BROCKVILLE

CITY OF THE 1000 ISLANDS

BROCKVILLE WATER POLLUTION CONTROL CENTRE UPGRADE

CLASS ENVIRONMENTAL
ASSESSMENT REPORT

Technical Memorandum No. 6
Evaluation of Effluent Disinfection Strategies

Prepared By:

Simcoe
SIMCOE ENGINEERING GROUP LIMITED
Consulting Engineers

in association with

Hydromantis, Inc.
Consulting Engineers

161.03
January 2005

Technical Memorandum No. 6: Evaluation of Effluent Disinfection Strategies

1. Introduction

The City of Brockville is proceeding to complete a Class Environmental Assessment to assess alternative solutions for a proposed Brockville Water Pollution Control Plant (WPCC) Upgrade.

The upgrade works, as a minimum, are to provide the current “normal” level of treatment prescribed by the Ministry of Environment (MOE), which is considered as being secondary treatment or equal and consistent with the Provincial Guideline F-5.

This Technical Memorandum (TM#6) has been prepared to evaluate the available effluent disinfection process options, including a review of economic, performance and other factors impacting the selection decision. An evaluation criteria matrix was developed for scoring the short listed disinfection processes.

2. Background

The plant currently uses liquid sodium hypochlorite for disinfection of primary effluent. The system consists of two (2) heat traced and insulated fiberglass tanks each with a capacity of 22.5 m^3 and two (2) variable speed reciprocating metering pumps each with a capacity of 3.13 L/min. The current chlorine contact chamber has a volume of 465 m^3 with a length to width ratio of 16:1.

3. Effluent Disinfection Options

3.1. Processes

Although all effluent disinfection options could be implemented at the Brockville plant, some processes may be better suited than others. This section provides a general discussion of the specific benefits and limitations of each process. The processes considered for evaluation for the Brockville WPCC Upgrade include:

1. Chlorination
2. Ozonation
3. Chlorine Dioxide
4. Bromine Chloride
5. Ultraviolet Radiation

3.2. Summary of Advantages and Disadvantages

A comparison of the advantages and limitations for the listed effluent disinfection technologies are summarized in **Table 1**.

TABLE 1:
Advantages and Disadvantages of the Main Wastewater Disinfection Methods

Method	Advantages	Disadvantages
1) Chlorination	• Equipment and mixing requirements well understood • Low capital and moderate operating cost • Common process • Effluent chorine residual can be eliminated by dechlorinating	• Process not completely understood, i.e. impacts with pH and wastewater quality • Effluent toxicity possible if no dechlorination • Chlorine gas is hazardous to store and sodium hypochlorite is expensive for large facilities
2) Ozonation	• Normally no toxic residual persists in plant effluent • Does not increase total dissolved solids levels of the liquid • Un reactive with ammonia at pH levels below 9 • Does not notably affect disinfection efficiencies at pH ranges 6 to 10 and temperatures ranging from 2 to 30'C • No toxic chemical stored on or hauled to site although ozone is a respiratory toxicant	• Higher capital and operational costs than chlorine • Competitive oxidant demands of certain industrial wastes may render ozone disinfection uneconomical • Pilot plant testing required to determine dosages • Design and operational familiarity has resulted in less than optimal first generation systems • Ozone is a respiratory toxicant
3) Chlorine Dioxide	• Does not react in aqueous solution to produce detectable trihalomethane concentrations • A more rapid disinfecting agent than chlorine • Dose requirements similar to chlorine on a mass basis	• Roughly an order-of-magnitude more expensive than chlorine, based on high cost of sodium chlorite • Must be generated onsite
4) Bromine Chloride	• Bromines are better disinfectants than the analogous chlorine species • NH_2BR dissipates much more rapidly when the disinfected effluent is released to the receiving water so there is much less residual toxicity to fish • Equipment requirements similar to chlorination	• Somewhat more expensive than chlorine although within the range of being competitive to the use of alternative methods such as ozone, and chlorination/dechlorination • Hazardous to handle
5) Ultraviolet Radiation	• No toxic residual in effluent wastewater • Compact design, minimal contact time required • Simple operation	• Reliability has been a problem in the past at some sites • More expensive than chlorine, but comparable with chlorination/dechlorination • Disinfection can be compromised if effluent conditions and/or quartz sleeve fouling reduce effective UV light intensity

