The City of Winnipeg

Winnipeg

- DRINKING WATER QUALITY ENHANCEMENT PROGRAM

PHASE III CONCEPTUAL DESIGN SUMMARY REPORT

Date: June 2002

WINNIPEG WATER CONSORTIUM

CH2M Hill EARTH TECH WARDROP

Abbreviations

2,3,6-TCA	2, 3, 6 – Trichloranisole
2,4,6-TCA	2, 4, 6 – Trichloranisole
AOC	Assimilable organic carbon
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
BAC	Biological activated carbon
BAF	Biological Activated Filter
BDOC	Biodegradability of Dissolved Organic Carbon
BOM	Biological Organic Manner
Ct	Concentration of disinfectant multiplied by the contact time
DAF	Dissolved air flotation
DBPs	Disinfection By-products
D/DBP	Disinfectant/Disinfection By-product
D/DBPR	Stage 1 & 2 Disinfectant/Disinfection By-products Rule (US EPA)
DNA	Deoxyribonucleic acid
DOC	Dissolved organic carbon
ESWTR	Enhanced Surface Water Treatment Rule (US EPA)
GAC	Granular activated carbon
GCDWQ	Guidelines for Canadian Drinking Water Quality
HAA	Haloacetic acids
IESWTR	Interim Enhanced Surface Water Treatment Rule (US EPA)
J	Joule
km	Kilometer
LTESWTR	Long-Term 1 Enhanced Surface Water Treatment Rule (US EPA)
LT2ESWTR	Long-Term 2 Enhanced Surface Water Treatment Rule (USEPA)
MIB	2-methylisoborneol
μg/L	Micrograms per litre
mJ	Mili Joule
mℓ	Millilitre
ML/d	Million litres per day
MS-2	Coliphage MS-2

mW	Mili watt
NDOC	Naturally Occuring Dissolved Organic Carbon (or Non-purgable)
ng/L	Nano grams per litre
Nm	Nanometers
NF	Nanofiltration
NOM	Natural organic matter
NTU	Nephelomatic turbidity unit
O_3	Ozone or ozonation
PAC	Powdered activated carbon
RNA	Ribonucleic acid
S	Second
SDS	Simulated Distribution System
Sec	Second
SDWA	Safe Drinking Water Act
SOC	Synthetic organic compounds
SWTR	Surface Water Treatment Rule (US EPA)
TCU	true colour units
TDS	Total Dissolved Solids
THAAs	Total Halo Acetic Acids
THMFP	trihalomethane formation potential
TM	Technical Memorandum
T&O	Taste and Odour
TOC	Total Organic Carbon
TON	Threshold Odour Number
torr	1 mm Hg (mercury) pressure
TTHMs	Total Trihalomethanes
UF	Ultrafiltration
UFRV	Unit Filter Run Volume
UMass	University of Massachusetts
US EPA	United States Environmental Protection Agency
UV	Ultraviolet
W	watt
WTP	water treatment plant

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Introduction

1.1 Background

Water treatment is about protecting and enhancing public health within the City of Winnipeg.

The City of Winnipeg has completed a number of activities, beginning in the early 1990's, to define a drinking water quality enhancement program to ensure a safe and reliable supply of potable water for the citizens of Winnipeg.

In 1993, a Regional Water Supply Conceptual Planning Study was completed and recommended that the City begin the planning process for implementing a water treatment plant. In response to this recommendation, the City undertook a testing program to begin to define the water treatment processes required to treat Winnipeg's raw water supply. Bench scale testing and a first phase of pilot scale testing were completed in 1994. Subsequently, to further define the water treatment process requirements, a second phase of pilot scale testing was carried out over a period of sixteen months in 1996 and 1997.

In the fall of 1999, the City began a program of consultation with the public regarding the need for water treatment. In 2000, the City committed to the construction of a water treatment plant to enhance public health within the City of Winnipeg.

1.2 Water Quality Goals

1.2.1 Raw Water Quality

The water in the Deacon Reservoir is characterised by moderate to high algae levels, low turbidity and moderate to high total organic carbon (TOC). As a result of chlorination at the Shoal Lake headworks, Deacon Reservoir water also contains significant background levels of disinfection by-products (DBPs). Taste and odour events in the distribution system normally coincide with or follow elevated algae levels in Deacon Reservoir and/or Shoal Lake. Historical raw water quality information is summarized in Table 1.1.

Table 1.1: Historical Raw Water Quality (1997-2001)

Parameter	Units	Average	Minimum	Maximum
Shoal Lake Intake				
pH	Units	8.0	7.0	9.0
TOC	mg/L	8.9	4	11
DOC	mg/L	8.9	3.5	12
Alkalinity (total)	mg/L as $CaCO_3$	79	71	89
Hardness (total)	mg/L as $CaCO_3$	79	66	90
Color (true)	TCU	7	<5	15
Deacon Reservoir Inlet				
Turbidity	NTU	0.80	0.25	1.9
Plankton	Cells/mL	14400	700	114300
TTHM	µg/L	113	26	192
Outlet from Deacon Reservoir Cells 1 & 3				
Turbidity	NTU	0.76	0.25	4.0
Plankton	Cells/mL	19900	790	285000
TTHM	µg/L	56	1.5	129

1.2.2 Water Treatability Issues

Several water quality and treatability issues were identified during the 1996/1997 pilot program. These included the following:

- Impact and treatability of preformed disinfection by-products (DBPs) resulting from chlorination at the Shoal Lake headworks
- Alternative strategies for zebra mussel and slime control that minimize production of DBPs
- Treatment strategies for taste and odour control
- Minimization of DBP formation through water treatment plant processes
- Prevalence and impact of algal toxins in Deacon Reservoir
- Treatability of Natalie Lake water
- Treatability of supplemental ground water sources
- Aluminum residuals in the finished water
- Removal and/or inactivation of pathogens in the water
- Treatment plant residuals management
- Disinfection efficacy
- Control of biological regrowth in the distribution system

These issues were addressed during the pilot test program and were part of the decision making process in identifying the most suitable treatment process.

1.2.3 Water Quality Goals

The City's water treatability issues together with existing and anticipated water quality guidelines and regulations were used to develop water quality targets for water treatment process evaluation. These targets are summarized in Table 1.2.

Table 1.2: 1996/1997 Pilot Plant Performance Targets

Treatment Goal	Specific Parameter	GCDWQ[1]	Pilot Target	Reasons for Pilot Target
Clear water	Turbidity	<1.0 NTU	<0.1 NTU	Future probable regulation; ensures best treatment
Particulate removal	Particles >2 μm	NG	<20 particles/mL	Pathogen protection i.e. *Giardia / Cryptosporidium*
DBP control	TTHMs THAAs	100 μg/L NG	100 (40) μg/L N/A (30) μg/L	Short-term (long-term future USEPA regulation)
TOC removal	TOC	NG	40%	Minimize DBP precursors
T&O control	TON	Aesthetic	Inoffensive / consistent	Level at which T&O should meet public expectations
Algae removal	% removed	NG	Maximize removal	Minimize T&O events and other aesthetic concerns
Colour reduction	TCU	15	<5	Value which should meet public expectations
Efficient filter water production rate	UFRV (Unit filter run volume)	NG	>200 m^3/m^2	Balance of filter construction costs, production rate, and wasted backwash water
Filter loading rate	m/hr	NG	>15 m/hr	Minimize filter construction costs
Treatment consistency	Opinion	NG	High degree	Ability to consistently meet treatment goals during changes in raw water quality

NG = No guideline

Since that time, some of the anticipated water quality guidelines and regulations have been somewhat modified but the treatment targets are still valid.

1.3 Baseline Water Treatment Process

Based on the foregoing water treatment goals and the 1996/1997 pilot program, a water treatment process was developed and included the following:

> Coagulation (ferric chloride) + Dissolved Air Flotation (DAF) + Ozone (O_3) + Biological Activated Carbon Filtration (BAC) + Chloramination (secondary disinfection)

This process is considered the "baseline" and addresses all the City's water quality goals and objectives into the foreseeable future.

The conceptual design of the water treatment plant based on the foregoing baseline water treatment process was developed in two phases. Phase I, completed in 1998, entailed the evaluation of various locations for the water treatment plant, resulting in the Deacon Reservoir and Booster Pumping Station site (the Deacon site) being identified as the preferred location. Phase II, completed in 1999, provided the overall conceptual design of a water treatment plant that would meet the City's needs. At the end of Phase II, an estimate of the cost to implement the facility was developed.

In the fall of 1999, the City began a program of consultation with the public. The City's proposed drinking water quality enhancement program, including the conceptual design of the water treatment plant, was presented to the public in a series of meetings in October 1999. Based on the input received from City Council and the public, the Water and Waste Department decided to conduct further conceptual design work to address the Council's and the public's comments as well as investigate other issues. This further work, the Phase III Conceptual Design, is documented in this report.

1.4 Objectives of Phase III Conceptual Design

The objectives of the Phase III Conceptual Design are summarized as follows:

- In response to comments and suggestions raised by the public and a directive from City Council, the Water and Waste Department wished to evaluate the benefits and costs of emerging technologies such as Ultraviolet (UV) disinfection and membrane filtration. This will ensure that the most cost effective and efficient processes are incorporated into Winnipeg's new facility. In order to have accurate information regarding the viability of UV disinfection, particularly for unfiltered water, the City implemented a pilot testing program. This program was conducted with funding and technical support from the American Water Works Association Research Foundation (AWWARF). The results from the AWWARF program are incorporated into this study with the full details of the AWWARF study reported separately.
- The City also decided to take the opportunity to conduct further study on the following issues:
  - Alternative oxidants – There are various alternatives for disinfection chemicals to be used in the overall water supply system. These alternatives have been reviewed with the view of meeting the various water quality goals, particularly minimizing the generation of disinfection by-products.
  - Taste and Odour – The City experienced an unusual taste and odour event in 1999. While this appears to have been an isolated event, the City wished to examine the event in more detail to determine whether the baseline water treatment process could mitigate the impact of a similar event.
- Based on the results of the foregoing evaluations, adjustments to the baseline water treatment process have been incorporated in order to provide the City with the most appropriate water treatment plant.
- In order to maintain an accurate estimate of the cost to implement the water treatment plant, the 1999 cost estimate was updated to reflect any changes resulting from the foregoing investigations.

It is noted that, since the time of completion of the Phase II Conceptual Design, research into the use of ozone for the inactivation of *Cryptosporidium* has shown that the requirements for ozone dosage and contact time are dramatically greater for cold waters such as that in Winnipeg than previously thought. As a result, the baseline water treatment process would require resizing to meet changed requirements for the ozone system. This issue is addressed within this report.

1.5 Organization of Summary Report

The evaluation of Ultraviolet disinfection and membrane filtration and the issues of alternative oxidants and taste and odour are documented in four Technical Memoranda (No. 6 through 9). A brief overview of these Technical Memoranda is provided in Sections 3 through 6 of this Summary Report.

Using the results from the four Technical Memoranda, the alternatives for water treatment process trains for Winnipeg have been re-examined. Section 2 describes the water treatment process trains that have been re-evaluated in this study.

Section 7 describes the evaluation of several alternative process trains, and provides a recommendation for revisions to the baseline water treatment process train.

Section 8 provides an update of the capital cost and annual operation and maintenance cost of the water treatment plant based on the recommended water treatment train.

Section 9 outlines an implementation program for the City's Drinking Water Quality Enhancement Program.

References

1. Guidelines for Canadian Drinking Water Quality, Federal Provincial Subcommittee on Drinking Water of the Federal Provincial Territorial Committee on Environmental and Occupational Health, March 2001.

Section 2

Potential Alternative Treatment Processes

2.1 Approach to Selecting Alternative Process Trains for Review

Due to the rapid development in water treatment technology, the Water and Waste Department is cognizant of the need to investigate emerging water treatment technologies as they develop in order to ensure that the most effective technology is incorporated into Winnipeg's new facility. To this end, considerable additional effort has been completed on various process issues, as documented in Technical Memoranda No. 6 through 9.

Based on this additional analysis and the City's original water quality targets, a total of 14 additional treatment options (including the City's existing treatment system) were identified for further evaluation and comparison. Some of the alternative treatment options are new processes while others are modifications to the baseline treatment process. All alternatives have been compared to the baseline treatment process.

The treatment options are listed as follows:

- Option 1: Baseline: DAF + Ozone + BAC Filtration + Chloramination
- Option 2: UV Disinfection + Chlorination + Chloramination
- Option 3: UV Disinfection + Chlorination + Chloramination (Staged with the WTP)
- Option 4: DAF + Filtration + UV Disinfection + Chlorination + Chloramination
- Option 5: DAF + Ozone + BAC Filtration + UV Disinfection + Chloramination
- Option 6: Ultrafiltration + Chlorination + Chloramination
- Option 7: Integrated Pretreatment Ultrafiltration + Chlorination + Chloramination
- Option 8: DAF + Ultrafiltration + Chlorination + Chloramination
- Option 9: Ultrafiltration + Ozone + BAC + Chloramination
- Option 10: Ultrafiltration + GAC Contactors + Chlorination + Chloramination
- Option 11: Ultrafiltration + Nanofiltration + Chloramination
- Option 12: Ultrafiltration + UV Disinfection + Chlorination + Chloramination
- Option 13: UV Disinfection + GAC Contactors + Chlorination + Chloramination
- Option 14: Existing Conditions: Chlorination
- Option 15: DAF + Ozone + BAC + Ultrafiltration + Chloramination

Following is a brief description of each process option being considered.

Option 1: Baseline: DAF + Ozone + BAC Filtration + Chloramination

The baseline water treatment process was selected as a result of the 1996 and 1997 pilot test program. This process is presented schematically in Figure 2.1 and addresses all of the City's water quality goals and objectives.

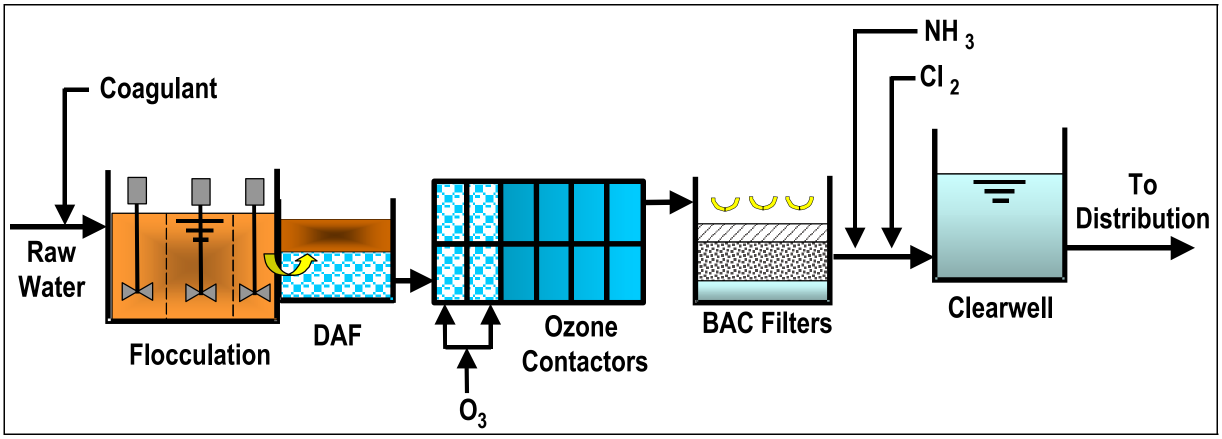

Figure 2.1: Treatment Option 1

Options 2 and 3: UV Disinfection + Chlorination + Chloramination

Options 2 and 3 are presented schematically in Figure 2.2. These process options were selected as recent research has shown that UV disinfection provides a high level of public protection from waterborne pathogens. Option 2 would be a stand-alone treatment process without a future water treatment plant (WTP). This process will achieve the required inactivation of pathogens under ideal conditions however, this option is essentially a single barrier and therefore there is a risk of pathogen breakthrough should conditions deviate from normal. Today, it is commonly acknowledged in the water treatment industry that a multi barrier approach to disinfection is the best way to protect public health. Further, this option would have little beneficial impact on taste and odour.

Option 3 would be a UV system that would be built prior to the future water treatment plant for near-term public health protection and would then be integrated with the baseline water treatment process once the plant has been constructed. While UV alone is not a recommended approach for the long term, this alternative could form the first step in a phased implementation program for the water treatment plant. Phase 1 could be for the near term and would include a UV process built to treat unfiltered water from the Deacon Reservoir. Phase 2 would involve integrating the UV system with the overall water treatment plant. Once integrated into the overall water treatment plant, the UV process would disinfect filtered water.

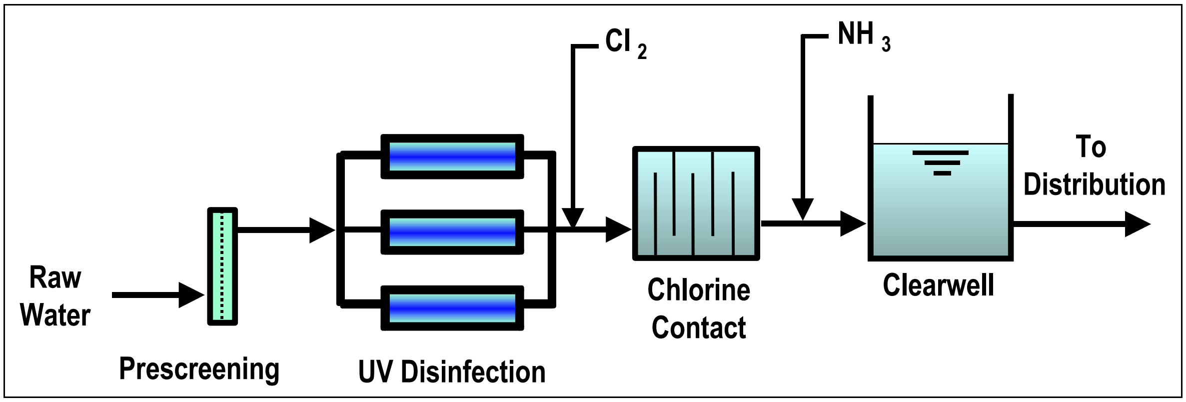

Figure 2.2: Treatment Options 2 and 3

Option 4: DAF + Filtration + UV Disinfection + Chlorination + Chloramination

This treatment option is presented schematically in Figure 2.3. This treatment option is a variation of the baseline process and was selected to determine the effects of replacing the ozone process with UV for primary disinfection. This may be preferred as ozone is more expensive than UV and is less effective a disinfectant on colder waters.

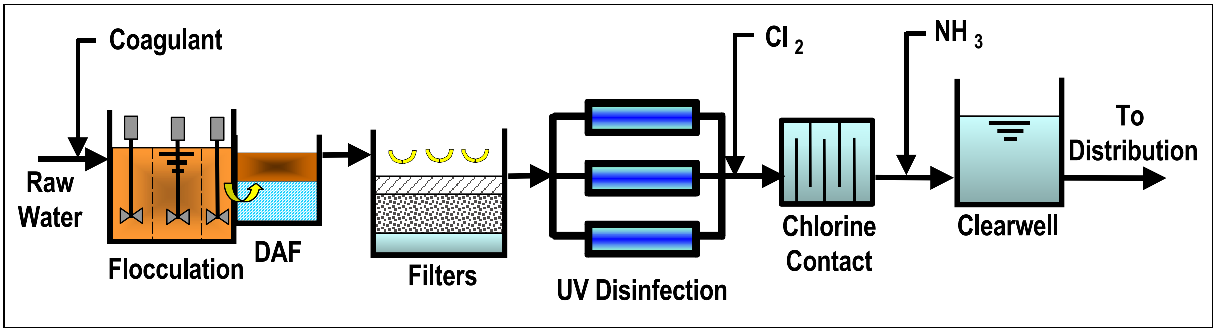

Figure 2.3: Treatment Option 4

Option 5: DAF + Ozone + BAC Filtration + UV Disinfection + Chloramination

This treatment option is presented schematically in Figure 2.4. It is a variation of the baseline process with the addition of UV disinfection downstream of BAC filtration. It was selected to evaluate ozone requirements for meeting water treatment objectives other than *Cryptosporidium* and *Giardia* inactivation (i.e., virus inactivation, filtration improvements, and taste and odour control) if UV is used for primary disinfection.

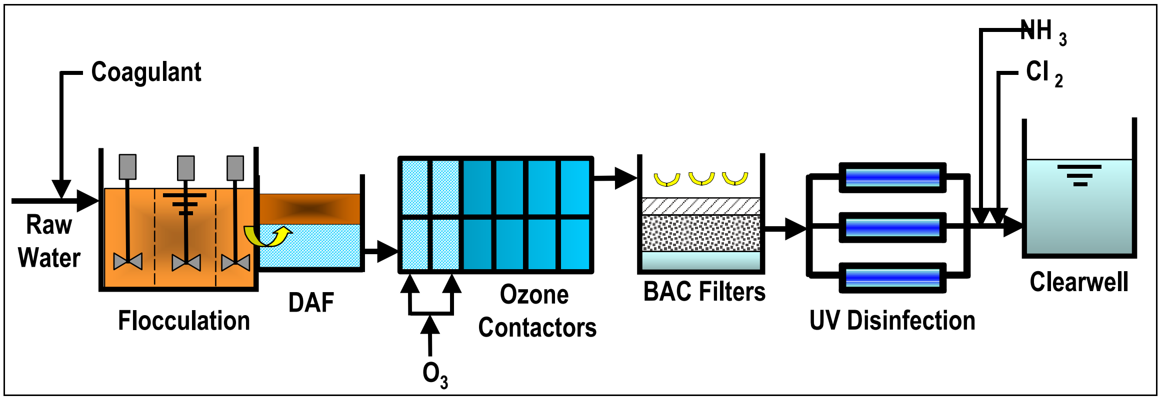

Figure 2.4: Treatment Option 5

Option 6: Ultrafiltration + Chlorination + Chloramination

This treatment option is presented schematically in Figure 2.5. For this option, the baseline treatment process has been replaced by the ultrafiltration membrane process. It was selected for evaluation as it was felt that of the four main membrane types available, ultrafiltration (UF) was best suited for Winnipeg's raw water quality. This process utilizes UF for physical removal of pathogens but would not be effective for removal of organics and taste and odour control.

