high inactivation during some time steps.

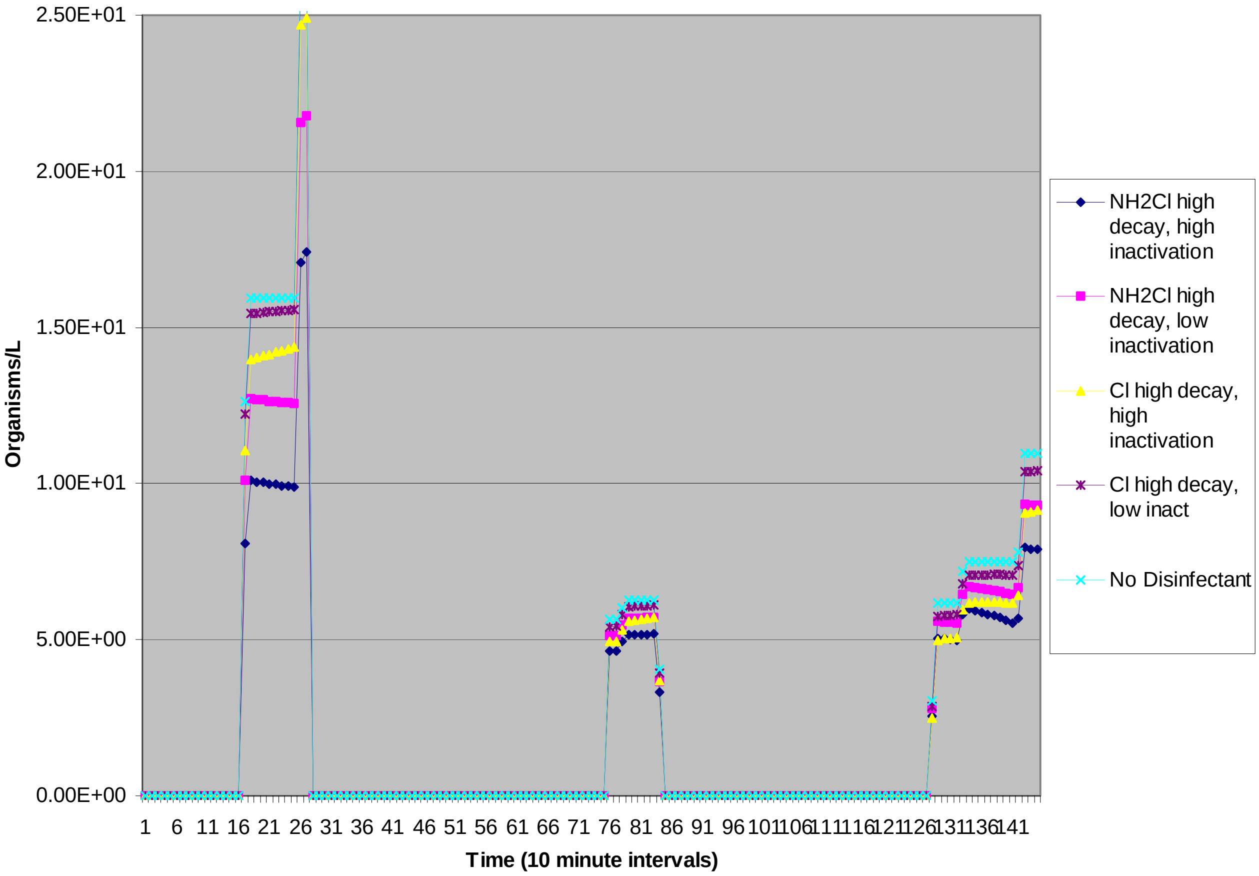

Figure 14: Node 27 Pathogen Concentrations

Figure 14 shows that there may be situations in which chloramines can provide better inactivation of distribution system contamination than chlorine. This shows that in a high chlorine decay environment with regions vulnerable to contamination further out in the distribution system, chloramines could potentially provide more inactivation than chlorine.

A check of these results was completed using the 95th percentile of chlorine decay constants and 95th percentile chlorine dose to compare to the 95th percentile of chloramines (5.71 1/day and 4.8 mg/L respectively). These results showed 18 NT providing 3-log inactivation, which is more comparable to the chloramines results, but still lower than the most effective chloramines simulations. Therefore, the observation that chloramines may achieve more inactivation than chlorine when contamination occurs in the extremities of a distribution system is likely to be real. While the decay and inactivation conditions in this study are not necessarily comparable on a one to one basis as being representative of the same range or conditions, this model suggests that there may be some cases in which chloramines may be a better residual disinfectant than chlorine, making this topic worthy of further investigation.

The model results show that use of disinfectant residual does provide some benefit in contaminant inactivation over the simulations without disinfectant. However, even the best performing disinfectant results in a reduction of only 0.56% in the number of NT receiving a concentration of concern, with 51 NT receiving unacceptable concentrations of contamination. Therefore it is important to consider what kind of disinfectant dose and conditions are necessary for all NT to receive an acceptable, or very low risk, concentration of contamination.

This analysis was completed using chlorine with low decay and high inactivation. Through additional model runs, it was determined that under optimal conditions (low decay and high inactivation) a chlorine dose of 3.5 mg/L would be required to receive an acceptable pathogen concentration at all NT other than the NT that receive the original contamination. This suggests that in cases of medium to low contamination in optimal distribution system conditions, some distribution systems may be able to realize complete benefits of maintaining a disinfectant residual at the levels required by EPA regulations. However, systems with these low decay conditions probably use lower disinfectant doses. Also, these results do not account for additional disinfectant demand that might enter the distribution system with the pathogen concentration.

4.2 Analysis of Contamination at Node 23

Figure 15 below shows the 24 nodes affected by contamination at node 23 during the 24-hour simulation period. A total of 1551 NT experienced pathogen presence during the simulation with no disinfectant. Actual contamination occurred during 53 of these NT, so 1498 NT could experience some reduction in pathogen concentration during simulations using disinfectant. As a result, 30% of total NT were affected in the no disinfectant simulation. The total number of NT with pathogen present ranged down to 1386 in simulations including disinfectant.

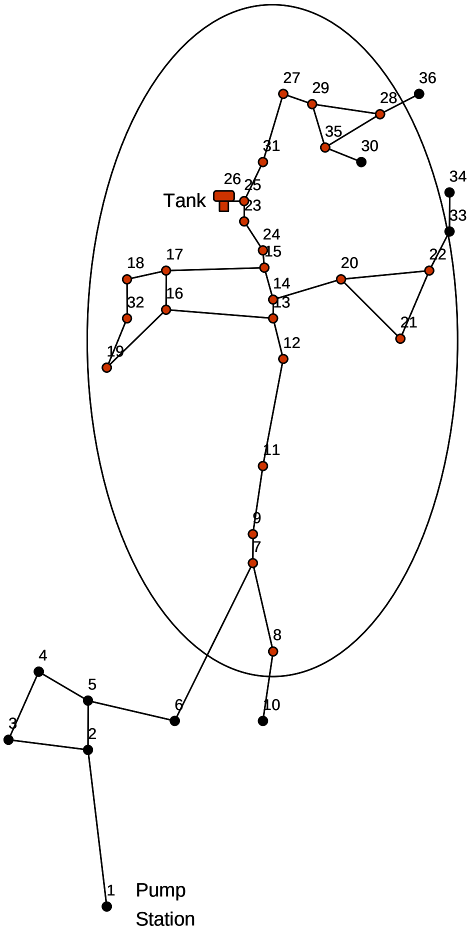

Figure 15: Node 23 Contamination – Contaminated Nodes

Figure 16 shows the contamination at each node during the case with no disinfectant.

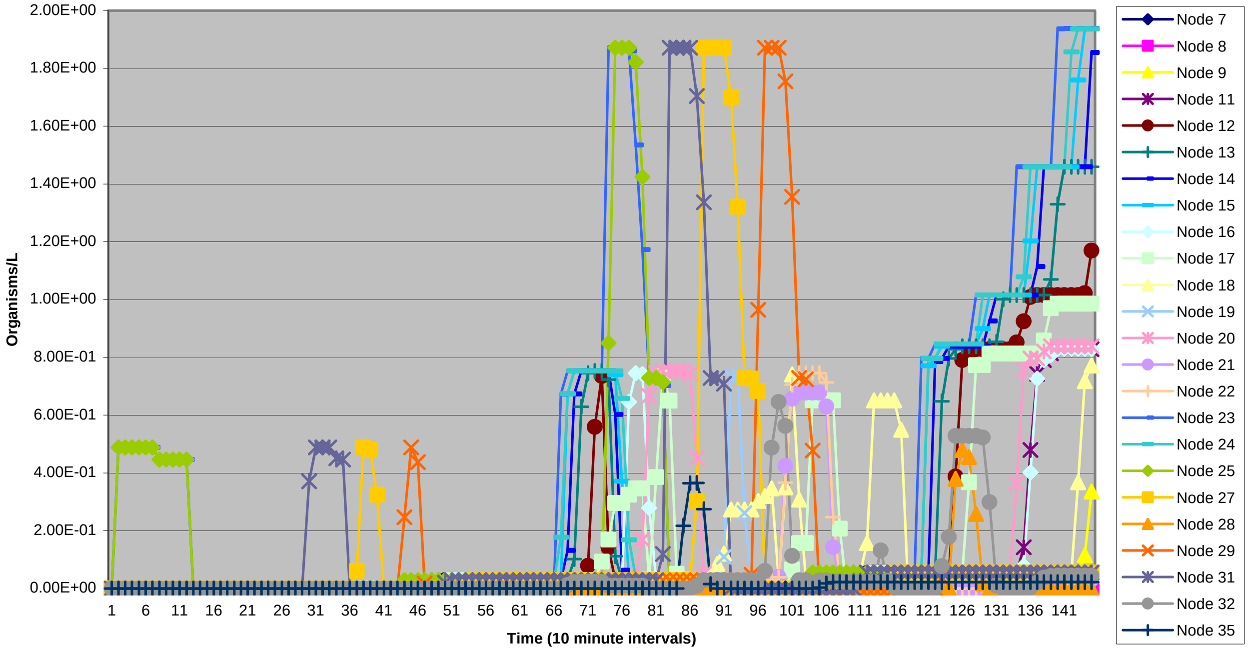

Figure 16: Node 23 Contamination with No Disinfectant

In the simulation with no disinfectant, 1433 NT showed a 3-log reduction through dilution alone. Between 95 and 99% of NT receiving a pathogen concentration achieved 3-log inactivation in the presence of disinfectant. All 24 nodes had some pathogen presence in all simulations. There were many cases in which disinfection resulted in a concentration below the 10^{-4} risk level (Regli et al., 1991). After accounting for these NT, a range of 239 to 1473 NT remained with an unacceptable pathogen concentration after disinfection, with 1485 in the no disinfection case.

Figure 17 compares the number of NT receiving 3-log inactivation for chlorine and chloramines at node 23 under the different model conditions. Again, chlorine outperforms chloramines in the percent of NT receiving 3-log inactivation of pathogens.

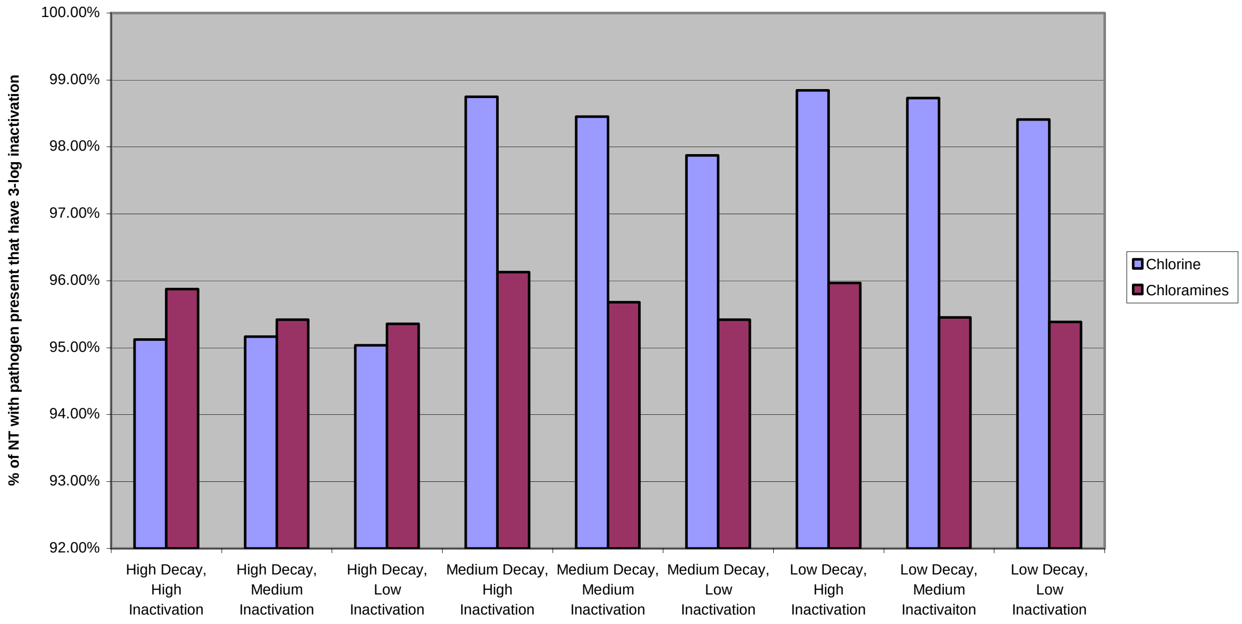

Figure 17: Node 23 Contamination, Chlorine vs. Chloramines

The same trends can be seen here that were identified in Figure 12 for node 31 contamination. Inactivation decreases with decreasing inactivation constant, and inactivation increases with decreasing decay constant. Again, this second relationship is not as strong for chloramines. A more consistent percentage of NT achieve 3-log inactivation in these contamination simulations compared to the node 31 scenario. This is probably due to the fact that much more of the contamination occurs earlier in the distribution system, has longer contact time with higher disinfectant concentrations, and has more opportunity to be diluted in the distribution system. Although it appears here that chloramines was more effective than chlorine under high decay conditions, it is necessary to examine the concentrations of concern to understand the whole story. This is because the calculation for NT achieving 3-log inactivation is based on the number of NT with pathogen present. If inactivation removes all pathogen concentration at a particular NT, it was not included in the calculation and a smaller number of NT achieved 3-log inactivation.