The main reason for considering alternative methods to chlorination is the environmental impact of releasing chlorine. Wastewater was first disinfected because of concern for human health and little concern was given at that time to the potential effects of chlorine on fish and other aquatic organisms. Recent research has shown that certain compounds may be formed during disinfection with chlorine that may be harmful [WPCF (1984) Wastewater Disinfection]. Therefore, in many areas other methods of disinfection are being considered and if chlorination is used dechlorination is being included. The Canadian Environmental Protection Act, 1999 (CEPA 1999) gives the Minister of the Environment the authority to require the preparation and implementation of pollution prevention plans (P2 plans) for CEPA-toxic substances. CEPA makes it clear that toxic substances will include ammonia and chlorine. Hence non-toxic disinfection processes are being evaluated for the Brockville WPCC.

The Brockville WPCC currently uses sodium hypochlorite for disinfection year round. The two main options that would result in a non-toxic effluent are:

- Chlorination/Dechlorination
- UV Disinfection

Because non-toxic effluent is an objective at the Brockville WPCC, only these two options will be considered further. The other disinfection options are not carried forward as short listed disinfection processes as they are either considered cost prohibitive or not generally used in wastewater applications, or both.

3.3. Technical Review of Short Listed Processes

Chlorination/Dechlorination

Sodium hypochlorite chlorination produces HOCl similar to gas chlorination and NaOH which tends to increase water pH. It is available in a chlorine solution of 12% and can be adversely affected by light, heat, low pH, and high metal concentration. Even under the most favourable storage conditions, it will over time degrade and lose its disinfectant strength. Typically, there is a loss of 10% in available chlorine per month. The best storage conditions are relatively low sodium hypochlorite concentration; low iron, copper, and nickel concentration; cool and dark storage; and buffering to pH 11, which tends to form OCl, but this will revert upon addition to the wastewater stream. Because sodium hypochlorite is already in use at the plant to treat the effluent, the storage and feed portion of this disinfection system is known and can remain intact with the exception the existing chlorine contact chamber. Due to the addition of secondary clarifiers and associated hydraulic gradelines the chlorine contact chamber must be relocated and reconstructed.

The current chlorination system consists of two (2) metering pumps (3.13 L/min) and two (2) 22,500L storage tanks. **Table 2** below displays the number of days of storage for the average design flow of 21.8 MLD at 12% solution and 8.5 % solution assuming a dosage rate of 8 mg/L. At peak design flow, the storage time would reduce to 40% of the indicated value.

TABLE 2:
Storage Times & Injection Rates for Sodium Hypochlorite Dose of 8 mg/L

Strength of NaOCl Solution (%)	Available Chlorine Concentration (g/L)	Injection Rate (L/hr) based on Peak Design Flow of 54.5 MLD	Storage Time (days) for 45,000L at Average Design Flow of 21.8 MLD
12	120	151	31
8.5	85	214	22

Wastewater effluent residual chlorine, consisting of chlorine dose remaining after reaction with demand components, can be problematic due to its potentially toxic effect on aquatic life. Sewage plant outfalls typically are designed with diffusers to disperse effluent residuals across the receiving water column to the greatest extent possible to minimize the mixing zone. The mixing zone as defined in the Provincial Water Quality Objectives is "an area of water contiguous to a point source or definable diffuse source where the water quality does not comply with one or more of the Provincial Water Quality Objectives". Therefore, a well designed outfall that minimizes the mixing zone will mitigate the negative impact of toxins (i.e., chlorine, ammonia) and other undesirable constituents on the environment. MOE policy with respect to chlorine is the virtual elimination of its release to the environment. Although, this policy has previously been applied with varying discretion in approving upgrades to existing sewage treatment plants, the MOE has indicated a design objective of 0.02 mg/L for total residual chlorine, and the likely requirement for lethality testing (i.e. non-toxic plant effluent) as being appropriate for the Brockville WPCC upgrade.