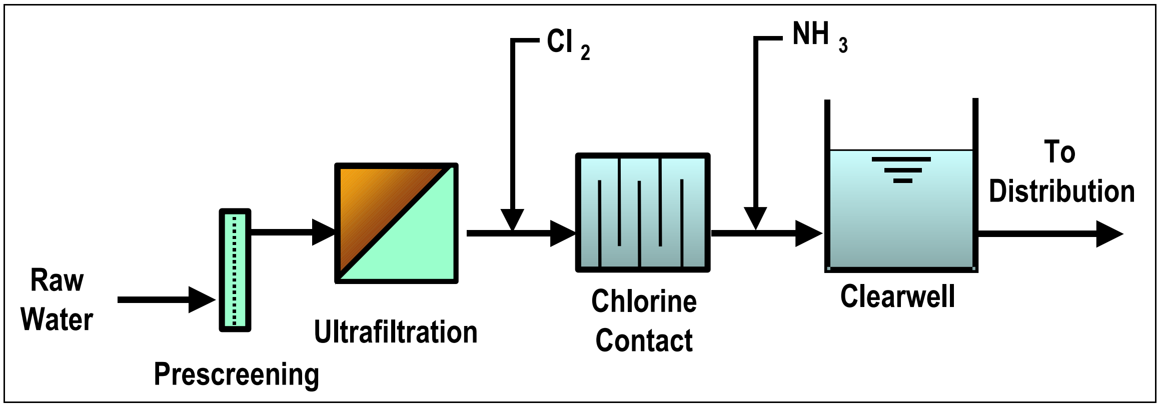

Figure 2.5: Treatment Option 6

Option 7: Integrated Pretreatment Ultrafiltration + Chlorination + Chloramination

This treatment option is presented schematically in Figure 2.6. This process utilizes coagulation/flocculation ahead of the UF membranes as a means of increasing organics removal through the membrane process. This process was selected to evaluate the effectiveness of the pretreatment step for organics reduction and taste and odour control.

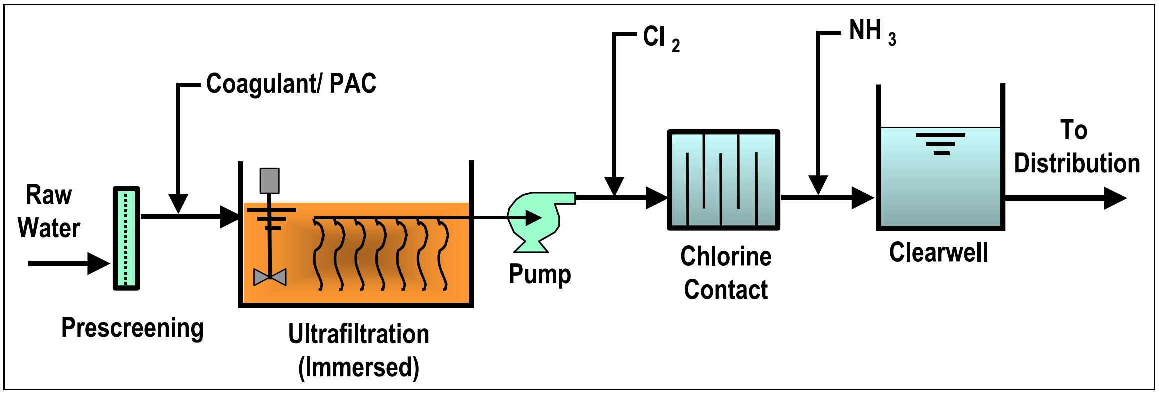

Figure 2.6: Treatment Option 7

Option 8: DAF + Ultrafiltration + Chlorination + Chloramination

This treatment option is presented schematically in Figure 2.7. This process utilizes a complete solids separation process ahead of UF. Based on the 1996/1997 pilot results, dissolved air flotation (DAF) was determined to be the most effective solids separation process for Winnipeg's raw water. This process was selected to compare the cost and benefits of this process over the integrated pretreatment process for taste and odour control and organics removal.

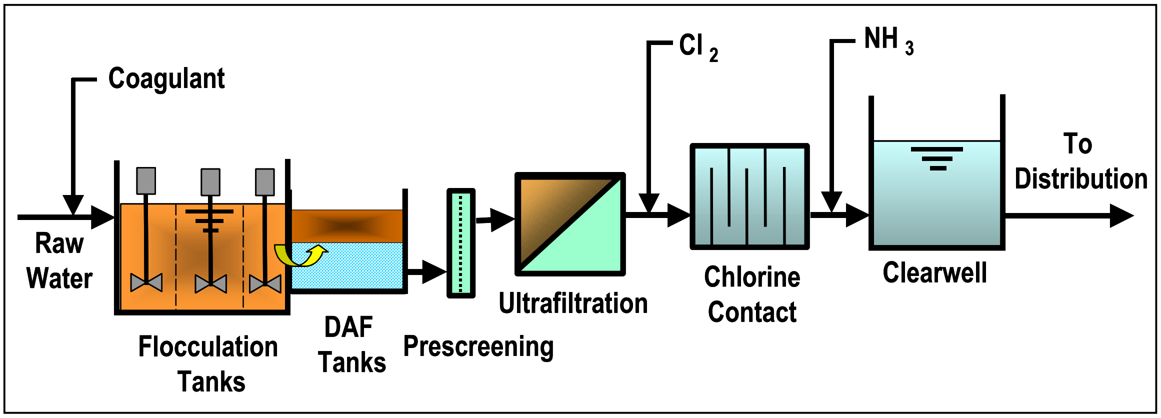

Figure 2.7: Treatment Option 8

Option 9: Ultrafiltration + Ozone + BAC + Chloramination

This process is presented schematically in Figure 2.8. This process includes ozone and BAC filters downstream of the UF membranes. It was selected to evaluate the cost and benefits of adding ozonation for increased pathogen control, taste and odour control, and mitigation of disinfection by-products.

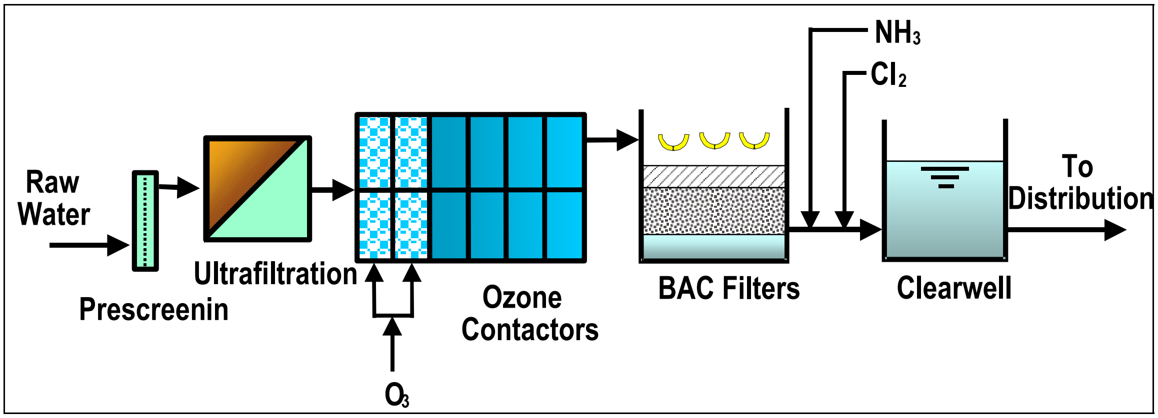

Figure 2.8: Treatment Option 9

Option 10: Ultrafiltration + GAC Contactors + Chlorination + Chloramination

This process is presented schematically in Figure 2.9. This process utilizes UF followed by GAC contactors. This process was selected to determine the cost and benefits of including GAC downstream of UF for taste and odour control and removal of organics.

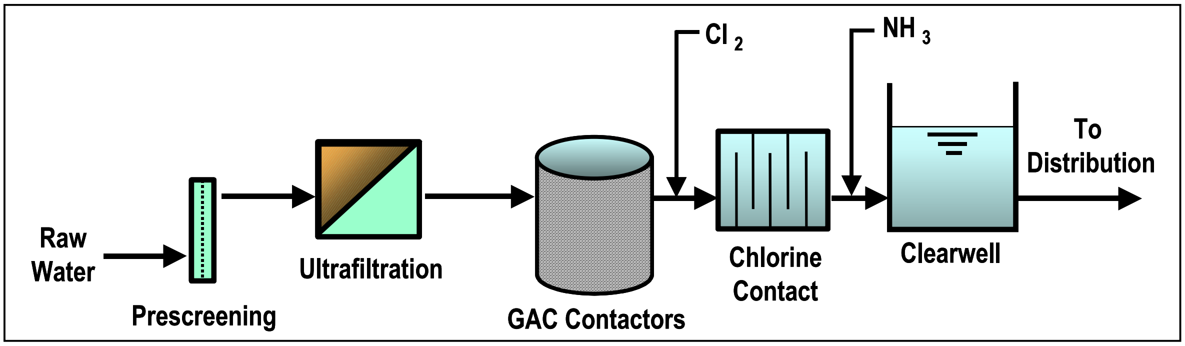

Figure 2.9: Treatment Option 10

Option 11: Ultrafiltration + Nanofiltration + Chloramination

This process is presented schematically in Figure 2.10. This process was selected for evaluation, as it will provide the safest and highest water quality. The UF membrane will remove particles and pathogens while the nanofiltration (NF) process will further remove pathogens and organics from the water and should result in the lowest levels of disinfection by-products. The NF process requires a higher feedwater quality, which is provided by the UF membrane.

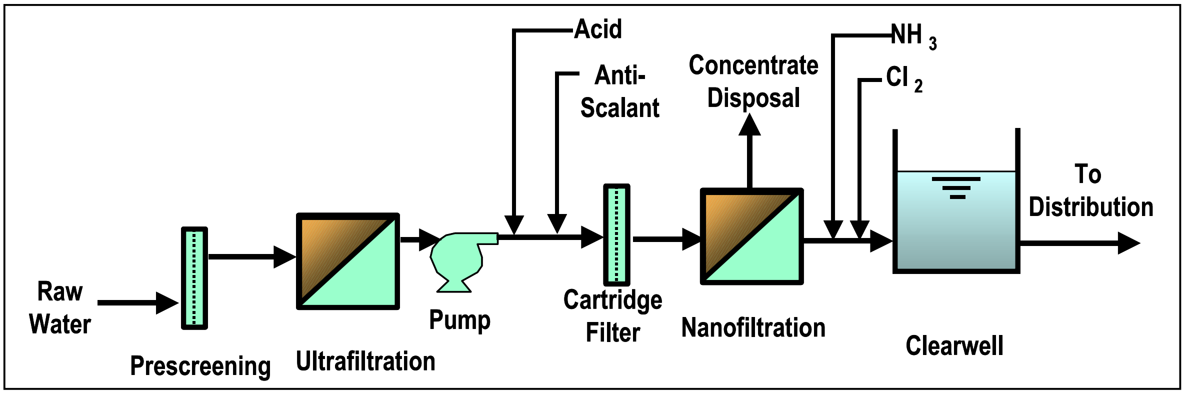

Figure 2.10: Treatment Option 11

Option 12: Ultrafiltration + UV Disinfection + Chlorination + Chloramination

This process is presented schematically in Figure 2.11. This process includes UV disinfection downstream of the UF process. This process was selected for evaluation as it provides multiple barriers and a high level of pathogen control and is relatively easy to operate. A cost/benefit analysis was carried out taking into consideration the organics and taste and odour control limitations of this process.

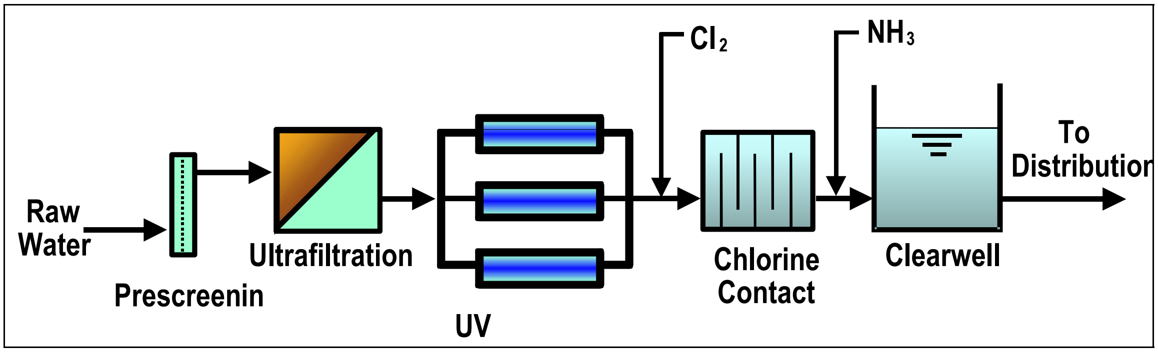

Figure 2.11: Treatment Option 12

Option 13: UV Disinfection + GAC Contactors + Chlorination + Chloramination

This process is presented schematically in Figure 2.12. With this process, the limitations of the UV process would be partially addressed by the inclusion of a granular activated carbon (GAC) filter downstream of the UV system. This process was selected to evaluate the cost and benefits of the GAC process for reducing organics such as disinfection by-product precursors, taste and odour compounds and colour.

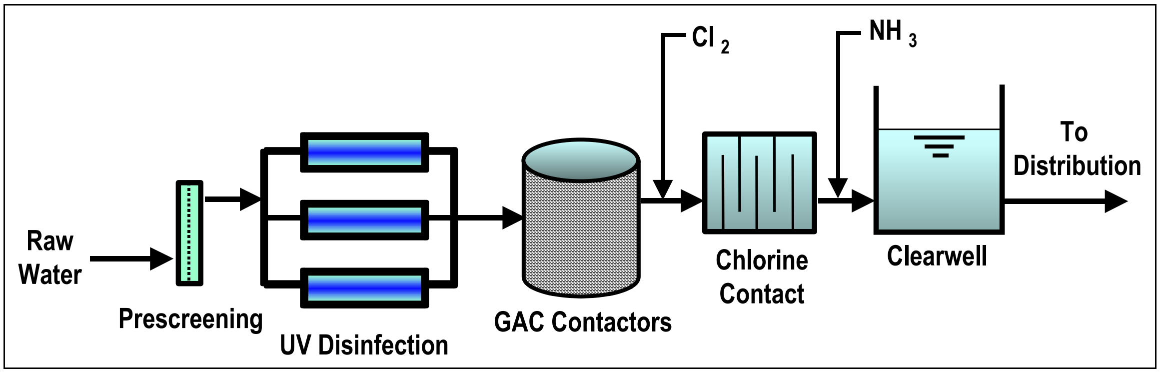

Figure 2.12: Treatment Option 13

Option 14: Existing Conditions: Chlorination

The City's existing water supply and treatment system is presented in Figure 2.13. Currently, water treatment in Winnipeg consists of screening, chlorine disinfection, fluoridation, and corrosion control. While this process is the simplest to operate and results in no additional costs to the City, it is not considered a viable option, as it does not meet the water quality goals and objectives. It is included for comparison purposes only.

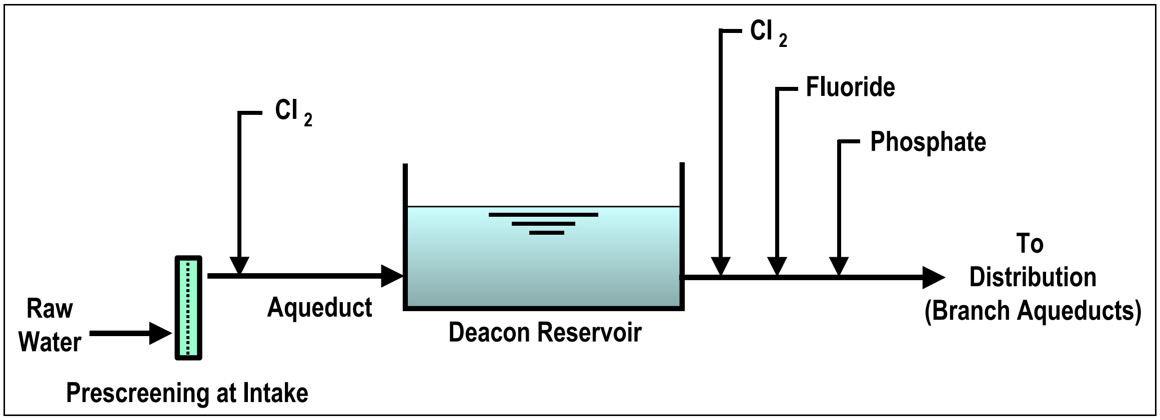

Figure 2.13: Current Water Treatment Process

Option 15: DAF + Ozone + BAC + Ultrafiltration + Chloramination

This process is presented schematically in Figure 2.14. This process is a modification of the baseline process but includes UF downstream of the BAC filters. This process was selected for evaluation as it provides an additional barrier to particles and pathogens.

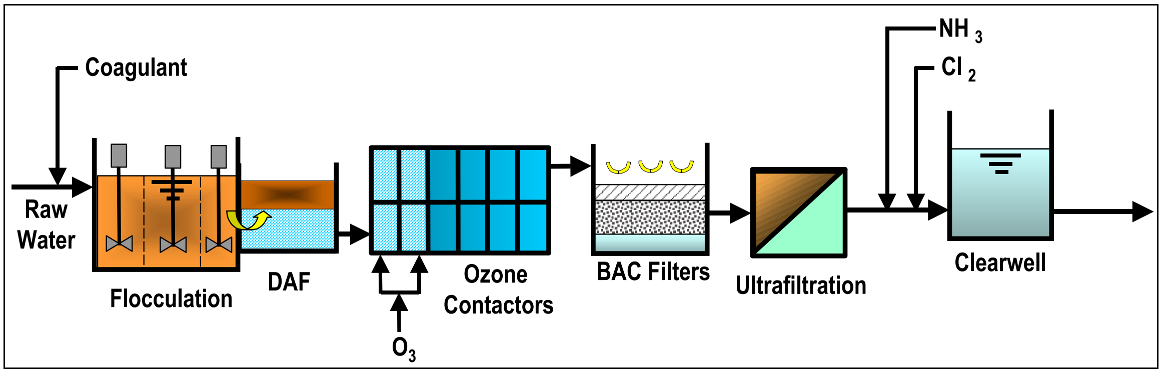

Figure 2.14: Treatment Option 15

2.2 Evaluation of Alternatives

Evaluation of each of these treatment processes was undertaken using a decision making model. The decision model and the results from its application are presented and discussed in Section 7.

Section 3

Ultraviolet Disinfection

3.1 Technology Overview

3.1.1 Introduction

Ultraviolet (UV) disinfection for primary disinfection in municipal water treatment is gaining popularity throughout the United States. One of the factors driving the need for UV disinfection is the Safe Drinking Water Act (SDWA) regulations. Advances in UV technology have resulted in more efficient lamps and more reliable equipment, and therefore, the use of UV technology has increased dramatically, particularly in the municipal sector.

UV radiation is classed as electromagnetic waves with a wavelength of 40 to 400 nm. The germicidal UV light wavelengths range from 200 to 300 nm, with the optimum germicidal effect occurring at 253.7 nm (Figure 3.1). Low-pressure lamps emit maximum energy at 253.7 nm while medium pressure lamps emit energy over a broad band of wavelengths, from approximately 200 to 1320 nm.

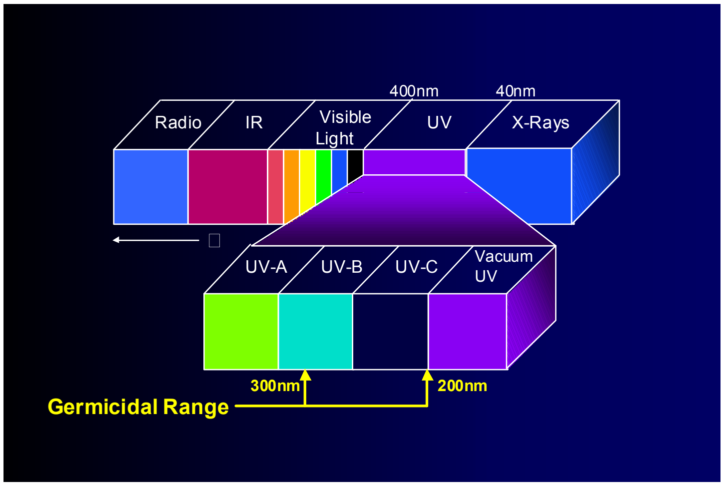

Figure 3:1: Spectrum of UV Light

UV electromagnetic energy is typically generated by the flow of electrons from an electrical source through ionized mercury vapor in a lamp. Several manufacturers have developed systems to align UV lamps in vessels or channels to provide UV light in the germicidal range for inactivation of microorganisms. The UV lamps are similar to household fluorescent lamps, except that fluorescent lamps are coated with phosphorous, which converts the UV light to visible light.

3.1.2 UV Equipment Manufacturers and Types of UV Systems

There are presently several manufacturers of UV disinfection equipment with a large number of lamp configurations, types, and intensities. Research is continuing into new types of UV systems, such as pulsed output lamps, which are not yet feasible options for full-scale application in the municipal water treatment market.

A summary of the characteristics of various types of UV lamp technologies currently being offered to the municipal market is provided in Table 3.1.

Table 3.1: General Characteristics of UV Disinfection Lamp Technologies

	Low-Pressure, Low-Intensity (LPLI)	**Low-Pressure, High-Intensity (LPHI)**	**Medium-Pressure, High-Intensity (MPHI)**
Mercury Vapor Pressure, torr	10^{-3} to 10^{-2} Optimal at 0.007	10^{-3} to 10^{-2} Optimal at 0.007	10^{2} to 10^{4}
Operating Temperature, °C	40	60 to 250	600 to 900
UV Light Spectrum	Monochromatic (near 254 nm)	Monochromatic (near 254 nm)	Polychromatic (200 to 1320 nm)
Electrical Input, W/cm of lamp length	0.5	1.5-10	50-150
Germicidal UV Output, W/cm of lamp length	0.2	0.5-3.5	5-30
Electrical to Germicidal UV Conversion Efficiency, %	35-38	30-35	10-20
Power Consumption, W	70	170 to 1,600	2,000 to 20,000
Arc Length, cm	45-150	45-150	120
Lamp Output	Constant	Adjustable	Adjustable
Relative Number of Lamps Required for a given Dose	High	Intermediate	Low
Rated Lifetime, hrs	8,000-10,000	8,000-10,000	3,000-5,000
Cleaning	Manual	Automatic	Automatic

nm = nanometers

3.1.3 Overall Advantage of UV Disinfection

The benefits of UV disinfection for water treatment are summarized below:

- Superior inactivation of pathogenic protozoa (i.e., *Giardia* and *Cryptosporidium*), and bacteria.
- No chemicals added to the water.
- No increase in the concentration of biodegradable or assimilable organic carbon (AOC), thereby limiting the re-growth potential within the distribution system.
- No concerns with respect to interactions with pipe material.
- No known formation of disinfection by-products (e.g., THMs, HAAs, aldehydes, bromate, ketoacids).
- To achieve the same log inactivation of *Giardia* and *Cryptosporidium*, it is less costly than ozone.

