UV DISINFECTION – CASE STUDY FOR ROTORUA DISTRICT' SPRING WATER SOURCES

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ABSTRACT

In this project, the credentials of Ultraviolet (UV) Disinfection as a means of reducing protozoa contamination risk in all the water supplies of Rotorua District is presented.

The Drinking Water Standards for New Zealand 2005, DWSNZ (2005), which became effective in October 2005, formally recognised the ability of UV disinfection to deal effectively with protozoan contamination, prescribing minimum raw water quality and operational conditions, in line with European and US Standards. Over recent years several UV disinfection systems have been installed across drinking water supplies in NZ, raising the profile of the technology as one of the most cost-effective means of meeting protozoa removal requirements set by the DWSNZ (2005). In addition to pathogenic protozoa, pathogenic bacteria and viruses are also effectively inactivated by UV irradiation. UV disinfection is based on the destruction of the DNA of micro-organisms by photochemical reactions.

This paper covers the experiences of the authors' in the recent implementation of eight UV systems for all water supplies in the Rotorua District, ranging in scale from 2 to 40 ML/d, and details up-to-date information on UV technologies and important design parameters and essential design factors considered for all these sites.

Rotorua District Council sources water mainly from natural springs for almost all its supplies, with chlorination as the only treatment practiced on these supplies. Springs´ raw water quality present ideal conditions (turbidity less than 0.5 NTU, UV transmittance over 95%) for the use of UV disinfection with minimal or no pre-treatment. It was proven that UV reactor validation to overseas reference standards was the most cost effective system to apply in this case, while innovative plant arrangements was necessary to accommodate the UV reactors in all supplies, matching diverse operational conditions and space availability. In many sites, high water pressure (over 10 bar) and availability of services proved to be the most critical site constraints. One of the key advantages of the use of UV disinfection is that it does not generate any known harmful by-products, such as those associated with chlorination and other disinfection methods.

For all Rotorua Water Supplies' upgrades, low-pressure high output (LPHO) UV lamps were selected, with primary emission at 254 nm in order to provide 3-log (99.9%) protozoan inactivation. Different UV reactors arrangements were selected to suit individual site conditions, serviceability, level of service associated with population served, and failure risk minimisation. Dose control was based on maintaining a minimum UV Intensity set by each UV reactor model validation against German Standards DVGW Technical Standard W294, which explicitly stipulate a verified fluence of 40 mJ/cm^2 is required for UV systems.

KEYWORDS

Ultraviolet (UV), Disinfection, *Cryptosporidium*, Water Treatment, Spring Water, DWSNZ (2005), Validation

1. INTRODUCTION

1.1 ROTORUA WATER SUPPLIES

In order to achieve protozoan criteria compliance with the Drinking Water Standards for New Zealand 2005, DWSNZ (2005), cost-effective Ultraviolet (UV) disinfection was selected from a range of treatment and disinfection methods, for the following Rotorua District's drinking supplies:

- Rotorua Central
- Rotorua Eastern/ Okareka
- Ngongotaha
- Hamurana/ Kaharoa
- Rotoiti
- Rotoma
- Reporoa – Wharepapa
- Reporoa - Deep Creek

Separate contracts were tendered for the UV equipment supply and for the construction/installation works, while design was also staged, as detailed design was subject final selection of UV disinfection units.

It should be noted that potential savings in protozoan and bacterial compliance monitoring efforts can be achieved by the successful implementation of UV Disinfection systems.

We recommended commencing *Cryptosporidium* testing for all sites that were required to have a monitoring programme in place (Central and Eastern) and at least test 2 samples for all other supplies to identify any potential contamination issues.

It has been identified that pH correction is needed at most Rotorua WTPs in order to protect reticulation assets, improve the aesthetic quality of the supplied water, and maintain effectiveness of residual chlorine disinfection. As a minimum it is recommended that the UV improvements be installed in such a way that provision is made for pH correction systems in future, including installation of blanks, provision of space within new buildings for additional pumps, controls and storage of chemicals.