Table 15 ranks the simulations from lowest to highest number of NT that receive a concentration of concern. It is interesting to note that, regardless of the low chlorine disinfectant dose in the low chlorine decay model runs, these simulations consistently outperform higher chlorine doses with higher decay constants. This indicates that the wide range of chlorine decay controls inactivation more than the initial concentration or the inactivation rate because a smaller quantity of disinfectant is available at the beginning of the low and medium decay model runs. For chloramines, due to the smaller range of decay, the inactivation rate appears to play a larger role in determining effectiveness.

Table 15: Summary of Node 23 Contamination Model Conditions and Results

Disinfectant and Dose	Decay	Inactivation	NT with 3-log	% of NT that achieve 3-log	#NT with unacceptable concentration	% of Total NT with unacceptable concentration
1.2 Cl	Low	High	1541	98.85%	239	4.79%
2.5 Cl	Medium	High	1421	98.75%	277	5.55%
1.2 Cl	Low	Medium	1553	98.73%	322	6.46%
2.5 Cl	Medium	Medium	1529	98.45%	370	7.42%
1.2 Cl	Low	Low	1548	98.41%	406	8.14%
2.5 Cl	Medium	Low	1520	97.88%	508	10.19%
10.0 Cl	High	High	1405	95.13%	840	16.84%
10.0 Cl	High	Medium	1476	95.16%	1369	27.45%
10.0 Cl	High	Low	1474	95.04%	1390	27.87%
9.0 NH2Cl	High	High	1487	95.87%	1406	28.19%
5.0 NH2Cl	Medium	High	1491	96.13%	1413	28.33%
9.0 NH2Cl	High	Medium	1480	95.42%	1421	28.49%
3.0 NH2Cl	Low	High	1498	95.96%	1426	28.59%
9.0 NH2Cl	High	Low	1479	95.36%	1437	28.81%
5.0 NH2Cl	Medium	Medium	1484	95.68%	1441	28.90%
5.0 NH2Cl	Medium	Low	1480	95.42%	1455	29.18%
3.0 NH2Cl	Low	Medium	1490	95.45%	1469	29.46%
3.0 NH2Cl	Low	Low	1489	95.39%	1473	29.54%
No Disinfectant			1433	92.39%	1485	29.78%

After observing the number of NT with a concentration of concern, it is clear that the trend of chloramines outperforming chlorine under high decay conditions is not present here as it was in the previous contamination scenario. This shows that high decay chlorine can be an effective disinfectant residual if contamination occurs closer to the entry point of the distribution system. Therefore, it may be appropriate to use chlorine in a high decay distribution system when there are no sensitive subpopulations far out in the distribution system to prevent near entry point contamination from spreading into the distribution system. However, one might choose to rely on chloramines if it is known that sensitive subpopulations are concentrated near the end of the distribution system.

Table 15 shows that in the no disinfectant simulation, 30% of NT receive a *Giardia* dose of concern. This number is reduced to 4.8% for the best performing disinfection scenario, a reduction of up to 25% through disinfection. This reduction in exposure risk is much larger than the 0.6% reduction in the node 31 contamination scenario. Figure 18 is an illustration of these trends.

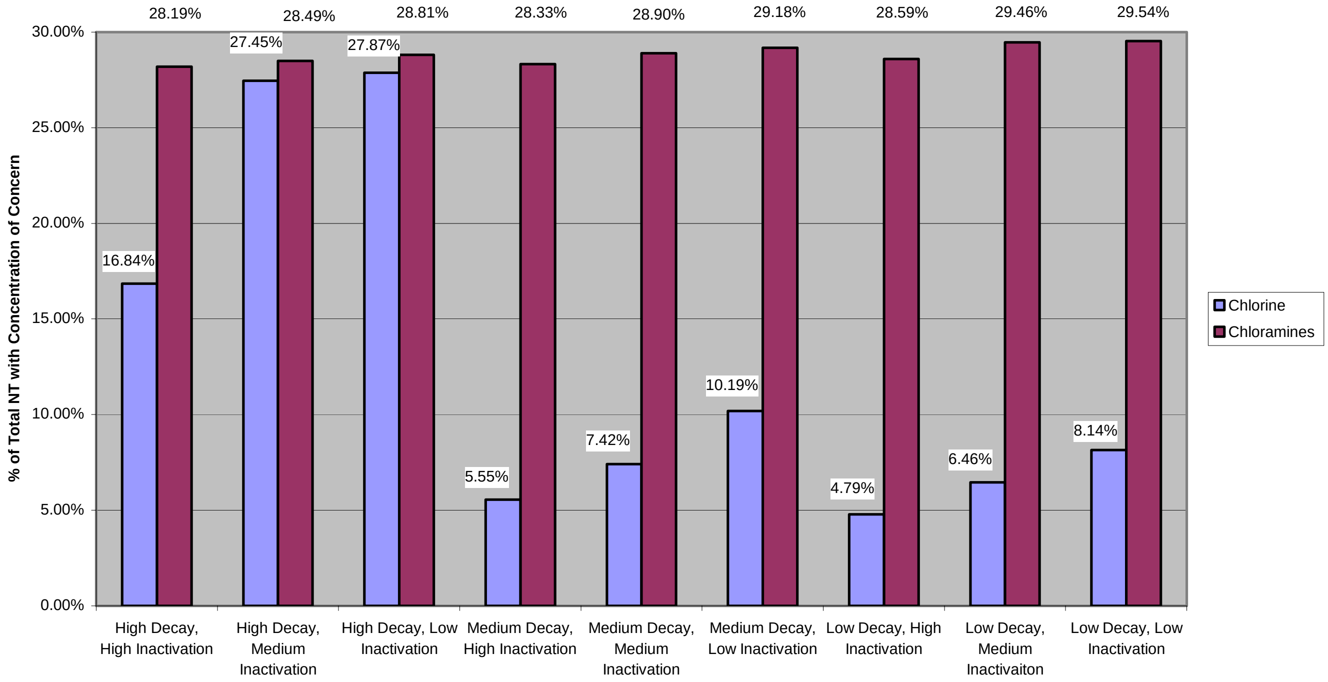

Figure 18: Node 23 Contamination - Percentage of Total NT with Concentration of Concern

These results show that contamination occurring earlier in the distribution system can result in a larger reduction in pathogen concentrations. However, the smallest number of NT receiving an unacceptable concentration of *Giardia* is 239. The chlorine model run with low decay and high inactivation and a contamination input of 50 pathogen/L was examined to determine if under these low input conditions, NT with unacceptable concentrations were still present. The number of NT with unacceptable pathogen concentration for this simulation was 139. The lower concentration input made a difference in the number of NT affected by a concentration of concern, but it did not eliminate all opportunities for consumers to be exposed to the contamination. For the high concentration input, 100,000 pathogen/L, this number was 291.

The two best-case results for node 23 contamination have almost three times the number of NT receiving an unacceptable concentration compared to the number of NT in the worst-case contamination at node 31. Although a larger amount is inactivated, a larger population is still potentially exposed to the contamination. A chlorine dose at the MRDL of 4.0 mg/L under optimum conditions still results in 114 NT with unacceptable concentration. With low decay and high inactivation, a chlorine dose of 5.0 mg/L is required for all NT to receive an acceptable concentration. It is not likely that many distribution systems are operating under conditions of low decay with chlorine doses above the MRDL due to the production of disinfectant byproducts and taste and odor concerns.

4.3 Sensitivity Analysis

Viruses are another category of organisms of concern in distribution systems. Viruses present a special case because, while many species are very sensitive to chlorine, some species are quite resistant to chloramines. They also have a different infectivity dose than *Giardia*. For this reason, additional model runs were completed to examine the range of inactivation constants for viruses. Metcalf and Eddy (2003) presented a range of wastewater concentrations of viruses as 10^3-10^4 MPN/100 mL. Secondary treated effluent ranged from 10^1-10^4 MPN/100 mL. Because of the close overlap with the range presented for *Giardia*, the virus input concentration selected for this sensitivity analysis was the same as for the *Giardia* analyses, 1000 individuals/min. Inactivation constants were derived from the SWTR (USEPA, 1989a) as done for the primary analysis and are presented in Table 16. While the virus CTs for chlorine include a safety factor, the virus CTs for chloramines do not include a safety factor. These were developed for application of chlorine prior to ammonia such that a significant portion of inactivation would be attributed to chlorine alone. Therefore, these CTs represent a best-case scenario for chloramines and may not be representative of conditions within the distribution system.

Table 16: Virus Inactivation Constants

	Temperature (°C)	3 log CT (min·mg/L)	k_p = -Ln(10^-3)/CT (L/mg·min)
Chlorine	5	6	1.1513
	Safety factor of 3:	18	0.3838
	20	2	3.4539
Chloramines	5	1423	0.0049
	20	534	0.0129

The CT values published in the SWTR were developed using laboratory data, and a safety factor of 3 was applied to chlorine CTs to represent different conditions in the field. Sobsey et al. (1991) suggested that cell or solids associated viruses may require chlorine CT values 5 to 10 times the values for disassociated viruses. Sobsey et al. (1991) found this relationship was much weaker for monochloramine. Contamination that enters the distribution system is likely to be associated with cells or solids, so an additional safety factor of 3 was applied to the chlorine CT values to reflect this potential uncertainty. However, the second of the two CTs selected for this study (6 min·mg/L) already reflects a safety factor of 3 applied to the first (2 min·mg/L). No safety factor was included for chloramines inactivation because Sobsey et al. (1991) did not identify a significant relationship.

Regli et al. (1991) identified the 10^{-4} risk level for rotavirus as $2.22\text{x}10^{-7}$ individuals/L. This value was used to analyze the number of NT that received an unacceptable concentration of viral contamination in the different disinfection scenarios. Node 23 contamination was used for this sensitivity analysis due to the larger number of affected nodes compared to node 31 contamination. Table 17 and Figure 19 examine the results of these virus model runs.

Table 17: Virus Model Data

Disinfectant and Dose	Decay (1/day)	Inactivation (L/mg·min)	#NT with unacceptable concentration	%of Total NT with unacceptable concentration
2.5 mg/L Cl	0.96	1.1513	0	0.00%
1.2 mg/L Cl	0.27	1.1513	0	0.00%
2.5 mg/L Cl	0.96	3.4539	0	0.00%
1.2 mg/L Cl	0.27	3.4539	0	0.00%
1.2 mg/L Cl	0.27	0.3838	113	2.27%
2.5 mg/L Cl	0.96	0.3838	179	3.59%
10 mg/L Cl	10.1	3.4539	308	6.18%
10 mg/L Cl	10.1	1.1513	389	7.80%
10mg/L Cl	10.1	0.3838	735	14.74%
5 mg/L NH2Cl	1	0.0129	1373	27.53%
9 mg/L NH2Cl	1.8	0.0129	1385	27.77%
3 mg/L NH2Cl	0.68	0.0129	1418	28.43%
9 mg/L NH2Cl	1.8	0.0049	1453	29.14%
5 mg/L NH2Cl	1	0.0049	1475	29.58%
3 mg/L NH2Cl	0.68	0.0049	1483	29.74%
No disinfectant			1495	29.98%

Table 17 shows that, under certain model conditions using chlorine, no NT beyond the contamination node received a viral dose of concern. However the same contamination scenario using chloramines as the residual disinfectant shows only a minor improvement over the case with no disinfectant. This is due in part to the lower concentration of concern for viruses compared to *Giardia*, because the inactivation rates are in the same range as the inactivation rates considered for chloramines in the *Giardia* contamination simulations. The results of these simulations also show that, depending on the organism, chlorine under high decay conditions can result in a significant amount of contaminant inactivation if no additional disinfectant demand is added with the contamination. Comparatively speaking, chloramines results in a minimal reduction of virus risk in all considered model conditions.

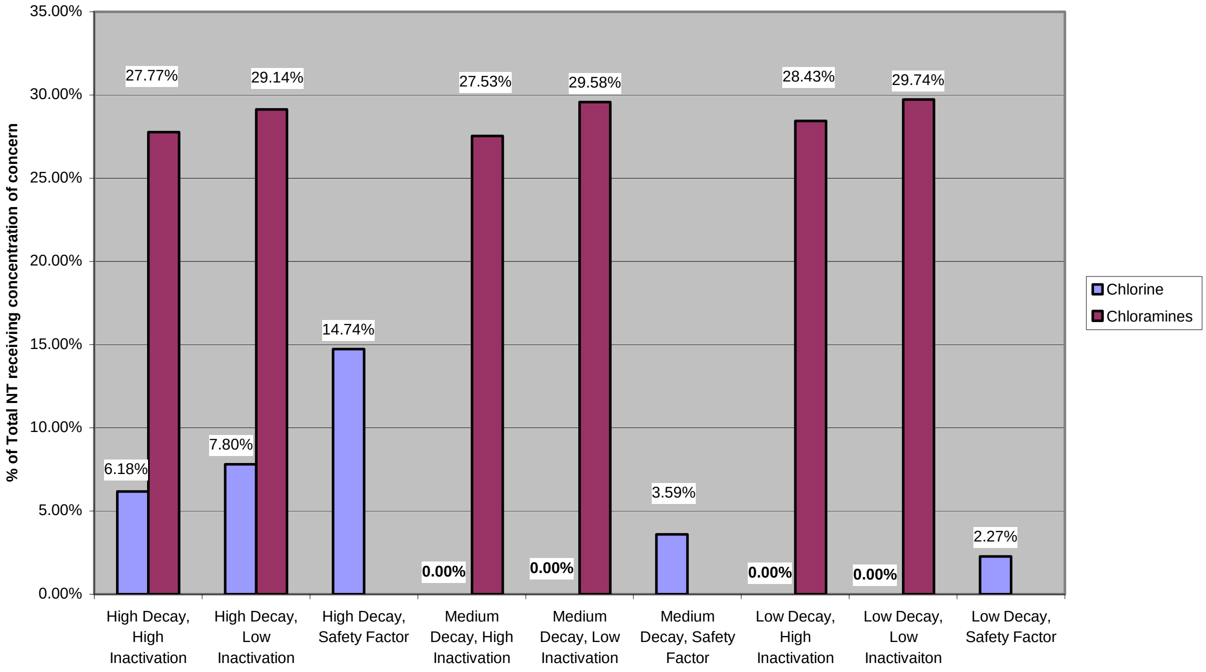

Figure 19: Virus Results - Percentage of NT with Concentration of Concern

4.4 Comparison of Disinfectants

The simulations using no disinfectant are representative of two scenarios in distribution systems, the most obvious one being ground water distribution systems that do not maintain a disinfectant residual. The second case is that of organisms that are entirely resistant to the disinfectant present, such as *Cryptosporidium*. The model runs using *Giardia* can be considered to be representative of *Giardia* contamination, or representative of contamination by any organism that has CT values within the same range. The same interpretation is appropriate for the simulations of virus inactivation. Figure 20 was developed to compare the performance of the different disinfectants at inactivating contamination of different species under different conditions. Different concentrations of concern were used for *Giardia* and viruses to prepare this figure. Table 18 presents the inactivation constants used for this analysis.