Therefore, it is recommended the evaluation for sodium hypochlorite disinfection analysis include effluent dechlorination prior to discharge to the receiver to reduce the potential toxic effect of an elevated chlorine residual in the effluent. Ultimately, it is believed that a non-toxic effluent will be required at the Brockville WPCC and this is outlined under CEPA as part of the P2 plans required for municipal plant.

Dechlorination uses a reducing agent to decrease the amount of chlorine in the effluent waste stream. Although the reaction occurs almost instantaneously, adequate mixing should be provided to ensure complete reaction. Common reducing agents for dechlorination include sulphur dioxide, activated carbon, sodium bisulphite, and sodium metabisulphite.

For the Brockville analysis, liquid sodium bisulphite ($NaHSO_3$) was selected as the reducing agent for dechlorination of the plant effluent. Generally the strength of a sodium bisulphite solution is between 38% to 40%, and can be stored in containers constructed of stainless steel, PVC or fibreglass reinforced plastic. For every 1 mg/L of chlorine residual to be removed, a minimum of 1.5 mg/L of sodium bisulphite is required. To determine the amount of sodium bisulphite required for the plant, a ratio of 1.5 mg/L of sodium bisulphite was applied assuming there would be no more than 1 mg/L of chlorine residual at a peak design flow of 54.5 MLD. Therefore, the system would require 6.65 L/hr of sodium bisulphite. Sodium bisulphite tends to be stable under normal temperatures; therefore it can be stored for a longer period of time compared to sodium hypochlorite. Based on the average design flow, two 2,000 L storage tanks will provide 62 days of storage. These storage tanks would require the construction of a containment area, and it is assumed the existing chemical storage building can house them.

UV Disinfection

Ultraviolet (UV) light is electromagnetic energy with wavelengths ranging from 100 to 400 nm. This energy spectrum lies between X-rays and visible light. The UV energy spectrum can be divided into four ranges:

- Vacuum UV (100 – 200 nm)
- UV-C (200 – 280 nm)
- UV-B (280 – 315 nm)
- UV-A (315 – 400 nm)

UV light, in relatively low doses, is effective on bacteria, viruses, and protozoa. UV light between 200 nm and 300 nm has a germicidal effect. The optimum germicidal UV range is between 250 and 270 nm. UV light inactivates microorganisms by causing photochemical damage to their nucleic acids (DNA and RNA) making them unable to reproduce. Mercury vapour lamps submerged in an open channel produce the UV light. As wastewater flows past the UV lamps, microorganisms are exposed to a lethal dose of UV energy. The dose is a product of UV light intensity and exposure time.

The major benefits of UV disinfection are that it is environmentally safe, producing no harmful disinfection by-products, and by virtue of replacing chlorine as a disinfectant, eliminates chlorine toxicity in the mixing zone. Although, recent research indicates that in water treatment plants there is a potential for a photoreactivation of organisms, as DNA damage is repaired with exposure to sunlight following UV irradiation; this is not considered a significant concern for sewage treatment plants. This phenomenon has been shown to decrease with higher initial UV dosage.

As a result of the above referenced advantages, UV light has gained popularity for disinfection of wastewater effluent over the past 10 years in Canada as well as throughout North America and Europe. In the U.S., UV installations have increased from about 50 smaller plants prior to 1986 to over 1,000 operating systems by 2000. In Europe, when disinfection is considered for a new installation or upgrade, UV is the most frequently used technology.

Ultraviolet light is produced in wastewater disinfection systems by mercury vapour lamps. Three main types of lamps are available that are characterized by both their operating pressure and their output level: low pressure/low intensity lamps (LP/LI), low pressure/high intensity lamps (LP/HI), and medium pressure/high intensity lamps (MP/HI). Conventional low pressure, low intensity UV lamps produce essentially monochromatic radiation at 253.7 nm. The advantage of high intensity lamps is increased UV output resulting in a lower number of bulbs being required.

Medium pressure lamps produce a wider wavelength than low intensity lamps; however, there is no more output from the medium pressure bulb in the 254 nm range, the most effective disinfection wavelength. The primary benefit of medium pressure systems are the greatly reduced number of lamps that are required. As a broad guideline, or rule of thumb, these systems are not practical for use at wastewater treatment plants having average flow rates less than 30 MLD - 40 MLD because equipment components are more expensive, power consumption is higher, and bulb life is shorter. Also, they operate at very high temperatures, requiring special cooling features, and require self-cleaning lamps to ensure the quartz sleeves do not foul.

