Challenges in Implementing Enhanced Disinfection: Negotiating Operational Flexibility for the City of Guelph's Upgraded Water Supply System

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ABSTRACT

The City of Guelph operates an integrated urban water supply system with water supplied from both groundwater and groundwater under the direct influence of surface water with effective in-situ filtration (GUDI WEF) sources. The regulating authority mandated that enhanced disinfection be provided for the GUDI WEF sources. The configuration of one of these sources, the Glen Collector system, does not allow it to be isolated; therefore, there is a constant inflow of GUDI WEF water into the treatment facility. This becomes a concern in terms of defining fail-safe operation. Loss of the UV unit process may occur in several scenarios. In each of these scenarios, the UV equipment could be offline for a variable period of time depending on the type of lamps used and the cause of the emergency. Through negotiations with the regulating authority, appropriate fail-safes were designed to permit a flexible operating license to be granted.

KEYWORDS

UV Disinfection, Ground Water Under the Direct Influence of Surface Water, Natural (in-situ) Filtration, Contingency Planning, Source Water Protection

INTRODUCTION

The City of Guelph is located in Southern Ontario and services a population of approximately 125,000 people. The City operates an integrated urban water supply system with water supplied from 20 operating groundwater wells, and a spring collector system (the Glen Collector) that is seasonally recharged from a surface water source.

The regulating authority mandated that the City of Guelph provide enhanced disinfection for the Glen Collector and Carter Wells water supply, after they were characterized as groundwater under the direct influence of surface water with effective in-situ filtration (GUDI WEF). These sources, blended with four other groundwater wells, deliver approximately 60% of the water supply for the City.

The Glen Collector configuration does not allow it to be isolated; therefore, there is a constant inflow of GUDI WEF water into the treatment facility. This becomes a concern in terms of defining fail-safe operation, while still providing operational flexibility. Loss of the UV unit process may occur in several scenarios such as a voltage sag or instantaneous power failure, switchover from normal to standby power or a building flood. In each of these scenarios, the UV equipment could be offline for a variable period of time depending on the type of lamps used and the cause of the emergency.

Through negotiations with the regulating authority, appropriate fail-safes were designed that along with documented response procedures, permit a flexible Certificate of Approval (operating license) to be granted. A key aspect of the negotiation has been the allowance of more operational flexibility in exchange for the development of software that tracks pathogen removal and inactivation credits on-line, and displays and stores this information in SCADA.

DESCRIPTION OF THE SYSTEM

The F.M. Woods Pumping Station is the main water treatment facility for the City and treats approximately 60% of the City's water. The facility receives water from two sources, the Arkell Spring Ground and the Carter wells. Each well field is described briefly below:

Arkell Spring Ground

The Arkell Spring Grounds is located on 350 ha of land owned by the City of Guelph within the Township of Puslinch. The existing water system at the site consists of several water sources. There are four groundwater wells (Arkell Wells Nos. 1, 6, 7 & 8) and one shallow groundwater collection system, the Glen Collector System (see Figure 1). This system collects shallow groundwater from the overburden through a series of small diameter perforated collector pipes. Finally, an Artificial Recharge System serves to enhance the shallow groundwater flow through pumping water from the nearby Eramosa River. During high flows, water is pumped from the river through a 30 cm diameter transmission main, a distance of approximately 900 m to the Recharge Pit. From the pit, the water is released into an infiltration trench where it then recharges into the overburden aquifer. It is estimated that the Glen Collector System captures approximately 50% of this recharge flow and the remainder is recycled naturally back into the Eramosa River.