1.3 UV IRRADIATION TECHNOLOGY

UV irradiation can be used to denature the DNA of microorganisms, causing them to die or lose their function (inactivation). Achieving microorganism inactivation with UV irradiation depends on the wavelength of the UV light source, the quantity of energy transmitted and the quality of the water (Rodriguez and Gagnon, 1991; Hunter et al., 1998).

Cryptosporidium is a harmful pathogenic protozoan that can cause severe illness and even death in extreme cases. *Cryptosporidium*, a chlorine-resistant protozoan, can be inactivated with a low UV dose. *Cryptosporidium* has become one of the most common waterborne diseases in the world. In 1993, over 400 people died and over 400,000 developed gastro-intestinal illnesses as a result of a *Cryptosporidium* outbreak in the drinking water supply of Milwaukee, USA. This water supply was sourced from Lake Michigan. Before the outbreak, severe storms caused the lake's turbidity and bacterial counts to rise dramatically.

While microorganism inactivation (including *Cryptosporidium* and *Giardia*) can be achieved at UV wavelengths ranging from 100 to 400 nm, research has proven that a wavelength of 254 nm is most effective. Low pressure (LP) UV Lamp systems are now an industry standard and supply monochromatic irradiation at 254.7 nm wavelength (Figure 1).

Medium pressure (MP) systems are also available. These are less bulky, and they supply a broader, polychromatic UV spectrum. To achieve a given UV dose, medium pressure UV systems generally require fewer lamps (5-20%

of the lamps compared to LP systems) but 2-3 times more power than traditional low pressure systems. Low pressure high intensity (LPHO) UV lamps system have recently been introduced to supply efficient mono-chromatic radiation that requires only one third or less of the energy required by traditional low pressure and low intensity lamp systems.

UV light intensity is denoted in units of mW/cm^2 (or $W/\ m^2$) and UV dose in units of $mW\ s/cm^2$ (or $mJ/\ cm^2$). Contact times of 10 to 30 seconds are typical for many commercial UV units. UV doses required to inactivate microorganisms can vary significantly, from only 2 $mJ/\ cm^2$ to more than 230 or $mJ/\ cm^2$ (at 254 nm), depending upon the target organism and the required kill rate (US EPA, 2006).

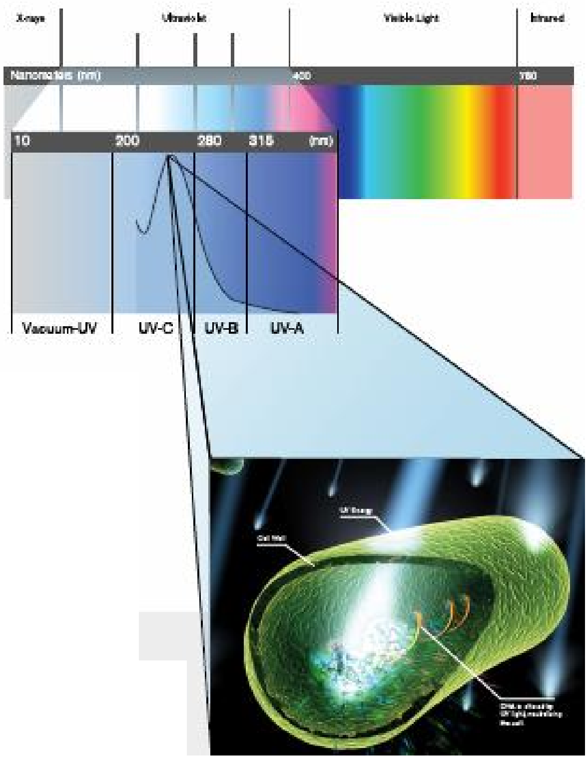
Before the UV dose can reach the target organism, it must be able to transmit through the water. Therefore, the lowest expected UV transmissivity (UVT) of the water should be established and used to predict how much UV intensity must be generated to transmit the desired UV dose. All Rotorua water supplies presented excellent transmissivity values to enable UV disinfection to be selected to meet DWSNZ (2005). The UV units were also sized to account for the 40% decline in UV Lamp intensity that normally occurs over the typical 10-12 month expected lamp life.