Table 18: Organisms and Inactivation Constants

Organism and inactivation	Cl k_p	NH_2Cl k_p
Giardia, 20°C (highest inactivation)	0.1874*C^0.85	0.00628
Giardia, 5°C (lowest inactivation)	0.0662*C^0.85	0.00314
Viruses, 20°C	3.45	0.0129
Viruses, 5°C	1.15	0.0049
Viruses, 5°C safety factor	0.38	****

Figure 20 is a comparison of various disinfectant conditions on different organisms. The figure clearly shows that chloramines does not result in a significant reduction in concentrations of concern over the case with no disinfectant for any organism, under all conditions. However, chlorine use can result in a large range of results depending on distribution system conditions and the organism of interest. Chlorine residual can result in complete inactivation of low resistance organisms such as viruses, but will offer no advantage against resistant organisms such as *Cryptosporidium*. Figure 20 shows that, while disinfectant residual offers some advantage over the case of no disinfectant acting on a low resistance organism, no disinfectant residual provides a benefit against all potential contaminating organisms.

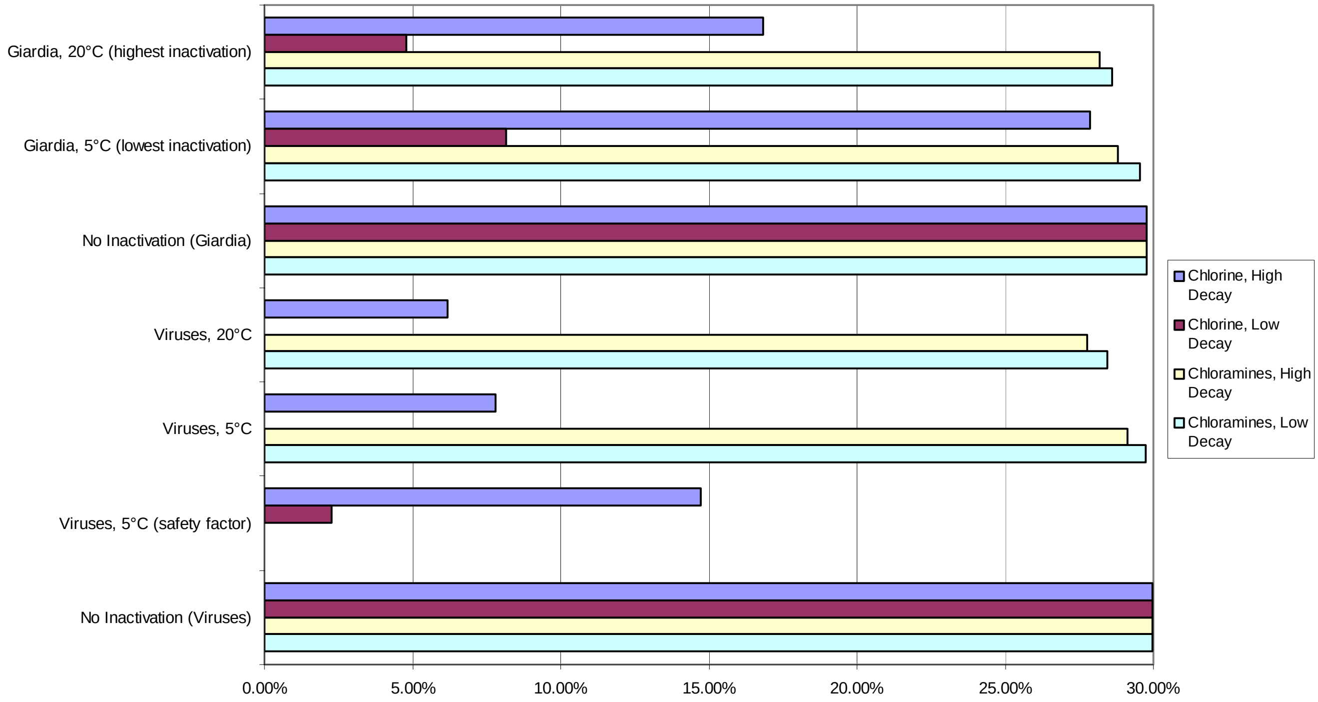

Figure 20: Comparison of Organisms - Percentage of Total NT with Concentration of Concern

4.5 Discussion

The majority of the results show that chlorine is a more effective disinfectant in the distribution system than chloramines, except for in high chlorine decay environments when contamination occurs farther out in the distribution system. In this case alone, chloramines may perform better than chlorine, although the resulting amount of inactivation in either case is low. For chlorine, the rate of disinfectant decay played a greater role in determining the final pathogen concentration in the distribution system than the inactivation rate. The pathogen inactivation rate had more control over the effectiveness of chloramines.

Examination of the time series concentration plots shows that the nodes in close proximity to the contamination are most likely to experience the highest exposure to the contamination. The further a node is from the node of contamination, the lower the contaminant concentration is at that node. This phenomenon is magnified when more effective disinfectant conditions exist, and more distant nodes may no longer receive a contaminant concentration of concern. The nodes adjacent to the actual contamination are the most challenging locations for inactivating a sufficient quantity of contaminant. In the *Giardia* simulations, a contaminant concentration below the concentration of concern at nodes adjacent to contamination was only possible at disinfectant doses and distribution system conditions that are unlikely in real life. For virus simulations, adjacent nodes in some chlorine model runs received no contamination at all.

Contamination closer to the entry point will affect more NT because it can be transported through a larger portion of the distribution system. It also can have more exposure to disinfectant because it is closer to the disinfectant entry point. This gives the contamination more potential to reach more consumers, but more opportunity to be inactivated by disinfectant. Contamination originating further in the distribution system affects a smaller number of NT and a smaller population, but it has less disinfectant available to inactivate contamination due to decay during travel through the system.

The combination of very high chlorine decay with low inactivation makes a very high dose of chlorine almost no different than no disinfectant when contamination occurred at a node far out in the distribution system. Chloramines under this condition was actually more effective at inactivation because it did not decay as rapidly.

In terms of the percent of contaminated nodes achieving inactivation, comparison of node 23 and 31 results shows that disinfectant is less likely to be effective when contamination exists further into the distribution system, especially when there is high decay. The total reduction of exposure opportunities (NT) was much greater for node 23 contamination (25%) than for node 31 contamination (0.56%), resulting in a much larger reduction from the overall potential exposure. Therefore, it may be appropriate to choose a disinfectant residual that will result in more inactivation closer to the entry point rather than one that will last longer in the distribution system but not achieve the same reduction in exposures of concern. This decision would be based solely on the potential population exposed to near entry point contamination. One situation in which this strategy may be inappropriate might be when known sensitive subpopulations exist farther out in the distribution system. For that situation a more persistent disinfectant residual or use of a booster station may be more appropriate management strategies.

A significant number of NT received 3-log inactivation in both contamination scenarios for several of the model conditions compared to the case with no disinfectant. This modeling effort demonstrated that chlorine or chloramines presence in the distribution system under all conditions does result in some inactivation benefit over no disinfectant at all when considering susceptible organisms. The range of this benefit can vary widely depending on the contaminating organism, distribution system conditions and disinfectant present. However, at conditions typical of distribution system operation, few simulations prevented all potential exposure to contamination. Therefore, disinfectant residual present in the distribution system can be expected to reduce the magnitude of most microbial contamination events, but it should not be expected to prevent all exposure to the contamination.

Assumptions and simplifications made for this investigation may affect its reflection of reality. There are four important distribution system assumptions to note. First, one bulk decay constant was used to represent the entire distribution system. Pipes in real distribution systems are typically made of a variety of materials, all of which have a different decay effect on disinfectant. These materials can have an additional effect when wall decay becomes significant. Second, the performance of the tank was not analyzed for this study. Tank operations can have a significant effect on water age and water quality. Third, it was assumed that the contaminating water had no disinfectant demand associated with the *Giardia*. Finally, this model assumed that the pressurized cross-connection adding contamination to the distribution system experienced high operating pressures at the same time the distribution system experienced low pressures. Although the assumed operating pressures were in a realistic range, it may not be realistic to assume that the two extremes coincide for the entire duration of each extreme. Further investigations can be made in these areas to better refine these assumptions, look at alternative contaminants, and investigate alternative decay and inactivation models. Study of a different distribution system with more looping might better represent actual distribution systems because many systems are adding loops to improve water quality and decrease water age.

Work of this nature is important because it begins to explain the potential impacts of distribution system contamination on public health. Further study of simultaneous contaminant entry points might provide a better estimate of real life contamination scenarios. It would also be useful to examine intrusion contamination resulting from pressure transients to determine the potential magnitude of that contamination scenario. In addition to applying this approach to other contamination pathways, this approach can be extended to estimate the actual risk to a consumer of drinking water that was contaminated in the distribution system. An estimate of exposure risk in the presence of disinfectant residuals would inform what next steps are necessary to assure the delivery of safe drinking water to consumers' taps.

The purpose of this project was to investigate only one of three purposes for which disinfectants are used. From this analysis it was determined that both chlorine and chloramines used as disinfectant residuals under conditions typical of distribution systems will provide some inactivation of distribution system contamination by susceptible organisms. However, at doses typically used, neither chlorine nor chloramines can be assumed to eliminate the risk of exposure to distribution system contamination. Further study of disinfectant residuals for biofilm control and as an indicator of contamination are necessary for a complete evaluation of the effectiveness of disinfectant residuals. A model using a similar approach could be used to evaluate the effectiveness of disinfectant residuals as an indicator of contamination, but significant modifications would be necessary to evaluate the effectiveness of disinfectant residuals for controlling biofilms.

5.0 CONCLUSIONS

Although the results of this study are specific to the distribution system studied, several trends were observed that apply to most distribution systems. First, chlorine inactivation had a wide range of results, ranging from inactivation of all contamination in the case of viruses to no inactivation at all in the case of *Cryptosporidium*. Similarly, high chlorine decay resulted in significant inactivation in near entry point contamination, but it resulted in very little inactivation when contamination occurred farther out in the distribution system. On the other hand, chloramines never resulted in a significant reduction in concentrations of concern.

Second, it was observed that all model runs examining contamination by an organism susceptible to chlorine or chloramines resulted in a reduction in concentration of organisms over the case with no disinfectant. In some cases this reduction was significant, such as four chlorine and virus simulations that resulted in no concentrations of concern in the distribution system. In other cases this reduction was very small.

Third, nodes closest to the contaminated node were at greatest risk of receiving a concentration of concern of the contaminating organism. The greatest potential for exposure in the distribution system occurred when contamination occurred near the entry point. However, this scenario also allowed the largest opportunity for inactivation because it was closer to the disinfectant entry point and had longer exposures to higher concentrations of disinfectant.

Finally, these results suggest that selection of a disinfectant residual for a particular distribution system would depend on the management objective. Different disinfectant residual strategies would be selected if the system is managing to control a particular organism of concern, to achieve the greatest reduction in potential exposures, or to protect sensitive subpopulations. In the first case, if a system is concerned about resistant organisms such as *Cryptosporidium*, a different management strategy from disinfectant residuals may be necessary. In the second case, the system would want to target near entry point contamination and use chlorine, which resulted in a much greater reduction in potential exposures than chloramines. In the last case, the system would target persistence in the distribution system, using either chloramines or booster disinfection in the distribution system.

6.0 SUMMARY

In many drinking water systems in the United States, disinfectant is added to water as it leaves the plant to maintain a residual concentration in the distribution system. The disinfectant residual is maintained to inactivate contamination that enters the distribution system, to control biofilms, and to act as a sentinel for contamination in the distribution system. This investigation modeled contamination of a hypothetical distribution system through backpressure at a cross-connection under different operating conditions to determine effectiveness of disinfectant residuals at inactivating contamination in the distribution system. The dilution, die-off, inactivation, and pathway of the hypothetical contaminant were examined as the contamination moved through the system. Disinfection and inactivation kinetic relationships under a variety of typical operating conditions were used to model the inactivation of the contaminant in the system by the amount of disinfectant present after decay.

The model showed that both chlorine and chloramines under each decay and inactivation condition considered provided some benefit over no disinfectant at all. Chlorine under medium and low decay conditions provided the best inactivation. Where 29.8% of total node time steps received a contamination of concern in the absence of disinfectant residual, as low as 4.8% of total node time steps received a contamination of concern in the presence of disinfectant residual. Chloramines was found to persist longer in the distribution system, but resulted in much lower inactivation compared to chlorine. The two different contamination scenarios investigated indicated that there may be some situations where chloramines could provide better disinfection than chlorine if distribution system conditions contribute to high chlorine decay.