UV treatment applications are well suited to, but need not be confined to tertiary effluent only. UV disinfection is used at a number of secondary treatment plants in Ontario, such as Windsor, London and Collingwood among others. When UV disinfection is considered at secondary treatment plants producing effluent at the upper range of the permitted effluent parameters, system sizing and layout is critical. Two banks in series will increase the detention time and chance for kill. In addition, most equipment manufacturers will add more bulbs for a safety factor to their warranted performance to account for times of poor effluent quality.

Recent advances in options offered by manufacturers of UV treatment systems include variable output electronic ballasts to match power output to effluent flow, and well as self cleaning lamps. Electronic ballasts, as opposed to electromagnetic ballasts, are now standard. Also, most low pressure UV lamps are non-proprietary, and have an effective useful life of more than10,000 hours in operation, and the cost of medium pressure lamps are now similar to the cost of low pressure lamps.

The effectiveness of UV disinfection depends on both the contact time and the intensity of the UV light. Contact times for UV disinfection of secondary wastewater effluent range from 5 to 14 seconds. CT for UV light is calculated based on the product of light intensity and time

$$\textit{Intensity } (W/m^2) \times \textit{time}(s) = J/m^2 = 10^3 \; mWs/cm^2$$

At Brockville WPCC, a low pressure/high intensity UV treatment system is recommended. A representative low pressure/high intensity UV system selection, and quotation was obtained from a supplier's application quotation.

The representative equipment selection includes a total of 160 lamps in a two bank open channel in-series configuration. The UV system control centre would be located in an outdoor panel (or building if required for secondary clarifier design). A new channel would be made to accommodate the low pressure/high intensity system. The two existing sodium hypochlorite metering pumps would remain to provide operational flexibility to continue with chlorine injection.

4. Other Considerations

4.1. Standby Power

Consideration of the power requirements associated with the proposed chlorination/dechlorination equipment is fundamental for determining the in-plant electrical needs. Depending on the final electrical demand, the electrical power distribution system within the plant may need to be upgraded. For this reason, the power requirements of each disinfection alternative were determined for potential future implementation. However, a detailed analysis of the existing in-plant electrical distribution system was not completed to determine if other power distribution system upgrades would be required.

Currently, the Brockville WPCC has a 50 kW Diesel Generator. This unit may require upgrading to provide backup for the future secondary processes. Therefore at this point the cost associated is not calculated but the energy requirements of each system must be considered at the time which a generator is selected for the site.

Chlorination. The electrical requirements of sodium hypochlorination with sodium bisulphite dechlorination includes two (2) sodium hypochlorite dosing pumps (existing), two (2) sodium bisulphite dosing pumps, two (2) level sensors, one (1) mechanical mixer, and two (2) residual chlorine analyzers. The total power requirement for the equipment is approximately 4 kW with an average power consumption of 2 kW. This option uses the least amount of energy and, consequently, there is a negligible associated incremental cost for standby power.

UV Disinfection. The electrical demand of a UV disinfection system was determined based on a low pressure/ high intensity design of 160 lamps having a total power draw of 40 kW, and an average power draw of 20 kW.

5. Conceptual Layouts of Effluent Disinfection Alternatives

5.1. Chlorination/Dechlorination

The Brockville wastewater pollution control centre (plant) is already equipped with a Sodium Hypochlorite injection system, of which many components could be reused. It is assumed that the storage tanks and metering pumps are in good functioning order and that they could be continued to be used. However the existing chlorine contact chamber is placed to receive effluent from the primary clarifiers and its location is not ideal for future secondary processes.

Also the chlorine contact chamber is slightly undersized to provide the recommended hydraulic retention time of 15 minutes at peak flow.

A new chlorine contact chamber would be required. This chamber would have a volume of 600 m^3 and a length to width ratio of 40 or more to provide sufficient hydraulic retention times. Provision for a mechanical mixer to aid in the injection of sodium bisulphite has been included.

