R E P O R T

TOWN OF SLAVE LAKE

Water Treatment Improvements

Parts 1-3

March
2000

For tables, figures and appendices please refer to hard copy located in file number 2001-3981-5.2.

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INTRODUCTION

SECTION 1

1.1 PURPOSE

The purpose of the study is to identify potential water treatment system improvements required over the next ten years. The study results are intended to serve as guide to develop a staged ten year Capital Improvement Plan.

Water quality concerns associated with taste and odor, high disinfectant consumption and corrosion have been expressed by the Town. Associated Engineering identified key areas of water treatment improvements in a 1997 preliminary study. The preliminary study focused only on the plant's ability to meet Alberta Environmental Protection (AEP) Treatment Guidelines and to provide an effective barrier against waterborne parasites such as *Giardia* and *Cryptosporidium*. Based on the study and follow-up discussions with Town officials, the following work was conducted.

- Pilot plant study to assess the merits of pre-ozonation and/or Granular Activated Carbon (GAC) Filtration.
- Tracer study to establish the effective contact time of oxidants/disinfectants and to help establish optimal feed locations.
- Tracer study to verify the hydraulic residence time through major unit processes.
- Bench scale evaluation of various chemicals and doses for chemical feed optimization.
- Computer modeling, simulation and desktop analysis.
- Water quality studies including *Giardia* and *Cryptosporidium* in the raw water supply, disinfectant by-products and organics.
- On-line instrumentation monitoring program using particle counters and turbidimeters to assess performance limiting factors.
- Cost evaluation for implementing the findings from the completed tasks.

Recommended improvements are presented with the aim of minimizing the risk of parasite passage, maximizing color reduction, reducing taste and odor, enhancing filtered water quality, and optimizing disinfection treatment.

1.2 NEED FOR IDENTIFYING WATER QUALITY IMPROVEMENTS

The primary objectives of water treatment are to: (1) produce water that is safe, and (2) produce water that is aesthetically pleasing *(i.e. clear and good tasting)*. Treatment of drinking water is the key reason for the dramatic reduction in water borne disease rates since the turn of the century. The need for safe and pleasing water has been and continues to be the primary driving force behind changing practices and the enhanced treatment requirements addressed in this study.

Public health concerns and recent developments in research have led to more stringent guidelines for filtration and disinfection. Parasites such as *Giardia* and *Cryptosporidium* and treatment by-products such Trihalomethanes (THMs) are the new water quality issues of concern. Revised chlorination practices, turbidity standards and monitoring practices are examples of changes being advocated by regulatory agencies to reduce the risk to consumers of various water borne parasites and treatment by-products.

1.3 STUDY APPROACH

This study was divided into ten tasks. Technical memorandum (Parts 2 and 3) were prepared for each of the following:

- Raw Water Quality Evaluation
- Disinfection By-product Evaluation
- *Giardia* and *Cryptosporidium* Evaluation
- Pilot Evaluation of Pretreatment by Ozone
- Granular Activated Carbon Pilot Study
- In-plant and Reservoir Tracer Study
- Water Distribution System Evaluation
- Evaluation of pH Control
- Bench-scale Chemical Optimization Study
- On-line Particle Counting and Turbidity Monitoring

Section 2.0 summarizes the objectives, findings and treatment implications for each of the above tasks.

TECH MEMO KEY FINDINGS

SECTION 2

Key findings, for the 10 work tasks undertaken, are summarized in this section. Detailed results are presented in Parts 2 and 3.

2.1 RAW WATER QUALITY EVALUATION

Purpose:
To conduct water quality testing and to evaluate historical data to establish treatment objectives

Key Findings:
Raw water contains high organics, colour and low turbidity, alkalinity, hardness. Seasonal algae, taste and odour problems are severe.

Treatment Implications:
The results indicate the need to target treatment towards: Turbidity, Color, Algae, Organics, Taste & Odor.

2.2 DISINFECTION BY-PRODUCTS (DBP) EVALUATION

Purpose:
To identify and categorize the formation potential of harmful disinfectant by-products (DBPs). Some DBPs are probable human carcinogens and consequently are of concern from a public health stand point.

Key Findings:
The test results of one treated water sample showed the DBP level to exceed the allowable limit.

TMH formation potential test results indicated that DBP precursors could be significantly reduced by employing GAC and chloramination treatment processes.

Treatment Implications:
Granular Activated Carbon (GAC) filtration could be deployed to minimize the DBP formation in the treated water. GAC however is a costly treatment option. Enhanced coagulation should be explored for maximizing reduction of DBP precursions.

Present chlorination practice for disinfection should be converted to chloramination to minimize DBP formation and to provide more stable disinfectant residuals.

2.3 *GIARDIA* AND *CRYPTOSPORIDIUM* EVALUATION

Purpose:
To quantify the existence of waterborne pathogens such as *Giardia* and *Cryptosporidium* in the raw water. *Giardia* and *Cryptosporidium* are known to cause illness in consumers. The extent of treatment required for inactivation/removal of such pathogens depends of their concentration in the raw water.

Key Findings:
The raw water contains *Giardia* cysts and *Cryptosporidium* oocysts.

Treatment Implications:
Based on the limited data collected to date, a 5-log inactivation/removal of *Giardia* cysts would be required for AEP approval. Further sampling is recommended to provide additional data needed to confirm the level of treatment required.

At this time, AEP has not stipulated any *Cryptosporidium* removal level targets. AEP, like other regulatory agencies, are waiting for the outcome of several research initiatives. The Interim Enhanced Surface Water Treatment Rule (IESWTR) recommends that a minimum of 2-log *cryptosporidium* removal be achieved by filtration. This requirement is satisfied by producing treated water turbidity of less than 0.3 NTU 95% of the time without exceeding 1 NTU.

2.4 PILOT EVALUATION OF OZONE PRETREATMENT

Purpose:
To evaluate the effectiveness of ozone pretreatment for taste & odor, color, organics, algae and turbidity reduction. A pilot ozonation plant was operated between the months of April (spring runoff season) and August (algal bloom). Optimum operating parameters for ozone were also established.

Key Findings:
Ozone provided good removals of colour, taste and odour. Ozone also effectively oxidized algal cells.

Ozone did not provide effective organic removal and therefore DBP formation potential was high.

Ozone provides an effective barrier against *Giardia* cysts which is otherwise not provided by the current free chlorination practice.

Treatment Implications:
A 10 mg/L ozone dose and 10 minute detention time are required for colour, taste and odour removals and to provide some TOC reduction. This also provides provides the necessary disinfection CT requirement for *Giardia* cyst inactivation.

GAC filtration following ozonation would provide additional treatment benefits.

2.5 GRANULAR ACTIVATED CARBON (GAC) PILOT STUDY

Purpose:
To evaluate the effectiveness of GAC and to establish the design criteria for supplementary organic, colour, taste and odour reduction of the ozonated water. GAC filtration is often used to prevent the biodegradable organics that are created by ozone treatment from entering the distribution system. These biodegradable organics can lead to bio-film accumulation in the distribution system. A GAC pilot column study was commissioned to assess the effectiveness of this technology for Slave Lake water.

Key Findings:
GAC provided excellent organic removals that was not provided by ozone. It also reduced the colour of the ozonated water.

GAC greatly minimized the DBP formation and removed ozonation DBPs.

GAC increased stability of disinfectant residual thus reduces the current chlorine usage by approximately 50%.

Treatment Implications:
The results indicate GAC absorbers would minimize DBP's and reduce the chlorine dosage requirements.