- When used in conjunction with chloramine as the secondary disinfectant, there is almost no formation of chlorinated DBPs of concern.

However, compared to ozonation, UV disinfection would not offer virus reduction, the possibility for any potential enhancements to the filtration process, taste and odour reduction, or provide a barrier to synthetic organic chemicals (SOCs).

Furthermore, UV leaves no residual with which to prevent re-growth in the distribution system. Therefore, a secondary disinfectant must be used to provide this residual. For Winnipeg's situation, Manitoba Health mandates the use of free chlorine for distribution system disinfection. The choice of the secondary disinfectant for Winnipeg is discussed in Section 5 and Technical Memorandum No. 8.

3.2 AWWARF Study and Pilot Testing Program

3.2.1 Overview of Program

In 2001, the City of Winnipeg, as part of a Collaborative Team initiated a study and pilot testing program titled "*UV Disinfection and Disinfection By-product Characteristics of an Unfiltered Water Supply*". The study was funded in part by the American Water Works Association Research Foundation (AWWARF). The pilot testing program began in June 2001 and is scheduled for completion in fall 2002. One of the objectives of the research project is to determine if UV disinfection is an applicable technology for Winnipeg's unfiltered water.

Past UV disinfection research has been focused on filtered water applications, however, research is now exploring the application of UV on surface waters such as Winnipeg's Shoal Lake water supply. The following is a list of specific objectives of the AWWARF project:

- Determine the impacts of turbidity, algae, and TOC on UV disinfection efficiency.
- Determine the impact of algae and TOC on lamp fouling characteristics and cleaning needs over a one-year period.
- Determine the possible reduction and change in disinfection by-products attainable after converting to UV as the primary disinfectant.

The results will provide the information necessary to determine the appropriateness of including UV disinfection in Winnipeg's water treatment system. The DBP information will demonstrate possible approaches and anticipated outcomes for changes in the disinfection system to control the type and concentration of disinfection by-products when using UV as the primary disinfectant.

Four inactivation studies are also included in the pilot studies. It is intended to carry out the inactivation studies during the following water quality periods:

- Average Turbidity, algae, and TOC
- High TOC
- High algae
- High turbidity or repeat session with high algae

3.2.2 Initial Results

Preliminary results of the pilot testing program indicate that UV will provide an effective means of disinfection for Winnipeg's unfiltered water supply.

3.3 Patent Issues

Calgon Carbon Corporation has registered a patent in the USA for the use of UV light for the inactivation of *Cryptosporidium* oocysts in drinking water. The patent is dated October 10, 2000. Calgon's patent covers "a method for the prevention of *Cryptosporidium* oocyst and other organism infection in water using low levels of ultraviolet light".

Calgon was granted a Canadian Patent for its UV technology on February 19, 2002.

Calgon has advised that its license fee in Canada for the use of technology that falls within its patent is $Canadian 0.015 per 1000 US gallons of water treated (approximately $4 Canadian per Million litres treated).

Although Calgon's patent was being challenged at the time of this report, it is prudent to include the Calgon license fees as an operating cost for this technology. For the ultimate design scenario for the City of Winnipeg, assuming an annual average demand of 300 ML/d, the annual license fee would be on the order of $Canadian 440,000 per year.

3.4 Incorporation of UV into the Water Treatment Process

3.4.1 Recommended Approach

When considering the applicability of UV process options for interim or long-term water treatment, the City's water treatability and water quality objectives are the most important factors. The optimum approach to incorporating UV disinfection is to add the UV process to the recommended baseline water treatment process downstream of the BAC filters.

This approach provides all of the benefits of the baseline water treatment process and meets all of the City's water treatment goals. By positioning the UV system downstream of the BAC filters, the feed water to the UV system will be of high quality and will allow the UV system to perform efficiently. As the UV system provides inactivation of *Giardia* and *Cryptosporidium*, the ozone system does not have to be designed for this function. The ozone system will still be required for virus inactivation, taste and odour control, and filter performance improvement, however the ozone system requirements will be less than for the inactivation of *Giardia* and *Cryptosporidium.*

3.4.2 Other Alternatives

In addition to the foregoing approach, various alternatives for utilizing UV disinfection were considered. However, none of these alternatives are capable of addressing all of the City's water quality goals and therefore, they have been ruled out from further consideration. These alternatives are documented in the following paragraphs. It should be noted that all options include the conversion from chlorine to chloramines to minimize disinfection by-product formation.

UV Disinfection + Chlorination + Chloramination

Currently, water treatment in Winnipeg consists of screening, chlorine disinfection, fluoridation, and corrosion control. One alternative is to provide UV disinfection as the only additional water treatment process. This would allow the distribution system disinfection system to be converted from chlorination to chloramination.

While achieving the required inactivation of pathogens under ideal conditions, this option is essentially a single barrier and therefore there is a risk of pathogen breakthrough should conditions deviate from normal. For example, should turbidity rise, the log inactivation through the UV system would decrease at the time when the risk may be the highest. Today, it is generally accepted that a multi barrier approach to disinfection is the best way to protect public health. Further, this option would have little impact on taste and odour reduction. DBP formation, however would be slightly reduced over the current system due to the use of chloramines over chlorine. Because it does not meet several of the City's water quality goals, the UV alone alternative was ruled out from further consideration as a long term option.

A UV system would be relatively compact. This provides an opportunity to install the UV system in advance of constructing the full treatment process, thereby providing some public health benefits. While UV alone is not a recommended approach for the long term, this alternative could form the first step in a phased implementation program for the water treatment plant. Phase 1 could be for the near term and would include a UV process built to treat unfiltered water from the Deacon Reservoir. Phase 2 would involve integrating the UV system with the overall water treatment plant. Once integrated into the overall water treatment plant, the UV process would disinfect filtered water.

GAC Contactors + UV Disinfection + Chlorination + Chloramination

The limitations of the UV alone process would be partially addressed by the inclusion of a granular activated carbon (GAC) filter up stream of the UV system. The GAC filter would have the effect of reducing organics such as disinfection by-product precursors, and taste and odour compounds. However, the GAC filter would have little if any capability for pathogen removal. Therefore, the advantage of this system is that it could address organics, disinfection by-products and taste and odour concerns as well as provide a more consistent water quality to the UV system. The disadvantage is the lack of a second barrier to pathogens and lack of turbidity control. Furthermore, with no pretreatment, the life of the GAC bed would be shortened thus increasing regeneration costs. Therefore, this process was ruled out from further consideration.

DAF + Filtration + UV Disinfection + Chlorination + Chloramination

The DAF and filtration in this option provide the multi-barrier approach missing from the above options. A significant proportion of the pathogens will be removed prior to the UV system. The DAF and filters will also ensure that good quality water with a high transmittance reaches the UV lamps. Taste and odour will be reduced by the action of the DAF and BAC filtration but will fall short of the removal levels achievable if ozone was to be included. Therefore, because not all of the City's water quality goals can be met, this option was ruled out from further consideration.

3.5 Ozone Requirements with UV for Primary Disinfection

3.5.1 Introduction

From the 1996/1997 water treatment pilot program, the water treatment objective of the ozone system was to achieve an additional 1-log of C*ryptosporidium* inactivation while addressing taste and odour concerns, providing disinfection by-product (DBP) reduction and improving filterability of the water. In the 1998 Conceptual Design Report, the ozone system was sized for this level of inactivation.

However, recent research data indicates that the ozone dose required for *Cryptosporidium* inactivation at low water temperatures (less than 5°C) is much greater than originally indicated in the preliminary inactivation data generated in 1997 by Finch. Based on the new Ct information for *Cryptosporidium* inactivation, the ozone system would be much larger in size than set out in the 1998 Conceptual Design Report. The updating and resizing of the original ozone system is presented in Appendix B of Technical Memorandum No. 6.

As previously noted, the UV system will provide inactivation of *Giardia* and *Cryptosporidium,* while the ozone system will provide inactivation of viruses to form a comprehensive primary disinfection system. This approach mitigates the need to increase the size of the ozone system to achieve the new requirements for *Cryptosporidium* inactivation.

3.5.2 Integration of UV and Ozone Processes

In addition to disinfection, ozone has many other uses such as taste and odour reduction, improvement of downstream processes (coagulation and filtration), reduction of DBP precursors, and increasing the biodegradability of dissolved organic carbon (BDOC) in the water. In conjunction with BAC, ozone can provide a significant reduction in DBP precursors.

Therefore, if ozone is not required for inactivation of *Giardia* and *Cryptosporidium*, the primary functions of the ozone system will be:

- Taste and odour control
- Virus inactivation
- Filterability improvement

By using ozone for addressing the treatment objectives of taste and odour control, virus inactivation and improving the filterability of the water, the overall contact time can be reduced to 10-15 minutes. The 1996/1997 pilot study also determined that an ozone residual of 0.5 mg/L was adequate for taste and odour control. It is recommended that three parallel ozone trains be installed, each capable of providing 15 minutes of contact time for the portion of flow passed through that contactor. It is estimated that the maximum ozone dose required is 1 mg/L, which leads to an ozone capacity of 515 kg per day. This is approximately the same as the original ozone system sizing but the ozone contactors have been reduced by approximately 20 percent.

Since UV can be used for the inactivation of *Giardia* and *Cryptosporidium*, using UV in conjunction with ozone will result in an improvement in water quality and reduction in pathogen risk. The required additional *Giardia* and *Cryptosporidium* inactivation can be achieved with a delivered target UV dosage of 40 mJ/cm^2.

3.6 UV System Conceptual Design

3.6.1 Design Criteria

Table 3.2 shows some historical raw water quality data for Winnipeg. Turbidity and algae are of particular interest since they can shield and could have a tendency to agglomerate with pathogens, resulting in a reduction in UV efficiency. In addition, the impact of medium to high TOC on the UV disinfection efficiency has not been investigated in great detail.

Table 3.2: Historical Raw Water Quality (1997-2001)

Parameter	Units	Average	Minimum	Maximum
Shoal Lake Intake				
pH	Units	8.0	7.0	9.0
TOC	mg/L	8.9	4	11
DOC	mg/L	8.9	3.5	12
Alkalinity (total)	mg/L as $CaCO_3$	79	71	89
Hardness (total)	mg/L as $CaCO_3$	79	66	90
Color (true)	TCU	7	<5	15
Deacon Reservoir Inlet				
Turbidity	NTU	0.80	0.25	1.9
Plankton	Cells/mL	14400	700	114300
TTHM	μg/L	113	26	192
Outlet from Deacon Reservoir Cells 1 & 3				
Turbidity	NTU	0.76	0.25	4.0
Plankton	Cells/mL	19900	790	285000
TTHM	μg/L	56	1.5	129

UV transmittance was monitored during the 1996/1997 pilot testing of various treatment/filtration processes. The data indicate the following:

- A minimum UV transmittance of 75 percent was observed for raw unfiltered water.
- An average filter effluent UV transmittance of 94 percent can be achieved.
- A minimum filter effluent UV transmittance of 90 percent was observed.

During the current AWWARF pilot study, the UV transmittance of the unfiltered Deacon water varied from 76 to 79 percent. It is anticipated that seasonal water quality changes will reduce the UV transmittance to as low as 75 percent.

Based on the foregoing information, the following UV transmittance design criteria were established to aid the sizing of the UV system required for Winnipeg:

- For raw unfiltered water, a UV transmittance of 75 percent is assumed for both equipment sizing and O&M cost evaluation.
- For effluent from the BAC filters, a UV transmittance of 90 percent is assumed for equipment sizing and a UV transmittance of 94 percent is assumed for O&M calculations.

A design dose rate of 40 mJ/cm^2 has been selected. This is based on the recommendation contained in the US EPA Draft Guidance Manual. The US EPA based this recommendation on the results of many experimental works and it builds in a reasonable safety factor to ensure effective UV disinfection.

The UV equipment has been sized for the following flow conditions for filtered water (90 Percent Transmittance):

- Maximum Flow: 515 ML/d
- Average Flow: 300 ML/d

The possibility of using the same UV system for the unfiltered condition as well has been investigated. The capacity for the unfiltered condition would be less due to the lower UV transmittance for the unfiltered water. The UV equipment selected for the filtered water scenario would be capable of treating the following flows in the unfiltered water scenario (75 Percent Transmittance):

- Maximum Flow: 300 ML/d
- Average Flow: 225 ML/d

3.6.2 UV System Sizing

As a first step, initial conceptual designs based on manufacturer's preliminary sizing have been developed for both the unfiltered and filtered water supplies. Equipment available from Wedeco has been used to represent the use of a low pressure high intensity system (LPHI). Equipment available from Aquionics has been used to represent the use of a medium pressure high intensity system (MPHI). Equipment available from other manufacturers will have similar features.

The LPHI (Wedeco) system design data for unfiltered and filtered water is summarized in Table 3.3.

Table 3.3: LPHI (Wedeco) System Design Data

Description	Units	Unfiltered Water	Filtered Water
Design Flow	ML/d		
Maximum flow rate		330 (no standby)	600 (1 standby)
Average flow rate		225	330
Maximum capacity of each reactor		66	165
Design UV Dose	mJ/cm²	40	40
UV Transmittance (253.7 nm)	%	75	90
Water Temperature	Min./max. °C	0.5/25	0.5/25
Configuration			
Unit model number		12/12-K143	12/12-K143
Number of units	Qty	5	5
Number of rows per unit		12	12
Number of lamps per row		12	12
Number of lamps per unit		144	144
Total number of lamps		720	720
Approximate Unit Dimensions	cm (inches)		
Approx. length		470 (185)	470 (185)
Flange / pipe diameter		163 (64)	163 (64)
Approx. height		269 (106)	269 (106)
Approx. width (total)		1168 (460)	1168 (460)
Water Pressure	kPa (psig)		
Operating		275 (40)	275 (40)
Headloss*	cm (inches)		
Through each reactor @ 60 ML/d		28 (11)	
Through each reactor @ 150 ML/d			89 (35)
Electrical Load	kW		
Total operating load per reactor		43.2	43.2
Total operating load for 300 ML/D		144	
Total operating load for 600 ML/D			216

*System can be designed with lower headlosses (elimination of baffle plates)

The MPHI (Aquionics) system design data for unfiltered and filtered water is summarized in Table 3.4.

Table 3.4: MPHI (Aquionics) System Design Data

DESCRIPTION	UNITS	Unfiltered Water	Filtered Water
Design Flow	ML/d		
Peak flow rate		330 (1 standby)	525 (1 standby)
Average flow rate		225	300
Maximum capacity of each reactor		66	75
Design UV Dose	mJ/cm²	40	40
UV Transmittance (253.7 nm)	%	75	90
Water Temperature	Min./max. °C	0.5/25	0.5/25
Configuration			
Unit model number		Inline 25000	Inline 25000
Number of units	Qty	6	8
Number of lamps per unit		16	16
Total number of lamps		96	128
Electrical Load	kW/lamp	3.5	3.5
Total operating load	KW	336	448
Approximate System Footprint	m (ft)		
Approx. system width		15.25 (50)	15.25 (50)
Approx. system length		13.40 (44)	15.25 (50)
Water Pressure	kPa (psig)		
Operating		275 (40)	275 (40)
Headloss	cm (inches)		
Through each reactor @ 60 ML/d		76 (30)	
Through each reactor @ 75 ML/d			100 (39)

3.6.3 UV System Layout Options

The foregoing initial conceptual designs provide the basic sizing of UV systems that would suit the characteristics of Winnipeg's water supply. This section examines available layout options for the UV systems that take into account the physical arrangements of the Deacon site and the proposed plans for the water treatment plant.

The existing Deacon Pumping Station could possibly provide adequate space for locating the UV system. Therefore, an attempt was made to configure a system that could be accommodated within the existing space. In addition, options for locating the UV system in newly constructed infrastructure on the proposed plant site at Deacon were considered.

The options considered were as follows:

- Inside Deacon Booster Pumping Station
- On-site at Proposed Water Treatment Plant
- In-ground Upstream of Deacon Booster Pumping Station
- In-ground Downstream of Deacon Booster Pumping Station

Two alternatives, In-ground Upstream of Deacon Pump Station and In-ground Downstream of Deacon Pump Station were ruled out from further consideration because of various disadvantages relative to the other alternatives. The estimated capital costs of the remaining two alternatives were evaluated as set out in the following paragraphs.

3.6.4 Preliminary Capital Cost Estimates

Inside Deacon Booster Pumping Station

Using the initial conceptual designs for both the low pressure high intensity (LPHI) and medium pressure high intensity (MPHI) systems, various equipment layouts were considered for installing the UV system inside Deacon Booster Pumping Station. It was determined that the LPHI system will not fit into the limited amount of space available. Therefore, the conceptual design for this option is based on the use of a MPHI system. Equipment offered by Aquionics has been used as the basis for the conceptual design and preliminary cost estimates. MPHI equipment available from other manufacturers will have similar characteristics.

The budget capital cost for placing the UV system inside the Deacon Booster Pumping Station based on the use of the Aquionics medium pressure high intensity reactors is as follows:

Table 3.5: Budget Capital Cost Estimate – Inside Deacon Booster Pumping Station

Item	Budget Cost $
UV reactor purchase (9 units)*	3,000,000
Process mechanical (pipes, valves, flow meters, installation)	1,000,000
Power, controls, misc. metals, miscellaneous	400,000
Sub-total	4,400,000
Contractor markups @ 35% (overhead, profit, GC's, 10% contingency)	1,500,000
Sub-total (construction costs N/I taxes)	5,900,000
PST (7%) & GST (3%)	600,000
Allowance for Engineering & Commissioning @ 15% of Construction Costs	900,000
Project contingency @ 20% of Construction Cost	1,200,000
Total Budget Estimate	**8,600,000**

* The number of reactors required is increased to 9 in order to accommodate the different operating requirements for the two sides (i.e., Branch I and Branch II Aqueduct) of the pumping station.

The key assumptions are as follows:

- All costs are based on conceptual level information and are intended to allow for comparison to other alternatives.
- No standby power capability is provided.
- City finance and administration costs are not included.
- Other costs (Alternative Service Delivery Study, Risk Assessment, Environmental Hearings/Approvals) that are associated with the overall project are not included.

On-site at Proposed Water Treatment Plant

The UV system could be sited at the downstream end of the proposed water treatment plant. If the UV system is installed in advance, construction of some components of the water treatment plant will also have to be constructed in advance. These components would include the low lift pumping station (not including the pumps), raw water feed piping and the clearwell. Additional raw water piping to avoid the area to be occupied by the overall water treatment plant would also have to be constructed as will the building structure to house the UV system. The design of the overall water treatment plant would have to be advanced to about the 30% complete stage in order be able to properly plan out and position some of the foregoing elements. The estimated cost of this alternative is as follows:

Table 3.6: Budget Capital Cost Estimate – On-Site At Proposed Water Treatment Plant

Item	Budget Cost $
Clearwell	1,700,000
Raw water pumping station (no pumps or electrics)	3,800,000
Raw Water Piping & Bypass around WTP site	3,400,000
Filter section bypass	600,000
Additional CW Piping	1,000,000
Building structure for UV system	3,300,000
Site civil work @ 15% of total WTP site civil cost	3,000,000
Sub-total of above	16,800,000
Contractor markups @ 35% (overhead, profit, GCs, 10% contingency)	5,900,000
Sub-total (construction costs N/I taxes)	22,700,000
UV system construction costs N/I taxes (same as Inside Deacon))	5,900,000
Total estimated construction costs N/I taxes	28,600,000
PST (7%) & GST (3%)	2,900,000
Allowance for Engineering & Commissioning of UV System @ 10% of Construction Costs	2,900,000
Allowance for 30% design of WTP	4,000,000
Project contingency @ 20% of Construction Costs	5,700,000
Total Budget Estimate	**$43,100,000**

The key assumptions are as follows:

- All costs are based on conceptual level information and are intended to allow for comparison to other alternatives.
- The cost of the UV system (process equipment, controls, electrical) is assumed to be the same as for the In-side Deacon alternative.
- The costs are based on the use of MPHI UV reactors. If LPHI reactors are used, the overall space requirements for the UV system will increase and the overall cost will increase.
- No standby power capability is provided.
- City finance and administration costs are not included.

3.6.5 Cost Comparisons

If the UV system is installed in advance, the foregoing preliminary cost analysis indicates that locating the UV system in the Deacon Booster Pumping Station will be significantly less costly than incorporating the UV system into the downstream end of the proposed water treatment plant. The main difference is that significant infrastructure related to the overall plant will have to be constructed for the On-site at Proposed Water Treatment Plant alternative. This is required to ensure that the UV system can be integrating into the overall water treatment plant once it is constructed.

The majority of the infrastructure constructed in advance for the On-site at Proposed Water Treatment Plant alternative will be required for the overall plant. The exception is the additional raw water pipework that is required to by-pass the future plant area, which has an estimated value of approximately $400,000.

Additional pumping capacity would be required at Deacon Booster Pumping Station between 2017 and 2022. At that time the UV system would have to be relocated to the downstream end of the water treatment plant. It is assumed that a similar system to that installed in 2003 would be used, although this will depend on the technology available at that time. By 2017, the UV equipment installed in either alternative will likely be near the end of its useful life and will have to be replaced in either scenario.

Therefore, it is expected that the total cost over the long term will be only marginally higher for installing the UV system inside the Deacon Booster Pumping Station versus installing the UV system at the downstream end of the future water treatment plant.

3.6.6 Preliminary Operating Cost Estimates

Most of the O&M costs associated with a UV disinfection system result from power costs and lamp replacement costs. From manufacturer’s literature, it was noted that typical lamp life is about 1 year. Therefore, the lamps will need to be replaced once per year.

Table 3.7 presents an unfiltered water operating cost summary and Table 3.8 presents the filtered water operating cost summary. Both are based on the use of a MPHI system assuming that the UV system is installed in the Deacon Booster Pumping Station. The operating costs are based on the data available from Aquionics, but MPHI reactors available from other manufacturers will have similar characteristics. The license fee to Calgon Carbon for use of UV technology has been assumed to be applicable and has been included in these estimates.