Disinfectant doses typical of common distribution system operation were able to reduce the impact of contamination once it entered the distribution system but, except for four cases, were unable to prevent contamination from spreading within the distribution system. Therefore, it was concluded that presence of a disinfectant residual will reduce the total number of exposure opportunities from a contamination event, but cannot be relied upon to eliminate the chance of exposure resulting from contamination.

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8.0 APPENDICES

Appendix A: Input File

```
[TITLE]
EPANET Example Network 2

[JUNCTIONS]
;ID               Elev              Demand            Pattern
 1                50                -694              2                 ;
 2                100               8                                   ;
 3                60                14                                  ;
 4                60                8                                   ;
 5                100               8                                   ;
 6                125               5                                   ;
 7                160               4                                   ;
 8                110               9                                   ;
 9                180               14                                  ;
 10               130               5                                   ;
 11               185               34.78                               ;
 12               210               16                                  ;
 13               210               2                                   ;
 14               200               2                                   ;
 15               190               2                                   ;
 16               150               20                                  ;
 17               180               20                                  ;
 18               100               20                                  ;
 19               150               5                                   ;
 20               170               19                                  ;
 21               150               16                                  ;
 22               200               10                                  ;
 23               222               8                                   ;
 24               190               11                                  ;
 25               210               6                                   ;
 27               175               8                                   ;
 28               110               0                                   ;
 29               110               7                                   ;
 30               130               3                                   ;
 31               221               17                                  ;
 32               110               17                                  ;
 33               180               1.5                                 ;
 34               190               1.5                                 ;
 35               140               0                                   ;
 36               110               1                                   ;

[RESERVOIRS]
;ID               Head              Pattern

[TANKS]
;ID               Elevation         InitLevel         MinLevel
      MaxLevel          Diameter          MinVol            VolCurve
 26               210               56.7              50                70
      50                0                                   ;

[PIPES]
```

```
;ID               Node1             Node2             Length
      Diameter          Roughness         MinorLoss         Status
 1                1                 2                 2400              12
      100               0                 Open          ;
 2                2                 5                 800               12
      100               0                 Open          ;
 3                2                 3                 1300              8
      100               0                 Open          ;
 4                3                 4                 1200              8
      100               0                 Open          ;
 5                4                 5                 1000              12
      100               0                 Open          ;
 6                5                 6                 1200              12
      100               0                 Open          ;
 7                6                 7                 2700              12
      100               0                 Open          ;
 8                7                 8                 1200              12
      140               0                 Open          ;
 9                7                 9                 400               12
      100               0                 Open          ;
 10               8                 10                1000              8
      140               0                 Open          ;
 11               9                 11                700               12
      100               0                 Open          ;
 12               11                12                1900              12
      100               0                 Open          ;
 13               12                13                600               12
      100               0                 Open          ;
 14               13                14                400               12
      100               0                 Open          ;
 15               14                15                300               12
      100               0                 Open          ;
 16               13                16                1500              8
      100               0                 Open          ;
 17               15                17                1500              8
      100               0                 Open          ;
 18               16                17                600               8
      100               0                 Open          ;
 19               17                18                700               12
      100               0                 Open          ;
 20               18                32                350               12
      100               0                 Open          ;
 21               16                19                1400              8
      100               0                 Open          ;
 22               14                20                1100              12
      100               0                 Open          ;
 23               20                21                1300              8
      100               0                 Open          ;
 24               21                22                1300              8
      100               0                 Open          ;
 25               20                22                1300              8
      100               0                 Open          ;
 26               24                23                600               12
      100               0                 Open          ;
 27               15                24                250               12
      100               0                 Open          ;
```

```
 28                23                25                300               12
      100                0                 Open          ;
 29                25                26                200               12
      100                0                 Open          ;
 30                25                31                600               12
      100                0                 Open          ;
 31                31                27                400               8
      100                0                 Open          ;
 32                27                29                400               8
      100                0                 Open          ;
 34                29                28                700               8
      100                0                 Open          ;
 35                22                33                1000              8
      100                0                 Open          ;
 36                33                34                400               8
      100                0                 Open          ;
 37                32                19                500               8
      100                0                 Open          ;
 38                29                35                500               8
      100                0                 Open          ;
 39                35                30                1000              8
      100                0                 Open          ;
 40                28                35                700               8
      100                0                 Open          ;
 41                28                36                300               8
      100                0                 Open          ;

[PUMPS]
;ID               Node1             Node2             Parameters

[VALVES]
;ID               Node1             Node2             Diameter          Type
      Setting           MinorLoss

[TAGS]

[DEMANDS]
;Junction         Demand            Pattern           Category

[STATUS]
;ID               Status/Setting

[PATTERNS]
;ID               Multipliers
;Demand Pattern
 1                0.46              .27               .31               .33
      .39               .83
 1                1.38              1.58              1.67              1.51
      1.46              1.3
 1                1.17              1.14              1.1               1.11
      1.25              1.37
 1                1.29              1.27              1.19              0.98
      .67               0.5
;Pump Station Outflow Pattern
 2                .96               .96               .96               .96
      .96               .96
```

```
 2               .62             0               0               0
     0               0
 2               .8              1               1               1
     1               .15
 2               0               0               0               0
     0               0

[CURVES]
;ID              X-Value         Y-Value

[CONTROLS]

[RULES]

[ENERGY]
 Global Efficiency      75
 Global Price           0.0
 Demand Charge          0.0

[EMITTERS]
;Junction        Coefficient

[QUALITY]
;Node            InitQual

[SOURCES]
;Node            Type            Quality         Pattern
1           2           5.0


[REACTIONS]
 Order Bulk             1
 Order Tank             1
 Order Wall             1
 Global Bulk            -0.42
 Global Wall            0.0
 Limiting Potential     0.0
 Roughness Correlation  0.0

[MIXING]
;Tank            Model

[TIMES]
 Duration               360
 Hydraulic Timestep     0:10
 Quality Timestep       0:05
 Pattern Timestep       1:00
 Pattern Start          0:00
 Report Timestep        1:00
 Report Start           0
 Start ClockTime        12 am
 Statistic              None

[REPORT]
 Status                 No
 Summary                No
 Page                   0
```

```
[OPTIONS]
 Units                  GPM
 Headloss               H-W
 Specific Gravity       1.0
 Viscosity              1.0
 Trials                 40
 Accuracy               0.001
 Unbalanced             Continue 10
 Pattern                1
 Demand Multiplier      1.0
 Emitter Exponent       0.5
 Quality                Chemical mg/L
 Diffusivity            1.0
 Tolerance              0.01
 NumSpecies             2

[COORDINATES]
;Node             X-Coord           Y-Coord
 1                21.00             4.00
 2                19.00             20.00
 3                11.00             21.00
 4                14.00             28.00
 5                19.00             25.00
 6                28.00             23.00
 7                36.00             39.00
 8                38.00             30.00
 9                36.00             42.00
 10               37.00             23.00
 11               37.00             49.00
 12               39.00             60.00
 13               38.00             64.00
 14               38.00             66.00
 15               37.14             69.18
 16               27.00             65.00
 17               27.00             69.00
 18               23.00             68.00
 19               21.00             59.00
 20               45.00             68.00
 21               51.00             62.00
 22               54.00             69.00
 23               35.00             74.00
 24               37.00             71.00
 25               35.00             76.00
 27               39.00             87.00
 28               49.00             85.00
 29               42.00             86.00
 30               47.00             80.00
 31               37.00             80.00
 32               23.00             64.00
 33               56.00             73.00
 34               56.00             77.00
 35               43.33             81.56
 36               53.00             87.00
 26               33.00             76.00

[VERTICES]
```

```
;Link              X-Coord           Y-Coord

[LABELS]
;X-Coord            Y-Coord          Label & Anchor Node
 24.00             7.00             "Pump"
 24.00             4.00             "Station"
 26.76             77.42            "Tank"

[BACKDROP]
 DIMENSIONS        8.75              -0.15             58.25             91.15
 UNITS             None
 FILE
 OFFSET            0.00              0.00

[END]
```

Appendix B: Program Code

```
#include <stdlib.h>
#include "epanet2.h"
#include <stdio.h>
#include <malloc.h>
#include <iostream.h>

char * epainpfile = "thesis.inp", * eparptfile = "rpt";
long tstep;
int i, hstep, nodetype;
int wrncnt, status = 0, version;
int nnodes, nlinks, ntanks, njunctions;
int qualcode, tracenode;
float value;
long time, starttime, rstep;
FILE *nodewq1;
FILE *nodewq2;
FILE *nodedemand;
FILE *nodep;
FILE *tankwq1;
FILE *tankwq2;
FILE *tankdemand;
FILE *tankh;
char atime[10];
char nodeid[16];
float TimeTracking[300];

void Terminate();
char *clocktime(char *atime, long time);
void StartFiles();
void Hydraulic(float lowerbound, float pathogen);
void Quality();

#define MOD(x,y) ((x)%(y))

int main()
{
	StartFiles();
	float lowerbound;			// set desired lower bound of pressure
						//  intrusion happens at pressures lower than this value
	lowerbound = 20;
	cout << endl;
	float pathogen;		// set strength of intruding water
	cout << "Enter the concentration in mg/L of intruding pathogens: ";
	cin >> pathogen;
	cout << endl;
	Hydraulic(lowerbound, pathogen);
	Quality();
	return 0;
}

void Hydraulic(float lowerbound, float pathogen)
{
	 /****************************************************/
```

```
/* This block performs the hydraulic simulation      */
/**************************************************/
status = ENopenH();
if (status) Terminate();
ENinitH(1);
hstep = 0;
wrncnt = 0;

int j = 0;

printf("Computing network hydraulics at time = ");
do
{
        status = ENrunH(&time);
        if (status)
        {
                if (status < 100) wrncnt++;
                else Terminate();
        }

  printf("%-7s", clocktime(atime, time));
  if (time >= 1209600)  // only write to files after system equilibrates
        {
                fprintf(nodedemand,"%10d ",time);
                fprintf(nodep,"%10d ",time);
                fprintf(tankdemand,"%10d ",time);
                fprintf(tankh,"%10d ",time);

                  /* Write the junction node and tank demands and pressures/heads */
                  for (i = 0; i < nnodes; i++)
                {
                        status = ENgetnodetype(i+1, &nodetype);
                        if(status) Terminate();
                        if (nodetype == EN_JUNCTION)
                        {
                          status = ENgetnodevalue(i+1, 1, EN_DEMAND, &value);
                         if(status) Terminate();
                         fprintf(nodedemand,"%13e ",value);

                         status = ENgetnodevalue(i+1, 1, EN_PRESSURE, &value);
                         if(status) Terminate();

                         if (i+1==23)                  // check pressure at cross-connection node 23
                        {
                                 float healthy = 0.0;
                                 if (value < lowerbound)
                                {         // record source quality for each time step
                                    TimeTracking[j] = pathogen;
                                    cout << TimeTracking[j] << endl;
                                }

                                else
                                {         //if pressure increases above lowerbound, pathogen input is 0
                                        TimeTracking[j] = healthy;
                                        cout << "the toilet is off now " << TimeTracking[j] << endl;
                                }
```

```
                              }

                    fprintf(nodep,"%13e ",value);
                    }

                    else if (nodetype == EN_TANK)
                    {
                               status = ENgetnodevalue(i+1, 1, EN_DEMAND, &value);
                              if(status) Terminate();
                              fprintf(tankdemand,"%13e ",value);

                              status = ENgetnodevalue(i+1, 1, EN_HEAD, &value);
                              if(status) Terminate();
                              fprintf(tankh,"%13e ",value);
                    }
          }
          fprintf(nodedemand,"\n");
          fprintf(nodep,"\n");
          fprintf(tankdemand,"\n");
          fprintf(tankh,"\n");
           j++;                                  // count once for each time step while recording to files
   }

   status = ENnextH(&tstep);
   if (status)
  {
     if (status < 100) wrncnt++;
     else Terminate();
   }
   printf("\b\b\b\b\b\b\b");
 }
while (tstep > 0);

printf("\n");

printf("Closing EPANET Hydraulic Simulator\n");
ENcloseH();

if (wrncnt)
{
   printf("One or more warnings occurred during the hydraulic\n");
   printf("analysis.  Check the EPANET output file.\n");
 }

}


void Quality()
{
           /**********************************************************/
 /* This block performs the water quality simulations        */
 /**********************************************************/

 status = ENgetqualtype(&qualcode, &tracenode);
 if (status) Terminate();
 if (qualcode == EN_NONE) Terminate();
```

```
/* Initialize EPANET quality simulation */
status = ENopenQ();
if (status) Terminate();
ENinitQ(0);
wrncnt = 0;
int j=0;

printf("Performing water quality analysis at time = ");
do
{
  status = ENrunQ(&time);
  if (status)
  {
    if (status < 100) wrncnt++;
    else Terminate();
  }

  printf("%-7s", clocktime(atime, time));
  if (time >= 1209600) // only write to files after system has equilibrated
 {
    fprintf(nodewq1,"%10d ",time);
    fprintf(nodewq2,"%10d ",time);
    fprintf(tankwq1,"%10d ",time);
    fprintf(tankwq2,"%10d ",time);
    /* Write the node and tank quality data */

// at each time step, set source quality based on pressure at node
status = ENsetnodevalue(23, 1, EN_SOURCETYPE, 1);
status = ENsetnodevalue(23, 1, EN_SOURCEQUAL, TimeTracking[j]);
cout << "Source Quality is " << TimeTracking[j] << endl;


for (i = 0; i < nnodes; i++)
{
      status = ENgetnodetype(i+1, &nodetype);
      if(status) Terminate();
      if (nodetype == EN_JUNCTION)
     {
        status = ENgetnodevalue(i+1, 1, EN_QUALITY, &value);
        if(status) Terminate();
        fprintf(nodewq1,"%13e ",value);

        status = ENgetnodevalue(i+1, 2, EN_QUALITY, &value);
        if(status) Terminate();
        fprintf(nodewq2,"%13e ",value);
     }

      else if (nodetype == EN_TANK)
      {
        status = ENgetnodevalue(i+1, 1, EN_QUALITY, &value);
        if(status) Terminate();
        fprintf(tankwq1,"%13e ",value);

        status = ENgetnodevalue(i+1, 2, EN_QUALITY, &value);
        if(status) Terminate();
```

```
          fprintf(tankwq2,"%13e ",value);
          }
      }
                fprintf(nodewq1,"\n");
                fprintf(nodewq2,"\n");
                fprintf(tankwq1,"\n");
                fprintf(tankwq2,"\n");
                j++;
    }

    status = ENnextQ(&tstep);
    if (status)
    {
      if (status < 100)
        wrncnt++;
      else Terminate();
    }

    printf("\b\b\b\b\b\b\b");

  } while (tstep > 0);
  printf("\n");

  printf("Closing EPANET WQ Simulator\n");
  ENcloseQ();

  /* Check for errors and issue warnings */
  if (wrncnt)
  {
      printf("\nOne or more warnings occurred during the water quality\n");
      printf("analysis, check EPANET output file\n");
  }

  return;
}

char *clocktime(char *atime, long time)
{
  int h, m;
  h = time/3600;
  m = (time%3600)/60;
  sprintf(atime, "%01d:%02d", h, m);
  return(atime);
}

void Terminate()
{    /* Terminate epanet */
  ENclose();
    printf("Error conditions resulted in abnormal termination\n");
    return;
}

void StartFiles()
{printf("Initializing EPANET \n");

    /* Open EPANET on input file */
```

```
 status = ENopen(epainpfile, eparptfile, "");
 printf("Trying EPANET \n");

 if (status) Terminate();

  /* Open output files */
 nodewq1 = fopen("nodewaterquality1.doc", "wt");
 if (nodewq1 == NULL) Terminate();
 nodewq2 = fopen("nodewaterquality2.doc", "wt");
 if (nodewq2 == NULL) Terminate();

 nodedemand = fopen("nodedemand.doc", "wt");
 if (nodedemand == NULL)  Terminate();
 nodep = fopen("nodepressure.doc", "wt");
 if (nodep == NULL)  Terminate();

 tankwq1 = fopen("tankquality1.doc", "wt");
 if (tankwq1 == NULL)  Terminate();

 tankwq2 = fopen("tankquality2.doc", "wt");
 if (tankwq2 == NULL)  Terminate();

 tankdemand = fopen("tankdemand.doc", "wt");
 if (tankdemand == NULL)  Terminate();
 tankh = fopen("tankheight.doc", "wt");
 if (tankh == NULL)  Terminate();

/* Write Epanet DLL version */
 ENgetversion(&version);
 printf("EpanetDump is using Epanet version %d\n",version);

 /* Get network size */
 status = ENgetcount(EN_NODECOUNT, &nnodes);
 if (status) Terminate();
 status = ENgetcount(EN_LINKCOUNT, &nlinks);
 if (status) Terminate();
 status = ENgetcount(EN_TANKCOUNT, &ntanks);
 if (status) Terminate();
 njunctions = nnodes - ntanks;
 printf("Nodes %d, links %d, tanks %d \n",nnodes, nlinks, ntanks);


 /* Get the start time and report time for writing simulation results */
 status = ENgettimeparam(EN_REPORTSTART, &starttime);
 if (status)  Terminate();
 status = ENgettimeparam(EN_REPORTSTEP, &rstep);
 if (status)  Terminate();
  /* Write data file headers */
 fprintf(nodewq1,"%10s ","Time(sec)");
 fprintf(nodewq2,"%10s ","Time(sec)");
 fprintf(nodedemand,"%10s ","Time(sec)");
 fprintf(nodep,"%10s ","Time(sec)");
 fprintf(tankwq1,"%10s ","Time(sec)");
 fprintf(tankwq2,"%10s ","Time(sec)");
 fprintf(tankdemand,"%10s ","Time(sec)");
 fprintf(tankh,"%10s ","Time(sec)");
```

```
 for (i = 0; i < nnodes; i++)
{
        status = ENgetnodetype(i+1, &nodetype);
        if (status) Terminate();
        if (nodetype == EN_JUNCTION)
        {
              status = ENgetnodeid(i+1,nodeid);
              if (status) Terminate();
              fprintf(nodewq1,"%13s ",nodeid);
              fprintf(nodewq2,"%13s ",nodeid);
              fprintf(nodedemand,"%13s ",nodeid);
              fprintf(nodep,"%13s ",nodeid);
        }

       else if (nodetype == EN_TANK)
        {
             status = ENgetnodeid(i+1,nodeid);
             if (status) Terminate();
             fprintf(tankwq1,"%13s ",nodeid);
             fprintf(tankwq2,"%13s ",nodeid);
             fprintf(tankdemand,"%13s ",nodeid);
             fprintf(tankh,"%13s ",nodeid);
        }
 }
 fprintf(nodewq1,"\n");
 fprintf(nodewq2,"\n");
 fprintf(nodedemand,"\n");
 fprintf(nodep,"\n");
 fprintf(tankwq1,"\n");
 fprintf(tankwq2,"\n");
 fprintf(tankdemand,"\n");
 fprintf(tankh,"\n");
}
```