Achieving UV disinfection requires maintaining a minimum UV dose that is the product of the UV Intensity, the exposure time to this constant intensity, and a transmissivity factor. Therefore, the actual UV dose applied depends on the water flowrate (Q), the operating volume within the UV unit, the lamp intensity (including losses through the quartz sleeve), and the UV transmissivity of water. An approximate empirical relationship is as follows:

UV dose = (UV intensity) x (exposure time) x (transmissivity factor)

This formula relies on specific knowledge of the UV reactor geometry and several disinfection performance studies. In addition, the design details specific to each individual UV reactor supplied by all approved manufacturers. This is referred to as validation. Validation is carried out internationally and DWSNZ (2005) relies on both Austrian and German Standards to certify local installations.

Figure 1. Emission Spectra of low Pressure UV Lamps and representation of radiation effect on a microorganism's cell (courtesy of Filtec)



3. ROTORUA CENTRAL WATER SUPPLY – CASE STUDY

Rotorua Central Water Supply is a 36 ML/d source which serves Rorotua Township, a main centre of 48,000 people. Average annual flowrate is 24.3 ML/d, peaking up to 32 ML/d during Summer.

Raw water flows by gravity from the Karamu-Takina Springs to a nearby dry-well pump station and is pumped to both Matipo and Utuhina Reservoirs, which distribute water to the reticulation system of Rotorua urban areas. The reticulation is considered a single bulk distribution zone. The raw water is chlorinated (using chlorine gas) prior to entering public supply.

The duty/standby pumps operate based on the water level in the Reservoirs. The Matipo line comprises three pumps in total. Two of them are 240 L/s fixed-speed pumps and a third pump fitted with a variable speed drive (VSD) capable of covering a flowrate envelope of 60 L/s to 190 L/s. The Utuhina line comprises three 130 L/s fixed speed pumps.

The Karamu-Takina Springs source has been identified as a low-risk for protozoa contamination and in order to achieve a minimum of 3-log removal of protozoa, a UV disinfection system was determined to be the most cost-effective means of meeting this requirement. Different arrangement options were considered these are presented in Section 3.2.

Figure 2. Rotorua Central Water Supply Layout showing new UV Disinfection Buildings