2.6 TRACER STUDY

Purpose:
To establish the effective residence times in the treatment plant and the reservoirs. A tracer study was conducted for flocculation, sedimentation and clearwell tanks.

Key Findings:
Short-circuiting of water in the sedimentation tank was observed which can compromise treatment effectiveness.

Collection troughs need to be re-aligned to minimize uneven flow distribution.

Disinfectant contact time provided by the clearwell is not adequate to meet the current disinfection guidelines of the Alberta Environment.

Treatment Implications:
Sedimentation system improvements and increased clearwell contact time are required to improve plant performance.

2.7 WATER DISTRIBUTION SYSTEM EVALUATION

Purpose:
To use a computer model to evaluate the distribution system capability.

Key Findings:
Certain areas of the water distribution system require upgrading to comply with the Fire Underwriters' Survey recommended fire flow requirements. Refer to page 8-3 of Part 2 for affected areas.

Chlorine residuals did not stay longer than 24 hours thus creating a zero chlorine zone in some parts of the distribution system.

Implications:
A more persistent residual such as chloramine is required and/or the installation of booster chlorination to ensure a residual maintenance through out the system.

2.8 EVALUATION OF pH CONTROL

Purpose:
To evaluate the corrosion potential of the treated water and to establish optimum characteristics of treated water to minimize corrosion currently experienced in the distribution system components. Computer models were used to estimate the corrosion indices and to find optimum pH to be maintained in the treated water.

Key Findings:
The computer model indicates the treated water is corrosive.

Treatment Implications:
Treated water pH should be increased to maintain a level between 8.2 and 8.5.

2.9 BENCH SCALE CHEMICAL OPTIMIZATION STUDY

Purpose:
To conduct jar tests to optimize chemical use and assess means of enhancing coagulation.

Key Findings:
Jar tests using low intensity mixing yielded inferior water quality in comparison to jar tests employing high intensity mixing.

The existing static mixer and the hydraulic flocculators do not provide adequate mixing of coagulant.

Alum/polymer combination performed equally or better than more expensive polyaluminum salts under high intensity mixing conditions.

A weighting agent (diatomaceous earth) improved the settleability of the flocs.

Treatment Implications:
A flash mixer in the raw water line and mechanical slow mixers in the flocculators are needed to improve chemical coagulation.

2.10 ONLINE PARTICLE COUNTING AND TURBIDITY MONITORING

Purpose:
To characterize the particle sizes and turbidity in the treated water for process monitoring and control. Filtration is often the final physical barrier to waterborne pathogens. By maintaining particle counts and turbidity of the filtered water below specified levels, the treatment process may provide effective barrier to pathogens such as *Giardia* and *Cryptosporidium*. Particle counts are better indicator than turbidity in describing the efficiency of the treatment plant performance and more useful for plant performance optimization.

Key Findings:
Higher than normal particle counts were found in the filtered water.

Large particle count and turbidity spikes are observed during filter ripening after a backwash.

Higher spikes were observed during initial start-up in mornings.

Treated water particle counts are higher (300 to 1000 particles per mL) than the recommended limit of 50 particles per mL.

Filtered water contained some zooplankton and unicellular bacteria but not algae. No *Giardia* and *Cryptosporidium* cysts were "found" (< 2.4 cysts/100 L) in the treated water.

Treatment Implications:
Particle counts in the treated water may be minimized by improving the mixing, coagulation, sedimentation and filtration processes.

Filter-to-waste piping is required to discard the poor quality initial filtrate during filter ripening.

An air scour system should be provided to improve backwash and enhance overall filter performance (i.e. minimize particle counts and turbidity levels) to meet AEP guideline requirements.

Adjust filter control weir to keep media submerged during filter shutdown.

TREATMENT SCHEME OPTIONS

SECTION 3

3.1 DESIGN CRITERIA

3.1.1 Future Treatment Capacity Requirements

Table 3.1 presents the projected treatment capacity requirements for the next 25 years based on:

- current service population of 7133
- linear population growth rate of 145 per year
- water consumption of 375 L/person/day
- peak factor of 1.75
- in-plant losses of 5%
- 233 L/s fire flow for a duration of 3 hours
- daily plant operations of 22 hours/day.

Table 3.1
Future Treatment Capacity Requirements

Component	Existing	2000	2005	2010	2020	2025
Treatment Plant, L/s	123	62.1	67.1	73.4	86.0	92.3
Storage (Fire, equalization and emergency), m^3	4797	4088	4216	4375	4695	4855
Storage (chlorine[1] CT), m^3	257	1658	1699	1859	2178	2338
Storage (chloramine[1] CT), m^3	257	6501	7030	7691	9013	9673

1 based on 3.0 mg/l chloramine or 1.0 mg/L chlorine residual, t_{10}/T ratio of 0.5, at a pH of 8.5, temperature of 4°C, and for a disinfection credit of 2.5-log of *Giardia* cysts. This storage does not include the hill top reservoir for CT purposes.

3.1.2 Treatment Objectives

It is recommended that future improvements be designed to meet or exceed the 1997 Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage System and the latest edition of the "Guidelines for Canadian Drinking Water Quality". Parameters of specific interest are as follows:

Parameter	Relevance
Turbidity	• water clarity indicator • indirect, rough indicator of treatment barrier provided against *Giardia* and crytosporidium
Organics	• contributes to taste and odour • contributes to THM's
Algae	• contributes to taste and odour • contributes to THM's • impacts filter performance
Colour	• unsightly • indicator of organic content and of DBP precursors
Taste and Odour	• objectionable to consumers
THM's	• health concerns
DBP Precautions	• health concerns
CT	• indicator of disinfectant effectiveness for water pathogens such as *Giardia* and *Cryptosporidium*

It is also recommended that plant improvements be implemented to permit installation of UV if required in the future to provide additional *Giardia* and *Cryptosporidium* removal capability. Recent research indicates UV irradiation as a viable option for *Cryptosporidium* oocysts inactivation. UV could be incorporated at the post filtration stage to address *Cryptosporidium* issues.

3.2 UNIT PROCESS OPTIONS EVALUATION

Table 3.1 summarizes the treatment processes reviewed and their anticipated ability to meet the treatment objectives based on the findings of pilot testing and bench scale work.

Table 3.1
Rating of Processes For Slave Lake Water Treatment

Objective	Process Rating*				
	Alum Coagulation	Ozone	GAC	Free Chlorination	Chloramination
Taste and Odour	G	VG	VG	-	-
Organic removal	G	P	VG	-	-
Algae removal	G	G	P	-	-
Turbidity removal	G	NR	NR	-	-
Colour removal	G	VG	VG	-	-
DBP precursor removal	G	P	VG	-	-
DBP removal	P	P	VG	-	-
DBP formation	G	P	VG	P	VG
Disinfectant demand	P		VG	-	-
Disinfectant residual stability	-	NR	VG	F	VG
Disinfection CT requirement - *Giardia*	-	VG	-	F	P
Disinfection CT requirement - *Crypto*	-	F	-	NR	NR

** VG = Very Good; G=Good; F=Fair; P; Poor; NR=Not Recommended*

3.3 TREATMENT SCHEME OPTIONS

Figure 3.1 illustrates four treatment scheme options. A description of each option is provided below:

3.3.1 Option 1 - CT Storage Expansion for Chlorine Disinfection

Option 1 involves:

- Installation of new PAC system to reduce DBP precursors to provide some taste and odour reduction and to act as weighting agent.

- Construction of new 9600 m^3 reservoir designed to achieve *Giardia* CT requirements via chloramination.

- Installation of an ammonia feed system to enable chloramination to be practiced. Switching from chlorination to chloramination has the potential for providing a longer lasting and less objectionable residual in the distribution system.