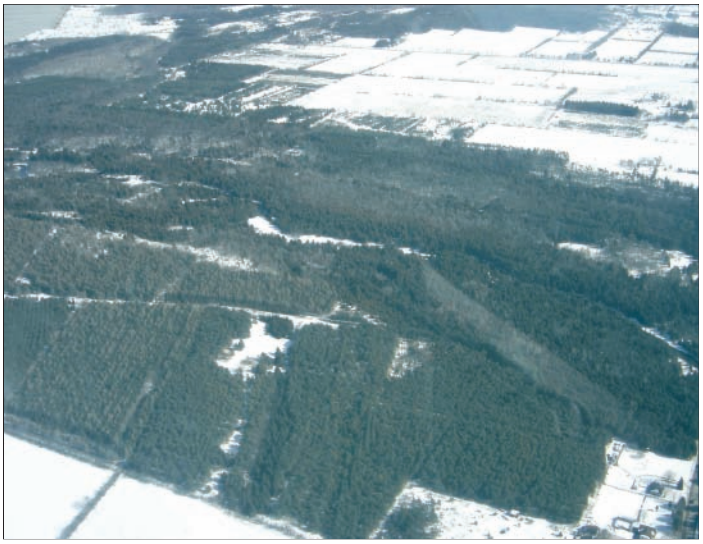

Figure 1 ***An aerial view of the protected source. South is to the top of the photo and the protected land is the forested land to the south of the Eramosa River. The North Side of the River is protected forest owned by the local conservation authority.***

The water is collected from these sources where it flows via a 900 mm diameter, concrete pipe gravity flow aqueduct known as the Lower Road Aqueduct to an underground reservoir at the Scout Camp Station. From there it continues via gravity through a 1050 mm diameter reinforced concrete gasketed pressure pipe water main to F.M. Woods Pumping Station where it is chlorinated and pumped into the distribution system.

Carter Well Supplies

The Carter well supplies are also located within the Township of Puslinch. The site consists of two bedrock groundwater wells which discharge to a common outlet through which water is pumped to Scout Camp. At this point the water combines with the water from the Arkell Spring Ground and continues to the F.M. Woods Pumping Station.

F.M. Woods Pumping Station

All of the water sources mentioned above are currently treated at the F.M. Woods Pumping Station located in the City of Guelph. The facility has a firm capacity of 1,061 L/s and houses treatment, storage and control facilities. There are three underground reservoirs of approximately 14,000 m^3, 9000 m^3 and 9000 m^3 respectively. A sodium hypochlorite disinfection system feeds into the reservoir inlet line providing primary disinfection (Figure 2). Five high-lift vertical turbine pumps draw water from the reservoirs and discharge into the distribution system (see Figure 3).

Figure 2. *A photo of the site prior to construction.*

Figure 3. *The highlift pumping station.*

Source Water Characterization and Design Flows

A source water characterization study was completed in July 2002 and identified several water sources at these sites as GUDI with effective in-situ filtration. Table 1 below summarizes the source water characterization for each source and the MOE permitted capacity as specified in the corresponding Permits to Take Water.

Table 1: Source Water Classifications and Design Flows

Water Source	Source Water Classification	Existing Permitted Capacity (MLD)	Potential[1] Future Permitted Capacity (MLD)
Arkell Well 1	GUDI with effective in-situ filtration	3.3	3.3
Arkell Well 6	Groundwater	6.5	28.2 from any four of five wells
Arkell Well 7	Groundwater	6.5	
Arkell Well 8	Groundwater	6.5	
Carter Wells 1 & 2	GUDI with effective in-situ filtration	7.9	7.9
Arkell Collection Systems	GUDI with effective in-situ filtration	25.0	25.0
Totals	Arkell GUDI with effective in-situ filtration	28.3	28.3
	Arkell Groundwater	19.5	28.2
	Carter GUDI with effective in-situ filtration	7.9	7.9
Grand Total	All Sources	55.7	64.4

1. Pending EA and PTTW Approvals for Two Additional Wells

Disinfection Requirements

Within the ODWR (2006) regulations, they outline the disinfection requirements for drinking water in the province. ODWR (2006) states that for water sources designated as GUDI with effective in-situ filtration, the disinfection processes must achieve a minimum of 2-log inactivation of Cryptosporidium oocysts, 3-log inactivation of Giardia cysts, and 4-log inactivation of viruses. It is widely accepted that the most cost-effective treatment technology to provide this level of inactivation is via ultraviolet (UV) irradiation.

To meet these disinfection levels, the Procedure requires a two-stage primary disinfection process consisting of UV light at a target UV dose of 40 mJ/cm^2 followed by chemical disinfection. The document is not clear on what level of chemical disinfection need be provided. In the Procedure, the requirement for groundwater primary disinfection is indicated as 2-log virus inactivation. The Procedure also indicates that a UV dose of 40 mJ/cm^2 is sufficient for groundwater primary disinfection. A reasonable person would assume, therefore, that the Province's interpretation is that 40 mJ/cm^2 is sufficient to achieve 2-log inactivation of viruses.