Appendix C: DLL MSbulkrate function

```
void MSbulkrate(int k, float * c, float v, float ** BC)
/*
**-----------------------------------------------------------
**   Input:   k = linkindex
**            c = current WQ in segment
**            v = segment volume
**           BC = reaction coefficient matrix that can be externally defined or null otherwise
**   Output:  none
**   Purpose: computes bulk rates in a pipe segment at a given time
**   NOTE: This function is user defined;
**             BR= bulk reaction rates The syntax BR cannot be changed;
**-----------------------------------------------------------
*/
{
        /*The reaction rates BR[i] have to be always in mg/ft^3/s and concentration c[i] are always in mg/ft^3 --
        independently on the units used in the net.inp file */

        float Kp, Kc;
        float conc;

        float CLMinacthigh, CLMinactmedium, CLMinactlow;
        float CLMdecayhigh, CLMdecaymedium, CLMdecaylow;
        float Clinacthigh, Clinactmedium, Clinactlow;
        float Cldecayhigh, Cldecaymedium, Cldecaylow;

        conc = pow(c[2], 0.85);

        CLMinacthigh = 0.00628;
        CLMinactmedium = 0.00373;
        CLMinactlow = 0.00314;

        CLMdecayhigh = 1.8;
        CLMdecaymedium = 1.0;
        CLMdecaylow = 0.68;

        Clinacthigh = 0.1874;
        Clinactmedium = 0.0909;
        Clinactlow = 0.0662;

        Cldecayhigh = 10.1;
        Cldecaymedium = 0.96;
        Cldecaylow = 0.27;

        Kp= Clinacthigh; //(l/mg/min)
        Kc= Cldecaylow;    //(1/d.)

        Kp=Kp*Ucf[QUALITY]/60; //(ft^3/mg/s)
        Kc=Kc/SECperDAY;          //(1/s)

        BR[1] = -Kp*c[1]*conc;
        BR[2] = -Kc*c[2];
        return;
}
```

Appendix D: Decay Coefficient Spreadsheets

Chlorine Decay

Published first order bulk decay coefficient	Units	Unit conversion for EPANET (1/day)	Source		
0.070	1/hour	1.680	Powell et al (Zhang et al)	**99th percentile:**	**10.11**
0.110	1/hour	2.640	Powell et al (Zhang et al)	**95th percentile**	**5.71**
0.020	1/hour	0.480	Powell (Clark et al (1993))	**50th percentile:**	**0.96**
0.030	1/hour	0.720	Powell (chambers)	**10th percentile:**	**0.27**
0.210	1/hour	5.040	Powell (chambers)		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.010	1/hour	0.240	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.020	1/hour	0.480	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		

0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.030	1/hour	0.720	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.040	1/hour	0.960	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.050	1/hour	1.200	Powell et al., 2000 factors		
0.060	1/hour	1.440	Powell et al., 2000 factors		
0.060	1/hour	1.440	Powell et al., 2000 factors		
0.060	1/hour	1.440	Powell et al., 2000 factors		
0.060	1/hour	1.440	Powell et al., 2000 factors		
0.060	1/hour	1.440	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.070	1/hour	1.680	Powell et al., 2000 factors		
0.080	1/hour	1.920	Powell et al., 2000 factors		
0.080	1/hour	1.920	Powell et al., 2000 factors		

0.080	1/hour	1.920	Powell et al., 2000 factors		
0.080	1/hour	1.920	Powell et al., 2000 factors		
0.090	1/hour	2.160	Powell et al., 2000 factors		
0.090	1/hour	2.160	Powell et al., 2000 factors		
0.090	1/hour	2.160	Powell et al., 2000 factors		
0.090	1/hour	2.160	Powell et al., 2000 factors		
0.090	1/hour	2.160	Powell et al., 2000 factors		
0.100	1/hour	2.400	Powell et al., 2000 factors		
0.100	1/hour	2.400	Powell et al., 2000 factors		
0.100	1/hour	2.400	Powell et al., 2000 factors		
0.110	1/hour	2.640	Powell et al., 2000 factors		
0.110	1/hour	2.640	Powell et al., 2000 factors		
0.110	1/hour	2.640	Powell et al., 2000 factors		
0.110	1/hour	2.640	Powell et al., 2000 factors		
0.120	1/hour	2.880	Powell et al., 2000 factors		
0.130	1/hour	3.120	Powell et al., 2000 factors		
0.140	1/hour	3.360	Powell et al., 2000 factors		
0.160	1/hour	3.840	Powell et al., 2000 factors		
0.180	1/hour	4.320	Powell et al., 2000 factors		
0.220	1/hour	5.280	Powell et al., 2000 factors		
0.240	1/hour	5.760	Powell et al., 2000 factors		
0.250	1/hour	6.000	Powell et al., 2000 factors		
0.260	1/hour	6.240	Powell et al., 2000 factors		
0.270	1/hour	6.480	Powell et al., 2000 factors		
0.320	1/hour	7.680	Powell et al., 2000 factors		
0.125	1/hour	3.000	Maier et al., 2000		
0.833	1/day	0.833	Vasconselos et al., 1996		
0.232	1/day	0.232	Vasconselos et al., 1996		
1.160	1/day	1.160	Vasconselos et al., 1996		
1.320	1/day	1.320	Vasconselos et al., 1996		
17.7	1/day	17.7	Vasconselos et al., 1996		
10.8	1/day	10.8	Vasconselos et al., 1996		
0.082	1/day	0.082	Vasconselos et al., 1996		
0.767	1/day	0.767	Vasconselos et al., 1996		
0.264	1/day	0.264	Vasconselos et al., 1996		
0.355	1/day	0.355	Vasconselos et al., 1996		
0.102	1/day	0.102	Vasconselos et al., 1996		
0.3	1/day	0.3	Vasconselos et al., 1996		
0.0010	1/min	1.440	Vasconselos et al., 1996		
0.00061	1/min	0.878	Vasconselos et al., 1996		
0.00070	1/min	1.008	Vasconselos et al., 1996		
0.00057	1/min	0.821	Vasconselos et al., 1996		

Chloramine Decay

Published first order bulk decay coefficient	Units	Unit conversion for EPANET (1/day)	Source		
0.0173	1/hour	0.4152	Maier et al., 2000	**95th percentile:**	**1.82**
0.0207	1/hour	0.4968	Maier et al., 2000	**50th percentile:**	**1.02**
0.0274	1/hour	0.6576	Maier et al., 2000	**10th percentile:**	**0.68**
0.0280	1/hour	0.6720	Maier et al., 2000		
0.0285	1/hour	0.6840	Maier et al., 2000		
0.0310	1/hour	0.7440	Maier et al., 2000		
0.0315	1/hour	0.7560	Maier et al., 2000		
0.0329	1/hour	0.7896	Maier et al., 2000		
0.0332	1/hour	0.7968	Maier et al., 2000		
0.0333	1/hour	0.7992	Maier et al., 2000		
0.0338	1/hour	0.8112	Maier et al., 2000		
0.0349	1/hour	0.8376	Maier et al., 2000		
0.0363	1/hour	0.8712	Maier et al., 2000		
0.0369	1/hour	0.8856	Maier et al., 2000		
0.0375	1/hour	0.9000	Maier et al., 2000		
0.0375	1/hour	0.9000	Maier et al., 2000		
0.0378	1/hour	0.9072	Maier et al., 2000		
0.0393	1/hour	0.9432	Maier et al., 2000		
0.0418	1/hour	1.0032	Maier et al., 2000		
0.0422	1/hour	1.0128	Maier et al., 2000		
0.0427	1/hour	1.0248	Maier et al., 2000		
0.0434	1/hour	1.0416	Maier et al., 2000		
0.0480	1/hour	1.1520	Maier et al., 2000		
0.0496	1/hour	1.1904	Maier et al., 2000		
0.0503	1/hour	1.2072	Maier et al., 2000		
0.0504	1/hour	1.2096	Maier et al., 2000		
0.0506	1/hour	1.2144	Maier et al., 2000		
0.0512	1/hour	1.2288	Maier et al., 2000		
0.0513	1/hour	1.2312	Maier et al., 2000		
0.0517	1/hour	1.2408	Maier et al., 2000		
0.0521	1/hour	1.2504	Maier et al., 2000		
0.0522	1/hour	1.2528	Maier et al., 2000		
0.0578	1/hour	1.3872	Maier et al., 2000		
0.0584	1/hour	1.4016	Maier et al., 2000		
0.0609	1/hour	1.4616	Maier et al., 2000		
0.0616	1/hour	1.4784	Maier et al., 2000		
0.0694	1/hour	1.6656	Maier et al., 2000		
0.0757	1/hour	1.8168	Maier et al., 2000		
0.0813	1/hour	1.9512	Maier et al., 2000		
0.0972	1/hour	2.3328	Maier et al., 2000		