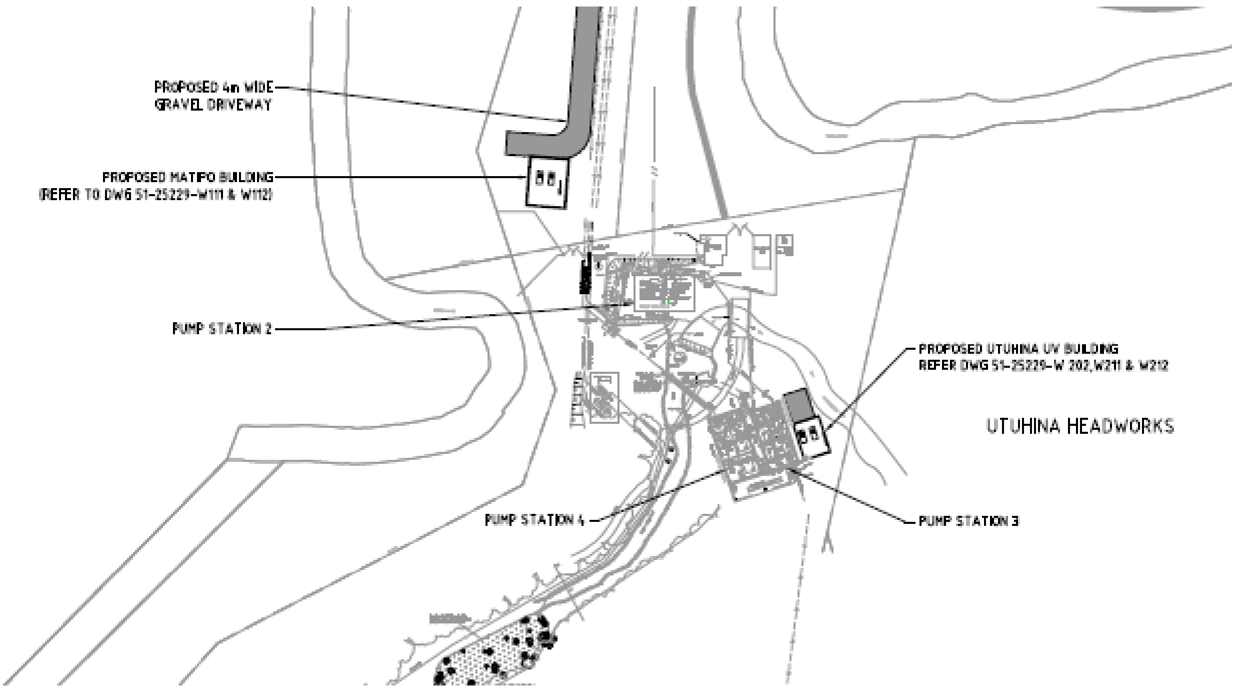


Figure 3. Rotorua Central Water Supply's Utuhina line UV Building Floor Plan

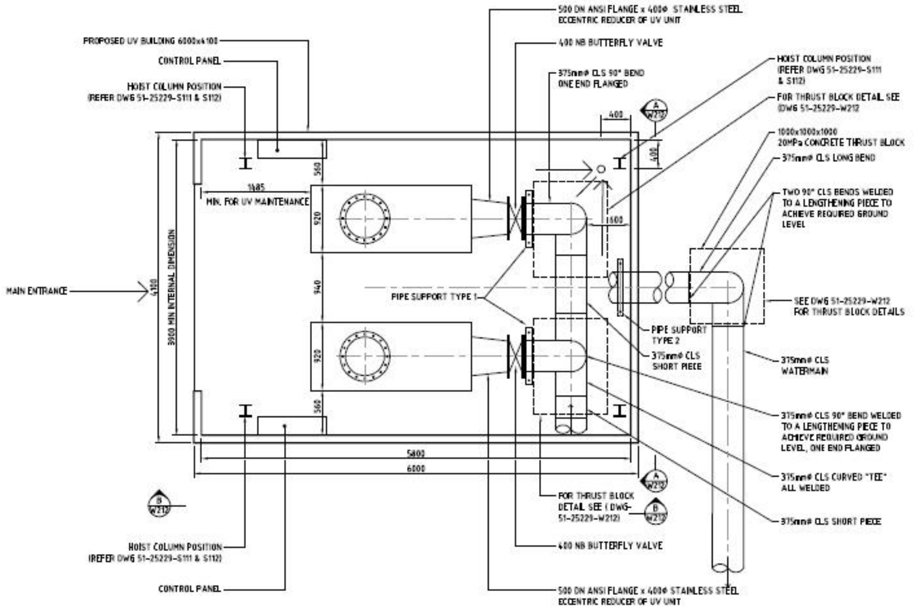


Figure 4. Rotorua Eastern Water Supply's UV Reactors Installation

3.1 RAW WATER QUALITY

The raw water quality is very similar among all spring water supplies at Rotorua. The water is of low turbidity and hardness, slightly acidic with low pathogenic contamination. However, none of these supplies can be classified as secure groundwater under DWSNZ (2005) as they are directly influenced by stormwater and potential run-off from surface agricultural activity. A summary of water quality from the Rotorua Central water supplied is presented in Table 1.