Table 3.7: MPHI (Aquionics) Operating Cost Summary – Unfiltered Water

	Unit	Qty.	Unit Cost	Total
Electricity	kWh	280 x 8,760	$0.06	$147,168
Lamps	each	80	$575.00	$46,000
Wiper rings	each	160	$25.00	$4,000
Quartz sleeves	each	16	$250.00	$4,000
Sleeve seals	each	16	$10.00	$160
Labour	hr	52	$30.00	$1,560
Calgon License Fee for use of UV Technology (approximate)				$330,000
Total Annual O&M				**$532,888**

*Basis: Max Flow: 300 ML/d Average Flow: 225 ML/d
UVT: 75% UV Dose: 40 mJ/cm^2
Labour: $30/hr

Table 3.8: MPHI (Aquionics) Operating Cost Summary – Filtered Water

	Unit	Qty.	Unit Cost	Total
Electricity	kWh	392 x 8,760	$0.06	$206,035
Lamps	each	112	$575.00	$64,400
Wiper rings	each	224	$25.00	$5,500
Quartz sleeves	each	22	$250.00	$5,600
Sleeve seals	each	22	$10.00	$224
Labour	hr	52	$30.00	$1,560
Calgon License Fee for use of UV Technology (approximate)				$440,000
Total Annual O&M				**$723,319**

*Basis: Max Flow: 515 ML/D Average Flow: 300 ML/D
UVT: 90% UV Dose: 40 mJ/cm^2
Labour: $30/hr

3.7 Conclusions

Based on the investigations as well as the AWWARF pilot testing program, Ultraviolet disinfection (UV) can be incorporated into the baseline water treatment process for Winnipeg.

UV will provide an effective additional barrier against water borne pathogens, for both the unfiltered water and the filtered water.

The baseline water treatment process currently includes ozonation for *Giardia* and *Cryptosporidium* inactivation. Based on recent research, the ozone dose requirements for inactivation of *Giardia* and *Cryptosporidium* for cold water have increased dramatically. Incorporation of UV into the baseline water treatment process will allow the ozone system to be used strictly for virus inactivation, taste and odour control, and filterability improvement.

The UV system can be installed in the Deacon Booster Pumping Station. This alternative will require the least capital expenditure and can be implemented in the least amount of time.

When the balance of the water treatment plant is constructed, the UV system installed in Deacon Booster Pumping Station can be integrated into the overall treatment process.

References

1. The City Of Winnipeg's Drinking Water Quality Enhancement Program, Final Report, 1999.

Section 4

Membrane Filtration

4.1 Introduction

This section of the Summary Report provides a summary of Technical Memorandum No. 7 – Membrane Filtration.

In 1999, the Conceptual Design and cost estimates for a water treatment facility to meet the City's water quality goals were completed (Winnipeg Water Consortium, 1999). The baseline water treatment process was selected based on extensive pilot testing and consists of enhanced coagulation and flocculation, dissolved air flotation, ozonation, biological activated carbon filtration, and monochloramination for secondary disinfection. Due to the projected rapid development in water treatment technology in the coming years, the Water and Waste Department is cognizant of the need to investigate emerging technologies as they develop in order to ensure that the most effective technology is incorporated into Winnipeg's new facility.

Membrane technology is one such alternative that the City wishes to have reassessed.

During the 1997 study period, membrane water treatment plants were of relatively low capacity and more costly than the baseline treatment process selected for Winnipeg at that time. However, since that time, the size of membrane plants has increased and the cost of membrane treatment has come down.

The following sections provide a review of currently available membrane technology that is applicable to the City of Winnipeg's requirements and present alternatives for incorporating membrane technology into the City's Water Quality Enhancement Program.

4.2 Membrane Technology Review

Membrane treatment technologies continue to develop rapidly. New membrane products for public water systems have been commercialized which provide a wide-variety of removal capabilities at competitive costs for small and large systems. What was once a relatively unknown treatment technique less than two decades ago is now recognized by the Environmental Protection Agency (EPA) as a "best available technology" (BAT) for meeting a wide variety of the Safe Drinking Water Act (SDWA) regulations.

Traditionally, membrane processes, represented by reverse osmosis (RO) and electrodialysis (ED), have been employed for brackish and seawater desalting applications, primarily when other, less expensive sources of water were not readily available. Most recently, these and other membrane processes are finding increasing applications in the advanced treatment of water and wastewater for purposes such as softening and particulate and organics removal.

The accumulative membrane capacity in North America has grown at an ever-increasing rate over the last ten years and now totals more than 2 billion litres per day (one-half billion gallons per day). At this time, about 50 percent of this installed capacity uses microfiltration and ultrafiltration membranes and the remainder incorporates nanofiltration, reverse osmosis, and electrodialysis technologies. It is anticipated that membrane capacity growth in North America will be somewhat greater for microfiltration and ultrafiltration over the next 10 years than for the other membrane processes, because microfiltration and ultrafiltration are being used as alternatives to conventional water treatment processes.

Several 400 ML/d (100 MGD plus) membrane plants are now in the design phase in the United States and are expected to be on-line within the next 2 to 3 years.

The membrane processes discussed in this section can be classified by function based on the type of driving force that causes components of a fluid to separate: either pressure or electricity. Membrane processes that use other driving forces (or more than one), such as membrane distillation, membrane air stripping, and pervaporation, have been researched, but will not have significant commercial application in the water and wastewater treatment industry for several years, if ever.

Membranes act as selective barriers, allowing some constituents to pass through the membrane while blocking the passage of others. The movement of material across a membrane requires a driving force (i.e., a potential difference across the membrane), and the membrane processes commonly employed in drinking water applications use pressure as the driving force. There are four categories of pressure-driven membrane processes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). RO and NF processes are typically used for the removal of dissolved constituents including both inorganic and organic compounds, and these processes operate at pressures significantly higher than MF and UF. Low-pressure membrane processes (i.e., MF and UF) are typically applied for the removal of particulate and microbial contaminants, and can be operated under positive or negative pressure (i.e., vacuum pressure).

A subset of the pressure-driven membrane processes exists for MF and UF systems. Some system suppliers offer vacuum-driven MF and UF systems where the permeate is sucked through membrane systems that are immersed in process tanks. In this arrangement, the feed pump is simply moved to the permeate stream downstream of the membrane system.

Membrane performance changes over time. To ensure that a system will continue to produce the desired quantity and quality of permeate over the expected life of the membrane, provisions must be made during the design to account for or counter changes.

The three main factors that cause time-related performance changes are as follows:

> **Membrane Fouling and Scaling.** To illustrate the effect of these factors on water flow through the membrane, system productivity is typically plotted as a function of operating time, referred to as a flux decline curve. Flux decline is defined as the loss in system productivity, expressed as a percentage of initial productivity that occurs with operating time. The principle cause for flux decline is membrane compaction and the effects of fouling and scaling that cannot be reversed by cleanings (referred to as

"irreversible" fouling or scaling). Additional pumping pressure must be included in the design to offset flux decline.

Alternatively, if pressure is automatically increased to maintain a constant flux rate, then transmembrane pressure is plotted as a function of operating time to determine when membrane cleaning is required. This is the typical membrane operating scenario.

Membrane Compaction. Membrane compaction occurs when the spongy support portion of an asymmetrical membrane compresses under the applied pressure of operation. A majority of the compaction (and flux loss) occurs during the first 100 hours of operation. This is the case for all membrane types.

Composite membranes do not typically experience compaction. However, initial flux loss occurs with some composite membranes, which membrane manufacturers refer to as irreversible fouling. The loss of productivity caused by irreversible fouling is generally less than that caused by compaction.

Membrane Degradation/Irreversible Fouling. RO/NF membrane projections allow for decreases in productivity over a period of time (generally 3 or 5 years). One of the principle reasons for pilot testing is to determine the flux decline rate due to irreversible fouling that ultimately dictates the need for membrane replacement.

Fouling is the act of depositing foulant (e.g., inorganic scales, suspended solids, organics, biofilms) on the RO membrane and impeding its proper functioning. Turbulence along the feed-concentrate side of the membrane is used to diffuse solutes away from the membrane surface. As a result, a concentration gradient exists between the membrane surface and the bulk feed-concentrate flow stream, with the highest solute concentrations occurring at the membrane surface. This gradient phenomenon is referred to as concentration polarization. As fouling increases, the degree of concentration polarization also increases. Because osmotic pressure is determined based on the difference in solute concentration across the membrane, fouling results in an increase in the osmotic pressure component. Conversely, holding feed pressure constant, an increase in the osmotic pressure results in a decrease in the available net driving pressure.

Membrane cleaning must be conducted to restore membrane performance, but should not be used as a remedy for significant membrane fouling. Modifications to system operation or pretreatment processes should be explored when frequent membrane cleaning is required i.e., more than every 3 months.

Membrane manufacturers typically provide a prorata warranty covering membrane performance in accordance with the specifications stated in the module specification sheet over a specified period of time. Standard warranty periods range from 3 years in the case of RO/NF modules to as long as 10 years for MF/UF modules. The manufacturer's warranty contains a number of specific conditions that will void the warranty in the event the conditions are not adhered to during the operation and storage of the membrane modules. The conditions relate primarily to feedwater composition, maximum recovery, permeate pressure, and module cleaning and preservation.

In addition, the warranty requires that the owner perform certain record-keeping functions to provide data to the membrane manufacturer or membrane system supplier if a claim is made. Because of the degree and nature of these limitations, it can be challenging for the owner to make good on a performance warranty claim because he or she must assemble sufficient data proving that factors relating to feedwater quality were not responsible for the performance loss. To avoid this problem, it is best for the owner to require the membrane module supplier (or party legally responsible for the membrane warranty) to review the necessary operating and maintenance data on an annual or biannual basis to ensure that the necessary information is being collected.

MF and UF membranes are made from a wide variety of materials, most commonly including polypropylene, polyvinyl difluoride (PVDF), polysulfone, polyethersulfone, and cellulose acetate. The various membrane materials have different properties, including pH and oxidant sensitivity, surface charge, and hydrophobicity. These material characteristics can affect the exclusion characteristic of a membrane as well as operating constraints, such as the potential use of pre-oxidation for iron and manganese oxidation, and, in the case of free chlorine, for the control of biological fouling.

All commercially available MF and UF membranes currently used for drinking water treatment are constructed in a hollow-fiber configuration. Hollow-fiber membranes are operated in either an inside-out or outside-in mode. During inside-out operation, the feed enters the fiber lumen and passes through the fiber wall to generate permeate. During outside-in operation, the permeate is collected in the fiber lumen after the feed is passed through the membrane.

MF and UF systems are designed to directly treat source waters having low-to-moderate levels of suspended solids and turbidity. However, these processes require pretreatment to prevent larger-sized suspended solids from becoming entrained with the fiber bundle and causing damage or performance degradation. Pretreatment is provided in the form of a 200 to 500 μm self-cleaning strainer or screen for pressurized module systems and 2 to 3 mm screening for submerged module systems.

For almost all of the membrane processes applicable to municipal water treatment, the membranes are prepared from synthetic organic polymers. The pressure-driven processes involving liquid transport use either cellulosic or non-cellulosic membranes. The cellulosic membranes are usually asymmetric (membrane made of one material but with a dense "barrier layer" and porous support), whereas non-cellulosic membranes are either asymmetric or composites (barrier and support layers made of different materials).

Nearly all RO/NF membrane systems require some form of pretreatment equipment to condition the treated water source prior to membrane processing. At a minimum, this may simply be a cartridge filter housing containing disposable micron-rated filter elements to protect downstream pumps and RO/NF membrane modules from damage by particulates present or introduced into the water. This is typical for groundwaters. In cases in which the quality of the feedwater is poor (e.g., high levels of suspended solids, sparingly soluble salts, dissolved organic carbon, and biological matter), some sort of solids clarification process (conventional treatment, direct filtration, or MF/UF) or lime softening may be necessary. The degree and complexity of the pretreatment equipment are determined by the feedwater requirements of the membrane, the quality of the raw water, and other design factors. If the feedwater contains significant microbial activity, pretreatment may include chlorination or disinfection/oxidation by other methods (e.g., ultraviolet, ozone).

Unless the treated water source is available at adequate pressure (e.g., from well pumps), booster pumps are required to provide the necessary head to overcome losses through the pretreatment equipment and associated piping and fittings, and to satisfy the minimum suction head requirements of the RO/NF feedwater pumps.

Microfiltration and ultrafiltration membranes are being used for increasingly more challenging applications where removal of dissolved matter with the aid of a chemical coagulant, powered activated carbon, or preoxidant is required. MF and UF alone are not effective in removing total organic carbon (TOC), disinfection by-product precursors, (true) colour, dissolved iron and manganese, and taste and odour compounds. With pretreatment prior to MF or UF (such as a high rate clarifier or simply arranged in a direct filtration scheme with chemical addition, rapid mix, and flocculation upstream of the membrane system), most removal requirements can be met where conventional treatment is normally considered. Furthermore, following MF and UF with other processes such as granular activated carbon (GAC), nanofiltration, or reverse osmosis and final disinfection, most water treatment challenges can be met.

MF and UF can be integrated into existing conventional water treatment plants at several locations, such as using immersed (vacuum-type) membranes as a combined clarification/filtration process following coagulant and/or PAC addition or installed as a filter retrofit inside an existing filter box. Additionally, pressure or vacuum membranes can be added as a polishing step following existing filtration or used for recovery of backwash water from existing filters. Currently, regulatory agencies in the U.S. require recovered backwash water to be recycled back to the treatment facility; if this is changed in the future to allow membrane permeate to be blended with the main treatment product water, filter backwash recovery with membranes will be increasingly attractive.

Table 4.1 lists the current and emerging applications of the various membrane processes.

Table 4.1: Current and Emerging Applications of Membrane Processes

Process	Application
RO, ED	Total Dissolved Solids Reduction - seawater desalination (RO only) - brackish water desalination - desalination of high-silica brackish water (ED favored) Inorganic Ion Removal - fluoride - nutrients (nitrogen, phosphorus) - radio nuclides (RO only) - other SDWA-regulated inorganic chemicals (e.g., arsenic) Synthetic Organics Removal (RO only)

Table 4.1: Current and Emerging Applications of Membrane Processes *(Cont'd)*

Process	Application
NF	Hardness Removal Organics Removal - disinfection by-product precursors - synthetic organic chemicals (pesticides) - colour
MF, UF	Particulate Removal - suspended solids - turbidity - viruses (dependent on pore size and membrane properties) - bacteria - protozoan cysts - colloids (dependent on pore size and membrane properties) - inorganic precipitants, co-precipitants (iron and manganese, arsenic) - organic co-precipitants (colour and DBP precursors)

RO and ED traditionally have been used for TDS reduction, RO for both seawater and brackish water desalting, and ED for brackish water desalting. More recently, both technologies are being applied to the removal of specific inorganic ions.

NF is currently used as an alternative treatment method to lime softening for reducing the level of calcium and magnesium in hard waters when total dissolved solids (TDS) reduction is not a primary goal. The NF process is more effective than lime softening for removing naturally occurring colour and dissolved organic species responsible for the formation of trihalomethanes (THMs) and other disinfection by-products (DBPs). NF is being used almost exclusively in Florida for this purpose. In many of these facilities, the NF permeate is of higher quality than desired and is blended with raw water to reduce required treatment capacity as well as post-treatment costs. In recent years, NF has been applied in Europe for the removal of pesticides such as atrazine, using specially designed membranes that have lower hardness and alkalinity removal.

MF and UF are being used increasingly in the United States for particulate removal in order to comply with the Surface Water Treatment Rule (SWTR) and the Enhanced SWTR (ESWTR). In many cases, the processes have been shown to be cost competitive with conventional treatment-based approaches to comply with these regulations while providing additional advantages (finished water turbidity independent of source water quality, smaller footprint, reduced residuals and operating labour). Applications are increasing due to the robust removal of both *Giardia* and *Cryptosporidium* protozoan cysts (>4 log), as well as reliable production of filtrate turbidities less than 0.05 nephelomatic turbidity units (NTU).

MF and UF can also be preceded by pretreatment systems to precipitate or co-precipitate dissolved inorganic and dissolved organic compounds for effective rejection by the membrane filtration system.

Membrane applications and installed capacity will continue to grow rapidly in the foreseeable future. It is anticipated that there will be trends toward:

- More difficult membrane applications using chemical addition and other pretreatment processes;
- Larger capacity plants, some exceeding 400 ML/d (100 MGD) as larger-scale modular membrane systems are developed;
- Product standardization in MF and UF (similar to NF and RO development over the years);
- Increased conventional filter retrofit applications using immersed vacuum-type MF/UF systems; and
- More developments in the membrane products themselves allowing more economical, reliable, and versatile membrane treatment systems.

4.3 Process Screening

From the 1996/1997 pilot test program, the recommended water treatment process for the water treatment plant is:

- Coagulation (ferric chloride) + DAF + O_3 + BAC + chloramination (secondary disinfection)

This process best addressed all the City's water treatability issues and all water quality targets to be met.

This section discusses the alternative membrane treatment options. The membrane treatment options have been screened based on water quality and process viability for the City of Winnipeg's water supply.

There are several membrane treatment processes that will be considered. These include the following:

- Option 6: Ultrafiltration + Chlorination + Chloramination
- Option 7: Integrated pretreatment + Ultrafiltration + Chlorination + Chloramination
- Option 8: DAF + Ultrafiltration + Chlorination + Chloramination
- Option 9: DAF + Ultrafiltration + Ozone + BAC + Chloramination
- Option 10: Ultrafiltration + GAC Contactors + Chlorination + Chloramination
- Option 11: Ultrafiltration + Nanofiltration + Chloramination
- Option 12: Ultrafiltration + UV Disinfection + Chlorination + Chloramination
- Option 15: DAF + O_3 + BAC + UF + Chloramination

Although the treatment options indicate an ultrafiltration process, microfiltration could also be used. Immersed membranes (used as a baseline for these discussions) are installed (immersed) in a raw water vessel and a small vacuum is applied to their downstream side. This process is more energy efficient and can result in a smaller footprint than pressure-driven configurations. Immersed membranes are available from Zenon (UF) and Memcor (MF) and are assumed for this analysis. Product water recovery for MF and UF membranes can be upwards of 95 percent.

MF membranes, because of the pore size, are limited to removal of *Giardia* and *Cryptosporidium*, while UF membranes have the added feature of removing not only *Giardia* and *Cryptosporidium* but also bacteria and, to some extent, viruses. NF membranes remove pathogens but also remove most DBP precursors and some dissolved salts.

The primary water quality parameters/objectives discussed in this section include:

- Pathogen reduction – *Giardia*, *Cryptosporidium*, bacteria, viruses
- Disinfection by-product control – THMs, HAAs, Ozone DBPs
- Aesthetic parameters – taste and odour control, colour
- Distribution system stability – AOC/BDOC, TOC
- Synthetic organics (SOCs) and algae toxins

In order to assist in selecting the most suitable membrane processes, a list of advantages and disadvantages of each option is presented in Table 4.2.

Table 4.2: Advantages/Disadvantages of Membrane Treatment Options

Treatment Option	Advantages	Disadvantages
Option 1 – Baseline DAF + O3 + BAC + NH_2CL	Meets all Water Quality Targets	
Option 6 UF + CL_2 + NH_2CL	Lowest Cost	Does not meet TOC reduction target Does not meet DBP targets Does not meet TON target
Option 7 Integrated UF + CL_2 + NH_2CL	Good pathogen control Meets TOC reduction target (50%)	Marginal DBP levels Higher residuals production Does not meet TON target
Option 8 DAF + UF + CL_2 + NH_2CL	Good pathogen control Good TOC reduction	Marginal DBP levels Higher pretreatment costs Does not meet TON target
Option 9 UF + O_3 + BAC + NH_2CL	Good pathogen control Meets all DBP targets Meets TON targets	Low TOC reduction High AOC/BDOC
Option 10 UF + GAC + CL_2 + NH_2CL	Good pathogen control Good TOC reduction Meets TON targets Good SOC/algal toxin control	Marginal DBP levels GAC regeneration required 6 times per year
Option 11 UF + NF + NH_2CL	Excellent pathogen control Best overall water quality Best TOC reduction	Concentrate disposal requirements Post chemical treatment for stabilization Marginal T&O control
Option 12 UF + UV + CL_2 + NH_2CL	Excellent pathogen control	Poor TOC reduction Does not meet DBP targets Does not meet TON target
Option 15 DAF + O_3 + BAC + UF + NH_2CL	Best pathogen control Meets all DBP targets Meets TOC and TON targets	More complex process
Existing Conditions	No cost	Unsatisfactory pathogen control No TOC reduction Does not meet DBP targets Does not meet TON target

Existing conditions are not acceptable as the City's water treatment goals will not be met. All membrane treatment options have adequate pathogen reduction. However, as an alternative to the baseline process, only 4 membrane options will meet all the City's water quality targets.

These include:

- Option 9: UF + O_3 + BAC + NH_2CL
- Option 10: UF + GAC + CL_2 + NH_2CL
- Option 11: UF + NF + NH_2CL
- Option 15: DAF + O_3 + BAC + UF + NH_2CL

In order to determine whether any of these membrane processes should be carried forward for Conceptual Design, a cost comparison with the baseline process has been undertaken.

4.4 Conclusions

From the review of available membrane treatment processes and comparison of expected finished water quality and water quality objectives, the conclusions are as follows:

- Based on our knowledge and pilot-testing to date, some form of pre-treatment will be required for a membrane plant design due to the high organic levels and T&O events in Shoal Lake water.
- Any membrane treatment option that can provide similar finished water quality to the baseline treatment process is not expected to be cost competitive within the timeframe of construction of the water treatment plant.

4.5 Recommendations

Since comparable membrane processes are significantly higher in costs than the baseline process, we do not recommend further investigation or pilot testing of these membrane treatment options at this time. It is therefore recommended that none of the membrane process options be carried forward to Conceptual Design.

Section 5

Alternative Oxidants and Disinfection By-products

5.1 Introduction

This section of the Summary Report provides a summary of Technical Memorandum No. 8 – Alternative Oxidants and Disinfection By-products.

The City of Winnipeg presently utilizes free chlorination at the Shoal Lake Intake for microbial inactivation, slime control, taste and odour control, and Zebra Mussel control in the aqueduct. After retention in the Deacon Reservoir, the City again utilizes free chlorination at the Deacon Booster Pumping Station and at the in-City pump stations to disinfect the water as it is conveyed into and throughout the distribution system. Although relatively simple and economical, this process generates elevated levels of disinfection by-products and does not fully address such water quality issues as taste and odour and *Cryptosporidium* inactivation.