Current Treatment Provided

Currently, disinfection at the F.M. Woods Station consists of chlorination only. Until the UV disinfection is installed, the City is required to operate in accordance with the interim treatment measures currently outlined in the station's Certificate of Approval (CofA). The interim measures outlined in the CofA are as follows:

1. maintain a target free chlorine residual of at least 0.85 mg/L in the treated water entering the distribution system;
2. provide for the activation of a centralized alarm when the free chlorine residual in water entering the distribution system is below 0.6 mg/L.
3. provide continuous monitoring of free chlorine residual and turbidity in the treated water entering the distribution system; and,
4. provide continuous monitoring of the level of water in the respective reservoirs.

The main feature of these interim treatment measures is that a target chlorine residual be maintained. The residual target level is based on studies conducted to achieve 3-log Giardia and 4 log virus removal. Removals depend on maximum flow (greater of inflow or outflow) and normal retention time (reservoirs at 70% full), water temperature and normal decay rate. With these parameters, 0.85 mg/L is required to achieve 3-log Giardia inactivation and 4-log virus inactivation is relatively simple to achieve.

The Source Water Characterization completed in July 2002 describes a variety of hydrogeological investigations and modeling tools used to assess the efficacy of the natural in-situ filtration occurring through the subsurface for several of the GUDI supplies. A variety of water quality analyzers including microscopic particulate analysis (MPA) and a conservative approach to evaluating levels of natural filtration were employed. A summary of the results of this study is shown in Table 2 below. This table distinguishes the log removals provided by natural in-situ filtration, chlorine disinfection currently in place at the station and with the addition of the UV equipment for each of the three pathogens of concern

Table 2: Summary of Existing Treatment Provided

Pathogen	Removal & Inactivation Requirement	Removal achieved by natural in-situ filtration	Inactivation achieved by Chlorine Disinfection[a]	Inactivation achieved by UV Disinfection[b]
Cryptosporidium	2.0 log	> 3.0 log for all sources except Carter Carter: > 2.0 log	0 log	2.0 to 3.0 log
Giardia	3.0 log	> 3.0 log for all sources except Carter Carter: > 2.0 log	> 3.0 log	2.0 to 3.0 log
Viruses	4.0 log	0 log	> 4.0 log	Variable

a. Under interim operating conditions imposed by the current CofA. This is routinely monitored using the City's on-line CT Calculator tool.

b. Dependent on the UV dose applied.

As shown in Table 2, the log removals indicated for the naturally occurring filtration are more than that usually afforded to man-made filtration, which are in the order of 2 to 3-log Giardia removal and none for Cryptosporidium.

Also of note is that the removal/inactivation credits required by the provincial drinking water standards can be achieved without the addition of the UV disinfection. The Province does not, however, recognize a quantified natural filtration treatment credit at this time.

The inactivation values shown for chlorine disinfection are determined using the CT tables and chlorine concentrations at levels mandated by the interim operating measures. The City has been operating under these interim treatment measures for the past three years, since these measures became a condition of their C of A. During this time, there are water sources classified as GUDI with effective in-situ filtration entering the station and subsequently, the distribution system. Over the course of these three years the City has not experienced any adverse water quality events. It is critical to note the UV system is being installed to meet the current regulations even though the high levels of the natural filtration in incoming waters makes UV treatment unnecessary to meet the level of treatment prescribed in the Provincial drinking water standards.

The Woods Station currently provides the majority of water for the City of Guelph and thus, is the most critical water supply in the City. Since it came into operation, the in-flow to the facility has rarely been shut-down and then not for a duration of more than 4 hours. The supply and demand balance is such that prolonged stoppage or diversion is unfeasible. This is coupled with the fact that the age and current configuration of the system is such that it is impossible to isolate all incoming flows. Parts of the system, including the GUDI WEF source water from the Glen Collector System, are currently lacking the valving necessary for isolation, and the consequences of isolating the system are unknown. Therefore, there is a constant incoming flow of GUDI WEF source water into the station. Although this source water is of very high quality, to meet the current regulations, in the event that the UV system is offline, every effort must be given to ensure a continuous supply of properly treated water.