Table 1: Raw Water Quality Analysis – Rotorua Central Supply

Parameter and units	MAV/GV	Average	Min - Max
pH	7.0 – 8.5	6.8	-
Langelier Saturation Index	-0.5 – +0.5	-2.7	-
Total Hardness (mg/L)	200	10	-
Turbidity (NTU)	< 1.0	0.11	0.04 – 0.19
Transmissivity (percent cm^{-1})	-	98.0	95.0 - 100
Iron (mg/L)	0.2	< 0.02	-
Manganese (mg/L)	0.04	< 0.001	-

3.2 UV DISINFECTION UPGRADE – UV REACTORS ARRANGEMENT

A number of arrangement options were considered and these are presented below. Option 1b was selected.

Option 1a. Separate UV Reactors for Matipo and Utuhina with 100% redundancy

The UV reactors for Matipo are located in a new building in between Pump Station #4 and #2 (see Figure 2), while the Utuhina UV System is located in a new shed adjacent to the main Pump Station #3. The existing pipe would be tapped in to downstream of the pumps and chlorine dosing point. A branch from the water main would direct flow through two UV reactors operating in a parallel arrangement while the existing pipe will remain, to act as a bypass of the UV installation. The two UV reactors will operate in a duty / standby configuration, with each reactor sized to handle the full duty flow, i.e. 430 L/s for Matipo and 260 L/s for Utuhina. Following the UV reactors, the pipework would rejoin the respective rising mains (Matipo 525 mm and Utuhina 375 mm). In the future, pH correction could be achieved by dosing Caustic Soda or Soda Ash on the common gallery inside the Pump Station #3.

Option 1b. Separate UV Reactors for Matipo and Utuhina, duty/assist configuration

The system is the same as described in Option 1a, except that the UV reactors will be of lower capacity for the Matipo stream. Each reactor will be capable of treating up to 260 L/s. The rationale behind this option is that during most of the operating time of the year, only one 240 L/s fixed-speed pump is needed. A second UV reactor will act as stand-by or back-up during specific times of high demand. It is during these short periods of time when the plant will not have UV disinfection redundancy. With this approach, savings in UV equipment could be in the order of $0.5M compared to Option 1a.

Option 2. Common UV Reactors for Matipo and Utuhina – Gravity Feed

This option was ruled out once the available head on the main raw water pipe was fully evaluated and understood. While this option could have benefited from a reduction in numbers of UV units required, the size of reactors necessary to cope with the combined duty flowrate would have been twice that assessed as being necessary for Options 1a and 1b. Thus, no savings are achieved. Furthermore, civil works associated with installing UV reactor under ground level and next to the stream could have substantially increased the capital cost for this option.

Option 3. Common UV Reactors for Matipo and Utuhina – Pumped Feed

The installation of a pumping system to provide sufficient head permitting treatment with a common UV reactor above ground has also been assessed. The main disadvantage is the operational cost related to electricity consumption required for this “extra” pumping lift, which could be in the order of $0.25M/ year.

3.3 UV DISINFECTION SYSTEM - DESIGN CRITERIA

The basic design conditions for the selected option were:

- Design maximum flowrate: 260 L/s (Matipo)
  260 L/s (Utuhina)
- Number of reactors: 2 units (1 No. duty / 1 No. assist/stand by)
  2 units (1 No. duty / 1 No. stand by)
- Design UV Transmittance: 95 percent cm^{-1}
- Design UV dose: 40 mJ/cm^2 (Low Pressure UV Lamps)
- Headloss through reactor: Less than 5 m
- Reactor certification: complying with DVGW Technical Standard W294 and DWSNZ (2005)

3.4 DESIGN THROUGHPUT

Consented maximum abstraction rate at Rotorua Central Water Supply is 36,368 m^3/day (420 L/s). The design capacity used for Rotorua Central was split between Matipo and Utuhina, being 430 L/s and 260 L/s respectively. Utuhina was designed for two 260 L/s UV reactors on duty/stand-by. However, Matipo duty/assist arrangement allowed for a reduction of the duty UV reactor capacity to 260 L/s, while the differential (170 L/s) was covered by a second 260 L/s unit (in assist mode). This arrangement also provides 20% spare throughput capacity, and comprises similar units used in the Utuhina stream. This gives the advantage of interchangeability of units, spare parts and consumables.