Appendix E: Model Run Descriptions and Data Summary

Node	Contamination Strength (#/L)	Disinfectant Decay	Disinfectant Dose	Inactivation	NT w/ pathogen present (NTPP)	NT with dose > 6.75*10-6 (NTCC)	NTCC - 39	Total NT with 3-log (NT3L)	NTCC/Total (NTCC/5001)	NTCC/NT in No Disinfectant run	NT3L/(NTPP-39)
NO INACTIVATION											
31	100000			0	118	118	79	2	1.58%	100.00%	2.53%
31	1000			0	118	118	79	2	1.58%	100.00%	2.53%
31	50			0	117	117	78	1	1.56%	98.73%	1.28%
CHLORINE MODEL RUNS											
31	100000	10.1	10.0	0.1874	118	118	79	2	1.58%	100.00%	2.53%
31	1000	10.1	10.0	0.1874	118	118	79	2	1.58%	100.00%	2.53%
31	50	10.1	10.0	0.1874	117	117	78	1	1.56%	98.73%	1.28%
31	100000	10.1	10.0	0.0909	118	118	79	2	1.58%	100.00%	2.53%
31	1000	10.1	10.0	0.0909	118	118	79	2	1.58%	100.00%	2.53%
31	50	10.1	10.0	0.0909	117	117	78	1	1.56%	98.73%	1.28%
31	100000	10.1	10.0	0.0662	118	118	79	2	1.58%	100.00%	2.53%
31	1000	10.1	10.0	0.0662	118	118	79	2	1.58%	100.00%	2.53%
31	50	10.1	10.0	0.0662	117	117	78	1	1.56%	98.73%	1.28%
31	100000	0.96	2.5	0.1874	111	96	57	72	1.14%	72.15%	100.00%
31	1000	0.96	2.5	0.1874	102	99	60	63	1.20%	75.95%	100.00%
31	50	0.96	2.5	0.1874	103	97	58	64	1.16%	73.42%	100.00%
31	100000	0.96	2.5	0.0909	118	118	79	55	1.58%	100.00%	69.62%
31	1000	0.96	2.5	0.0909	117	99	60	54	1.20%	75.95%	69.23%
31	50	0.96	2.5	0.0909	110	96	57	47	1.14%	72.15%	66.20%
31	100000	0.96	2.5	0.0662	118	118	79	41	1.58%	100.00%	51.90%
31	1000	0.96	2.5	0.0662	118	117	78	41	1.56%	98.73%	51.90%
31	50	0.96	2.5	0.0662	112	110	71	35	1.42%	89.87%	47.95%
31	100000	0.27	1.2	0.1874	118	93	54	79	1.08%	68.35%	100.00%
31	1000	0.27	1.2	0.1874	93	90	51	54	1.02%	64.56%	100.00%
31	50	0.27	1.2	0.1874	77	68	29	38	0.58%	36.71%	100.00%
31	100000	0.27	1.2	0.0909	118	96	57	66	1.14%	72.15%	83.54%
31	1000	0.27	1.2	0.0909	110	96	57	58	1.14%	72.15%	81.69%
31	50	0.27	1.2	0.0909	93	93	54	41	1.08%	68.35%	75.93%
31	100000	0.27	1.2	0.0662	118	115	76	53	1.52%	96.20%	67.09%
31	1000	0.27	1.2	0.0662	114	96	57	49	1.14%	72.15%	65.33%
31	50	0.27	1.2	0.0662	118	102	63	53	1.26%	79.75%	67.09%
					77	39	0	38	0.00%	0.00%	100.00%
CHLORAMINE MODEL RUNS											
31	100000	1.8	9.0	0.00628	118	118	79	17	1.58%	100.00%	21.52%
31	1000	1.8	9.0	0.00628	118	118	79	17	1.58%	100.00%	21.52%

Node	Contamination Strength (#/L)	Disinfectant Decay	Disinfectant Dose	Inactivation	NT w/ pathogen present (NTPP)	NT with dose > 6.75*10-6 (NTCC)	NTCC - 39	Total NT with 3-log (NT3L)	NTCC/Total (NTCC/5001)	NTCC/NT in No Disinfectant run	NT3L/(NTPP-39)
31	50	1.8	9.0	0.00628	117	117	78	16	1.56%	98.73%	20.51%
31	100000	1.8	9.0	0.00373	118	118	79	2	1.58%	100.00%	2.53%
31	1000	1.8	9.0	0.00373	118	118	79	2	1.58%	100.00%	2.53%
31	50	1.8	9.0	0.00373	117	117	78	1	1.56%	98.73%	1.28%
31	100000	1.8	9.0	0.00314	118	118	79	2	1.58%	100.00%	2.53%
31	1000	1.8	9.0	0.00314	118	118	79	2	1.58%	100.00%	2.53%
31	50	1.8	9.0	0.00314	117	117	78	1	1.56%	98.73%	1.28%
31	100000	1	5.0	0.00628	118	118	79	19	1.58%	100.00%	24.05%
31	1000	1	5.0	0.00628	118	118	79	19	1.58%	100.00%	24.05%
31	50	1	5.0	0.00628	117	117	78	18	1.56%	98.73%	23.08%
31	100000	1	5.0	0.00373	118	118	79	4	1.58%	100.00%	5.06%
31	1000	1	5.0	0.00373	118	118	79	4	1.58%	100.00%	5.06%
31	50	1	5.0	0.00373	117	117	78	3	1.56%	98.73%	3.85%
31	100000	1	5.0	0.00314	118	118	79	4	1.58%	100.00%	5.06%
31	1000	1	5.0	0.00314	118	118	79	4	1.58%	100.00%	5.06%
31	50	1	5.0	0.00314	117	117	78	3	1.56%	98.73%	3.85%
31	100000	0.68	3.0	0.00628	118	118	79	19	1.58%	100.00%	24.05%
31	1000	0.68	3.0	0.00628	118	118	79	19	1.58%	100.00%	24.05%
31	50	0.68	3.0	0.00628	117	117	78	18	1.56%	98.73%	23.08%
31	100000	0.68	3.0	0.00373	118	118	79	4	1.58%	100.00%	5.06%
31	1000	0.68	3.0	0.00373	118	118	79	4	1.58%	100.00%	5.06%
31	50	0.68	3.0	0.00373	117	117	78	3	1.56%	98.73%	3.85%
31	100000	0.68	3.0	0.00314	118	118	79	3	1.58%	100.00%	3.80%
31	1000	0.68	3.0	0.00314	118	118	79	3	1.58%	100.00%	3.80%
31	50	0.68	3.0	0.00314	117	117	78	2	1.56%	98.73%	2.56%
31	1000	0.27	3.5	0.1874	112	96	57	55	1.14%	72.15%	75.34%

Node	Contamination Strength (#/L)	Disinfectant Decay	Disinfectant Dose	Inactivation	NT w/ pathogen present (NTPP)	NT with dose > 6.75*10-6 (NTCC)	NTCC - 53	Total NT with 3-log (NT3L)	NTCC/Total (NTCC/4987)	NTCC/NT in No Disinfectant run	NT3L/ (NTPP-53)
NO INACTIVATION											
23	100000			0	1551	1551	1498	1433	30.04%	100.00%	95.66%
23	1000			0	1551	1538	1485	1433	29.78%	99.13%	95.66%
23	50			0	1551	1529	1476	1448	29.60%	98.53%	96.66%
CHLORINE MODEL RUNS											
23	100000	10.1	10.0	0.1874	1477	1390	1337	1405	26.81%	89.25%	98.67%
23	1000	10.1	10.0	0.1874	1477	893	840	1405	16.84%	56.07%	98.67%
23	50	10.1	10.0	0.1874	1477	779	726	1404	14.56%	48.46%	98.60%
23	100000	10.1	10.0	0.0909	1551	1454	1401	1475	28.09%	93.52%	98.46%
23	1000	10.1	10.0	0.0909	1551	1422	1369	1476	27.45%	91.39%	98.53%
23	50	10.1	10.0	0.0909	1551	1396	1343	1476	26.93%	89.65%	98.53%
23	100000	10.1	10.0	0.0662	1551	1488	1435	1474	28.77%	95.79%	98.40%
23	1000	10.1	10.0	0.0662	1551	1443	1390	1474	27.87%	92.79%	98.40%
23	50	10.1	10.0	0.0662	1551	1430	1377	1474	27.61%	91.92%	98.40%
23	100000	0.96	2.5	0.1874	1437	359	306	1419	6.14%	20.43%	102.53%
23	1000	0.96	2.5	0.1874	1439	330	277	1421	5.55%	18.49%	102.53%
23	50	0.96	2.5	0.1874	1436	212	159	1418	3.19%	10.61%	102.53%
23	100000	0.96	2.5	0.0909	1561	634	581	1537	11.65%	38.79%	101.92%
23	1000	0.96	2.5	0.0909	1553	423	370	1529	7.42%	24.70%	101.93%
23	50	0.96	2.5	0.0909	1553	307	254	1530	5.09%	16.96%	102.00%
23	100000	0.96	2.5	0.0662	1561	1073	1020	1528	20.45%	68.09%	101.33%
23	1000	0.96	2.5	0.0662	1553	561	508	1520	10.19%	33.91%	101.33%
23	50	0.96	2.5	0.0662	1553	364	311	1526	6.24%	20.76%	101.73%
23	100000	0.27	1.2	0.1874	1560	344	291	1542	5.84%	19.43%	102.32%
23	1000	0.27	1.2	0.1874	1559	292	239	1541	4.79%	15.95%	102.32%
23	50	0.27	1.2	0.1874	1552	192	139	1534	2.79%	9.28%	102.33%
23	100000	0.27	1.2	0.0909	1573	482	429	1553	8.60%	28.64%	102.17%
23	1000	0.27	1.2	0.0909	1573	375	322	1553	6.46%	21.50%	102.17%
23	50	0.27	1.2	0.0909	1573	274	221	1553	4.43%	14.75%	102.17%
23	100000	0.27	1.2	0.0662	1577	804	751	1552	15.06%	50.13%	101.84%
23	1000	0.27	1.2	0.0662	1573	459	406	1548	8.14%	27.10%	101.84%
23	50	0.27	1.2	0.0662	1573	318	265	1550	5.31%	17.69%	101.97%
					53	53	0	35	0.00%	0.00%	#DIV/0!

Node	Contamination Strength (#/L)	Disinfectant Decay	Disinfectant Dose	Inactivation	NT w/ pathogen present (NTPP)	NT with dose > 6.75*10-6 (NTCC)	NTCC - 53	Total NT with 3-log (NT3L)	NTCC/Total (NTCC/4987)	NTCC/NT in No Disinfectant run	NT3L/ (NTPP-53)
CHLORAMINE MODEL RUNS											
23	100000	1.8	9.0	0.00628	1551	1482	1429	1487	28.65%	95.39%	99.27%
23	1000	1.8	9.0	0.00628	1551	1459	1406	1487	28.19%	93.86%	99.27%
23	50	1.8	9.0	0.00628	1544	1390	1337	1487	26.81%	89.25%	99.73%
23	100000	1.8	9.0	0.00373	1551	1529	1476	1480	29.60%	98.53%	98.80%
23	1000	1.8	9.0	0.00373	1551	1474	1421	1480	28.49%	94.86%	98.80%
23	50	1.8	9.0	0.00373	1547	1451	1398	1482	28.03%	93.32%	99.20%
23	100000	1.8	9.0	0.00314	1551	1534	1481	1479	29.70%	98.87%	98.73%
23	1000	1.8	9.0	0.00314	1551	1490	1437	1479	28.81%	95.93%	98.73%
23	50	1.8	9.0	0.00314	1551	1471	1418	1479	28.43%	94.66%	98.73%
23	100000	1	5.0	0.00628	1551	1502	1449	1491	29.06%	96.73%	99.53%
23	1000	1	5.0	0.00628	1551	1466	1413	1491	28.33%	94.33%	99.53%
23	50	1	5.0	0.00628	1543	1388	1335	1492	26.77%	89.12%	100.13%
23	100000	1	5.0	0.00373	1551	1534	1481	1483	29.70%	98.87%	99.00%
23	1000	1	5.0	0.00373	1551	1494	1441	1484	28.90%	96.19%	99.07%
23	50	1	5.0	0.00373	1545	1468	1415	1483	28.37%	94.46%	99.40%
23	100000	1	5.0	0.00314	1551	1537	1484	1480	29.76%	99.07%	98.80%
23	1000	1	5.0	0.00314	1551	1508	1455	1480	29.18%	97.13%	98.80%
23	50	1	5.0	0.00314	1545	1480	1427	1480	28.61%	95.26%	99.20%
23	100000	0.68	3.0	0.00628	1561	1533	1480	1498	29.68%	98.80%	99.34%
23	1000	0.68	3.0	0.00628	1561	1479	1426	1498	28.59%	95.19%	99.34%
23	50	0.68	3.0	0.00628	1553	1436	1383	1496	27.73%	92.32%	99.73%
23	100000	0.68	3.0	0.00373	1561	1546	1493	1490	29.94%	99.67%	98.81%
23	1000	0.68	3.0	0.00373	1561	1522	1469	1490	29.46%	98.06%	98.81%
23	50	0.68	3.0	0.00373	1555	1492	1439	1491	28.86%	96.06%	99.27%
23	100000	0.68	3.0	0.00314	1561	1548	1495	1489	29.98%	99.80%	98.74%
23	1000	0.68	3.0	0.00314	1561	1526	1473	1489	29.54%	98.33%	98.74%
23	50	0.68	3.0	0.00314	1557	1503	1450	1487	29.08%	96.80%	98.87%
					1527	257	204	1508	4.09%	13.62%	102.31%
Viruses - Chloramines											
23	1000	1.8	9	0.0049	1551	1506	1453	1485	29.14%	97.00%	99.13%
23	1000	1	5	0.0049	1551	1528	1475	1485	29.58%	98.46%	99.13%
23	1000	0.68	3	0.0049	1561	1536	1483	1495	29.74%	99.00%	99.14%
23	1000	1.8	9	0.0129	1551	1438	1385	1503	27.77%	92.46%	100.33%
23	1000	1	5	0.0129	1551	1426	1373	1508	27.53%	91.66%	100.67%
23	1000	0.68	3	0.0129	1561	1471	1418	1515	28.43%	94.66%	100.46%

Node	Contamination Strength (#/L)	Disinfectant Decay	Disinfectant Dose	Inactivation	NT w/ pathogen present (NTPP)	NT with dose > 6.75*10-6 (NTCC)	NTCC - 53	Total NT with 3-log (NT3L)	NTCC/Total (NTCC/4987)	NTCC/NT in No Disinfectant run	NT3L/ (NTPP-53)
Viruses - Chlorine											
23	1000	10.1	10	1.1513	1386	442	389	1349	7.80%	25.97%	101.20%
23	1000	0.96	2.5	1.1513	53	53	0	35	0.00%	0.00%	#DIV/0!
23	1000	0.27	1.2	1.1513	53	53	0	35	0.00%	0.00%	#DIV/0!
23	1000	10.1	10	0.3838	1431	788	735	1371	14.74%	49.07%	99.49%
23	1000	0.96	2.5	0.3838	1123	232	179	1105	3.59%	11.95%	103.27%
23	1000	0.27	1.2	0.3838	1380	166	113	1362	2.27%	7.54%	102.64%
23	1000	10.1	10	3.4539	378	361	308	360	6.18%	20.56%	110.77%
23	1000	0.96	2.5	3.4539	53	53	0	35	0.00%	0.00%	#DIV/0!
23	1000	0.27	1.2	3.4539	53	53	0	35	0.00%	0.00%	#DIV/0!