Two (2) 2,000 L sodium bisulphite storage are needed for dechlorination, which would provide the plant with 62 days of storage based on average design flow. The sodium bisulphite tanks would be heat traced and located in a containment area.

5.2. Ultra Violet (UV)

A low pressure/high intensity UV system will provide the optimum arrangement for the Brockville WPCC. This choice provides a durable and proven system. The UV system comes complete with automatic chemical self-cleaning technology.

A new channel is required to hold the UV system. This channel would be of concrete construction and the channel volume required for the UV lamp installation would be approximately 15m^3. Our preferred system would include dual channels to allow redundancy. This option should be further explored in the pre and detailed design phase.

6. Preliminary Costing

6.1. Chlorination/Dechlorination

Capital Cost

Costing for sodium hypochlorite chlorination followed by dechlorination includes a combination of existing and new equipment and systems. The two (2) existing chlorination metering pumps provide sufficient feed rate capacity for disinfection under peak design conditions. In addition, two chlorine analysers; and one duty and one standby dechlorination metering pump would be provided. Storage tanks are required for chemical storage. 45,000 L of sodium hypochlorite storage is currently available which provides 31 days of storage for average design flow conditions. These tanks are located in a containment area within the chemical storage building, and heat traced.

Two (2) new 2,000 L sodium bisulphite storage tanks would provide the plant with 62 days of storage based on average design flow. The sodium bisulphite tanks would be heat traced and located in the area where the sodium hypochlorite tanks are currently being stored.

A new chlorine contact chamber with a volume of 600 m^3 and a mechanical mixer to aid in the injection of sodium bisulphite has been included in the costing.

It is not expected that an upgrade to the existing genset would be required for this system. Costing for electrical, I & C and SCADA programming upgrades were provided.

The total capital cost for this option was estimated to be $518,720.

Operational Cost

Annual operational cost was determined based on an annual supply of 198,925 L of sodium hypochlorite, an annual supply of 57,390 L of sodium bisulphite, power consumption, equipment repair and replacement, and labour.

Equipment repair and replacement was derived from approximately 5% of the equipment cost and the average power consumption was estimated at 2 kW. Labour costs were estimated based on 397 total hours including process controls, basin cleaning, and delivery of chemicals at a rate of $22/hr.

Therefore, the annual operating cost for chlorination/dechlorination was estimated to be $63,420.

6.2. Ultra Violet (UV)

Capital Cost

A low pressure/high intensity system was reviewed. A representative supplier quotation was received to support the equipment cost estimates (see Appendix A).

A new UV channel would be required to house the UV system. A channel approximately 9 m in length, 1.1 m wide and 1.6 m deep would be required to house the quoted UV system equipment.

The total capital cost for this option was estimated to be $988,220.

Operational Cost

UV annual operational cost was estimated based on power consumption, replacement and repair and labour, and back-up sodium hypochlorite supply.

The total average power consumption used to determine power cost was 16 kW.

Annual replacement items include sodium hypochlorite drums ordered on an as-need basis (assumed to be two 300 kg drums), and 58 lamp bulbs for the UV system. Lamp replacement is based on 12,000 hour guaranteed lamp life and 8,760 hour operation per year for 50% of the lamps. Periodic replacement of ballasts, wipers, and quartz sleeves were also accounted for in the operations and maintenance costing. Total time used for estimating labour cost was 250 hours per year.

The total annual operating cost for this alternative was estimated to be $34,820.

7. Life Cycle Cost Summary

A direct comparison of capital cost, annual operating cost, life cycle cost and unit cost of disinfection are outlined in **Table 3** for each disinfection alternative. Capital costs were estimated with a 10% contingency, 35% construction cost allowances.

Life cycle costing was established assuming an interest rate of 6% and an inflation rate of 2.5% over a period of 20 years to calculate the capital and annual operating costs.

The comparative unit cost of disinfection was determined from the life cycle cost divided by the average design flow to generate a dollar per cubic meter cost.