Disinfection by-products (DBPs) on the City's water supply are currently being studied as part of the American Water Works Association Research Foundation (AWWARF) program on UV disinfection of unfiltered water supplies. Alternative oxidants/disinfectants are being studied at bench scale to assess DBP formation. Utilizing this current data as well as pilot study data conducted in previous years, the City wishes to develop an overall disinfection strategy from Shoal Lake to the consumer that will address the multiple goals of microbial inactivation, DBP control, slime and Zebra Mussel control in the aqueduct, and maintenance of a disinfectant residual throughout the distribution system.

5.2 Alternative Oxidants and Disinfectants

There are numerous disinfectants that have been used in the drinking water industry including ozone, ultraviolet light (UV), chlorine, chlorine dioxide, and chloramines. Table 5.1 provides a summary of the characteristics of the most common disinfectants used in the production of potable water.

Table 5.1: Summary of Disinfection Techniques

Subject	Cl_2	Cl_2/NH_3	ClO_2	Ozone	UV
Bactericidal	Good	Fair	Good	Very Good	Very Good
Virucidal	Good	Fair	Good	Very Good	Good
Protozoa	Fair	Poor	Good	Very Good	Very Good
DBP Formation	High	Low	High	Moderate	Low
Residual Stability	Moderate	Long	Moderate	None	None
Contact Time Required	Moderate	Long	Moderate	Short	Short
pH Dependant	Yes	Yes	Yes	No	No
Reliability	Excellent	Excellent	Very Good	Good	Good
Complexity of Equipment	Simple	Moderate	Moderate	Complex	Moderate
Process Controls	Well developed	Well developed	Developing	Developing	Developing
Safety Concerns	High (gas)	High	High	Moderate	Minimal
Typical Size of Plant	All	All	Small to Medium	Medium to Large	All
Relative Cost	Low	Moderate	Moderate	High	Moderate

AWWA (1999), amended by WWC.

The difference in purposes of primary and secondary disinfection in water treatment allows each to be optimized independently. Primary disinfection refers to the inactivation of microorganisms to meet the microbial reduction requirements. Secondary disinfection refers to application of a disinfectant to meet requirements to maintain a safe microbiological quality within the distribution system.

Table 5.2 lists the potential primary disinfectants for the most common microbial contaminants.

Table 5.2: Potential Primary Disinfectants

Target Organism	**Potential Primary Disinfectants**	
	With Filtration [1]	**Without Filtration**
Coliform Bacteria	Chlorine Chloramines Chlorine dioxide Ozone UV Interactive disinfection [4]	Chlorine Chlorine dioxide Interactive disinfection [3,4] UV
Giardia cysts	Chlorine [2] Chlorine dioxide [2] Ozone [2] UV Interactive disinfection [4]	Chlorine [2] Chlorine dioxide [2] Interactive disinfection [3,4] UV
Viruses	Chlorine [2] Chlorine dioxide [2] Ozone [2] UV [2] Interactive disinfection [4]	Chlorine [2] Chlorine dioxide [2] UV [2] Interactive disinfection [3,4]
Cryptosporidium oocysts	Chlorine dioxide Ozone Interactive disinfection [4] UV	Chlorine dioxide Interactive disinfection [3, 4] UV

Notes:
1 Natural or treatment filtration reduces disinfection inactivation requirements
2 Inactivation credit established in SWTR
3 Any interactive disinfection that uses ozone or peroxone without filtration is strongly discouraged
4 Two or more disinfectants applied simultaneously or sequentially

The choice of a secondary disinfectant is limited to those disinfectants that remain stable in the distribution system. The most commonly used secondary disinfectants are chloramines, chlorine, and chlorine dioxide. Other disinfectants, including ozone, UV, peroxone, and in some cases chlorine dioxide, while producing effective microbial inactivation, do not produce a long-lasting residual.

Various combinations of primary and secondary disinfectants are possible. Viable combinations can be determined based on water quality characteristics, such as pH, that can affect the disinfectants. Table 5.3 lists the combinations of disinfectants and their typical applications in water treatment. The table has been amended to note the new information on UV inactivation of protozoa. These combinations consider DBP formation and a comment is made on the degree of protozoa inactivation.

Table 5.3: Primary/Secondary Disinfectant Combinations and Typical Applications in Water Treatment

Primary / Secondary	Typical Application	Comment
Chlorine/Chlorine	Low DBPFP raw water, low TOC, conventional treatment with optimal coagulation.	Most commonly used disinfection scheme. Effective system for most pathogens. However, ineffective for *Cryptosporidium.*
Chlorine/Chloramine	Moderate DBP precursor and DBP production situation, typically with conventional treatment.	Chlorine to provide primary disinfection and monochloramine to limit DBP formation.
Chlorine dioxide/ Chlorine dioxide	Stronger oxidation/disinfection requirement Low chlorine dioxide demand in treated water.	High DBP production at high doses. Primary and secondary usage requires a limit on chlorine dioxide dose to reduce residual chlorate/ chlorite.
Chlorine dioxide/ Chloramine	Low DBP requirement, low CLO2 demand.	Primary chlorine dioxide dose limited to residual chlorate/chlorite. Stable, low reactive secondary disinfectant.
Ozone/Chlorine	Strong oxidation/disinfection, taste and odour and colour control, low DBP requirements, low bromide levels.	Highly effective disinfection to achieve high log inactivation; low DBPFP to allow free chlorine.
Ozone/Chloramine	Strong oxidation/disinfection, taste and odour and colour control, low DBP levels, higher organic levels, low bromide levels.	Highly effective disinfection to achieve high log inactivation, higher DBPFP to require combined chlorine residual.
UV/Chlorine	Low turbidity, low DBPFP raw water, low TOC.	New research suggests low UV doses for *Giardia*/*Cryptosporidium* inactivation.
UV/Chloramine	Moderate DBPFP, typically with short initial free chlorine contact for virus inactivation.	Relatively new process, especially for unfiltered supplies.

Most disinfectants are also effective oxidants that react with organic and inorganic compounds in water. Hence, the disinfectants discussed above, as well as other oxidants, can be used for other purposes in drinking water treatment such as taste and odour control, colour reduction, and improved flocculation. For Winnipeg, the oxidants considered for taste and odour control include:

- Chlorine
- Ozone
- Chlorine dioxide
- Potassium permanganate
- Peroxone

Of these, only potassium permanganate is added to the list of disinfectants. Although it has many potential uses as an oxidant, it is a poor disinfectant.

A variety of drinking water quality regulations and guidelines were reviewed in Canada and the United States. Over the next several years, water quality regulations in Canada and the United States will become more stringent. The USEPA has a formal regulatory agenda that strongly influences the direction of water quality guidelines in Canada. The USEPA regulatory agenda that would affect the City of Winnipeg include the D/DBP and the ESWTR rules.

The anticipated Stage 2 D/DBP Rule and the anticipated Long-Term ESWTR are expected to require increased levels of *Giardia* and *Cryptosporidium* removal/inactivation, while at the same time effectively limiting the maximum free chlorine residual level for the disinfection process. Since free chlorine is ineffective for *cryptosporidium* inactivation, many utilities may need to consider an alternative primary disinfectant, such as ozone or UV, in order to balance the requirements of the two upcoming regulations.

These regulations were used to develop water treatment goals and objectives for the water treatment plant. This information is presented in Table 5.4.

Table 5.4: Water Treatment Plant Performance Targets

Treatment Goal	Specific Parameter	GCDWQ[1]	Ontario DWPR[2]	USEPA Regulations	Anticipated US Regulations	Water Treatment Plant Target	Reasons for Target
Clear water	Turbidity	<1.0 NTU	<1.0 NTU	0.3 NTU	0.1 NTU	<0.1 NTU	Future probable regulation; ensures best treatment
Particulate removal	Particles >2 µm	N/R	N/R	N/R	50-100 #/mL	<20 particles/mL	Pathogen reduction i.e. *giardia / cryptosporidium*
DBP control	TTHMs THAAs	100 µg/L N/A	100 µg/L N/A	80 µg/L 60 µg/L	80 µg/L 60 µg/L	100 (40) µg/L N/A (30) µg/L	Short-term (anticipated future USEPA regulation)
TOC removal	TOC	N/A	DOC <5	NR	0-50	40%	Minimize DBP precursors
T&O control	TON	Aesthetic	Inoffensive	Inoffensive	3-5	Consistent <10	Level at which T&O should meet public expectations
Algae (toxins)	Microcystin LR	N/R	N/R	NR	1.5 µg/L	Maximize removal	Minimize T&O events and other aesthetic concerns
Colour reduction	TCU	15	5	15	5	<5	Value which should meet public expectations
Treatment consistency	Reliability	N/R	N/R	N/R	N/R	High degree	Ability to consistently meet treatment goals during changes in raw water quality
Viruses	Log reduction	See note 5	≥4-Log[3,4]	≥4-Log	≥4-Log	4 log	Pathogen Protection
Giardia	Log reduction	See note 5	≥3-Log[3,4]	≥3-Log	≥3-Log	3 log	Pathogen Protection
Cryptosporidium	Log reduction	See note 5	See note 5	≥2-Log[3]	≥2-Log	3 log	Pathogen Protection

Notes:
1. Guidelines for Canadian Drinking Water Quality.
2. Ontario Drinking Water Protection Regulation.
3. Higher reductions are required for source waters with elevated risk.
4. 0.5 log reduction of *Giardia* and 2 log reduction of viruses must be achieved through disinfection.
5. Numerical guidelines are not proposed at this time. It is desirable that no human enteric viruses or viable protozoa be detected.

N/R Not regulated.

The City of Winnipeg is the Member Utility of the ongoing AWWARF project titled "UV Disinfection and Disinfection By-product Characteristics of Unfiltered Waters". As part of the collaborative team, the University of Massachusetts (UMass) is investigating the impacts of changes in Winnipeg's oxidation/disinfection scheme on disinfection by-product formation. This includes the possible use of chlorine dioxide, chloramines, or intermittent chlorination pre-disinfection/oxidation, the possible use of UV for primary disinfection (with free chlorine for viral inactivation), and the use of chloramines for distribution system residual. Aside from the three predisinfectant options, three chloramination options are being considered (pre-chlorination, pre-ammoniation and application of pre-formed chloramines) and two different dose locations or post chlorination (before and after UV).

Free chlorination pretreatment resulted in significant total THM and total HAA5 levels. Total THMs were in the range of 90 and 120 µg/L, while HAA5 levels were in the range of 140 to 155 µg/L.

Using chlorine pretreatment, total THM levels as produced by the various intermediate and post-disinfection scenarios resulted in concentrations between 30 and 55 µg/L. The HAA5 levels were found in the final treated samples across a range of 30 to 50 µg/L. Some biodegradation of DCAA might have occurred in pretreatment, but this compound also showed long-term formation over the 5 day contact with chloramines in final treatment.

The DBP data showed some consistent qualitative trends that assist in process selection. First, no clear advantage was evident in the sequencing of UV before versus after chlorination. Secondly, there was no clear indication that preformed chloramines led to reduced levels of DBPs as compared to *in situ* formed chloramines.

Based on the UMass DBP analysis of the various oxidation/disinfection alternatives, TTHM and HAA5 levels will meet anticipated Canadian Guidelines and USEPA regulations with the use of chloramination for the aqueduct and distribution system and implementation of the recommended water treatment process train.

The chlorine dioxide testing showed that it could not be used as a pretreatment disinfectant with the City's raw water as it was not possible to maintain a lasting residual without exceeding the chlorite standard.

5.3 Aqueduct

Drinking water for the City of Winnipeg originates in Shoal Lake. Water is conveyed by gravity through a 137 km long closed aqueduct to the Deacon Reservoir, located in the Rural Municipality of Springfield, east of Winnipeg. The aqueduct is unpressurized and there is some headspace inside the aqueduct. A gate at the intake regulates water flowing to the aqueduct. The flow capacity of the aqueduct is approximately 385 ML/day and the hydraulic retention time of the aqueduct is approximately 30 hours.

Continuous chlorination has been used at the intake for aqueduct disinfection to achieve the following objectives:

- Pathogen control for public health protection
- Taste and odour (T&O) control by oxidizing taste and odour causing compounds
- Control slime on the aqueduct wall, which decreases flow capacity and deteriorates water quality
- Deterrent to Zebra Mussels entering the aqueduct, colonizing on the wall and decreasing flow capacity. Also to prevent the migration of Zebra Mussels to the Deacon Reservoir by killing the veligers entering the aqueduct

The major concern caused by continuous chlorination of the aqueduct is the formation of disinfection by-products (DBPs). When disinfectants such as chlorine are added to the water, they react with the natural organic matters (NOM) and form DBPs, which could cause health risk to the public. Typical DBPs formed by free chlorination include trihalomethanes (THMs), haloacetic acids (HAAs), aldehyes and ketoacids.

The interim maximum acceptable concentration (IMAC) in the Guidelines for Canadian Drinking Water Quality (GCDWQ, March, 2001) for total trihalomethanes (TTHMs) is 100 µg/L, expressed as a running annual average of quarterly samples. This IMAC is based on the risk associated with chloroform, the THM that is generally found in the greatest concentration in drinking water. There is no current Canadian guideline for HAAs, aldehydes, and ketoacids. The USEPA Stage I DBP regulation set limits of 80 µg/L and 60 µg/L for TTHM and HAA5, respectively.

Total organic carbon (TOC) is an indicator of the amount of organic material available for DBP formation. The formation of DBPs increases with TOC concentration and disinfection contact time. Because the TOC levels in Shoal Lake water are moderate to high (4 to 17 mg/L), and the retention time of the aqueduct is very long (approximately 30 hrs), the potential for DBP formation is significant. In 2001, the average TTHM level in Winnipeg's distribution system was 119 µg/L while the average HAA5 level was 102 µg/L. The TTHM levels in the distribution system exceed the current Canadian guideline on an intermittent basis. The majority of DBPs are formed during aqueduct chlorination.

The future water treatment plant (WTP) at the Deacon Reservoir will change the role of intake/ aqueduct disinfection. The WTP will provide the primary barrier for pathogen reduction using physical removal and primary disinfection. The WTP will remove taste and odour compounds using oxidation and BAC filtration. Consequently, disinfection of the aqueduct would be only for slime and Zebra Mussel control to maintain its hydraulic capacity. If chlorination is continued in the aqueduct, THM and HAA removal would be required for the future WTP, which would significantly increase the capital and O&M costs. Thus, an alternative treatment process that has low production of DBPs should be used for slime and Zebra Mussel control in the aqueduct.

A summary of the alternative oxidants/disinfectants for future potential use in the aqueduct is presented in Table 5.5.

Table 5.5: Comparison of Different Approaches in Aqueduct Disinfection

Approach	Disinfection for Pathogens	DBPs	Slime Control	Zebra Mussel Control	Cost
Continuous Chlorination	Good for *Giardia* Poor for *Crypto*	High THMs and HAA	Very good	Excellent	Low
ClO_2	Excellent for *Giardia* Good for *Crypto*	High chlorite and chlorate	Good	Good	High
$KMnO_4$	Poor	No THMs and other harmful DBPs	Fair	Poor	High
Chloramines	Poor	Low THMs and HAA	Excellent	Very good	Middle
O_3/H_2O_2	Poor	Aldehydes, Bromate	Fair	Poor	High
UV	Excellent	Negligible at drinking water dosages	No protection	No protection along the aqueduct	Low

From a cost-benefit perspective, the best alternative for aqueduct disinfection in Winnipeg is chloramination.

When the WTP is in place, the conversion of continuous chlorination to continuous chloramination will meet all the goals for aqueduct treatment:

- Pathogen control to protect public health will be accomplished by physical removal (DAF and filtration) and primary disinfection (UV or ozone) in the WTP.
- Taste and odour will be reduced in the WTP through DAF, ozone oxidation, and BAC filtration.
- Slime formation on the aqueduct will be controlled by continuous chloramination of the aqueduct.
- Prevention of Zebra Mussels in the aqueduct will be achieved by chloramines. Free chlorination is still the only approved molluscicide in Canada for potable water. The free chlorine injection system will be kept in the existing locations for zebra mussel control. Immediately downstream of the chlorine injection, ammonia will be injected to the aqueduct to maintain the chloramine residual and improve slime control.

One issue that will need to be addressed is the potential for aqueduct leaks/overflows to the environment. As chloramines are more persistent than free chlorine, impacts on fisheries can be more significant. The City's proposed aqueduct level monitoring system should help alleviate this concern as mitigative measures will be able to be implemented prior to significant overflows occurring.

The hydraulic retention time from the intake to the Deacon Reservoir is approximately 30 hrs. When the water reaches the Deacon Reservoir, the chloramine residual will be low (about 0.2-0.5 mg/L). The water will stay in the Deacon Reservoir for approximate 8 to 20 days, depending on the mode of operation of the Deacon Reservoir, before being treated in the WTP. By that time the chloramine residual will be negligible. Thus chloramination will not cause any adverse effects to the water treatment process. After primary disinfection in the WTP, chloramines may be used as the secondary disinfectant to protect the water distribution system against slime accumulation and regrowth.

There are two primary alternatives for chloramination of the aqueduct: use of either aqueous ammonia (29 percent) or anhydrous ammonia (100 percent). In either case, it is proposed to retain the existing chlorine injection point at the intake screens for enhanced Zebra Mussel control and to apply ammonia downstream of the headworks. Although a chlorine contact period will result, the DBP formation will be low due to the very short contact time. Furthermore, the ammonia injection location will partially address Manitoba Conservation's concerns regarding chloramines in the environment. Additional water level monitoring of the aqueduct may alleviate the balance of Manitoba Conservation's concerns regarding leaks or spills of chloraminated water. Both the aqueous and anhydrous ammonia options have been presented for information purpose. Previous conceptual designs have been based on utilizing aqueous ammonia.

Depending on the selected form of ammonia (anhydrous or aqueous), capital costs for the facility to be located at Shoal Lake are estimated to be between $900,000 and $1,400,000. Annual chemical costs are estimated to be approximately $200,000.

It is likely that *in situ* formed chloramines will be used for aqueduct disinfection. Table 5.6 summarizes the estimated DBP levels in Deacon Reservoir when using chloramines for disinfection of the aqueduct. The chlorine dose at the aqueduct intake was assumed as 3.0 mg/L, and the chloramine residual entering the Deacon Reservoir was assumed as 0.2 mg/L.

Table 5.6: DBP Concentration in Deacon Reservoir

DBPs	Concentration (μg/L, summer)
TTHM	< 20
HAA5	< 20
Total Aldehyde	< 20
Total Ketoacid	< 20

Volatilization and biodegradation in the reservoir would decrease the DBP levels. TTHMs could be reduced by 85 percent during the summer, but little reduction would occur in winter when the surface is covered with ice. HAA5 concentrations would not be significantly reduced through the Deacon Reservoir at any time, although some reduction is expected in the summer due to biodegradation. The formation of DBPs could decrease in winter when the water temperature drops.

5.4 Distribution System

The purpose of this section is to review the options available to provide disinfection residual maintenance for water carried through the distribution system.

Treatment objectives for water quality in the distribution system include:

- Maintain disinfectant residuals across the distribution system
- Maintain the microbiological safety of the water, as defined by the Guidelines for Canadian Drinking Water Quality
- Control disinfection by-products

Alternatives for secondary disinfection include free chlorine, chloramines, and chlorine dioxide. Free chlorine is used in the majority of distribution systems across North America, although an increasing number of systems are converting to chloramines. Chloramines are an appropriate alternative for systems that are looking for improved residual persistence and/or to avoid the further formation of disinfection by-products in the distribution system. Enhanced monitoring efforts are necessary for systems that chloraminate for: i) process control, to avoid over feeding ammonia to the system and to limit the formation of dichloramine and nitrogen trichloride, compounds for which low odour threshold numbers have been identified, and ii) to anticipate possible nitrification episodes. Chlorine dioxide is used in relatively few systems for residual maintenance. Results from bench-sale testing with raw water for the City of Winnipeg suggest that at the required chlorine dioxide dose levels, chlorite would be formed at levels exceeding the US EPA's standard of 1 mg/L.

To meet the treatment objective for disinfection by-products, the use of chloramines for residual maintenance is being pursued.

The AWWARF DBP results showed that there was no clear indication that preformed chloramines lead to reduced levels of TTHMs and HAA5 as compared with the *in situ* formation of chloramines (pre-ammoniation or pre-chlorination).

Post-treatment with chloramination does not appear to have a significant impact on the formation of aldehydes in water treated by pre and intermediate treatment. It appears that aldehyde levels are marginally higher with preformed chloramines relative to chloramines formed *in situ* (pre-ammoniation). From the 20 day pre-treatment contact data it can be seen that post-treatment with chloramination will result in aldehyde levels of less than 40 μg/L.

The formation of ketones in Winnipeg's water attributable to pre and intermediate treatment occurs in levels ranging up to 50 μg/L. From data with pre-treatment contact times of both 8 and 20 days it is apparent that post-treatment with chloramines serves to reduce ketones to levels less than 20 μg/L, with marginally higher levels measured in samples generated from 20 days of pre-treatment contact. There is no apparent benefit to using preformed chloramines instead of *in situ* chloramines (pre-ammoniation) with respect to biodegradability as represented by these oxidation by-products.

The potential for regrowth due to chloramination is not expected to be exacerbated by the use of ozone in Winnipeg's water. The use of BAC in combination with ozone is proposed for Winnipeg, where the BAC will be used to control increases in the assimilable organic carbon typically observed with ozone use.

Regulator consultation and approval and public notification will be required prior to implementing chloramination.

Features of the chloramination system proposed for the City include:

- The use of a chlorine gas feed system
- The use of anhydrous ammonia
- Dedicated and separate chemical storage rooms, piping systems, and applications points for each chemical
- Forming chloramines at adequate Cl_2:NH_3-N ratios; the necessary amount of ammonia to add to the treatment process may vary according to raw water levels
- Adequate mixing is critical to the effective dispersion of both chemicals and G values of 300 to 1000 sec^{-1} are recommended; mixing can be provided hydraulically or mechanically, depending on how the chloramination system is integrated into the treatment train as a whole
- Adequate ventilation for the ammonia system, as ammonia has a strong pungent odour; direct off-gas to outside and provide means to control leaks to the room; should a leak occur, ammonia vapours will rise to the ceiling of a room as ammonia gas is lighter than air
- Adequate heating and cooling controls
- Adequate access to ammonia injection equipment to allow for cleaning if a scale deposit is formed (this has been observed in feed water with more than 35 mg/L $CaCO_3$ hardness)

The most likely location for the ammonia feed system would be at the Deacon Booster Pumping Station site, or at the future water treatment plant chemical feed area. As booster chloramination is not expected to be required, ammonia dosing facilities will not be required at the in-City pump stations.