CONTINGENCY PLANNING

A contingency plan was developed to ensure safe water is provided in the event of a UV system failure. The plan identified a listing of emergency scenarios that could result in the loss of the UV equipment, the frequency with which they are likely to happen and formulated plans to provide appropriate treatment in the event of any of the scenarios. The emergency scenarios identified included a UV reactor failure, power failure or voltage sag, mercury leak, UV building flood (the building is located partially within the floodplain and the UV equipment is in the basement to provide for the ongoing gravity operation of the system), and a catastrophic failure resulting in the total loss of the UV building and all equipment and processes within it.

The plan then identified existing, designed and future contingency provisions that could be used to ensure proper treatment was provided in the event of a UV system failure. The existing provisions included use of the interim treatment measures. As noted previously, the facility has been operating under these conditions for several years without any adverse water quality incidents. Reinstatement of the interim treatment measures during an extended UV outage recognizes the high level of treatment currently provided through natural filtration and other contingencies in place. An on-line CT tracking tool (see Figure 1) was developed to aid in the determination of log removals. This program uses flow and retention time to calculate the log removals for Giardia and viruses. It is a predictive (flow-forward) tool, calculating in one hour projections and can be used to ensure action is taken to avoid insufficient treatment.

Other existing contingency provisions include the use of existing drains and overflows. However, in using these provisions, water is wasted and the City would like to contain as much of the raw water as possible.

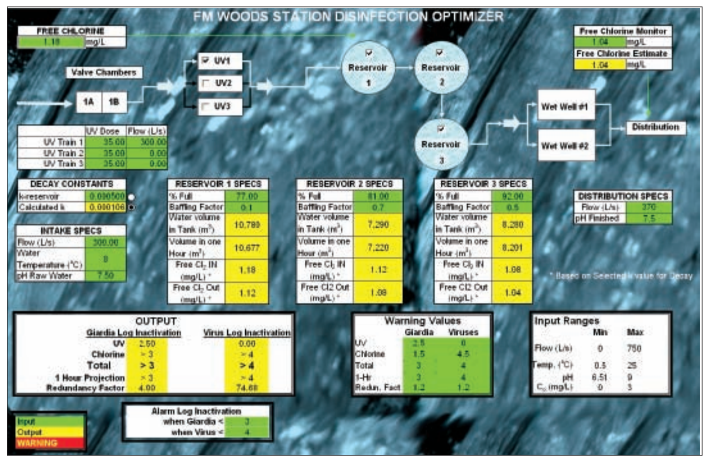

Figure 4. *Online CT tracking tool*

The design for the UV treatment incorporated various contingency provisions as well.

These included (see Figure 5)

Figure 5. *shows the UV Building process area*

- UV system redundancy - Three parallel treatment trains were provided and sized such that two reactors are capable of treating the maximum flow. The third train provided is to serve as a back-up unit in the event of a malfunction with either of the duty reactors.
- Uninterruptible Power Supply - Through conversations with the hydro utility, it was noted that the circuit for the F.M. Woods Station experiences on average 50 voltage sags and 6 instantaneous power outages per year. During each of these events, power to the UV reactors would be lost which would result in a system shutdown and restart; a process which could result in the UV system being offline for up to 10 min. To minimize the system downtime, an uninterruptible power supply (UPS) was installed for the UV system. The UPS will condition the incoming power feed, supplement the current when a voltage sag occurs and maintain continuous power supply to the UV units during an instantaneous outage. The UPS is capable of maintaining power to the UV system for a period of up to 10 min. The UPS is also used to maintain continuous operation of the UV units in the event of a switchover from normal to standby power, and the ensuing return to normal power from stand-by power.
- Standby Power - In the event of a long-term power outage, a 1.5 MW standby diesel generator provides power to all station loads required to sustain potable water delivery to the distribution system during such an event. The generator room will be equipped with 24 hours of fuel storage and additional diesel storage is available in an underground storage tank on the station site, and through pre-arranged fuel delivery arrangements. Additionally, a manual transfer switch is installed at the main station building to allow the connection of an external portable diesel generator in the event that the standby generator fails, or is unavailable (see Figure 6).

Figure 6. ***The generator set being rigged into the main FMWoods Building***

- UV Service Contract - As part of the UV equipment for this contract, the UV manufacturer is required to enter into a two-year service contract with the City of Guelph. This contract includes the requirement for maintaining a spare parts inventory on site at the Woods Station. This inventory includes most consumable parts required for the successful operation of the UV equipment including but not limited to lamps, ballasts, quartz sleeves, mercury spill kits, and capacitors.