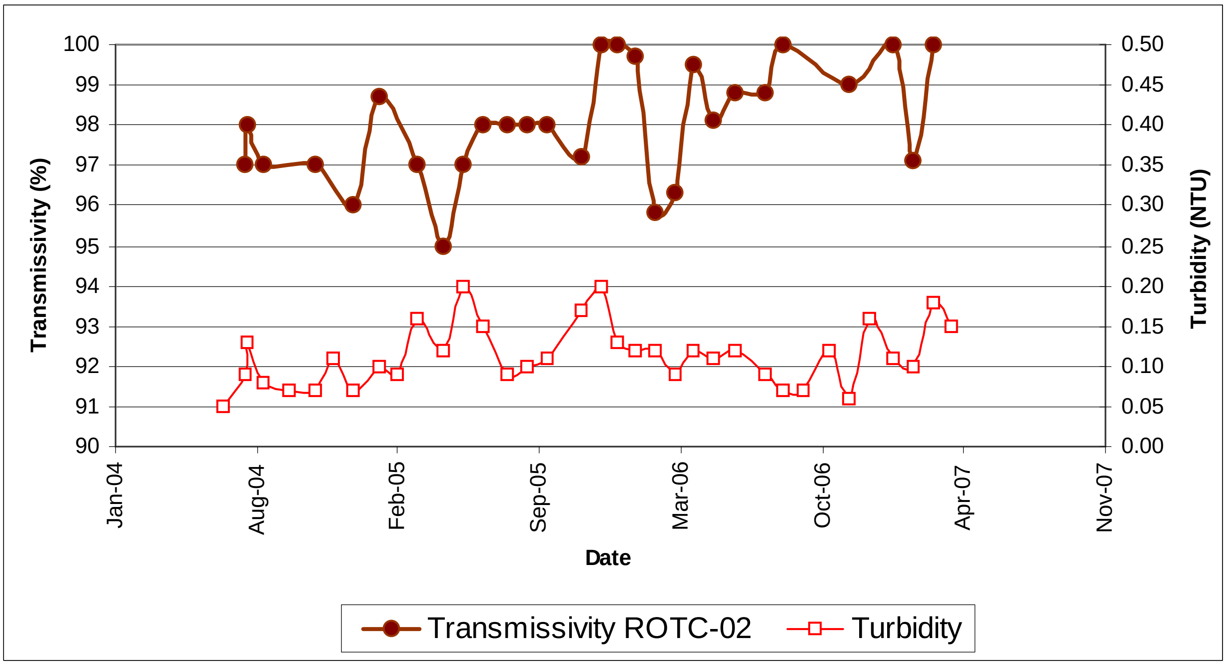
3.5 DESIGN UV TRANSMISSIVITY

The basis of the design UV Transmissivity (UVT) value of 95 percent cm^{-1} criterion is shown in Figure 4, which illustrates monthly data collected over the period 2004-2007 at Rotorua Central Water Supply.

Based on this data, the 99%ile of UVT is 95.2 percent cm^{-1}. Therefore if a design value for UVT of 95 percent cm^{-1} is used, and considering online continuous UVT monitoring, then in order to comply with the criteria of DWSNZ 2005 the measured UVT must not be below 90 percent cm^{-1} for more than 36 hours. Or, below 86 percent cm^{-1} for more than 8 hours on any given month. While only non-continuous UVT data was available at the time of the design, it was assumed that the quality of the spring water will not decrease significantly below those recorded values.

The minimum UVT of 95 percent cm^{-1} measured in the Rotorua Central WTP water, therefore, was used as a conservative design value. It must be noted that in case a design value of 98 percent cm^{-1} were used, savings up to $150k could potentially be achieved by using a smaller UV reactor. This highlights the importance of the accurate determination of the UVT quality of the raw water, particularly for water supplies in excess of 10 ML/d.