An enhanced monitoring program will be required to properly assess the impacts of chloramination. Specifically, nitrogen compounds are to be added to the City's existing monitoring program.

A rigorous distribution system cleaning program will also be required to reduce disinfectant demands and regrowth potential.

5.5 Water Treatment Plant

The water treatment plant (WTP) will be the main barrier protecting the public from water-borne diseases. Pathogen reduction in the WTP is accomplished by physical removal and inactivation.

Pathogen reduction in the WTP is accomplished via multiple barriers. The solids separation process is very effective in the removal of some microorganisms. US EPA credits the processes for pathogen removal if they meet the turbidity requirements. Since DAF is a solids separation process, conventional treatment credits will also apply. The reduction by solids separation alone, however, is not sufficient for the target reduction. Inactivation of pathogenic microorganisms by disinfection/oxidation would be essential for the WTP.

In addition to pathogen reduction, oxidation would be used to achieve the other water quality goals and operational benefits. The major objectives of primary disinfection/oxidation systems are:

- **Inactivation of pathogens**: The disinfection process would work with the solids separation processes to reduce the pathogenic microorganisms to a safe level.
- **Minimize the formation of disinfection by-products (DBPs)**: Due to the health concerns related to some DBPs, the oxidation process should not produce excess amount of DBPs.

Additional objectives of oxidation/disinfection include:

- **Reduction of taste and odour (T&O):** The water in Shoal Lake has T&O issues primarily during the periodic algal blooms but T&O problems can also occur during periods of relatively low algal counts. DAF and the BAC filters are not sufficient for T&O removal when the T&O levels in the raw water are high, so additional treatment for T&O removal would be required.
- **Improved filter performance**: To achieve particle and turbidity removal goals using lower coagulant doses.

The water in Deacon Reservoir will contain some DBPs formed during the proposed chloramination of the aqueduct. Using chloramines instead of free chlorine produces fewer DBPs. Volatilization in the Deacon Reservoir also decreases the DBPs concentration. At the WTP intake, TTHMs will be <20 μg/L and THAA would be < 20μg/L.

A clearwell with a balancing volume of 15 ML was presented in the Conceptual Design. A separate unchlorinated water reservoir would serve as the backwash water supply. Normally chloramines would be added to the clearwell for control of slime growth. Some DBPs would form in the clearwell, however the concentration would be low due to the following reasons:

- Low THM and HAA formation potential: The water treatment trains would remove 70 percent of the TOC, so filtered water would have low TOC concentration.
- Short contact time and low Ct: The minimum water demand is projected as 200 ML/day in winter, so the hydraulic retention time of the clearwell would be approximately 1.8 hours. In the summer peak day demand of 515 ML/day, the hydraulic retention time of the clearwell would be approximately 0.7 hours.
- Low temperature: High Ct in the clearwell normally occurs in winter when the water demand is low. Low temperature in the winter results in lower DBPs formation.

It is estimated that under the worst conditions, the amount of TTHM and HAA5 formed during chloramination of the clearwell would be less than 5 µg/L.

Preliminary estimates of DBPs in the clearwell are listed in Table 5.7 for the baseline process. The estimates suggest that the treatment plant will meet the long-term goal for THMs and HAA. Note that the estimate was based on the results of the Phase II Pilot Study (1997) and a limited amount of data collected recently.

Table 5.7: Estimate of DBP in the Clearwell

Treatment	DBP Concentration (µg/L)			
	TTHMs	HAA5	Bromate	Total Aldehydes
Ozone + chloramines (baseline)	<25	<5	<10	<10

5.6 Conclusions

Based on the evaluations completed in the previous sections, the following conclusions have been reached:

- It is estimated that there will be no significant difference in DBP formation between preformed chloramines and *in situ* formed chloramines.
- Chlorine dioxide is not a feasible option for aqueduct oxidation/disinfection. A very high dose would be required to maintain a residual at Deacon, and resultant chlorite concentration would exceed guidelines.
- Chloramines are an effective alternative for aqueduct disinfection. Treatment objectives are met without elevated DBPs.
- Potassium permanganate is not viable for the aqueduct due to its poor zebra mussel control abilities and the excessive contact time requirements.
- Aqueous or anhydrous ammonia dosing facilities at Shoal Lake are viable alternatives with capital costs ranging from $750,000 to $1,400,000.
- Ammonia dosing downstream of the headworks at Shoal Lake will mitigate environmental concerns and maximize zebra mussel control via free chlorine at the screens.

- Chloramination of the distribution system is the preferred option for the City of Winnipeg. Booster disinfection facilities should not be required.
- Increased water quality monitoring in the distribution system will be necessary to ensure regrowth and nitrification are controlled.
- Regulator consultation and approval and public notification is necessary prior to conversion to chloramination.
- Rigorous distribution system cleaning will be required to minimize disinfectant demand.

5.7 Recommendations

It is recommended that the conclusions of Technical Memorandum No. 8 be revisited when additional results are published from the current AWWARF study. It is anticipated that the conclusions will remain unchanged; however, it will be prudent to apply the most current data to this assessment prior to final publication.

The following are the general recommendations made regarding oxidation/disinfection of the overall water supply and distribution systems:

- Maintain existing free chlorination system at the Shoal Lake intake screens.
- Construct a new ammonia dosing station at Shoal Lake with injection downstream of the headworks.
- Rely on the water treatment plant for pathogen reduction, taste and odour control, and other treatment objectives.
- Construct a new ammonia dosing system at the Deacon Booster Pumping Station.
- Initiate a public notification and regulator consultation and approval program for the proposed conversion to chloramination.
- Initiate an extensive monitoring program to ensure satisfactory system operation.

The preceding sections have confirmed that chloramination is the preferred disinfection process for both the aqueduct and the distribution system. Disinfection by-product formation is controlled, yet stated objectives of slime control and regrowth prevention are achieved.

It must be recognized, however, that these changes are not insignificant and have several important ramifications including:

- Current regulations
- Current facility infrastructure
- Consumer notification requirements
- Water treatment plant implementation
- Continued DBP exposure vs. microbial inactivation.

Manitoba regulations currently do not allow chloramination; however, the City of Dauphin has been able to get its chloramination scheme licensed. The City of Winnipeg must follow a similar licensing procedure and this will take time. Current regulations require a free chlorine residual; however, alternatives are allowed if reviewed and approved by the Province.

The existing chlorination facilities at the intake and distribution system pumping stations are equipped for gaseous chlorination only. Historically, ammonia storage and dosing facilities did exist at the pump stations; however, these have been long since been decommissioned. Incorporating or reinstalling such facilities may require significant upgrades to meet current design and safety standards.

Chloramination in the distribution system can have a significant impact on hospitals/dialysis units, fish rearing facilities/aquariums, and the environment (potential spills). Consumers may also notice a different taste and odour in the water. Although usually not objectionable, complaints can occur if adequate notification and consultation is not provided. Accordingly, an extensive public notification and regulator consultation program is mandatory. Such programs require detailed planning and can take a year or longer to implement.

Possibly the most significant factor affecting the switch to chloramination is that of the overall water treatment plant implementation. It is recognized that the current free chlorination practice provides a quantifiable safety measure against microbial contamination. Although elevated disinfection by-product levels occur, these are generally chronic issues that are far outweighed by the reduced risk of acute health impacts associated with water borne pathogens. Some recent data suggests that some DBPs may be associated with spontaneous abortions; however, definitive research has yet been completed. Until the new water treatment plant is constructed and additional barriers against microbial contamination are provided, free chlorination practices at the aqueduct should continue.

Recognizing the above, a suggested staging strategy is as follows:

- Continue with free chlorination of the aqueduct and distribution system until additional microbial barriers are in place and proven, such as the UV system presently under investigation. (See Technical Memorandum No. 6.)
- Once some form of additional treatment is operational and proven, commence chloramination of the distribution system by injecting ammonia downstream of the Deacon Booster Pumping Station. As design commences, so too should the public and regulator consultation program. The ammonia application point should be such that adequate free chlorine contact is provided for virus inactivation. It is expected that booster chloramination will not be required and that all dosing facilities will be located at the Deacon Booster Pumping Station site. This approach will provide maximum microbial protection as the aqueduct free chlorine contact is maintained until the water treatment plant is operational.
- Initiate a rigorous distribution system cleaning program. Swabbing, disinfection, and directional flushing options are to be evaluated and implemented as needed. It must be recognized that treated water quality characteristics will change once the new WTP is on-line and the distribution system could be impacted. As a minimum, any historical build-up of sediment or slime should be removed so that the piping network has a minimal disinfectant demand.
- Chloramination of the aqueduct is to commence after the water treatment plant is complete and fully operational. New ammonia storage and dosing facilities will be constructed at the Shoal Lake intake.

Section 6

Taste and Odour Control

6.1 Introduction

This section of the Summary Report provides a summary of Technical Memorandum No. 9 – Taste and Odour Control.

One of the City of Winnipeg's water quality goals is development of treatment strategies for taste and odour control. High nutrient and organic levels in both Shoal Lake and Deacon Reservoir have lead to periodic algae blooms each year. These algae blooms can last for weeks and can cause taste and odour events, which result in public complaints. In addition, the City can also experience taste and odour events even when the source water has relatively low algae levels. As the consumer becomes more aware of taste and odour issues, public expectations for superior drinking water quality will increase. At present, there is little capability in the City's infrastructure to control taste and odour.

During the Phase 2 Pilot Program, a detailed evaluation of taste and odour control techniques was conducted. The pilot results showed that the baseline process using ferric coagulation, DAF, intermediate ozonation, and BAC filters will consistently provide filtered water with threshold odour numbers (TONs) less than the target value of 10 even with raw water TON values as high as 175.

Since the completion of the pilot testing program in 1997, the City has experienced unusual taste and odour events in its water supply. These events resulted in TON levels of greater than 200 for extended periods during times of the year when taste and odour problems did not typically occur.

6.2 Taste and Odour Causing Compounds

The compounds that can cause taste and odour (T&O) problems in water are generally as follows:

- Naturally produced
- Industrially made
- Produced as by-products during disinfection of drinking water and during finished water distribution
- Leached from materials of water pipes or storage facilities.

One of the most widely reported causes is microbial, such as the blue algae and actinomycetes (during both growth and decay stages). Geosmin and 2-methylisoborneol (MIB) are among the two odourants identified. Because the threshold odour concentrations for many of the compounds are in the nano-gram (10^{-9} gram, or parts per trillion) per liter range, the causes of tastes and odours can be difficult to identify, and many taste and odour causing compounds still remain unknown today. Table 6.1 summarizes the typical biological origin of tastes and odours in source waters.

Table 6.1: Typical Biological Origin of Tastes and Odours

Microorganisms	***Odour Characteristics***	**Known Species May Cause Problem**
Blue-green algae (also known as cyanobacteria	Earthy, musty, fishy, grassy, cucumber, etc.; warmer months in late summer and early fall	*Oscillatoria*, *Anabaena*, *Aphanizomenon*, *and Symploca*
Yellow-brown algae (diatoms)	Geranium, fishy, grassy, musty colder waters; early spring, fall and into the winter	*Asterionella*, *Cyclotella*, *Tabellaria*, and *Melosira*
Green algae	Grassy, fishy; early summer	
Golden-brown algae	Strong, fishy odours; cold water	*Synura*, *Dinobryon*, *Uroglenopsis*,
Actinomycetes	Earthy, musty	*Nocardia*, *Streptomyces*,

In 1998, the only tested T&O compound detected was geosmin. Levels ranged from not detected to 53 ng/L. The data indicates that there are other T&O compounds in the water that are not being tested for. For example, on July 15, 1998, the raw water TON was over 200 with a grassy characteristic. Blue-green algae counts were relatively high but all the odour compounds tested were below detection limits. Conversely, on Sept.23, 1998, the TON was greater than 200 with a fishy characteristic. The blue-green algal counts were again, relatively high but the geosmin level was 53 ng/L. MIB was not detected in the water throughout the year.

For most of 1999, the only tested T&O compound that was detected was geosmin. High odour numbers occurred in some months when no tested T&O compounds were detected. However, during November 1999, a severe T&O event occurred. Algae counts were relatively low, TON levels exceeded 200, geosmin levels were as high as 98 ng/L, and 2,4,6-TCA, and 2,3,6-TCA levels were as high as 57 ng/L and 44 ng/L, respectively. It is interesting to note that geosmin levels during this period were approximately 3 times higher than the geosmin levels measured during the 1997 pilot test program.

Generally, 2,4,6-TCA is a chlorination byproduct, with 2,3,6 TCA being the precursor. During the testing period 1998 through 2001, November and December of 1999 are the only months where 2,4,6-TCA, and 2,3,6-TCA were detected. It is difficult to determine what caused the higher levels of 2,3,6-TCA, especially in Shoal Lake, during this period.

In 2000, the only tested T&O compound detected was geosmin. Levels were comparable to those detected during the 1997 pilot test program. The highest geosmin levels were seen during the warm water period (July/August).

In 2001, the only tested T&O compound detected was geosmin. Again, during July and August, a severe T&O event occurred. Geosmin levels were comparable to those detected during the 1997 pilot test program.

The City's T&O data from 1997 to 2001 suggests that geosmin is the primary compound causing T&O problems in the water supply. Other than 1999, most geosmin levels were in the range of those detected during the 1997 pilot test program. MIB was never detected and only two other tested T&O compounds, 2,4,6-TCA, and 2,3,6-TCA, were detected but only during one event (Nov/Dec 1999) over the 4 year monitoring period. Algae toxins as measured by Microcystin-LR were not detected. It should be noted that an increase in consumer complaints was associated with higher geosmin levels rather than higher TON levels.

There appears to be no correlation between odour numbers and algal counts. There are also periods when TON numbers were high but algae levels and the levels of tested T&O compounds were relatively low. This would suggest that periodically, there are compounds contributing to T&O that are not currently being tested by the City.

However, since the baseline treatment process as recommended after the 1997 pilot test program was primarily tested for overall TON control, the actual T&O causing compounds may not be critical to the effectiveness of the treatment process. The following section discusses the performance of the baseline process and possible limitations.

6.3 Taste and Odour Control

One of the City's primary water treatability issues is the ability to control taste and odour. During the pilot program odour levels were monitored and odour compounds were analyzed. In order to develop a database for relative odour intensities and specific odour compounds, two outside sources were used. The Philadelphia Suburban Water Company (PSWC) was contracted to assist in evaluating odours and odour intensities. Okanagan University College was contracted to assist in identifying specific odour causing compounds.

Some observations made on the PSWC data are as follows:

- The DAF process is effective in reducing odour intensities.
- Ozonation changes the odour characteristics from creeky/algae/fishy to a more sweet/fruity type odour. Although post-ozone odour intensities are similar to post-DAF, this type of odour may be more palatable to the public.
- Odour intensities in the BAC/GAC filtered water are less than from the anthracite filters.

During the 1997 pilot test program, water samples were analyzed for target odour compounds using closed-loop stripping tests.

The results indicated that of the 7 odour compounds analyzed, only geosmin was detected. The geosmin levels detected during the pilot program are consistent with the geosmin levels detected in 1998, 2000, and 2001. However, in 1999, the City experienced geosmin levels as high as 98 ng/L, which is approximately 3 times higher than seen during the pilot program.

Therefore, the baseline process was never tested at the higher geosmin levels and an evaluation on the process limitation has to be made based on the pilot program experience and information provided on similar studies.

From the closed-loop stripping tests, it was found that the DAF process effectively removes geosmin in the range of 56 to 59 percent. Intermediate ozone oxidizes post-DAF geosmin levels an additional 20 to 33 percent. Geosmin was not detected in any of the ozonated stream BAC/GAC filters. BAC/GAC is more effective for geosmin removal than anthracite. Without intermediate ozonation, geosmin removal was primarily achieved through adsorption.

The primary TON removal mechanism in the DAF process is air stripping although some removal of T&O compounds through chemical coagulation may also be taking place. The results would indicate that T&O compounds in the raw water are generally volatile in nature. The DAF process appears to be more efficient at TON reduction as the raw water TON levels increase. At a peak TON of 175, the DAF process reduced the TON by about 70 percent. Therefore, at peak TON events (>200), it would be expected that TON reduction through the DAF would be in the 70 percent range. Some of the variation in DAF performance is likely due to changing water temperature (which affects volatilization), changes in TON compounds, and the volatility of the T&O compounds present in the water. The DAF process has already been optimized through the pilot testing and cannot be improved any further to address higher than normal T&O events.

The primary TON reduction mechanism through the ozone process is oxidation. Ozone's effectiveness in post DAF TON reduction generally ranged from 40 to 70 percent. During ozone pilot testing, an ozone residual level of 0.3 to 0.5 mg/L was used. However, the sizing of the ozone process will be affected by the elevated levels of T&O compounds. Since higher than normal T&O events were not tested during the 1997 pilot program, experience with other utilities will be used for guidance.

In the baseline process, the BAC filters also provided some TON reduction. Generally, post-ozone TON values were less than 20. The TON reduction through the BAC filters ranged from 10 to 60 percent of post-ozonated levels. BAC filters were also compared to GAC filter/adsorbers. It was found that there was little difference between BAC filters and GAC filter/adsorbers for TON reduction. The results indicate that biodegradation of geosmin through the BAC filters is as effective as GAC adsorption. However, the limits of biodegradation and/or adsorption at higher geosmin inlet levels is not known. It is likely however, that the empty bed contact time (EBCT) in the filters would have to be increased to allow more time for geosmin removal. The baseline process filter design has an EBCT of approximately 4 minutes. A more typical value for T&O control is 10 minutes. This will essentially double the size and cost of the filtration process. If GAC adsorption is required for high T&O events, GAC regeneration requirements and costs will be significant.

Due to the variations in water quality at Winnipeg and other municipalities, the ozone dose required to control high levels of geosmin in Winnipeg's water cannot be determined without some confirmation bench testing. This is also true for the ozone dose required to control 2,4,6-TCA and 2,3,6-TCA. Although the TCA compounds are less common in Winnipeg's water, information is needed on ozone requirements for their control.

The UV process has little to no effect on T&O compounds.

Alternative membrane filtration trains have also been considered for the City of Winnipeg including ultrafiltration (UF) and nanofiltration (NF) membranes.

Using an assumed TON level of 100, the UF process without pretreatment will not address the T&O issues. Membrane options including DAF pretreatment should reduce TON by approximately 50%. Adding ozone and BAC should reduce TON by 90%. Use of NF membrane will require pretreatment but will result in very effective TON reduction.

6.4 Conclusions

Based on the foregoing analysis, the following conclusions have been reached.

- The City's T&O data from 1997 to 2001 suggests that geosmin is the primary compound causing T&O problems in the water supply.
- In November 1999, the odour causing compounds 2,3,6-TCA and 246-TCA were also detected during an unusually high T&O event.
- In late 1999, geosmin levels were as high as 98 ng/L. Other than in late 1999, most geosmin levels were in the range of those detected during the 1997 pilot test program.
- MIB has not been detected during the period of record.
- There appears to be no correlation between odour numbers and algae counts.
- The baseline treatment process as recommended after the 1997 pilot test program was effective in reducing raw water TON levels as high as 175 to consistently low levels.
- The DAF process generally reduces T&O compounds by 40-60 percent.
- The DAF process appears to be more efficient in TON reduction at higher raw water TON levels.
- Since the DAF process has already been fully optimized, no further improvements can be made to address higher than normal T&O events.
- The intermediate ozone process is effective for T&O control and reduces post-DAF TON levels 40-70 percent.
- Although during the 1997 pilot test program, the ozone process was not tested for higher than normal geosmin levels typically found in Winnipeg's water, similar studies on other water supplies indicate that ozone can be used to control elevated geosmin levels. Ozone requirements for control of 2,3,6-TCA and 2,4,6-TCA is not known for Winnipeg's water.
- If the baseline process is modified to include UV for primary disinfection, the ozone process will be primarily used for T&O and virus control.
- Similar studies indicate that powdered activated carbon is not a viable option in Winnipeg due to the high dose requirements due to geosmin and TOC levels in Winnipeg's water.

- GAC filter/absorbers instead of BAC filters may provide some additional T&O benefit during unusual T&O events; however, costs related to sizing the GAC adsorbers to increase contact time and GAC regeneration requirements make this a less attractive option.
- There will be some T&O control benefit through normal GAC replacement of lost BAC media (approx 10%) over an annual operation.
- The UV process will have no effect on T&O reduction.
- The Ultrafiltration process by itself will have no effect on T&O reduction.
- UV and membrane process options that incorporate pretreatment and downstream ozone and BAC or GAC processes will effectively control T&O.

6.5 Recommendations

Test results for other utilities clearly indicate that ozone is effective for taste and odour control even at elevated geosmin levels. Since ozone was not tested for T&O control at TON levels greater than 200 during Winnipeg's 1997 pilot test program, bench-scale ozone testing is recommended to verify performance and to develop a relationship between ozone dose and geosmin and TCA reduction.

In Winnipeg, geosmin appears to be the primary T&O compound and cause of elevated TON levels. Only two other odour causing compounds, 2,4,6-TCA and 2,3,6-TCA, were detected during the period of record. These were detected on Shoal Lake raw water. Since 2,4,6-TCA is primarily a chlorination byproduct with 2,3,6-TCA being the precursor, these compounds may be less of a concern once free chlorination is discontinued. However, ozone bench-scale testing should include geosmin and TCA control.

From a full-scale design perspective, the full-scale plant should include the flexibility to inject hydrogen peroxide upstream and downstream of the ozone contactors. The downstream dose point would be for ozone residual quenching prior to filtration. The upstream dose point would enable advanced oxidation if and when required for unusual taste and odor events.

Section 7

Evaluation of Alternative Treatment Trains

7.1 Introduction

In previous sections of this report, the City's water treatment goals and objectives and the approach to selecting and reviewing alternative water treatment processes were presented. Several alternative water treatment options to the City's baseline process were identified and discussed.

The water treatment goals, alternative process performance, and cost estimates were then compiled and used as input to a comprehensive decision making model. The model is an effective way of balancing water quality goals and requirements and associated costs to help identify a cost-effective solution that is acceptable to all stakeholders.

This section discusses the development and use of the decision making model. Based on initial water quality goals and priorities, outputs from the model are discussed and a final recommendation is presented.

7.2 Treatment Train Evaluation

7.2.1 Decision Making Model

Once all appropriate water treatment process options have been identified and evaluated, making the decision on the final treatment process can be difficult. The decision process typically includes a variety of water treatment goals, priorities, and cost considerations. In many cases, water treatment goals and/or their order of priority are not common to all stakeholders and decision makers.