TABLE 3:
Capital, Annual Operating and Life Cycle Costs

Disinfection System	Capital Cost	Annual Operating Cost	Life Cycle Cost	ADF Unit Cost ($ per m^3)
Chlorination/ Dechlorination	$518,720	$63,420	$1,451,464	$66.58
Ultra Violet (UV)	$988,220	$34,820	$1,500,290	$68.82

8. Evaluate Alternatives

The above sections contributed to the evaluation criteria used to compare the two alternatives. A comparative evaluation matrix, **Table 4 and 5** were developed in order to rank the alternatives. This table displays the two alternatives ranked against the various evaluation criteria. Each of the alternatives were evaluated from 1 to 3 for each evaluation criteria. These scores were then weighted according to **Table 4** and a total weighted score was obtained.

TABLE 4:
Evaluation Matrix for the Brockville WPCC Disinfection

Factor	Weight (1,2,3)	Relative Score			Factor Score (Weight Score)
		1	2	3	
Ability to treat peak:					30
Flows	5	Difficult	Modest	Easy	
Loading (incl. shock)	5	Difficult	Modest	Easy	
Capital cost	15	High	Medium	Low	45

Ongoing Expenses Maintenance Staff requirements/costs Operations (excl. staff)	 5 5 5	 High High High	 Medium Medium Medium	 Low Low Low	45
Disinfection bi-products	5	Excessive	Some	Minimal	15
Health and safety concerns	5	High	Medium	Low	15
Common / Proven application and experience of technology	3	Not Common	Modest	Common	9
System complexity	3	High	Modest	Low	9
System flexibility	3	Low	Modest	High	9
Ability to achieve consistent non-toxic effluent	3	Lower	Medium	Higher	9
Contact time	3	High	Medium	Low	9
Operator expertise requirements	1	High	Medium	Low	3
Modular design/expansion potential	1	Poor	Medium	Excellent	3
TOTAL SCORE FOR ALTERNATIVE					201 (100%)

Table 5:
Scoring of Disinfection Process Options for Brockville

Factor	Score	
	Chlorination / Dechlorination	Ultra Violet (UV)
Ability to treat peak: Flows Loading (incl. shock)	 3 3	 3 2
Capital cost	3	2
Ongoing Expenses Maintenance Staff requirements/costs Operations (excl. staff)	 3 2 1	 3 2 3
Disinfection by products	2	3
Health and safety concerns	1	3
Common / Proven application and experience of technology	3	2
System complexity	3	2
System flexibility	3	2
Ability to achieve consistent non-toxic effluent	3	3
Contact time	1	3
Operator expertise requirements	3	3
Modular design/expansion potential	3	3
TOTAL WEIGHTED SCORE:	**165**	**167**

Based on all of the above evaluation criteria receiving equal weighting, either UV or Chlorination/Dechlorination would be acceptable alternatives for the Brockville WPCC.

9. Conclusions

The trend in the municipal industry, in response to the changing regulatory environment, is toward eliminating chlorine toxicity in wastewater treatment plant effluent. Therefore, this report has reviewed two disinfection options that have been used in Ontario to meet a non-toxic effluent objective. Both of these alternatives produce an effluent having no chlorine toxicity impacts on receiving water aquatic life. They consist of:

- Chlorination / Dechlorination
- Ultra violet (UV) Irradiation

The Brockville WPCC currently uses sodium hypochlorite for wastewater disinfection. The most cost effective approach for upgrading the disinfection system would be to modify the existing system. This would be accomplished by adding chemically assisted dechlorination (by sodium bisulphite or sulphur dioxide). This alternative is the basis for comparison to the other disinfection alternative of UV irradiation.

Based on the total weighted score presented in **Table 5,** Scoring of Disinfection Process Options for Brockville, both UV and chlorination/dechlorination are equally ranked for implementation at Brockville WPCC. Chlorination/dechlorination requires significantly less capital expenditures, and less energy requirements. On this basis the chemical disinfection option is considered more cost effective. Another consideration of the chlorination/dechlorination option, is that it can provide disinfection during episodes of higher effluent suspended solids, as by design may occur during a secondary bypass.

Ultra violet disinfection is also considered a perfectly viable option. The difference in estimated life cycle cost between the two options is minimal, and the UV system provides lower operation and maintenance costs as well as fewer health and safety and effluent concerns.

Therefore, either of these two alternatives would be acceptable for the Brockville WPCC and both should be carried forward to the design phase of the project.