- Making provision for installation of a UV disinfection systems in the future to address more stringent *Cryptosporidium* CT requirements in the future.

The benefit of this system is that very little in-plant construction would be required. The drawback is the high O&M costs that would be incurred for PAC use which would not be as effective as GAC. The additional drawback is extent of land required for construction of a new reservoir.

3.3.2 GAC Filters & CT Storage Expansion for Chlorine Disinfection

Option 2 involves:

- Construction of new GAC filters to reduce taste and odour, DBP precursors and chlorine demand.

- Construction of a new 2900 m^3 reservoir designed to achieve *Giardia* CT requirements via chlorination. The residual would be converted to chloramines before entering the distribution system.

- Installation of an ammonia feed system to enable post-chloramination to be practiced.

- Making provision for installation of a UV disinfection systems in the future to address more stringent *Cryptosporidium* CT requirements in the future.

The benefit of this system is that stringent *Giardia*, THM and future *Cryptosporidium* treatment levels are expected to be achieved with this treatment scheme. The drawback is that new GAC filters would need to be constructed and the Town would incur higher O&M costs as a result of using GAC. The O&M however is expected to be more favourable than that incurred for the Option 1 treatment scheme.

3.3.3 Option 3 - Pre Ozonation and GAC Filtration

Option 3 involves:

- Construction of a pre-ozonation facility near the low-lift pump station to reduce color, taste and odours and provide an effective barrier against *Giardia*.

- Construction of a new GAC filter to absorb ozonation by-products, reduce DBP precursors and reduce taste and odour.

- Making provision for installation of a UV disinfection systems in the future to address more stringent *Cryptosporidium* CT requirements in the future.

The benefit of this option is that stringent standards would be achievable with this treatment scheme. This option also has the potential of providing the best tasting water as a result of both ozone and GAC treatment. One drawback is the higher O&M associated with the ozonation facility and GAC contactors.

3.3.4 Option 4 - Membrane Treatment - Conversion of Filters to GAC

Option 4 includes:

- Retrofitting the existing cross flow clarifiers to accept membrane manholes.
- Converting the existing filters into GAC contactors.

The principal benefits of this option are:

- The ability to achieve stringent *Giardia* and *Cryptosporidium* log removal without increased chemical additions.
- The ability to further increase plant capacity without constructing new tankage.
- That the upgrade involves retrofitting and not replacement of existing tankage. Hence, use of existing infrastructure is maximized.
- The possibility for longer GAC life than what would be achieved using dual media filtration upstream of the GAC contactors.

The principal drawback is the cost of membranes. It is typically necessary to replace membranes every 5 to 7 years. While the costs were high in the past, dramatic price reductions have been observed over the last 5 years. Further reductions are expected over the next 5 years. The competition and demand is simply driving the price lower.

The removal of microfiltration and ultrafiltration membranes in comparison to conventional filtration is presented in Appendix A.

Table 3.3 compares expected performance of the alternatives in terms of achieving the required treatment objectives.

Table 3.3
Process Capability Comparison of Options

Objective	Option 1 Chloramine CT Storage	Option 2 GAC +Chlorine CT Storage	Option 3 Ozone/GAC	Option 4 Membrane/GAC
Taste & Odour Removal	F	VG	VG	VG
Organic Removal	F	VG	VG	VG
Algae Removal	F	F	G	VG
Turbidity Removal	G	G	G	VG
Colour Removal	G	VG	VG	VG
DBP precursor removal	P	VG	VG	VG
DBP removal	P	VG	VG	VG
DBP formation	VG	VG	VG	VG
Disinfectant demand	P	VG	VG	VG
Disinfectant residual stability	VG	G	G	G
Disinfection CT requirement - *Giardia*	G	G	VG	VG
Disinfection CT requirement - *Crypto*	P	P	F	G

** VG = Very Good; G=Good; F=Fair; P; Poor; NR=Not Recommended*

A membrane pilot study would be required by AEP as part of the approval process before this type of system could be installed. Costs of a membrane based treatment system in comparison to the conventional based treatment system are provided in the next subsection.

COSTS

SECTION 4

4.1 CAPITAL COSTS

Table 4.1 presents preliminary cost estimates for the treatment scheme options. The lowest capital cost options are Option 2 and Option 4. A government grant of 40% is expected for Slave Lake based on the current population of 7100.

4.2 PRESENT WORTH COSTS

Table 4.2 shows the present worth costs for the four options using an interest rate of 8%.

Appendix B shows the O & M costs of components of various scenarios.

IMPLEMENTATION OPTIONS

SECTION 5

For the purpose of comparison, several different implementation scenarios were considered based on assumed viewpoints from different stakeholders (Figure 5.1).

Implementation Scenario No. 1 is based on the assumption that Alberta Environment would want the plant to meet the more stringent turbidity and CT requirements as soon as possible. The focus under this scenario is achieving CT compliance first before doing anything else.

Implementation Scenario No. 2 is based on the assumption that the most important issue to the public is improved taste and odour and that the improvement dollars should be targeted towards making this a reality as soon as possible. The focus is on improving the taste and reducing the DBPs first before doing anything else.

Implementation Scenario No. 3 is a plan designed to address assumed Alberta Environment requirements and public needs while minimizing unnecessary expenditures. The focus under this scenario is on assessing the viability of membranes as soon as possible prior to making a decision on GAC. If the long term plan is to install membranes, there is no point constructing new GAC filters in the short term. The existing filters would be converted to GAC contractors making construction of new tankage unnecessary.

Scenario #3 (membrane based system) is deemed worthy of serious evaluation since it holds the potential for:

- Providing consistent treated water quality under highly varying raw water quality conditions.
- Free operators time to attend to other system duties. Since removal is accomplished via the straining action through ultra fine pores less attention needs to be paid to chemical feed optimization (eg. assessing the best polymer coagulant combinations).
- Minimizing chemical costs.
- Providing superior *Cryptosporidium* and *Giardia* removals.
- Extending the useful life of GAC (in comparison to the life span of GAC if installed downstream of the dual media filters).
- Extending the useful life of the existing treatment plant. Since increased capacity is achieved by simply adding additional treatment modules, the system is easy to expand. It is possible to install treatment modules in the existing sedimentation basins that have the capability of providing 2.5 times greater capacity than the

existing cross flow clarifiers. The attractive feature is that no additional clarifier tankage needs to be constructed to increase the capacity.

While the potential exists for achieving the above, it is critical the pilot testing be conducted to confirm the performance of membranes when dealing with the Slave Lake water.

SECTION 6

RECOMMENDATIONS

6.1 CAPITAL IMPROVEMENTS

Capital improvements to the water treatment plant should be undertaken to ensure the treated water quality produced complies with treatment targets set forth in the 1997 Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage System.

6.2 IMPROVEMENTS

Improvements be phased-in based on the Implementation Plan presented in Table 6.1 and Figure 6.1.

6.2.1

The membrane based system is worth a serious consideration since it holds the potential for:

- Providing consistent treated water quality under highly varying raw water quality conditions.
- Free operators time to attend to other system duties. Since removal is accomplished via the straining action through ultra fine pores less attention needs to be paid to chemical feed optimization (eg. assuming the best polymer coagulant combinations).
- Minimizing chemical costs.
- Providing superior *Cryptosporidium* and *Giardia* removals.
- Extending the useful life of GAC (in comparison to the life span of GAC if installed after the dual media filter).
- Extending the useful life of the existing treatment plant. Since increased capacity is achieved by simply adding additional treatment modules in the existing sedimentation basins that have the capability of providing 2.5 times greater capacity than the existing cross flow clarifiers. The attractive feature is that no additional clarifier tankage needs to be constructed to increase the capacity.