In order to help facilitate decision making and final process selection, the consultant team has developed a multi-attribute decision model to evaluate the 15 treatment process alternatives on the basis of existing and estimated performance data, relative importance, and cost information. This model will also be the key element to building consensus, not only among the City's stakeholders but also with local and provincial Health and Regulatory agencies.

Information inputs to the model include:

- Treatment process options
- Evaluation criteria
- Relative importance of each of the evaluation criteria
- Relative capital and operating cost information

The relative importance of each evaluation criteria can be adjusted to test the sensitivity of that criterion with respect to how it affects the final decision.

7.2.2 Processes Evaluated

As outlined in Section 2, the alternative processes that were identified and evaluated are summarized as follows:

- Option 1: Baseline: DAF + Ozone + BAC Filtration + Chloramination
- Option 2: UV Disinfection + Chlorination + Chloramination
- Option 3: UV Disinfection + Chlorination + Chloramination (Staged with the WTP)
- Option 4: DAF + Filtration + UV Disinfection + Chlorination + Chloramination
- Option 5: DAF + Ozone + BAC Filtration + UV Disinfection + Chloramination
- Option 6: Ultrafiltration + Chlorination + Chloramination
- Option 7: Integrated Pretreatment Ultrafiltration + Chlorination + Chloramination
- Option 8: DAF + Ultrafiltration + Chlorination + Chloramination
- Option 9: Ultrafiltration + Ozone + BAC + Chloramination
- Option 10: Ultrafiltration + GAC Contactors + Chlorination + Chloramination
- Option 11: Ultrafiltration + Nanofiltration + Chloramination
- Option 12: Ultrafiltration + UV Disinfection + Chlorination + Chloramination
- Option 13: UV Disinfection + GAC Contactors + Chlorination + Chloramination
- Option 14: Existing Conditions: Chlorination
- Option 15: DAF + Ozone + BAC + Ultrafiltration + Chloramination

7.2.3 Evaluation Criteria

Evaluation criteria were developed so that they could be used as a basis for evaluating and comparing the treatment options. The evaluation criteria are specific to Winnipeg's situation and were based on the City's water quality goals and treatment objectives. The evaluation criteria are summarized in Table 7.1.

Table 7.1: Evaluation Criteria for Decision Model

Evaluation Criteria	Primary Parameters
Pathogen Treatment	*Giardia* *Cryptosporidium* Bacteria Viruses
Minimize DBPs	Trihalomethanes (THMs) Haloacetic Acids (HAAs) Ozone By-products
Aesthetic Parameters	Taste and Odour Colour
Distribution System Stability	AOC and BDOC TOC
Operating Complexity	Process Stability Automation Maintenance
Residuals and Chemical Minimization	Chemical Usage Residuals Quantity Residuals Quality
SOCs and Algal Toxins	SOCs Microcystin LR

Of the seven evaluation criteria, five are water quality related and two are related to operations. Water quality criteria are generally evaluated based on regulatory requirements and/or risks versus consequences. For example, for Winnipeg, the risk and consequences could be as follows:

LOW RISK	HIGH CONSEQUENCE
- water quality generally good	- disease - cancer - widespread illness - threat of death for vulnerable groups - economic losses - social costs - loss of public trust

Where some groups may be willing to accept more risk, others may not.

7.2.4 Weighting of Criteria and Sensitivity

Some evaluation criteria may be more important than others. For example, meeting a specific regulatory and/or health protection requirement will have a very high importance while minimization of residuals may not be as important.

The initial weighting of the evaluation criteria, which is based on discussions with the City Advisory Committee, is presented in Table 7.2. The primary parameters that make up the evaluation criteria are also weighted, as some will be more important than others. The table shows that public protection from water-borne pathogens is viewed as the most important criteria with *Giardia* and *Cryptosporidium* protection being the critical parameters. This is followed closely by minimization of disinfection by-products, mainly THMs and HAAs, which are public health concerns. Both criteria are becoming more stringently regulated and this trend is expected to continue.

Table 7.2: Relative Importance of Evaluation Criteria

Evaluation Criteria	Weight %	Primary Parameters	Weight %
Pathogen treatment	30	*Giardia* *Cryptosporidium* Bacteria Viruses	30 30 20 20
Minimization of DBPs	25	THMs HAAs Ozone By-products	40 40 20
Aesthetic Parameters	20	Taste and Odour Colour	80 20
Distribution System Stability	10	AOC and BDOC TOC	50 50
Operating Complexity	5	Process Stability Automation Maintenance	50 20 20
Residuals and Chemical Minimization	5	Chemical Usage Residuals Quantity Residuals Quality	40 35 25
SOCs and Algal Toxins	5	SOCs Microcystin LR	40 60

Aesthetic parameters such as colour, taste, and odour, while not health concerns, are important as they relate directly to public perception and stakeholder support. Colour is ranked much lower than taste and odour because Winnipeg's raw water colour is generally quite low and not a concern.

Parameters such as SOCs and Algal Toxins show up so infrequently and at such low levels in Winnipeg's water supply that this criterion is ranked very low as well.

While the weighted importance of each criterion may be arrived at by consensus by one group of individuals, it is a subjective process and another group of individuals may prioritize the criteria differently. Depending on the evaluation criteria, major changes to the weighted value may have little impact on the final process selection. However, even minor changes to some of the evaluation criteria can have a large impact on the final selection. Adjusting these values measures the sensitivity of the evaluation criteria. Once the program is developed, adjusting and testing the sensitivity can easily be done and can help facilitate the final decision.

7.2.5 How the Model is Used

Table 7-3 presents an example evaluation of pathogen treatment. Pathogen log reduction for each primary parameter is estimated for each process option. Once this is completed, each process is ranked relative to one another on a scale of 1 to 5 (1 worst, 5 best), for each of the primary parameters. The ranking of the primary parameters is then multiplied by the weighting factors to come up with an overall pathogen ranking for each process option.

The pathogen treatment evaluation shows that while all options except Option 14 (Existing Conditions: Chlorination) meet the pathogen reduction targets, Options 11 (UF + NF + Chloramination), 12 (UF + UV + Chlorination + Chloramination), and 15 (DAF + Ozone + BAC + UF + Chloramination) provided the highest overall level of pathogen reduction.

Similar evaluations are carried out for all the evaluation criteria. Once all criteria were evaluated, the results were entered into the model. The evaluation criteria weighting factors were then applied to each evaluation criterion to develop relative comparisons.

Once all the data is entered into the model, it generates comparative charts that can be sorted by lowest to highest water treatment and water quality benefits. After the water quality benefits are sorted, costs for each process option are displayed on the benefits chart so that relative costs versus benefits of each alternative can be evaluated.

The final selection will be the process that provides the highest benefits for the lowest costs.

Table 7.3: Pathogen Treatment Evaluation Criteria

		Weight	1 DAF Ozone BAC Chloramine (base line)	2 UV Chlorine Chloramine	3 UV (phased) Chlorine Chloramine	4 DAF Filter UV Chlorine Chloramine	5 DAF Ozone BAC UV Chloramine	6 UF Chlorine Chloramine	7 Integrated Pre Treatment UF Chlorine Chloramine	8 DAF UF Chlorine Chloramine	9 UF Ozone BAC Chloramine	10 UF GAC Chlorine Chloramine	11 UF NF Chloramine	12 UF UV Chlorine Chloramine	13 UV GAC Chlorine Chloramine	14 Existing Conditions 0 0	15 DAF O3 BAC UF
Pathogen Treatment	Giardia	30	3.32	2.26	2.26	3.53	4.58	2.68	2.89	2.89	3.74	2.68	4.16	3.95	2.26	1.00	5.00
	Cryptosporidium	30	2.75	2.50	2.50	4.00	4.25	3.00	3.25	3.25	3.25	3.00	5.00	4.50	2.50	1.00	4.75
	Bacteria	20	3.00	2.25	2.25	3.50	4.00	3.25	3.50	3.50	3.75	3.25	4.25	4.25	2.25	1.00	5.00
	Virus	20	2.33	1.67	1.67	3.00	3.00	3.67	4.00	4.00	3.67	3.67	4.33	4.33	1.67	1.00	5.00
Summation Pathogen Treatment			2.89	2.21	2.21	3.56	4.05	3.09	3.34	3.34	3.58	3.09	4.46	4.25	2.21	1.00	4.93
Log Removals	Giardia		6	3.5	3.5	6.5	9	4.5	5	5	7	4.5	8	7.5	3.5	0.5	10
	Cryptosporidium		3.5	3	3	6	6.5	4	4.5	4.5	4.5	4	8	7	3	0	7.5
	Bacteria		6	4.5	4.5	7	8	6.5	7	7	7.5	6.5	8.5	8.5	4.5	2	10
	Virus		5	4	4	6	6	7	7.5	7.5	7	7	8	8	4	3	9

7.3 Results From Decision Making Model

Summary outputs from the decision making model are presented in the following paragraphs to demonstrate the decision making process.

Figure 7.1 presents the output from the model showing the relative benefits associated with each alternative. The process options have been sorted from lowest to highest overall water quality and operating benefits.

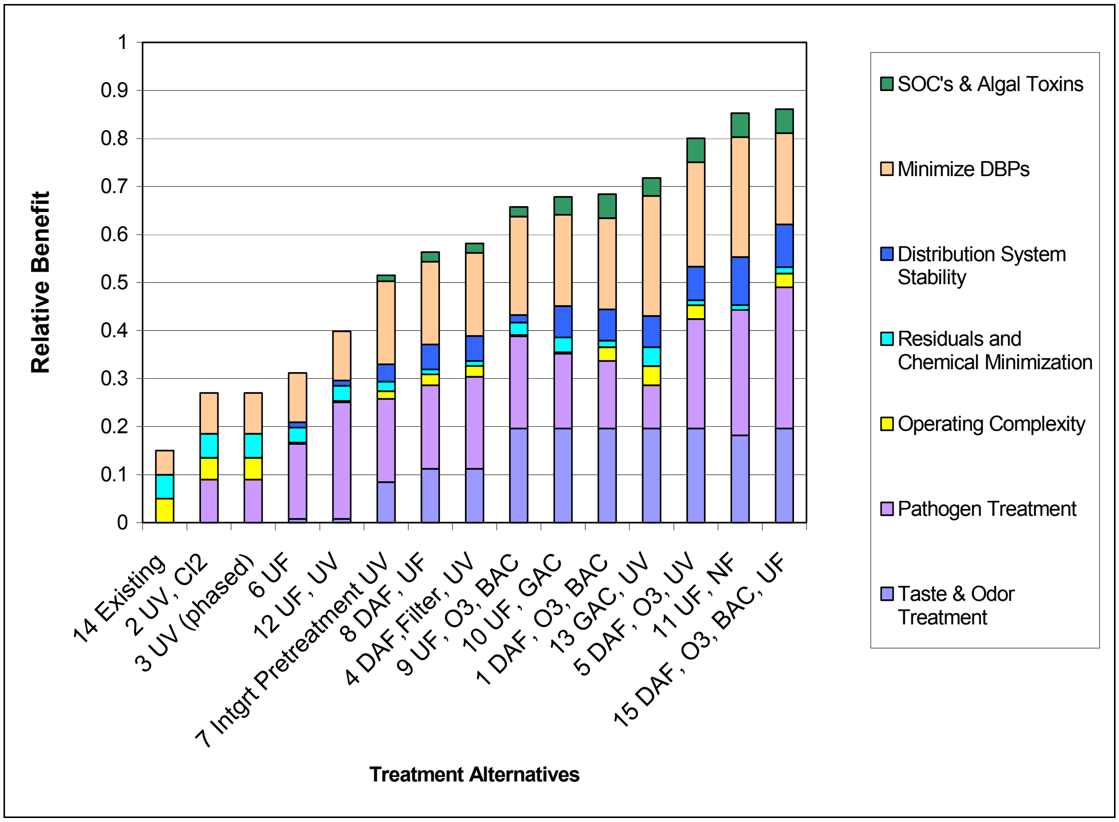

Figure 7.1: Treatment Alternatives

From an overall benefits perspective, Option 15 (DAF + Ozone + BAC + Ultrafiltration + Chloramination) provides the highest overall benefit. The baseline process (Option 1) is ranked fifth and the baseline process with the addition of UV disinfection (Option 5) is ranked third.

The next step in the decision making process is to add relative costs to the benefits chart so that process option with higher costs versus benefits can be filtered out. Figure 7.2 presents the relative benefits and cost data for each treatment option.

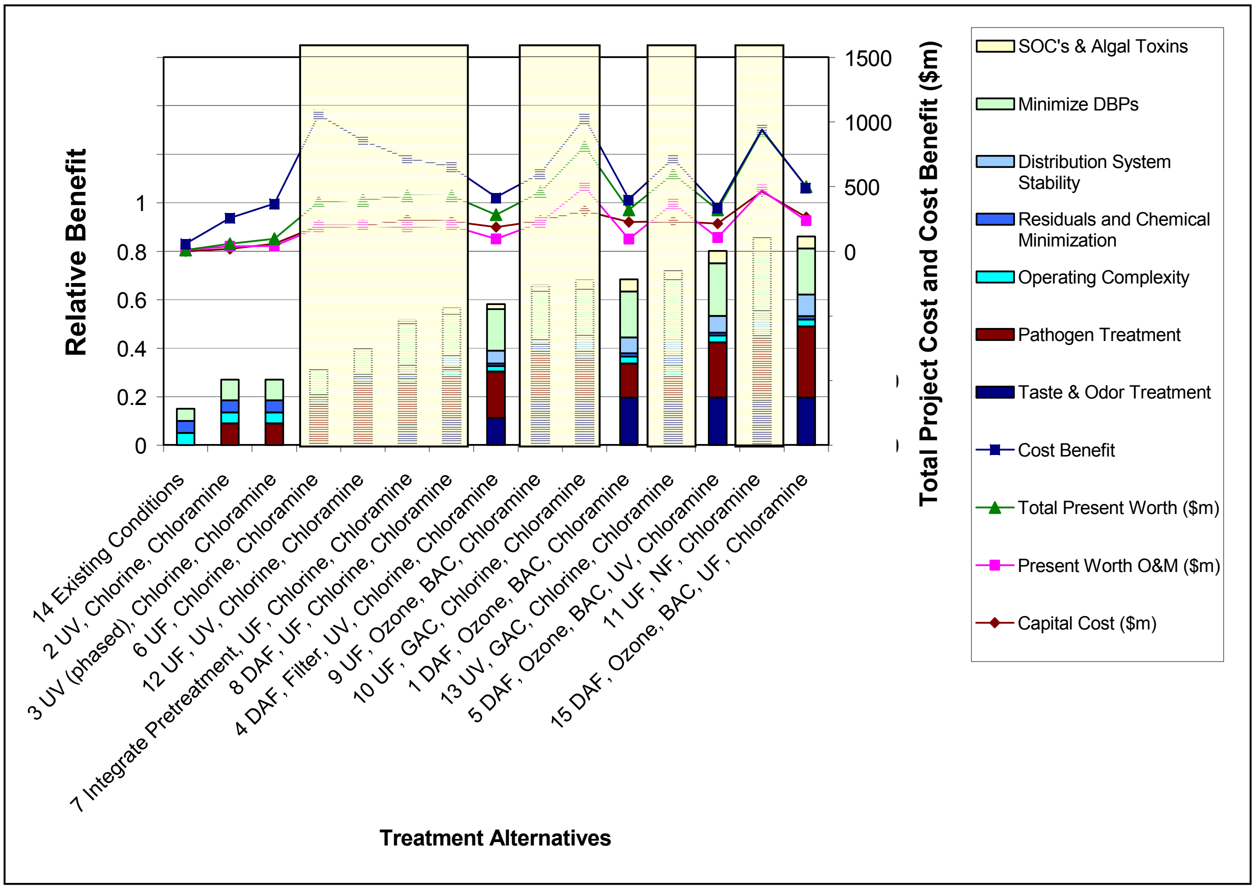

Figure 7.2: Cost Benefit Screening

Option 11 (UF + NF + Chloramination) has the highest estimated capital costs. Option 10 (UF + GAC + Chlorination + Chloramination) results in the highest operating costs due to GAC regeneration requirements. The options including GAC also represent the highest present worth costs. The top line indicates the relative cost versus benefit of the treatment options. The shaded areas indicate the treatment options with the highest costs versus benefits. These processes are screened out as they are expected to be not as cost effective as the other options.

The remaining processes are presented in Figure 7.3.

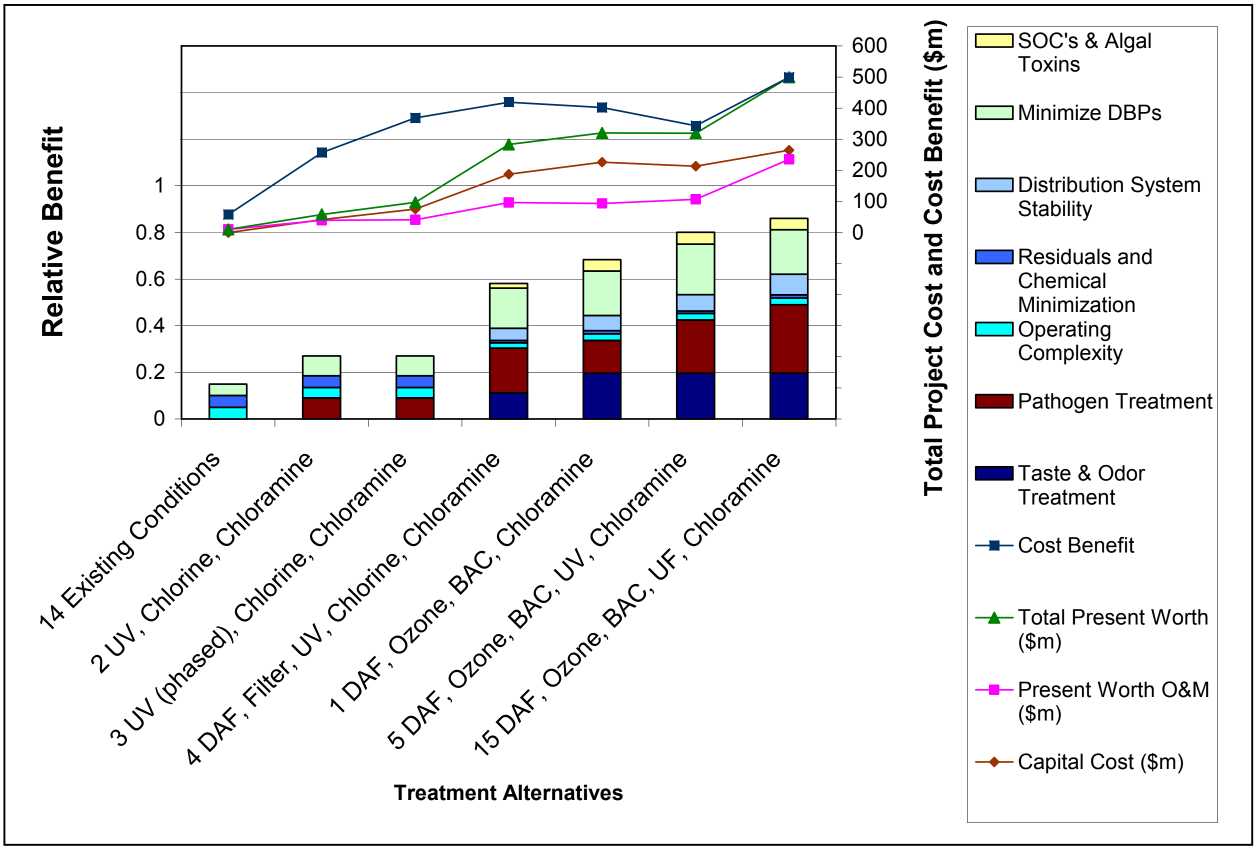

Figure 7.3: Treatment Alternatives Remaining After First Screening

A similar screening process can then be carried out on the remaining treatment alternatives. Figure 7.4 presents a screening process on these options.

Option 15 has the highest cost benefit ratio and is therefore screened out. Options 14, 2, and 3 have the lowest overall benefits and do not address all the City's water quality goals and objectives and are therefore screened out. Option 4 has lower benefits and a higher cost benefit ratio than Options 1 and 5 and is therefore screened out. Options 1 and 5 have the lowest cost to benefit ratios and represent the most cost effective options. Of these two, Option 5 has the lowest overall cost benefit.

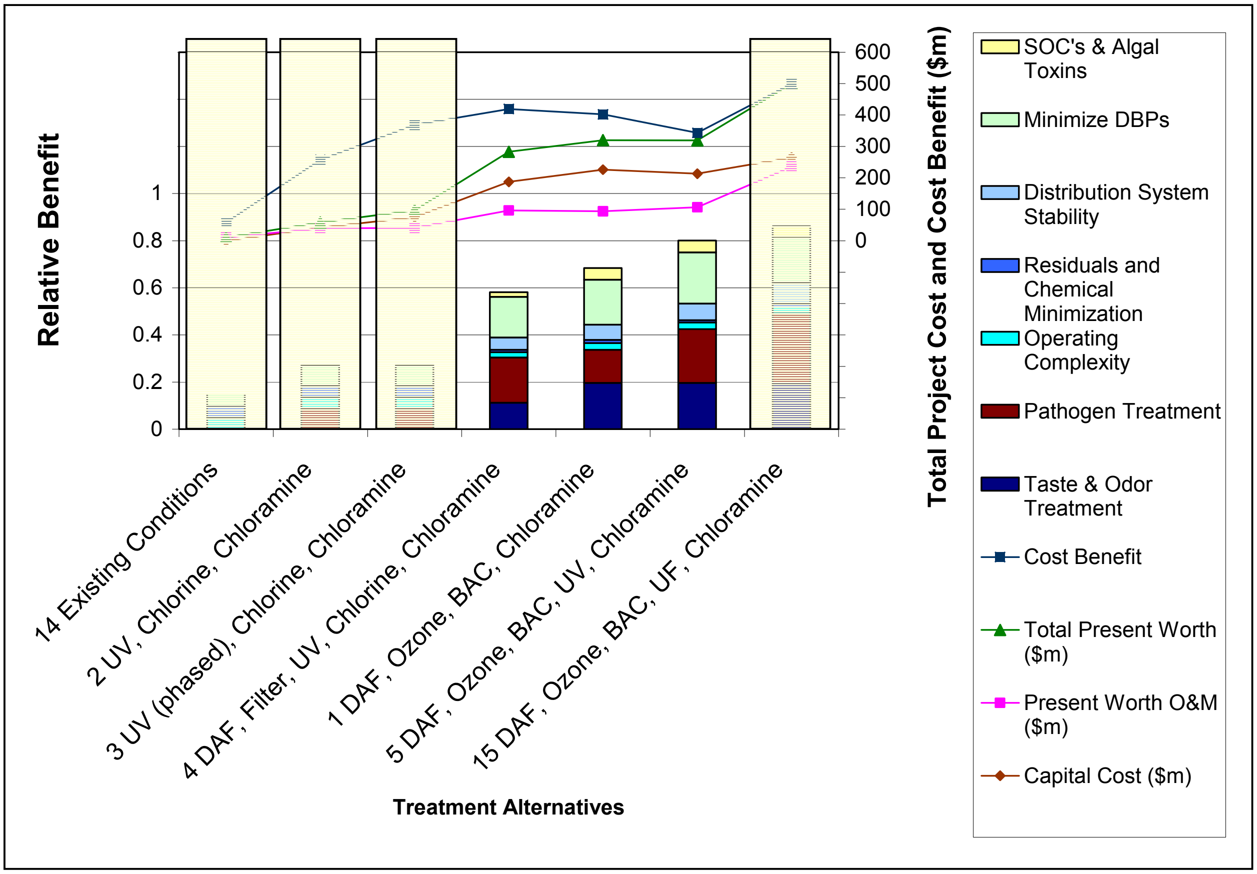

Figure 7.4: Final Treatment Alternative Screening

7.4 Recommended Treatment Train

Based on the results of the decision making model, the two most favourable treatment trains are:

- Option 1: Baseline: DAF + Ozone + BAC Filtration + Chloramination
- Option 5: DAF + Ozone + BAC Filtration + UV + Chloramination

This procedure confirms that the baseline process is still a valid recommendation for the City of Winnipeg.