Appendix F: Sample Model Output: 23.1000 No Disinfectant, Pathogen Concentration

Time(sec)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1209600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1210200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1210800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1211400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1212000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1212600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1213200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1213800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1214400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1215000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1215600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1216200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1216800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1217400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1218000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1218600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1219200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1219800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1220400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1221000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1221600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1222200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1222800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1223400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1224000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1224600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1225200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1225800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1226400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1227000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1227600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1228200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Time(sec)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1228800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1229400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1230000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1230600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1231200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1231800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1232400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1233000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1233600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1234200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1234800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1235400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1236000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1236600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.82E-03	2.91E-02	0.00E+00
1237200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-02	2.91E-02	2.91E-02	0.00E+00
1237800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-04	2.91E-02	2.91E-02	2.91E-02	0.00E+00
1238400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00
1239000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00
1239600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00
1240200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00
1240800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00
1241400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.30E-04	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00
1242000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	1.27E-02
1242600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1243200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E-05	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1243800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.19E-03	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1244400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.39E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1245000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.98E-04	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1245600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1246200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1246800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1247400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1248000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02

Time(sec)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1248600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1249200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02	2.91E-02
1249800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	2.91E-02	1.32E-01	6.74E-01	2.91E-02
1250400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	1.02E-01	6.74E-01	7.53E-01	2.91E-02
1251000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.91E-02	6.29E-01	7.53E-01	7.53E-01	2.91E-02
1251600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	7.91E-02	7.46E-01	7.53E-01	7.53E-01	2.91E-02
1252200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	5.60E-01	7.53E-01	7.53E-01	7.53E-01	2.91E-02
1252800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	7.35E-01	7.53E-01	7.53E-01	7.53E-01	2.91E-02
1253400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	1.42E-01	7.23E-01	7.53E-01	7.53E-01	2.91E-02
1254000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.36E-04	0.00E+00	2.48E-02	0.00E+00	2.91E-02	2.91E-02	1.11E-01	6.03E-01	7.40E-01	2.91E-02
1254600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.89E-02	2.91E-02	2.91E-02	6.29E-02	3.70E-01	2.91E-02
1255200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	3.87E-02	6.46E-01
1255800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-02	2.91E-02	2.91E-02	2.91E-02	7.46E-01
1256400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.58E-03	2.64E-02	2.90E-02	2.91E-02	7.42E-01
1257000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-03	1.39E-02	2.71E-02	2.79E-01
1257600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.55E-05	1.72E-03	2.91E-02
1258200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.11E-07	2.91E-02
1258800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-02
1259400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.06E-03
1260000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.86E-06
1260600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00
1261200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00
1261800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00
1262400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00
1263000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00
1263600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00
1264200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-04	0.00E+00
1264800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-04	0.00E+00
1265400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-04	0.00E+00
1266000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-04	0.00E+00
1266600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-04	0.00E+00
1267200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-04	0.00E+00
1267800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Time(sec)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1268400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1269000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1269600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.81E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1270200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.71E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1270800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1271400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1272000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1272600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-02	0.00E+00
1273200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E-02	5.44E-02	0.00E+00
1273800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-04	5.46E-02	5.57E-02	0.00E+00
1274400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-02	5.57E-02	5.57E-02	0.00E+00
1275000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.56E-02	5.57E-02	5.57E-02	0.00E+00
1275600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	3.04E-03	5.57E-02	5.57E-02	5.57E-02	0.00E+00
1276200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	5.33E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00
1276800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00
1277400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00
1278000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00
1278600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-02	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00
1279200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-04	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00
1279800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	5.92E-04
1280400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.08E-03	5.57E-02	5.57E-02	5.57E-02	5.57E-02	1.70E-02
1281000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.35E-02	5.57E-02	5.57E-02	5.57E-02	5.57E-02	5.21E-02
1281600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	7.71E-01	5.57E-02
1282200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	7.85E-01	7.97E-01	5.57E-02
1282800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.19E-03	0.00E+00	5.57E-02	5.57E-02	6.48E-01	7.97E-01	8.38E-01	5.57E-02
1283400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.03E-02	0.00E+00	5.57E-02	5.57E-02	7.97E-01	8.38E-01	8.46E-01	5.57E-02
1284000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.55E-02	0.00E+00	5.57E-02	3.88E-01	8.29E-01	8.38E-01	8.46E-01	5.57E-02
1284600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.62E-04	0.00E+00	5.57E-02	0.00E+00	5.57E-02	7.91E-01	8.38E-01	8.38E-01	8.46E-01	5.57E-02
1285200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.54E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.14E-01	8.38E-01	8.38E-01	8.46E-01	5.57E-02
1285800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.37E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.29E-01	8.38E-01	8.38E-01	8.46E-01	5.57E-02
1286400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.29E-01	8.38E-01	8.38E-01	8.99E-01	5.57E-02
1287000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.29E-01	8.38E-01	9.26E-01	1.02E+00	5.57E-02
1287600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.29E-01	8.53E-01	1.02E+00	1.02E+00	5.57E-02

Time(sec)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1288200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.29E-01	1.00E+00	1.02E+00	1.02E+00	5.57E-02
1288800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.29E-01	1.02E+00	1.02E+00	1.02E+00	5.57E-02
1289400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	8.52E-01	1.02E+00	1.02E+00	1.02E+00	5.57E-02
1290000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	1.42E-01	9.25E-01	1.02E+00	1.02E+00	1.02E+00	7.91E-02
1290600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	4.79E-01	1.01E+00	1.02E+00	1.02E+00	1.20E+00	4.01E-01
1291200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	7.43E-01	1.02E+00	1.02E+00	1.11E+00	1.46E+00	7.27E-01
1291800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	7.91E-01	1.02E+00	1.02E+00	1.46E+00	1.46E+00	7.91E-01
1292400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	8.14E-01	1.02E+00	1.07E+00	1.46E+00	1.46E+00	8.08E-01
1293000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	8.28E-01	1.02E+00	1.33E+00	1.46E+00	1.46E+00	8.28E-01
1293600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	8.29E-01	1.02E+00	1.46E+00	1.46E+00	1.46E+00	8.29E-01
1294200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	8.29E-01	1.02E+00	1.46E+00	1.46E+00	1.46E+00	8.29E-01
1294800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	8.29E-01	1.02E+00	1.46E+00	1.46E+00	1.76E+00	8.29E-01
1295400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	1.16E-01	0.00E+00	8.29E-01	1.02E+00	1.46E+00	1.46E+00	1.94E+00	8.29E-01
1296000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	3.35E-01	0.00E+00	8.29E-01	1.17E+00	1.46E+00	1.86E+00	1.94E+00	8.29E-01
NT with present	0	0	0	0	0	0	36	18	42	0	50	67	72	75	89	59
NT with >6.74*10^-6	0	0	0	0	0	0	36	18	42	0	50	67	72	75	89	59

Time(sec)	18	19	20	21	22	23	24	25	27	28	29	30	31	32	33	34	35	36
1209600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1210200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1210800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1211400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1212000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1212600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1213200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1213800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-01	0.00E+00	4.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1214400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-01	0.00E+00	4.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1215000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-01	0.00E+00	4.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1215600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-01	0.00E+00	4.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1216200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-01	0.00E+00	4.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1216800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1217400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1218000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1218600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1219200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1219800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1220400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1221000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1221600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1222200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1222800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1223400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1224000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1224600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1225200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1225800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1226400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1227000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.71E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1227600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1228200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Time(sec)	18	19	20	21	22	23	24	25	27	28	29	30	31	32	33	34	35	36	
1228800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1229400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.51E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1230000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1230600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1231200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.06E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1231800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1232400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.79E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1233000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1233600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1234200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1234800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1235400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.47E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1236000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	1.06E-02	2.91E-02	0.00E+00	0.00E+00	4.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1236600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	4.37E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1237200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	1.79E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1237800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1238400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1239000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1239600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1240200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1240800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	8.26E-03	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1241400	0.00E+00	0.00E+00	4.90E-03	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1242000	0.00E+00	0.00E+00	2.86E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1242600	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1243200	2.51E-04	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1243800	2.07E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1244400	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	7.88E-03	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1245000	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	2.77E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1245600	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1246200	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1246800	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1247400	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1248000	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	

Time(sec)	18	19	20	21	22	23	24	25	27	28	29	30	31	32	33	34	35	36	
1248600	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	2.91E-02	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1249200	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	6.74E-01	1.77E-01	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	1.78E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1249800	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	7.53E-01	6.75E-01	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	1.27E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1250400	2.83E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	7.53E-01	7.53E-01	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.23E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1251000	2.83E-02	0.00E+00	2.91E-02	5.85E-03	4.90E-03	7.53E-01	7.53E-01	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1251600	2.83E-02	0.00E+00	2.91E-02	2.46E-02	2.46E-02	7.53E-01	7.53E-01	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1252200	2.83E-02	0.00E+00	2.91E-02	2.65E-02	2.91E-02	7.53E-01	7.53E-01	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1252800	2.83E-02	0.00E+00	2.91E-02	2.65E-02	2.91E-02	7.53E-01	7.53E-01	2.91E-02	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	2.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1253400	2.83E-02	0.00E+00	2.91E-02	2.65E-02	2.91E-02	1.87E+00	7.53E-01	8.49E-01	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	9.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1254000	2.83E-02	0.00E+00	2.91E-02	2.65E-02	2.91E-02	1.87E+00	7.53E-01	1.87E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	9.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1254600	2.83E-02	0.00E+00	2.91E-02	2.65E-02	2.91E-02	1.87E+00	6.58E-01	1.87E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	9.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1255200	2.83E-02	0.00E+00	2.91E-02	2.65E-02	2.91E-02	1.86E+00	1.68E-01	1.87E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	9.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1255800	2.83E-02	0.00E+00	2.91E-02	2.65E-02	2.91E-02	1.53E+00	3.87E-02	1.82E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	9.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1256400	2.83E-02	0.00E+00	1.69E-01	2.65E-02	2.91E-02	1.17E+00	3.87E-02	1.42E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	9.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1257000	2.83E-02	0.00E+00	6.67E-01	2.65E-02	2.91E-02	7.28E-01	2.91E-02	7.28E-01	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1257600	2.83E-02	2.52E-02	7.45E-01	2.65E-02	2.91E-02	7.27E-01	1.39E-02	7.28E-01	2.91E-02	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1258200	2.83E-02	2.91E-02	7.53E-01	2.65E-02	2.91E-02	7.02E-01	5.55E-05	7.15E-01	2.91E-02	0.00E+00	2.91E-02	0.00E+00	1.20E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1258800	2.83E-02	2.91E-02	7.53E-01	2.65E-02	2.91E-02	4.67E-05	0.00E+00	1.45E-03	2.91E-02	0.00E+00	2.91E-02	0.00E+00	1.87E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1259400	2.83E-02	2.91E-02	7.53E-01	2.65E-02	2.91E-02	0.00E+00	0.00E+00	3.46E-07	2.91E-02	0.00E+00	2.91E-02	0.00E+00	1.87E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1260000	2.83E-02	2.91E-02	7.53E-01	2.65E-02	2.91E-02	0.00E+00	0.00E+00	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	1.87E+00	0.00E+00	0.00E+00	0.00E+00	2.17E-01	0.00E+00	
1260600	2.83E-02	2.91E-02	7.42E-01	2.65E-02	2.91E-02	0.00E+00	2.64E-04	0.00E+00	2.91E-02	0.00E+00	2.91E-02	0.00E+00	1.87E+00	0.00E+00	0.00E+00	0.00E+00	3.64E-01	0.00E+00	
1261200	2.83E-02	2.91E-02	4.52E-01	2.65E-02	2.91E-02	2.88E-04	3.77E-04	5.56E-05	3.02E-01	0.00E+00	2.91E-02	0.00E+00	1.70E+00	8.88E-03	0.00E+00	0.00E+00	3.65E-01	0.00E+00	
1261800	2.83E-02	2.91E-02	5.15E-02	2.65E-02	2.91E-02	3.77E-04	3.77E-04	3.77E-04	1.87E+00	0.00E+00	2.91E-02	0.00E+00	1.34E+00	2.91E-02	0.00E+00	0.00E+00	2.75E-01	0.00E+00	
1262400	4.65E-02	2.91E-02	2.91E-02	2.65E-02	2.91E-02	3.77E-04	3.77E-04	3.77E-04	1.87E+00	0.00E+00	2.91E-02	0.00E+00	7.28E-01	2.91E-02	0.00E+00	0.00E+00	1.60E-02	0.00E+00	
1263000	8.55E-02	2.91E-02	2.91E-02	2.65E-02	2.91E-02	3.77E-04	3.77E-04	3.77E-04	1.87E+00	0.00E+00	2.91E-02	0.00E+00	7.27E-01	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1263600	1.20E-01	1.09E-01	2.90E-02	2.65E-02	2.91E-02	3.77E-04	3.77E-04	3.77E-04	1.87E+00	0.00E+00	2.91E-02	0.00E+00	7.09E-01	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1264200	2.74E-01	7.35E-01	1.48E-02	2.65E-02	2.91E-02	3.77E-04	2.83E-04	3.77E-04	1.70E+00	0.00E+00	2.91E-02	0.00E+00	9.51E-04	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1264800	2.74E-01	7.36E-01	2.62E-04	2.65E-02	2.91E-02	2.83E-04	2.83E-04	3.59E-04	1.32E+00	0.00E+00	2.91E-02	0.00E+00	2.41E-07	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1265400	2.74E-01	2.61E-01	7.33E-08	2.65E-02	2.91E-02	2.83E-04	2.83E-04	2.83E-04	7.28E-01	0.00E+00	2.91E-02	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1266000	2.74E-01	2.91E-02	0.00E+00	2.65E-02	2.91E-02	2.83E-04	2.83E-04	2.83E-04	7.27E-01	0.00E+00	4.80E-02	0.00E+00	0.00E+00	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1266600	3.03E-01	2.91E-02	0.00E+00	2.65E-02	2.91E-02	2.83E-04	2.83E-04	2.83E-04	6.83E-01	0.00E+00	9.65E-01	0.00E+00	1.22E-04	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1267200	3.20E-01	2.64E-02	0.00E+00	2.65E-02	2.91E-02	2.83E-04	2.83E-04	2.83E-04	8.63E-04	0.00E+00	1.87E+00	0.00E+00	3.77E-04	6.13E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1267800	3.47E-01	5.62E-03	0.00E+00	2.65E-02	2.91E-02	2.83E-04	0.00E+00	2.83E-04	1.67E-07	0.00E+00	1.87E+00	0.00E+00	3.77E-04	4.87E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	