While the potential exists for achieving the above, it is critical the pilot testing be conducted to confirm the performance of membranes when dealing with the Slave Lake water and re-assess requirements based on those findings.

CLOSURE

SECTION 7

This report was prepared for the Town of Slave Lake based on the results obtained from bench scale testing, pilot testing and input from Town personnel.

The services provided by Associated Engineering Alberta Ltd. in the preparation of this report were conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions. No other warranty expressed or implied is made.

Respectfully submitted,

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SEPARATION PROCESSES COMPARISON

APPENDIX A

TECHNICAL MEMORANDUM

TOWN OF SLAVE LAKE

Water Treatment Improvements

Part 2

March
2000

For tables, figures and appendices please refer to hard copy located in file number 2001-3981-5.2.

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PREFACE

SECTION 1

The Town of Slave Lake reported taste and odor concerns and high chlorine dose requirements to maintain an adequate residual in the water leaving from the reservoir system. Corrosion in the water treatment plant has also been of concern to the Town. The treatment plant has also had difficulty achieving the turbidity removal targets set forth by the Alberta Environmental Protection.

Associated Engineering conducted a preliminary review of the water treatment plant in December 1997 and identified the need for water quality improvements. The town requested Associated Engineering in 1998 to conduct follow-up pilot and bench scale tests to help define upgrade requirements. Key pilot study findings and recommendations are presented in the executive summary (Part 1).

This report provides a description of the work undertaken and the findings related to the following:

- Raw Water Quality Evaluation
- Disinfection By-product Evaluation
- Giardia and Cryptosporidium Evaluation
- Pilot Evaluation of Pretreatment by Ozone
- Granular Activated Carbon Pilot Study
- In-plant and Reservoir Tracer Study
- Water Distribution System Evaluation
- Evaluation of pH Control
- Bench-scale Chemical Optimization Study
- On-line Particle Counting and Turbidity Monitoring
- Future requirements of water treatment

RAW WATER CHARACTERISTICS

SECTION 2

The focus of this task was to identify and categorize recognizable trends in the historical raw water quality data and to establish treatment objectives.

2.1 PHYSICAL & CHEMICAL QUALITY

Appendix A contains detailed water quality analysis of the raw water. A summary of selected raw water parameters that characterize Lesser Slave Lake quality are shown in Table 2.1

Table 2-1

Raw Water Quality

Parameter	Range	Guidelines*
Turbidity	2 - 10 NTU	0.1 NTU
True Colour	10 to 30 tcu	15 tcu
pH	8.0 - 8.5	6.5 - 8.5
Total Alkalinity	60 - 100 mg/L	-
Total Hardness	< 100 mg/L	-
Iron	< 0.3 mg/L	0.3 mg/L
Manganese	< 0.05 mg/L	0.05 mg/L
Bromide	< 0.01 mg/L	0.010 mg/L
Chlorophyll	3.4 mg/m^3 (during algal bloom)	-
Total Organic Carbon	10 to 15 mg/L	-
Dissolved Organic Carbon	10 to 14 mg/L	-
Odour	Slightly fishy during ice spring run-off musty and peaty during algal blooms	-

* Canadian Guidelines for Drinking Water Quality (1996)

2.2 ALGAE & ZOOPLANKTON FINDINGS

Raw water collected during an algal bloom contained high concentrations of the chrysophyte *Synura* sp. (400 cfu/mL), diotoms *Asterionella* sp. (300 cfu/mL), and *stephanodiscus* sp. (100 cfu/mL). Both *Synura* sp. & *Asterionella* sp. are known to create taste and odour. *Stephanodiscus* sp. & *Asterionella* sp. are known to block filter media. Other difficult to remove species *Anabaena* (blue-green algae) and filamentous green algae were also found. *Frageliara crotonensis*, a diatom with extremely hard silica dominated shells were found in very high quantities (1000 cfu/mL). High counts of filamentous bacteria were also found (700 cfu/mL). Algae evaluation details are presented in Appendix B.

Rotifers (0.1 to 1 mm long) and copepods (0.02 to 0.4 mm long) dominated the zooplankton species found. The dominance of species may very well change seasonally. Table 2.2 shows the zooplankton data on June 5, 1999 for the raw and treated water.

Table 2-2

Zooplankton Data

Type	Genus	Stage	Length (mm)	Raw Water	Filter 1A
Rotifers	*Keratella cochlearis*		0.165	98	121
	Keratella earlinae		0.243	2	0
	Keratella hiemalis		0.256	14	2
	Keratella quadrata		0.347	2	1
	Kllicottia longispina		0.769	1	0
	Nothoca labis		0.192	11	19
Copepods	Cyclopoida *sp.*	Nauplius larvae	0.141	6	1
		Nauplius	0.020	5	1
		Copepodid 1-3		0	0
		Copepodid 4-6		0	0

Type	**Genus**	**Stage**	**Length (mm)**	**Raw Water**	**Filter 1A**
Copepods	Calanoida *sp.*	Nauplius larvae	0.146	2	1
		Nauplius		0	0
		Copepodid 1-3		0	0
		Copepodid 4-6		0	0
	Harpacticoida *sp.*	Nauplius larvae	0.150	0	5
		Nauplius	0.233	0	3
		Copepodid 1-3	0.362	0	2
		Copepodid 4-6		0	0

2.3 TREATMENT TARGET IMPLICATIONS

Based on the raw water quality data, we recommend that treatment be targeted to address the following parameters:

- Organics
- Turbidity
- Colour
- Taste and Odour
- Algae (Chlorophyll)
- Zooplankton

DISINFECTANT BY-PRODUCT EVALUATION

SECTION 3

Work was undertaken to identify and categorize the formation and reduction of harmful disinfectant by-products (DBPs) under different treatment regimes.

3.1 DBP FORMATION & REMOVAL

Table 3.1 summarizes the DBP formation and subsequent reduction by various processes. Appendix C includes the detailed results of DBP (THM, aldehydes and Haloacetic acids).

Table 3-1

DBP Formation and Reduction

DBP (mg/L)	Ozone	Ozone + Alum	Ozone + Alum + GAC [1]	Plant treated	Limits [2]
Bromate	<0.01	<0.01	<0.01	-	0.01
Aldehydes, Total	0.195	0.127	0.081	-	-
Formaldehyde	0.046	0.048	0.023	-	0.900
Haloacetic acid (HAA) 7-day	0.137	0.280 [3]	0.018	0.133	0.06
Total Trihalomethanes (TTHM), 3-day	0.087	0.058	0.045	0.118	0.08

1 GAC sample was collected ahead of contact time to simulate near exhaustion conditions.

2 USEPA Stage 1 DBP rule except to formaldehyde (WHO standards)

3 High due to lowered pH by alum addition. Expected to be lower than 0.137 if pH is increased after coagulation.

3.2 THM FORMATION POTENTIAL RESULTS

THM Formation potential testing yielded the following results:

- Alum coagulated water - 0.068 mg/L
- GAC Treated Water - 0.004 mg/L
- Plant Treated Water (By chloramination) - 0.026 mg/L

3.3 SIMULATED DISTRIBUTION SYSTEM (SDS) FOR DBP FORMATION

The formation potential test for THM uses super-chlorination to assure its reaction with all available organics. SDS is recommended to obtain realistic formation of DBPs under plant operating conditions using plant's chlorine dose. Ultimate DBP formation is measured after free chlorine becomes zero (no further reaction possible).