  Also included in the service contract is the requirement for quarterly site visits to the station to inspect the UV equipment and assist the station staff in maintenance duties. Additionally, the UV manufacturer must provide a 24 h, 7-day a week, 365-day a year contact telephone/pager number and must provide technical staff that are available for site visits to assist in troubleshooting and maintenance within 48 h from the time of a request. These provisions will assist the City to minimize the time that the UV system is offline.

  At the completion of the two-year time period, City staff will be more familiar with the operation of the UV system and able to assume further responsibilities with respect to troubleshooting and maintenance tasks.
- UV Facility Bypass - The upgrades to the Woods Station facility included the construction of a new valve chamber to allow for the control of inflow routing. A by-pass was installed as a part of this chamber to allow for the diversion of flow into the reservoirs without this flow passing through the UV facility. This by-pass was included as a contingency should there be a catastrophic failure in the UV facility, such that water can no longer flow through the facility (see Figure 7).

Figure 7. ***A construction photo of the interconnecting piping being installed from the new UV facility to the Valve Chamber where incoming flow is directed throughout the Woods site.***

With the current configuration of the Glen Collector system, it is impossible to isolate this source and eliminate the constant inflow of GUDIWEF water to the station. As part of several works proposed to be undertaken at the Arkell Spring Ground, a Glen Collector system isolation valve chamber and overflow has been installed. This allows the flow from the Glen Collector to bypass the Lower Road

Aqueduct and discharge directly to the Eramosa River. With this valve chamber installed the flow from all GUDIWEF sources may be isolated allowing groundwater only to continue to feed the station in the event that the UV system is offline for an extended period of time and eliminates disruption to the continuous operation of the station.

OTHER OPERATING FLEXIBILITY CONSIDERATIONS

The "Procedure for Disinfection of Drinking Water in Ontario" (Procedure) clearly states that 2-log inactivation of Cryptosporidium is required for GUDI with effective in-situ filtration sources. The inactivation values for UV disinfection shown in Table 2, are taken from the draft UV Disinfection Guidance Manual (UVDGM) issued by the United States Environmental Protection Agency (USEPA). This document provides UV dose tables for UV disinfection of Cryptosporidium, Giardia and viruses. The tables are based on significant scientific research, and have incorporated significant safety factors for validation of UV equipment. The Tier I values are based on a set of standardized reactor design criteria and a set of standardized validation criteria, which then standardizes the safety factor applied to the required UV dose. These tables clearly identify that a UV dose of 40 mJ/cm^2 will provide no credit for virus inactivation. These tables also identify that a UV dose of 21 to 24 mJ/cm^2, depending on bulb type, is sufficient for 2-log Cryptosporidium inactivation and a UV dose of 34 to 40 mJ/cm^2 is sufficient for 3-log Giardia inactivation.

As noted in Table 2 above, the log removal credits for Giardia and viruses can be achieved through the existing chlorine disinfection without supplemental removals from the UV equipment. The UV system is required only to achieve the 2-log Cryptosporidium inactivation. This can be achieved at the lower UV dose of 24 mJ/cm^2.

In an attempt to achieve operational flexibility, the City requested and received permission to reduce the UV dose from 40 mJ/cm^2 to 24 mJ/cm^2. The UV dose is continuously monitored at the UV reactor control panel and the UV dose varied to maintain this minimum level. At this reduced UV dose, one reactor will be capable of treating near 100% of the incoming flow. With three reactors in place, this will provide almost 200% redundancy of UV treatment and provide additional security with respect to the overall UV system.

CONCLUSIONS

The Woods facility upgrade has been commissioned and has been on-line and operating since mid-June, 2007.

A certificate of approval (CofA) application has been approved by the licensing body in Ontario, the Ministry of the Environment (MOE), which:

- Permits a target UV dose of 24 mJ/cm^2.
- Acknowledges and incorporates the City's contingency plan which allows for:
    - Interim treatment in the event of a short or medium duration UV system outage
    - Diversion of flows requiring UV treatment if a long-term system outage is anticipated.

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The authors would also like to acknowledge the efforts of Ranee Mahalingam of the MOE and her ability to work within the rules while providing the flexibility required to deliver potable water in unique situations.

REFERENCES

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