Option 5 is essentially the baseline process with the addition of UV disinfection, which provides an additional barrier against water borne pathogens and allows downsizing of the ozone system. It provides the multiple barrier approach that is recognized in the water supply industry as the best way to maximize public health protection. Because Option 5 provides greater benefits and has a lower estimated capital cost than Option 1, it is recommended for Winnipeg's water treatment plant.

7.5 Future Application of the Model

One of the key advantages of the decision making model is that it is dynamic and can be used as a tool for future evaluations. This can include:

- Evaluation of the sensitivity to changing criteria and/or weighting
- Evaluation of the impact of updated cost estimates
- Evaluation of emerging or new treatment processes

The model is therefore a cost effective means of updating and evaluating the treatment process selection if alternative processes need to be evaluated prior to implementation of the water treatment plant.

Section 8

Update of Capital Cost Estimates

8.1 Update of Capital Cost Estimates

8.1.1 1999 Estimate of the Baseline Water Treatment Plant

In October 1999, a cost estimate for the baseline water treatment plant was generated[1]. At that time, the total estimated cost was determined to be $204,000,000. A summary of the estimate is presented in column 1 of Table 8.1. At that time, it was assumed that the construction of the water treatment plant would commence 2003 and an inflation allowance of 2.5% per year for 3 years was included.

The present schedule now envisions the construction of the water treatment plant commencing in early 2005 with a proposed in service date late 2007. The 1999 estimate has been reviewed in light of the changed schedule. The total estimated cost for the baseline water treatment plant remains at $204,000,000.

8.1.2 Revision to Ozonation System for Increased Ct Requirements

As noted in Technical Memorandum No. 6, based on recent research, the requirements for Ct for use of ozone for inactivation of *Cryptosporidium* and *Giardia* have increased dramatically for cold water applications such as Winnipeg. As a result, the ozonation system included in the baseline water treatment process train would have to be increased in size by a significant amount. The estimated cost of the baseline water treatment plant, taking into account the increased ozone system requirements is $229,000,000. A summary of the estimate is presented in column 2 of Table 8.1.

8.1.3 Incorporation of UV Disinfection

In Section 7 of this report, it is recommended that the baseline water treatment process be modified to incorporate Ultraviolet (UV) disinfection. This alternative is referred to as Option 5. UV will provide another barrier against water borne pathogens. Since UV would provide inactivation of *Cryptosporidium* and *Giardia,* the ozone system could be sized for only virus inactivation, taste and odour control and filterability improvement. This would avoid the extra costs associated with the new Ct requirements for ozonation for *Cryptosporidium* and *Giardia* inactivation.

The estimated cost of Option 5 is $214,000,000. A summary of the estimate is presented in column 3 of Table 8.1.

Table 8.1: Budget Capital Cost Estimates

	Column 1	**Column 2**	**Column 3**
Item	**Baseline Water Treatment Process – 1999 Estimate**	**Revision to Ozonation System for Increased Ct**	**Option 5 – Incorporation of UV Disinfection**
Assumed Construction Start Date	2003	2005	2005
Construction Cost	149,000,000	168,700,000	157,400,000
Contingency	14,900,000	16,900,000	15,800,000
Inflation allowance	11,000,000	12,500.000	11,600,000
Engineering	22,600,000	24,400,000	22,700,000
Spent to date	2,500,000	2,500,000	2,500,000
Finance and Administration	3,000,000	3,000,000	3,000,000
ASD Study, Risk Assessment, Environmental Approvals	1,000,000	1,000,000	1,000,000
Total Estimated Cost	**$ 204,000,000**	**$ 229,000,000**	**$ 214,000,000**

8.1.4 Operating and Maintenance Costs

In 1999, the estimated annual operating and maintenance (O&M) cost of the baseline water treatment process was estimated to be $12,000,000 per year.

The UV process has an estimated operating and maintenance cost of $750,000 per year, resulting in an estimated total annual O&M cost of $12,750,000 for Option 5.

8.1.5 Conversion from Chlorination to Chloramination

As set out in Technical Memorandum No. 8, it is recommended that the aqueduct and distribution system disinfection systems be converted to chloramination. The estimated cost for converting the aqueduct chlorination system to chloramination is $1.4 million as set out in Section 3 of Technical Memorandum No. 8. The cost for this conversion is not included in the estimates of the water treatment plant presented above.

The estimated cost for converting the distribution system disinfection system to chloramination is $3 million as set out in Technical Memorandum No.8. This cost has been incorporated into the estimates for the new water treatment plant.

References

1. Winnipeg Water Consortium, “Final Report, Class II Construction Cost Estimate, Water Treatment Plant Project”, September, October 1999.

Section 9

Recommended Implementation Program

9.1 Preamble

Following the completion of the conceptual design of the water treatment plant in 1999, the City developed a preliminary approach for the implementation of its Drinking Water Quality Enhancement Program. This program was presented to and adopted by Council. The implementation approach proposed the construction of a new water treatment plant commencing in 2004 with an in service date of 2006.

As recommended by Council, additional investigations into alternative processes were completed during 2001 and early 2002. The results of these investigations are documented in the previous sections of this Summary Report.

This final section of this Summary Report sets out the updated program for implementing the City of Winnipeg's Drinking Water Quality Enhancement Program, taking into account all of the evaluations completed thus far for the project.

9.2 Basis of Implementation Program

9.2.1 The Need for Water Treatment

The previous reports adopted by Council in November 2000 have set out the rationale for implementing water treatment for Winnipeg's water supply. The key information is summarized here to provide a synopsis of the need to construct a water treatment plant.

Reduce the Risk of a Waterborne Disease Outbreak

In 1996, a Health Risk Assessment of Winnipeg's water supply was conducted with input from international experts and City and Provincial Health Officials. The risk assessment concluded that while the risk of a waterborne disease outbreak in Winnipeg is low, the consequences are high. An outbreak could result in large numbers of residents becoming sick as well as some deaths. The population with severely weakened immune systems, such as persons with HIV/AIDS, persons with cancer, recipients of organ or bone marrow transplants and those being treated with immunosuppressing drugs, would be particularly vulnerable.

During the public consultation program held by the City during 1999, City and Provincial Health Officials reiterated their views that water treatment should be implemented. Dr. James Popplow (Medical Officer of Health with the Province of Manitoba) and Dr. Margaret Fast (at the time the City's Medical Officer of Health) both strongly urged the City to construct a water treatment plant and they maintain that position today.

Winnipeg currently uses chlorine as the primary disinfectant, providing a barrier against some water borne pathogens. However, it is now recognized that chlorine resistant pathogens such as *Cryptosporidium* and *Giardia* are present in Shoal Lake. Although chlorine provides one level of protection against some pathogens, a multiple barrier approach is commonly implemented in the water supply industry in order to mitigate the risk of a waterborne disease outbreak. An effective multi-barrier approach consists of source protection, water treatment, and disinfection throughout the distribution system. The water treatment plant is a critical component of the multiple barrier approach and should be designed to provide multiple barriers in itself.

Reduce the Levels of Disinfection By-products

A water treatment plant is required to reduce the levels of disinfection by-products in the water supply. Currently, the chlorine used by the City for primary disinfection reacts with organic matter in the raw water to form chlorinated disinfection by-products. Studies have shown an association between the long term exposure to these by-products and cancer. Also, the most recent research indicates a possible association with spontaneous abortions. The Guidelines for Canadian Drinking Water Quality establish a maximum concentration for TTHMs, which are intended to reduce the risk of cancer. The Canadian interim maximum acceptable concentration for Total Trihalomethanes (TTHMs) is 100 micrograms per litre. This guideline is currently under review and may be further reduced. The USA limit for TTHMs is 80 micrograms per litre and the US EPA may lower this limit to 40 micrograms per litre. The USA limit for Total Halo Acetic Acids (THAAs) is 60 micrograms per litre. In 2001, the City's water supply had an average disinfection by-product concentration of 119 micrograms per litre. A water treatment plant would ensure that the Canadian guidelines for disinfection by-products are met at all times.

Improve the Appearance, Taste and Odour of the Water

Finally, the present water supply does not meet Canadian guidelines for three additional parameters - turbidity, and taste and odour. Turbidity is a measure of the cloudiness of the water, and the City's water treatment goal is to provide clear water to its consumers. The Canadian guideline for turbidity is less than 1 NTU, and the City's water supply exceeds this value at times. Taste and odour are also aesthetic parameters. Undesirable taste and odour occurs as a result of episodes of algae blooms in Shoal Lake or Deacon Reservoir. During these episodes, the taste and odour of the water becomes objectionable to some consumers. The City's 2002 surveys suggest that 43% of its customers are not satisfied with the taste and odour of the water. A full water treatment plant would produce treated water that is in compliance with the guidelines for turbidity, taste and odour, resulting in improved customer satisfaction.

9.3 Recommended Water Treatment Process Train

9.3.1 New Baseline Process

As set out in the previous sections of this report and the Technical Memoranda, various additional investigations into a variety of issues related to the water treatment processes have been completed. These investigations have resulted in the refinement of the recommended baseline water treatment process train, which is described in Section 7. The recommended water treatment process train now consists of the following:

> Coagulation (ferric chloride) + Dissolved Air Flotation (DAF) + Ozone (O_3) + Biological Activated Carbon (BAC) Filtration + UV Disinfection + Chloramination (secondary disinfection)

It is recommended that this process become the new baseline process. It is recommended that the design and construction of Winnipeg's new water treatment plant be based on this process.

9.3.2 Entire Water Treatment Plant

It is recommended that the City construct the entire water treatment plant, based on the recommended water treatment process train, as soon as practicable. The decision making model used to select this process train, as described in Section 7 of this Summary Report, can be applied to assess any other process alternatives that are suggested between now and the time of commencement of construction of the new water treatment plant. This will provide a mechanism to continually review and update the treatment process train so that the most beneficial and cost effective water treatment system is constructed.

9.4 The Recommended Implementation Program

9.4.1 Introduction

There is a need to move ahead quickly with the implementation of the City's Drinking Water Quality Enhancement Program to provide an increased level of public health protection. However, there will be practical and financial capability limits that must be taken into consideration in implementing a major public works project such as this. The following implementation program has been developed to provide a reasonable balance between these two objectives.

The recommended program has been divided into five major components, which are described in the following paragraphs.

9.4.2 Ultraviolet Disinfection (A first phase of additional treatment)

The investigations carried out in this phase of the work (Technical Memorandum No. 6), combined with the results of the American Water Works Association Research Foundation (AWWARF) pilot testing program have shown that Ultraviolet (UV) disinfection will provide an effective barrier against some water borne pathogens, particularly the chlorine resistant organisms such as *Cryptosporidium*. Furthermore, the research and pilot testing completed by the City in the AWWARF program have confirmed that UV will be an effective disinfectant on Winnipeg's unfiltered water supply.

Two viable alternatives for incorporating UV into the water treatment process train exist. These are described in detail in Technical Memorandum No. 6 and are summarized briefly in the following paragraphs:

Alternative 1 - Inside Deacon Booster Pumping Station

The UV reactors and ancillary equipment could be installed inside of the Deacon Booster Pumping Station. The pump room at the lowest level of the station has space reserved for the future addition of additional pumps. Based on the current projections for water usage, these pumps are not likely to be required for 15 to 20 years. Therefore, this space is available for locating the UV system for that period of time.

Alternative 2 - At the Back End of the Proposed Water Treatment Plant

In the Phase II Conceptual Design, a preliminary layout for the water treatment plant based on the baseline water treatment process was developed. The UV system could be integrated into this layout, downstream of the BAC filters.

The AWWARF research program has confirmed that UV will be effective as a disinfectant on the City's unfiltered water supply. Alternative 1 – Inside Deacon Booster Pumping Station has an estimated capital cost of $8,600,000 and will be the more cost effective approach. Further analysis indicates that installing UV in advance of the full water treatment plant will have little impact on the total cost of the overall water treatment plant.

Therefore, it is recommended that the City proceed with the installation of UV disinfection equipment inside the Deacon Booster Pumping Station to provide a first phase of additional treatment. It would be possible to implement this component by early 2004 if it commences during 2002. This will provide a significant increase in the level of treatment and, within a short time frame, will result in a reduction in the risk of a waterborne disease outbreak.

9.4.3 Distribution System Cleaning

The existing water distribution system has a build up of sediments and other particulates in it due to the many years of delivering unfiltered water. In order to avoid the degradation of the treated water once the water treatment plant is operational, and to minimize the disinfection demand in the distribution system, it is recommended that the distribution system be thoroughly cleaned as soon as practicable.

In particular, the distribution system should be cleaned prior to commissioning of the full water treatment plant. Without a thoroughly cleaned distribution system, the treated water from the newly commissioned water treatment plant would be subject to degradation in the water distribution system. In addition, the use of chloramines for distribution system disinfection may promote nitrification in the system, which could have adverse impacts on the quality of the water distributed to the consumers. Cleaning of the distribution system will minimize this possibility.

The distribution system cleaning program would consist of uni-directional flushing, swabbing, and disinfection. The City is presently developing a detailed plan for the distribution system cleaning program that contemplates completing one pass through the distribution system over three summer seasons commencing in 2003. The uni-directional flushing program will become an ongoing program in 2006.

9.4.4 Conversion of Distribution System to Chloramination

In Technical Memorandum No. 8, various alternatives to the present use of free chlorine for disinfection were examined. Based on these evaluations, it is recommended that chloramination be used in place of free chlorination in the aqueduct and the distribution system. This change will reduce the concentration of disinfection by-products (DBPs) in the water supply. Therefore, the conversion to chloramines should be implemented as soon as practicable to minimize the public health risk associated with DBPs.

However, as chlorination is the only microbial barrier presently in place, the conversion needs to be carefully phased such that other microbial barriers are functioning before chlorination is ceased.

The conversion of the disinfection system from free chlorination to chloramination for the distribution system can be implemented once the UV system at Deacon Booster Pumping Station is installed, commissioned and proved to be operating satisfactorily. The UV system, once fully operational, will provide an additional barrier against many water borne pathogens including *Cryptosporidium* and *Giardia*. UV will be less effective against viruses so in designing the chloraminatin system for the distribution system, care will have to be taken to continue to provide adequate free chlorine contact time to provide virus inactivation prior to the addition of the ammonia. This will involve applying the chlorine just downstream of the UV system to be located in Deacon Booster Pumping Station and applying the ammonia far enough downstream along the two branch aqueducts to provide the required free chlorine contact time to effect virus inactivation. Once the full water treatment plant is in place, this free chlorine contact time becomes less critical and the application points for both the chlorine and the ammonia can be relocated to the tail end of the water treatment plant.

The conversion to chloramination involves significant changes to many aspects of the water supply system, requiring that the implementation be planned out carefully. Preliminary consideration of the issues to be addressed is set out in Technical Memorandum No. 8. In summary, the following issues will have to be addressed in the implementation program for conversion to chloramination:

- Regulator review and acceptance: Further discussions are required with Manitoba Conservation and Manitoba Health to gain acceptance of the use of chloramines as a disinfectant in place of free chlorine, because at the present time, chlorine is the only approved disinfectant for use in distribution systems in Manitoba.
- Public education program: The conversion to chloramination will impact many of the consumers. In addition to the general consumer, special users such as certain industrial and commercial operators, hospitals, and aquarium owners will need specific guidance because of their unique circumstances. A comprehensive education program must be developed and implemented. The City has conducted similar information campaigns in the past and the American Water Works Association offers guidance on this matter, which will be drawn upon as appropriate.
- Conversion of the existing chlorine feed systems to chloramination: Several items will have to be attended to including:
  - Selection of form of chemicals to be used (e.g., liquid versus gaseous).
  - Location and configuration of chlorine and ammonia storage systems, feed systems and injection points, both for the interim and following completion of the overall water treatment plant.
  - Design of the infrastructure required to support the chemical feed facilities (e.g., chemical delivery methods, site services.)

  Basic concepts for the last two items are included in Technical Memorandum No. 8.

9.4.5 Water Treatment Plant

The Health Risk Assessment conducted by the City in 1996 concluded that there is an identifiable risk to public health with the present water supply system that can be mitigated significantly with available prevailing technology. It was also concluded that implementation of comprehensive water treatment facilities for Winnipeg is justified from a public health perspective.

The implementation of UV disinfection as the first phase of the Drinking Water Quality Enhancement Program will provide an added level of public health protection with respect to waterborne pathogens. However, this step alone does not eliminate the risk of a waterborne disease outbreak and does not provide any beneficial impact with respect to many of the City's other water quality goals. As previously noted, a multiple barrier approach to protection against waterborne pathogens is recommended in the water supply industry. The additional unit processes included in the recommended water treatment process provide the additional barriers.

Therefore, it is still essential that the balance of the water treatment plant be constructed as soon as practicable to ensure that the City's water supply meets all of the requirements of the Guidelines for Canadian Drinking Water Quality and to ensure a safe and reliable water supply for the citizens of Winnipeg. The implementation of the balance of the water treatment plant will result in all of the City's water quality goals being met on an ongoing basis.

The implementation of the water treatment plant would involve the following:

- An environment assessment and approval under the Manitoba Environment Act
- A Certificate of Approval under the Public Health Act
- Engineering, including design of the proposed water treatment plant
- Construction of the proposed water treatment plant
- Start up and commissioning of the works

9.4.6 Conversion of Aqueduct to Chloramination

Currently, chlorination at the intake of the Shoal Lake aqueduct provides an effective barrier against many waterborne pathogens and thus some degree of public health protection. In addition, the use of free chlorine in the aqueduct provides many other benefits including slime control along the aqueduct walls, protection against infestation by Zebra Mussels, and taste and odour benefits. Conversely, the free chlorine combines with organic material in the raw water, creating a public health risk associated with disinfection by-products.

In Technical Memorandum No. 8, the foregoing issues were examined and it was recommended that the aqueduct chlorination system be converted to chloramination. The conversion should be implemented as soon as the water treatment plant is constructed. The water treatment plant will provide suitable multiple barriers and will provide taste and odour control. Chloramination in the aqueduct will continue to provide the slime control. The existing chlorination system at the intake can be left in place to be used occasionally to provide protection against Zebra Mussels. Therefore, the conversion of the aqueduct disinfection system from chlorination to chloramination can proceed after the full water treatment plant is fully operational.

The conversion to chloramination in the aqueduct involves many of the same issues as for the distribution system. In summary, the implementation program would address the following items:

- Regulator review and acceptance: Further discussions are required with Manitoba Conservation and Manitoba Health to gain acceptance of the use of chloramines in place of free chlorine. It is anticipated that Manitoba Conservation would also have some concerns with respect to the environmental impacts associated with potential spills from the aqueduct of water containing chloramines. Also, at the present time, chlorine is the only approved mulloscicide.
- Conversion of the existing chlorine feed systems to chloramination: Several items will have to be attended to including:
  - Final selection of the form of chemicals to be used (e.g., liquid versus gaseous).
  - Location and configuration of chlorine and ammonia storage systems, feed systems and injection points.
  - Design of the infrastructure required to support the chemical feed facilities (e.g., chemical delivery methods, site services.)

9.5 Implementation Schedule

The schedule associated with the foregoing implementation program is summarized in Figure 9.1.

9.6 Cash Flow

Based on the foregoing implementation program and schedule, the following cash flow requirements are estimated.

Table 9.1: **Cash Flow - Implementation Program ($‘000’s)**

COMPONENT	Prior to 2002	2002	2003	2004	2005	2006	2007	TOTAL
UV Disinfection at Deacon Booster Pumping Station		500	8,100					$ 8,600
Convert Distribution System to Chloramination			375	2,625				$ 3,000
Water Treatment Plant			4,600	10,000	60,400	60,400	60,500	$ 195,900
Spent to Date	2,500							$ 2,500
Financing and Administration						1,500	1,500	$ 3,000
ASD Study, Risk Assessment, Environmental Approvals			500	500				$ 1,000
TOTAL ANNUAL	**2,500**	**500**	**13,575**	**13,125**	**60,400**	**61,900**	**62,000**	**$ 214,000**

Notes:
* The conversion of the Aqueduct from chlorination to chloramination and the distribution system cleaning program will be funded from the Water and Waste Department's capital and operating budgets. These costs are not included in the above cash flow estimates.

9.7 Impact on Rate Structure and Reserve

The Water and Waste Department has updated its analysis of the impact that the drinking water quality enhancement program will have on the water utility rate structure and the water treatment plant capital reserve. This analysis is summarized as follows:

- As of December 31, 2001 there was $53 million in the Water Treatment Plant Reserve.
- The proposed implementation program would delay the in-service date of the plant by one year.
- The addition of UV disinfection to the baseline water treatment process train increases the estimated cost of the water treatment plant from $204 million to $214 million.
- The impact of adding UV disinfection and delaying the start of construction by one year is estimated to be cost neutral with respect to the impact on water rates. Cost savings from delayed debt financing and operating costs will offset the additional reserve contributions needed to fund the UV disinfection facility.