An SDS test was conducted using a chlorine dose of 5 mg/L. DBPs were measured after 3.5 days and 5.5 days if free chlorine existed after 3.5 days. Results are presented in Table 3.2 and Figure 3.1.

Figure 3.1 suggests that use of GAC can result in a more stable and persistant residual. The data also suggests that lower chlorine dosages (i.e. less than 5 angle) could be applied to address disinfection needs if a GAC process was in place.

3.4 SUMMARY

The present treatment system did not produce water meeting the DBP guidelines. Ozonation by-products were within the guidelines. GAC provided excellent removals of DBP precursors and therefore produced lesser DBPs. Employment of chloramination holds great promise for greatly reducing formation of DBPs.

GIARDIA & CRYPTOSPORIDIUM EVALUATION

SECTION 4

Testing was conducted to quantify the existence of waterborne pathogens such as *Giardia* and *Cryptosporidium* in Lesser Slave Lake and determine the required degree of disinfection according to the AEP guidelines.

4.1 RESULTS

The sampling program is on-going and the results will be refined as more data becomes available preliminary findings are presented below: Microscopic analysis results are presented in Appendix D.

Raw water *Giardia*	<100 cysts /100 L
Raw water *Cryptosporidium*	100 oocysts /100 L

Treated water *Giardia*	<2.4 cysts /100 L
Treated water *Cryptosporidium*	<2.4 oocysts /100 L

4.2 SUMMARY

4.2.1 *Giardia* Inactivation Requirements

Based on the raw water giardia concentration, a total of 5 log removals must be achieved through a combination of physical removal and disinfection. Assuming a 2.5 log removal credit is granted for Giardia by conventional treatment, a 2.5 log removal needs to be achieved by disinfection. The CT (disinfectant residual concentration x effective contact time t_{10}) values required to achieve 2.5-log inactivation of Giardia cysts are presented in Table 4.1.

Table 4-1

CT Requirements for Selected Disinfectants for 2.5-log Giardia Inactivation

Disinfectant	CT required at 4 °C	Maximum Residual Disinfectant Level (MRDL)
Free Chlorine*	222 min.mg/L	4.0 mg/L*
Chloramine	2165 min.mg/L	3.0 mg/L
Ozone	1.8 min.mg/L	-
Chlorine Dioxide	30 min.mg/L	0.3 mg/L

** at pH = 8.0, residual concentration = 2.0 mg/L is used instead of MRDL of 4.0 mg/L due to taste and odour concerns..*

4.2.2 *Cryptosporidium* Inactivation Requirements

The Enhanced Surface Water Treatment Rule (USEPA) requires 2-log inactivation/removal of cryptosporidium oocysts based on the raw water concentration of oocysts. This could be achieved by maintaining filtered water turbidity below 0.3 NTU at 95% of the time and below 1 NTU all the time.

Based on a published research (not yet approved as guideline) for 2-log inactivation of a tough Iowa strain of cryptosporidium, a CT of 38.1 min.mg/L is required for ozone at 4 degree C temperature. This may require high residual ozone concentrations and long contact times that could deter ozone as a viable disinfection process for cryptosporidium. However, partial inactivation may be accomplished at low CT values.

Latest research indicate the viability of UV disinfection for cryptosporidium inactivation.

OZONATION PILOT STUDY

SECTION 5

A pilot plant study was commissioned to establish the optimum dose and contact time for ozonation of the raw and clarified water for color, taste and odor reduction.

Details of ozonation pilot study results are presented in Part 3 of the Technical Memorandum.

GAC FILTRATION PILOT STUDY

SECTION 6

This task involved establishment of design criteria and assessment of activated carbon for supplementary color, taste and odor reduction of the ozonated and non-ozonated water.

6.1 PILOT PLANT

A pilot filtration column containing GAC filter media was installed to treat the ozonated, ozone-quenched and sand -filtered water. The pilot plant was operated at a loading rate of (6 $m^3/m^2/h$) - Empty bed contact time EBCT (25 minutes).

6.2 GAC PERFORMANCE

Table 6.1 summarizes the GAC performance. Details of test results are shown in Appendix E.

Table 6.1
Performance Summary - GAC

Parameter	**Performance**	**Comment**
TOC	Good removal. However, ozone normally increases the biodegradability of organics that could trigger biological growth it not removed.	GAC filtration is necessary to reduce organics and to remove biodegradable carbon through biological activity on the media surface.
True colour	Good	Improved ozonated water.
Odour	Not tested	Expected to adsorb most of the odour causing compounds.
Chlorine Demand	Lowest	Provided at better stability of chlorine residuals, May reduce the present chlorine dose of 5 mg/L by 50%.

Parameter	**Performance**	**Comment**
DBP precursor removal	Excellent and the lowest among tested.	GAC filtration provides better precursor and ozonation by-product removals. The results may be further improved by chloramination instead of chlorination

TRACER STUDY

SECTION 7

The residence time distribution of the treatment process components such as flocculation basins, sedimentation tanks and the contact time available for the disinfection process before the treated water reaches the first consumer was assessed under this task.

7.1 TRACER STUDY PROCEDURE

A known quantity of sodium chlorine solution was injected as slug dose at the influent and the outgoing concentration measured at various time intervals at several locations in the sedimentation tank. For the clearwell assessment, the fluoride feed was stopped and the fluoride decay in the water leaving the clearwell was recorded.

An assessment of the Hilltop Reservoir was not conducted since it does not provide any additional CT. If water flowed from the plant clearwell directly into the Hilltop Reservoir and then to consumer (which is not the case) additional disinfection credit would be available.

7.2 TRACER STUDY FINDINGS

Table 7.1 summarizes the results of the tracer study. Tracer curves are presented in Appendix F.

Table 7.1
Tracer Study Results

Characteristics	Clearwell	Floc tank #2	Sedimentation Basin #2			
			Basin Outlet	South Weir	North Weir	
				Middle	Middle	End
Flow, m^3/min (L/s)	4.8 (80)	1.65 (27.5)	1.65 (27.5)	-	-	-
Cumulative Results (measured from Floc tank entrance)						
t_{10}, min	-	18	191	180	195	189
t_{50}, min	-	33	331	224	331	241
t_{90}, min	-	73	610	335	607	368
Volume, m^3	-	70	792	-	-	-
Average T, min	-	42	480	-	-	-
t_{10}/T ratio	-	0.43	0.39	-	-	-
Individual Results (measured/estimated for each process component)						
t_{10}, min	16	18	173	162	177	171
Volume, m^3	112	70	722	-	-	-
Average T, min	23.3	42	438	-	-	-
t_{10}/T ratio	0.68	0.43	0.39	-	-	-

7.3 SUMMARY

The t_{10}/T ratio for the flocculation basins, sedimentation tank and the clearwell are 0.43, 0.39 and 0.68, respectively.

Short-circuiting of flow was seen in the south weir of the clarifier #2 (t_{10} is 15 minutes earlier than that of the north weir).

At the plant capacity flow rate of 123 L/s, the clearwell will provide 10.5 minutes of disinfectant contact time.

The clearwell contact time is inadequate; the chlorine disinfection CT requirement is not satisfied with the existing system and chlorination regime.

TREATED WATER DISTRIBUTION SYSTEM EVALUATION

SECTION 8

For the purpose of this study, the 1989 Area Structure Plan prepared by Associated Engineering Alberta Ltd., design criteria is adopted. The following is an extract from the 1989 report:

- Peak Day = 1.8 x average day
- Peak Year = 1.5 x peak day (2.7 x average day).

8.1 PROJECTED FUTURE WATER CONSUMPTION

The future water consumption used in this report for the preliminary design of waterworks components is 450 L/c/d (100 igpcd).