Time(sec)	18	19	20	21	22	23	24	25	27	28	29	30	31	32	33	34	35	36	
1268400	3.11E-02	4.86E-06	0.00E+00	4.04E-02	3.84E-02	0.00E+00	0.00E+00	2.83E-04	0.00E+00	0.00E+00	1.87E+00	0.00E+00	3.77E-04	6.45E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1269000	3.50E-01	0.00E+00	0.00E+00	4.24E-01	3.67E-01	0.00E+00	0.00E+00	0.00E+00	1.16E-05	0.00E+00	1.75E+00	0.00E+00	3.77E-04	5.63E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1269600	7.41E-01	0.00E+00	0.00E+00	6.56E-01	7.05E-01	0.00E+00	0.00E+00	0.00E+00	3.16E-04	0.00E+00	1.36E+00	0.00E+00	3.71E-04	1.13E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1270200	3.08E-01	0.00E+00	0.00E+00	6.78E-01	7.45E-01	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00	7.28E-01	0.00E+00	2.83E-04	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1270800	3.14E-02	0.00E+00	0.00E+00	6.78E-01	7.45E-01	0.00E+00	0.00E+00	0.00E+00	3.77E-04	0.00E+00	7.25E-01	0.00E+00	2.83E-04	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1271400	2.19E-02	0.00E+00	0.00E+00	6.78E-01	7.45E-01	0.00E+00	0.00E+00	5.57E-02	3.77E-04	0.00E+00	4.77E-01	0.00E+00	2.83E-04	1.85E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
1272000	1.06E-06	0.00E+00	0.00E+00	6.78E-01	7.45E-01	5.57E-02	0.00E+00	5.57E-02	3.74E-04	0.00E+00	2.09E-05	0.00E+00	2.83E-04	2.79E-02	0.00E+00	0.00E+00	3.38E-03	0.00E+00	
1272600	0.00E+00	0.00E+00	0.00E+00	6.30E-01	7.13E-01	5.57E-02	4.70E-02	5.57E-02	2.96E-04	0.00E+00	0.00E+00	0.00E+00	2.83E-04	2.78E-02	0.00E+00	0.00E+00	1.80E-02	0.00E+00	
1273200	0.00E+00	0.00E+00	0.00E+00	1.43E-01	2.47E-01	5.57E-02	5.57E-02	5.57E-02	2.83E-04	0.00E+00	6.10E-06	0.00E+00	7.10E-06	2.55E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1273800	0.00E+00	0.00E+00	0.00E+00	2.65E-02	2.91E-02	5.57E-02	5.57E-02	5.57E-02	2.83E-04	0.00E+00	2.54E-04	0.00E+00	0.00E+00	2.55E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1274400	0.00E+00	0.00E+00	0.00E+00	2.65E-02	2.91E-02	5.57E-02	5.57E-02	5.57E-02	2.83E-04	0.00E+00	3.77E-04	0.00E+00	0.00E+00	2.28E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1275000	0.00E+00	0.00E+00	0.00E+00	2.55E-02	2.85E-02	5.57E-02	5.57E-02	5.57E-02	2.83E-04	0.00E+00	3.77E-04	0.00E+00	0.00E+00	2.39E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1275600	5.45E-02	0.00E+00	0.00E+00	4.61E-03	8.34E-03	5.57E-02	5.57E-02	5.57E-02	6.55E-05	0.00E+00	3.77E-04	0.00E+00	2.79E-02	2.30E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1276200	1.57E-01	0.00E+00	0.00E+00	6.09E-06	5.36E-05	5.57E-02	5.57E-02	5.57E-02	0.00E+00	0.00E+00	3.77E-04	0.00E+00	5.57E-02	2.30E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1276800	6.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	0.00E+00	0.00E+00	3.09E-04	0.00E+00	5.57E-02	2.29E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1277400	6.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	0.00E+00	0.00E+00	2.83E-04	0.00E+00	5.57E-02	1.32E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1278000	6.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	1.33E-02	0.00E+00	2.83E-04	0.00E+00	5.57E-02	2.62E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1278600	6.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00	2.83E-04	0.00E+00	5.57E-02	5.39E-03	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1279200	5.49E-01	0.00E+00	7.74E-03	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00	2.83E-04	0.00E+00	5.57E-02	2.08E-07	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1279800	1.22E-02	0.00E+00	4.62E-02	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00	2.41E-04	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1280400	0.00E+00	0.00E+00	5.57E-02	0.00E+00	0.00E+00	5.57E-02	5.57E-02	5.57E-02	5.57E-02	0.00E+00	1.64E-06	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1281000	0.00E+00	0.00E+00	5.57E-02	0.00E+00	0.00E+00	7.97E-01	5.57E-02	5.57E-02	5.57E-02	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1281600	0.00E+00	0.00E+00	5.57E-02	0.00E+00	0.00E+00	7.97E-01	7.97E-01	5.57E-02	5.57E-02	0.00E+00	0.00E+00	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1282200	3.56E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	8.46E-01	7.97E-01	5.57E-02	5.57E-02	0.00E+00	0.00E+00	0.00E+00	5.57E-02	7.71E-04	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1282800	5.37E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	8.46E-01	8.46E-01	5.57E-02	5.57E-02	0.00E+00	3.68E-02	0.00E+00	5.57E-02	7.80E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1283400	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	8.46E-01	8.46E-01	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	1.78E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1284000	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	8.46E-01	8.46E-01	5.57E-02	5.57E-02	3.80E-01	5.57E-02	0.00E+00	5.57E-02	5.28E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1284600	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	8.46E-01	8.46E-01	5.57E-02	5.57E-02	4.80E-01	5.57E-02	0.00E+00	5.57E-02	5.28E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1285200	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	8.46E-01	8.46E-01	5.57E-02	5.57E-02	4.55E-01	5.57E-02	0.00E+00	5.57E-02	5.28E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1285800	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	1.02E+00	8.46E-01	5.57E-02	5.57E-02	2.58E-01	5.57E-02	0.00E+00	5.57E-02	5.28E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1286400	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	1.02E+00	1.02E+00	5.57E-02	5.57E-02	1.79E-02	5.57E-02	0.00E+00	5.57E-02	5.22E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1287000	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	1.02E+00	1.02E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	2.99E-01	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1287600	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	1.02E+00	1.02E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	9.93E-03	0.00E+00	0.00E+00	2.21E-02	0.00E+00	

Time(sec)	18	19	20	21	22	23	24	25	27	28	29	30	31	32	33	34	35	36	
1288200	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	1.02E+00	1.02E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1288800	5.41E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	1.02E+00	1.02E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1289400	5.41E-02	0.00E+00	3.65E-01	0.00E+00	0.00E+00	1.46E+00	1.02E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1290000	5.41E-02	0.00E+00	7.58E-01	0.00E+00	0.00E+00	1.46E+00	1.08E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	0.00E+00	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1290600	5.41E-02	0.00E+00	7.97E-01	0.00E+00	0.00E+00	1.46E+00	1.46E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	2.94E-03	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1291200	5.41E-02	0.00E+00	7.97E-01	0.00E+00	0.00E+00	1.46E+00	1.46E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	2.00E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1291800	5.41E-02	0.00E+00	8.20E-01	0.00E+00	0.00E+00	1.46E+00	1.46E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	3.79E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1292400	5.41E-02	0.00E+00	8.38E-01	1.54E-04	0.00E+00	1.46E+00	1.46E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	4.35E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1293000	5.41E-02	0.00E+00	8.38E-01	7.65E-04	8.41E-04	1.94E+00	1.46E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	4.38E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1293600	5.41E-02	0.00E+00	8.38E-01	7.04E-03	7.74E-03	1.94E+00	1.46E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	4.39E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1294200	5.41E-02	0.00E+00	8.38E-01	2.31E-02	1.62E-02	1.94E+00	1.86E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	4.39E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1294800	3.68E-01	0.00E+00	8.38E-01	3.54E-02	2.54E-02	1.94E+00	1.94E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	4.39E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1295400	7.18E-01	0.00E+00	8.38E-01	4.29E-02	4.62E-02	1.94E+00	1.94E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	4.39E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
1296000	7.72E-01	0.00E+00	8.38E-01	4.98E-02	5.47E-02	1.94E+00	1.94E+00	5.57E-02	5.57E-02	0.00E+00	5.57E-02	0.00E+00	5.57E-02	4.39E-02	0.00E+00	0.00E+00	2.21E-02	0.00E+00	
NT with present	81	19	70	50	49	103	90	107	93	5	87	0	97	64	0	0	46	0	1551
NT with >6.74*10^-6	81	19	69	50	49	103	90	107	92	5	87	0	97	63	0	0	46	0	1548

9.0 VITA

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EDUCATION:

Virginia Polytechnic Institute and State University, Blacksburg, VA
MS in Environmental Engineering, Summer 2004

Carnegie Mellon University, Pittsburgh, PA
BS in Environmental Science, Minor in Chemistry, May 1999
BFA in Piano Performance, May 1998

EXPERIENCE:

Environmental Protection Specialist, 3/02 – Present
Environmental Protection Agency, Office of Ground Water and Drinking Water

- Analyze health effects, occurrence, and technical issues on drinking water contaminants to support drinking water regulations
- Write guidance manuals and technical papers supporting rule development and implementation
- Focus on disinfection byproducts and distribution system issues

Environmental Protection Specialist, 10/00 – 3/02
Environmental Protection Agency, Office of the Chief Financial Officer

- Analyzed EPA performance against annual performance goals for EPA Annual Reports.
- Maintained familiarity with international news and EPA actions pertaining to cross-border environmental risks, including IPCC and US Global Change Research publications.
- Reviewed and edited goal chapters for EPA Annual Reports in the areas of cross-border environmental risk and better waste management.

Patent Examiner, 7/99 - 10/00, GS-09
United States Patent and Trademark Office, Department of Commerce

- Authored reports synthesizing and interpreting scientific publications to communicate legal and technical opinions regarding patent applications to attorneys and applicants.
- Researched international scientific literature in hazardous waste destruction, gas scrubbers, nuclear waste disposal, and fertilizers for patent examination.
- Analyzed patent applications to identify technical properties in common with previously described inventions and determined obviousness of the invention from the viewpoint of an expert in the field.

President, 8/97 - 5/99
Earth Environmental Club, Carnegie Mellon University

- Researched university-wide availability of recycling facilities and student participation in recycling program; delivered multiple presentations of study results to the student body; developed outreach campaign to increase student participation.
- Developed program structure and budget for student environmental club; collaborated on mission and goals for the organization; implemented procedures for achieving goals; oversaw meetings; facilitated workshops and lecture series.

- Conducted outreach and publicity campaigns in the form of lecture series and workshops to increase student interest in environmental club. As a result, membership grew from 5 to 100.

Research Assistant, 8/97 - 5/99
Department of Chemistry, Carnegie Mellon University

- Prepared and delivered presentations on independent chemistry research project to technical and general audiences. Received the Carnegie Mellon University Environmental Research Award and the Richard Schoenwald Research Award for presenting technical information to a general audience.
- Determined reaction mechanisms of long-lived, environmentally benign catalysts that use hydrogen peroxide to bleach organic dyes in a graduate chemistry laboratory.
- Funded by the Howard Hughes Medical Institute Undergraduate Biological Sciences Education Program and Carnegie Mellon's Undergraduate Research Initiative