In the analysis of preliminary design of the waterworks system the following population densities were used:

- Residential — 36 ppha (15 ppac)
- Commercial and Light Industrial — 25 eqppha (10 eqppac)

8.2 FIRE FLOWS

Fire flow rates and duration of fire flows are in accordance with the 1981 Guide to Recommended Practice for water Supply and Public Fire Protection of the Fire Underwriter Survey.

The fire flow rates and duration of the fire used in this report are:

- Residential Area — 76 L/s (1,000 igpm)
- Institutional Area — 114 L/s (1,500 igpm)
- Multi-Family Area — 167 L/s (2,200 igpm)
- Commercial Area — 200 L/s (2,600 igpm)
- Industrial Area — 233 L/s (3,100 igpm)

Duration of fire in hours are:

Fire Flow Rates	Duration in Hours
167 L/s (2,200 igpm) or less	2.0
220 L/s (2,600 igpm)	2.5
233 Ll/s (3,100 igpm)	3.0

8.3 EXISTING WATER DISTRIBUTION SYSTEM

The water distribution system is modeled using Cybernet, an AutoCAD add-in program that calculates pressure network using the built-in numerical

KYPIPE2 computational algorithms.

The Town's existing water distribution system is entered in the Cybernet program. The pipes are connected using nodes. Node's property includes its elevation and consumption demand.

The pipe diameter, length/pipe material and roughness coefficient are also entered to the model.

The following Roughness coefficient © value) is used:

- Cast Iron (C.I.) = 110
- Ductile Iron (D.I.) = 120
- Asbestos Cement (A.C.) = 110
- Plastic (PVC) = 130
- Poly (P.E.) = 135

The C value used in case is taken from other models having the same material and approximately about the same age.

The model was run to depict the normal daily operation of the Town's water distribution system. From the plant's record, the pump at the water treatment plant (WTP), one pump runs from 8:30 a.m. to about 5:00 p.m. The water elevation at the remote reservoir during pump start is 635.00 m, which is 78% full. The pump supplies the Town's consumption and also to fill the reservoir. It shuts down when the reservoir level reaches 92% full, which will be at around 5:00 p.m.

By using the Extended Period Simulation (EPS), the model was calibrated to behave and match the existing operating conditions over a 48 hour window. Based on the model, the average day consumption is lower than projected in the 1989 report. Using the fire flow demand at the specific land use areas, the model indicated several fire flow deficient areas.

The areas are (shown in Figure 8.1):

.1 Along Balsam Road N.E.; and South of Tamarack Road.
.2 At the intersection of 12th Avenue N.E. and 7th Street N.E.
.3 Industrial Site - along 10th Avenue N.W. between 3rd Street N.W and 8th Street N.W.
.4 The main supply to Woodland Place.
.5 At the intersection of 6th Avenue N.E. and 4th Street N.E. (C.J. Schuster School).
.6 At 9th Street N.E. cul-de-sac.
.7 At McBeak apartments.
.8 Along 3rd Street S.W. (west side of Sawridge Plaza).
.9 Westside of Northwest Inn.
.10 At 12th Avenue S.W. (northside of Sawridge Hotel).

The model is calibrated to have the peak hour occur at 21:00 hour (9:00 p.m.). The peak hour factor is 3.0 (the 1989 report used 1.5 times the Peak Day or 2.7 times the average day (1.8 x 1.5)).

To meet the fire flow, the Town has to initiate a watermain replacement/upgrading program. Below is the list of upgrading or improvements required (as shown in Figure 8.2):

.1 Along Balsam Road N.E. and South of Tamarack Road:
- provide a new 400 mm watermain along Main Street and Tamarack Road N.E. to connect the existing 350 mm HDPE pipe to the existing 200 mm D.I. at Balsam Road.
- replace the existing 200 mm D.I. with 300 mm diameter pipe along Balsam Road between Birch Road N.E. and 4th Street N.E.

.2 At the Intersection of 12th Avenue N.E. and 7th Street N.E.:
- upgrading the existing 250 mm diameter to 300 mm diameter along Birch Road N.E. between 3rd Street N.E. and 7th Street N.E.

.3 Industrial Site - along 10th Avenue N.W. between 3rd Street N.W. and 8th Street N.W.:
- provide a new 400 mm diameter watermain from the existing 350 mm HDPE south of airport to the northwest corner of 10th Avenue N.W. Replace the existing 150 mm diameter with 400 mm along 10th Avenue N.W. from 3rd Street N.W. to 8th Street N.W.
- replace a section of existing 150 mm diameter with 300 mm diameter on 8th Street N.W. (approximately 200 m).
- replace a section of existing 150 mm diameter with 300 mm diameter on 8th Street N.W. (approximately 160 m).

.4 The main supply to Woodland Place:
- replace the existing 150 mm diameter supply with 200 mm diameter main.

.5 At the intersection of 6th Avenue N.E. and 4th Street N.E. (C.J. Schuster School):
- replace existing 150 mm diameter main with 200 mm diameter from Main Street to 4th Street N.E.

.6 At the 9th Street N.E. Cul-de-Sac:
- install a 150 mm diameter from eastside of hospital to Cul-de-Sac.

.7 At McBeak Apartments:
- extend existing 150 mm diameter along 8th Street N.W. to connect to existing 150 mm diameter on 6th Avenue N.W. (40 m).
- replace existing 150 mm diameter along 8th Street N.W. between 2nd and 3rd Avenue N.W. with 200 mm diameter (approximately 180 m).

.8 Along 3rd Street S.W. (westside of Sawridge Plaza):
- install a 300 mm diameter under the railway tracks from 2nd Avenue N.W. to 3rd Street S.W. (approximately 200 m).
- replace existing 200 mm diameter with 300 mm diameter along 6th Avenue S.W. between Main Street and 3rd Street S.W. (approximately

220 m).

- replace existing 150 mm diameter with 300 mm diameter along 3rd Street S.W. (approximately 100 m).

.9 Westside of Northeast Inn:

- cross-connect the existing 150 mm diameter and 400 mm diameter mains.

.10 At 12th Avenue S.W. (northside of Sawridge Hotel):

- replace existing 150 mm diameter with 300 m diameter on 12th Avenue S.W. approximately 150 m long.

8.4 ULTIMATE SYSTEM

The computer model is also used to analyze the ultimate development scenario. This scenario was established in the 1989 report. The land south of Highway No. 2 would be developed. This development has plan for 243 ha of residential area; six schools with student population of 4,470 persons; 106 ha of industrial site; Neighborhood Commercial will take up 2.5 ha and 17 ha for Highway Commercial.

Due to the steep terrain south of the Highway, the report proposed to separate the system into a two zone system. This will provide a more manageable pressure to the consumers.

Part of the new development, south of Highway No. 2 will be serviced by the existing system. Other parts of the new development, further south, higher than 600 m contour elevation will be served by a completely new system, or Zone 2.

The new system will have a new reservoir on the southwest corner of the study area. A new pumping station is required to boost pressure form the reservoir. This reservoir is filled by a 300 mm supply main extended from the existing system just north of Highway No. 2.

A second pumping station is proposed at the existing remote reservoir. It will have a dedicated feedline from the reservoir to the pumphouse. Water from this reservoir will be boosted to supply Zone 2. Zone 2 system is also connected to the existing system at two locations. Each location has a pressure reducing valve to prevent Zone 1 from experiencing too much pressure.

The model was ran to simulate Peak Hour Flow using the existing pumps and a proposed system head at the pumphouses in Zone 2. All three pumps were turned on during the Peak Hour run. The proposed head at the new pumphouses was set at 600 m or 61 psi above the highest ground elevation in Zone 2.

It was found that the existing pumps were able to handle the Ultimate Peak Day demand. The proposed head at the new pumphouses would be adequate at 660 m hydraulic head. The proposed pipe diameter is shown in Figure 8.2. The pipe will be adequate to provide Peak Hour and more importantly, will be able to satisfy the fire flow demand during Peak Day (see appendix on Fire Flow report).

8.5 CHLORINE RESIDUE

Based on the model, the residual chlorine in the system is depleted before it reaches the remote reservoir. Therefore, during the off pump period (after 5:00 p.m.), the remote reservoir will be feeding zero residual chlorine back into the system.

In order to alleviate this problem, a chlorine injector can be installed at the remote reservoir. Water entering the reservoir will be dosed with chlorine.

SECTION 9

PH CONTROL

An assessment of data from 1989 to 1999 using Langlier Index (LI) calculation indicates the water to be corrosive. The LI value was calculated to be "-1.0".

Calculation indicate that the Ph should be chemically adjusted to maintain valves between 8.2 and 8.5.

BENCH SCALE TESTING

SECTION 10

This task involved optimization of the chemical type and dose in view of turbidity, organics and color removal objectives. Test results are provided in Appendix H.

10.1 JAR TEST FINDINGS

Ozonation improved the floc formation and resulted in reduced coagulant requirement.

Low-intensity mixing tests currently resulted in poor coagulation performance when compared to high-intensity mixing tests. The low mixing test run was conducted to mimic the low level mixing taking place in the plant.

Alum/polymer combination performed comparable to polyaluminum salts/polymer chemical combinations.

With proper mixing, approximately 50% TOC reduction could be achieved by coagulation alone.

Enhanced coagulation did not improve organic removals.

Powdered activated carbon did not improve organic removals significantly in the limited bench scale tests that were conducted.

Diatomaceous earth as a weighting agent increased the settleability of the flocs.

10.2 PLANT TRIAL OF ALUM

Based on the positive results achieved during Jar Testing operations staff conducted a plant trial using alum. Jar test results could not be duplicated in the plant trial due to lack of coagulant mixing in the full scale plant. Appendix H also includes the plant alum trial report prepared by the operator.

10.3 CHLORINE DEMAND

Appendix I includes the analytical results of chlorine residual demand and decay testing. The test involved dosing of four (4) different water samples with 5 mg/l of chlorine followed by determination of the free chlorine residual and decay over time.

For plant treated water, free residuals of 1.0, 0.02 and 0.0 mg/l were present after 1, 3.5 and 5.5 days, respectively. However, for the same dose, free chlorine residual readings, after 1, 3.5 and 6.5 days were 3.9, 2.4, and 1.7 mg/L for the GAC treated water.

10.4 SUMMARY

Mechanical mixing is needed to improve coagulation/flocculation and therefore, improving treated water quality and plant performance.

A weighting agent may be added to improve settleability.

GAC greatly improved the stability of chlorine residual.

ON-LINE PARTICULATE & TURBIDITY MONITORING

SECTION 11

This task involved characterization of particle sizes and turbidity in the filtered water for process monitoring and control and to assess the potential for the passage of *Giardia* cysts and *Cryptosporidium* oocysts in the filtered water. Appendix J includes particle counts and turbidity data during filter ripening and during a filter cycle. Appendix J also contains graphical representation of lack of particle count correlation with turbidity.

11.1 EQUIPMENT

One particle counter and a turbidimeter were installed in filter #1A outlet on a trial basis.

11.2 TURBIDITY

Turbidity values were in the order of 0.1 to 0.3 NTU indicating lack of compliance with AEP's filtered water turbidity guidelines.

Turbidity values increased to the order of 0.5 NTU during filter ripening (initial maturation of filter bed after backwashing)

11.3 PARTICLE COUNTS

A vast majority of the treated water particle counts were between the sizes on 2 to 10 microns. Figure 11.1 shows the particle size distribution of the filtered water.

During October 1999, likely just before the lake turn-over process at the Lesser Slave Lake, the particle counts of size greater than 2 microns were in the order of 700 - 1000 per mL.

After the Lake turn-over, the treated water particle counts dropped to the order of 300 to 400 per mL.

The treated water particle counts did not meet the AEP recommendation of less than 50 particles per mL.

11.4 FILTER PERFORMANCE

During daily plant start-up, large turbidity and particle count spikes were observed. Same spikes of lesser magnitude were observed during filter ripening.

Filter ripening periods of up to one hour were observed. Longer ripening times may have been caused by low filtration rates experienced in the filters.

High particle counts may be due to lack of pretreatment (mixing, coagulation and sedimentation.

No algae was present in the filtered water. However, large number of unicellular bacteria were observed.

RAW WATER QUALITY

APPENDIX
A

ALGAE EVALUATION

APPENDIX

B

LABORATORY RESULTS - DBP EVALUATION

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GAC FILTRATION DATA

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PARTICLE COUNT DATA

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T E C H N I C A L   M E M O R A N D U M

TOWN OF SLAVE LAKE

Water Treatment Improvements

Part 3

OZONATION PILOT STUDY

March
2000

For tables, figures and appendices please refer to hard copy located in file number 2001-3981-5.2.

TABLE OF CONTENTS

INTRODUCTION

SECTION 1

A pilot plant study was commissioned to establish the optimum dose and contact time for ozonation of the raw and clarified water for color, taste and odor reduction.

1.1 HISTORY OF OZONATION

Ozone was first used for drinking water treatment in 1893 in the Netherlands. While being used frequently in Europe for drinking water disinfection and oxidation, it was slow to transfer to North America. In 1987, the Los Angeles Aqueduct Filtration Plant was placed in service and now treats up to 2270 ML/d of drinking water. In 1991, approximately 40 water treatment plants each serving more than 10,000 people in the United States utilized ozone. This number has grown significantly to 265 operating plant in the US as of April 1998. Among those, 149 plants with a capacity below 4 ML/d are in operation.

1.2 PRIMARY USES OF OZONE

Ozone is used in drinking water treatment for a variety of purposes including:

- Disinfection;
- Inorganic pollutant oxidation, including iron, manganese and sulphide;
- Organic micro-pollutant oxidation, including colour removal, increasing biodegradability of organic compounds, DBP precursor control and reduction of chlorine demand.
- Coagulation and filtration improvement

1.3 IMPACT OF OZONE ON OTHER TREATMENT PROCESSES

The impacts include the following:

- The use of ozone generates biodegradable organic matter that can result in biological growth which may also increase corrosion rates in the distribution systems if not removed by biologically active filtration (typically by granular activated carbon or slow sand filters).

- Ozone is a strong oxidant that reacts with other oxidants such as chlorine.

- Ozone oxidation of iron and manganese generates insoluble oxides that should be removed by sedimentation and filtration.

- Using pre-ozonation on some raw waters reduces the subsequent chlorine demand of the finished waters.

- Ozone does not provide a stable disinfectant residual and therefore ozonation must be supplemented by use of stable disinfectants such as chlorine or chloramine before leaving the water treatment plant to meet the disinfectant residual requirements in the treated water distribution system

OZONATION PILOT PLANT

SECTION 2

2.1 PILOT PLANT

A pilot ozonation system was installed in the water treatment plant. The pilot system included one ozone generator and one ozone contactor. The set up is illustrated in Figure 1.

The pilot plant was operated during the months beginning April 1999 to August 1999. This period included the spring run-off (high colour, taste and odour in the raw water), warm raw water during summer, algal bloom season and the fall turn-over of the Lesser Slave Lake.

Ozone doses up to 10 mg/L and three contact times (5, 10 and 30 minutes) were assessed in the pilot testing runs. Ozone feed gas concentration, dissolved ozone residual in the ozonated water and the ozone decay were measured regularly. Color, Total Organic Carbon (TOC), chlorophyll (algae), reduction were evaluated at various dose-contact time combinations.

SUMMARY OF RESULTS

SECTION 3

Following sections describe the findings of the ozonation pilot study.

3.1 RAW WATER QUALITY

An overview of typical raw water quality from Lesser Slave Lake is summarized in Table 3.1

Table 3.1
Raw Water Quality

Parameter	Range	Guidelines*
Turbidity	2 - 10 NTU	0.1 NTU
True Colour	10 to 30 tcu	15 tcu
pH	8.0 - 8.5	6.5 - 8.5
Total Alkalinity	60 - 100 mg/L	-
Total Hardness	< 100 mg/L	-
Iron	< 0.3 mg/L	0.3 mg/L
Manganese	< 0.05 mg/L	0.05 mg/L
Bromide	< 0.01 mg/L	0.010 mg/L
Chlorophyll	3.4 mg/m^3 (during algal bloom)	-
Total Organic Carbon	10 to 15 mg/L	-
Dissolved Organic Carbon	10 to 14 mg/L	-
Odour	Slightly fishy during ice spring run-off musty and peaty during algal blooms	-

* Canadian Guidelines for Drinking Water Quality (1996)

3.2 COLOUR REMOVAL

A summary of colour removal data is presented in Appendix A. Excellent colour removals during spring run-off season and good colour removals in other seasons are achieved by ozonation. Figure A-1 (Appendix A) suggests that no correlation between ozone operating parameters and true colour removals.

3.3 ODOUR REMOVAL

A summary of odour reduction data is presented in Appendix B. Excellent odour removals during spring run-off season are achieved by ozonation. Odour removal performance of ozone was found to be better than coagulation/sedimentation process.

3.4 ORGANIC REMOVAL

A summary of colour removal data is presented in Appendix C. Poor organic removals are evident throughout the study period. Figure C-1 (Appendix C) reveals no correlation between ozone operating parameters and organic removals.

3.5 EFFECTS OF GRANULAR ACTIVATED CARBON (GAC) FILTRATION

A biologically active GAC filter would be required to prevent the biodegradable organic matter created by ozone from entering the distribution system. GAC filtration of the ozonated water provided excellent removal of organics (Figure D-1) and further reduced colour (Figure D-2). Those charts are included in Appendix D.

3.6 EFFECTS ON CHLORINE DEMAND

Table E-1 (Appendix E) contains chlorine demand due to various treatment combination including ozone, alum coagulation, GAC filtration and compares with the existing water treatment plant's performance. Only GAC filtration provided substantial reduction of chlorine demand due to its efficiency in organics removal. Ozonation did not provide significant reduction of chlorine demand.

3.7 DISINFECTANT BY-PRODUCT (DBP) REMOVAL

Table 3.2 summarizes the DBP formation and subsequent reduction by various processes.

Table 3.2
DBP Formation & Reduction

DBP (mg/L)	Ozone	Ozone + Alum	Ozone + Alum + GAC [1]	Plant treated	Limits [2]
Bromate	<0.01	<0.01	<0.01	-	0.01
Aldehydes, Total	0.195	0.127	0.081	-	-
Formaldehyde	0.046	0.048	0.023	-	0.900
Haloacetic acid (HAA) 7-day	0.137	0.280 [3]	0.018	0.133	0.06
Total Trihalomethanes (TTHM), 3-day	0.087	0.058	0.045	0.118	0.08

1 GAC sample was collected ahead of contact time to simulate near exhaustion conditions.

2 USEPA Stage 1 DBP rule except to formaldehyde (WHO standards)

3 High due to lowered pH by alum addition. Expected to be lower than 0.137 if pH is increased after coagulation.

Ozonation by-products were within the guidelines. GAC provided excellent removals of DBP precursors and therefore produced less DBPs. Using chloramines instead of chlorine for disinfection could greatly reduce the formation of harmful DBPs.

3.8 ALGAE INACTIVATION

Raw water collected during algal bloom contained high concentrations of the chrysophyte *Synura* sp. (400 cfu/mL), and diotoms *Asterionella* sp. (300 cfu/mL), and *stephanodiscus* sp. (100 cfu/mL). Both *Synura* sp. & *Asterionella* sp. are known to create taste and odour. *Stephanodiscus* sp. & *Asterionella* sp. are known to block filter media. Other difficult to remove species *Anabaena* (blue-green algae) and filamentous green algae were also detected. *Frageliara crotonensis*, diatom with extremely hard silica dominated shells are also noted in very high quantities (1000 cfu/mL).

Ozonation effectively removed chlorophyll contents of the algal species found in the raw water. Plate 1 shows the effects of ozonation on algae.

3.9 OZONATION EFFECTS ON COAGULATION

Appendix F shows the results from Jar tests of raw and ozonated water. Ozonated water coagulation resulted in better floc formation that resulted in faster settling and better quality than raw water coagulation.

3.10 PERFORMANCE SUMMARY

Table 1 shows the performance summary of ozonation.

Table 1
Performance Summary - Ozone

Parameter	Performance	Comment
TOC	Very poor removal. However, ozone normally increase the biodegradability of organics that could trigger biological growth if not removed.	GAC filtration is necessary to reduce organics and to remove biodegradable carbon through biological activity on the media surface.
True colour	Excellent removals during spring run-off and good removals otherwise.	
Odour	Excellent removal of fishy, musty and peaty odors during spring run-off and high algal bloom seasons.	Slightly better than coagulation in odour removal.
Turbidity	None	Normally not expected
Dose/Contact time	10 minutes contact time & 10 mg/L dose were required.	
Residual Ozone Decay	10 to 20 minutes	Decay tank is required. Chemical quenching is also possible.

Parameter	**Performance**	**Comment**
CT for *Giardia* cysts	above dose/contact time provides up to 15 time more CT than required by ozone.	This is important as the existing reservoir system is not capable of providing CT by chlorination or even by post-ozonation due to smaller clearwell.
CT for *Cryptosporidium* oocysts.	May provide some degree of inactivation.	No guidelines are available.
Algae /Chlorophyll	Good algae removal evident by microscopical examination - removal of chlorophyll and destruction of algal cells that are known to cause taste and odour.	No algae was seen also in the plant treated water.
DBP precursor removal	Not effective.	GAC filtration provides better precursor and ozonation by-product removals.

KEY FINDINGS

SECTION 4

Following is a summary of key findings from the ozonation pilot study.

- Ozone provided good removals of colour, taste and odour. Ozone also effectively oxidized algal cells.
- Ozone did not provide effective organic removal and therefore DBP formation potential was high.
- Ozone improved the coagulation/flocculation process and improved sedimentation process.
- GAC filtration process is required to follow ozonation which also adds many benefits to the treatment.
- Ozone provides an effective barrier against Giardia cysts which is otherwise not provided by the current free chlorination practice.

COLOUR REDUCTION BY OZONE

APPENDIX
A

ODOUR REDUCTION BY OZONE

APPENDIX
B

ORGANIC REDUCTION BY OZONE

APPENDIX C

GRANULAR ACTIVATED CARBON FILTRATION EFFECTS

APPENDIX D

CHLORINE DEMAND

APPENDIX
E

EFFECTS OF OZONE ON COAGULATION

APPENDIX

F