Figure 4. Raw Water Transmissivity and Turbidity – Rotorua Central Water Supply



3.6 DESIGN UV DOSE

In order to achieve 3-log credits for protozoan inactivation with UV, DWSNZ (2005) requires that no less that the design UV dose (40 mJ/cm^2, based on Low Pressure Lamps) be applied for more than 36 hours on any given month (5% of the compliance monitoring period, which is 1 month for the Rotorua Cental water supply). UV Dose is indirectly measured, or interpolated, via UV Intensity which is monitored online. The UV Dose could potentially be recorded for monitoring purposes by means of estimating it using UV Intensity, flowrate and geometric parameters specific to the UV reactor.

3.7 DESIGN UV DOSE CONTROL - UV INTENSITY SETPOINT APPROACH

The selected UV Dose Control approach, UV Intensity Setpoint, relies on one or more “setpoints” for UV intensity that are established during validation testing of the UV reactors to determine UV dose. At the Rotorua water supplies, a single setpoint control approach was selected.

The UV intensity, as measured online by the UV sensors must meet or exceed the setpoint to ensure delivery of the required UV Dose. Reactors must also operate within validated operation conditions for flow rates and lamp status.

The intensity readings by the sensors automatically account for changes in UVT. The UV Reactor’s Programmable Logic Controller (PLC) automatically controls the Intensity and UV lamp outage to maintain the Intensity Setpoint. The PLC can turn down power by up to 60% of maximum capacity allowing for energy savings, particularly at the beginning of the lamp life, where the fouling is low and the lamps are new.

3.8 OTHER DESIGN PARAMETERS

Other design criteria for the UV installation at Rotorua Central are illustrated in Table 2.

Table 2: UV Installation for Rotorua Central Water Supply

	Requirements	Supply Characteristics	Comments
Turbidity (NTU)	< 1	0.11 (avg)	Max recorded = 0.19 Online turbidimeter required
Pumping Profile	Max 4 start-up per day	2-3 (Matipo) 3-4 (Utuhina)	Based on online SCADA data
Pressure	< 16 bar	10 bar (Utuhina) 8 bar (Matipo)	Duty Head of existing pumps. Water Hammer effect tempered by slow closing valves.
UV Housing/ Space Availability	See comments	Limited space available within existing sheds	Various options discussed in Section 3.2
Electrical Power Availability	15 kW	No electrical power limitations	Based on two UV reactors running at the same time
Disruption of existing supply	-	Some disruption foreseen	Existing reservoirs will minimise the effect of the installation disruption.
Ease of installation	-	Moderate	Various options discussed in Section 3.2

A special non-slam non return valve were installed downstream the UV reactors to provide protection of the quarts and lamps of the UV system against water hammer effect produced by the sudden stop of the supply pumps.

UV reactors must be kept free of air to prevent lamp overheating. Air release valves were installed to prevent air pockets developing.

4. UV DISINFECTION EQUIPMENT OPERATION

4.1 START-UP

The following aspects were considered during the design of the functional philosophy and incorporated into the operational procedures for all the installations at the Rotorua Water Supplies:

» The duty UV shall switch on when the reservoir level or reticulation pressure signals a pump start, depending on the supply.

» The pump start will be delayed by 120 seconds, to give the UV lamps sufficient time to warm-up ("burn time").

» Once the pump start delay is complete, the pumps will start and water will flow through the UV reactors and into the reservoir prior chlorination.

» The PLC will control the spring pumps and allow flow up to the maximum design flow rates at each site.

» Once in normal operation, the UV will be controlled based on information received from the UV Intensity, the flow meter and the UVT meter.

» Turbidity and UV Transmissivity parameters can not be controlled as they are derived from the raw water. These parameters must be monitored to ensure that the UV system and its operation complies with DWSNZ (2005) at all times. Failure to monitor as required by the DWSNZ (2005) may lead to non-compliance.

4.2 CHANGE OF DUTY

The duty UV shall be rotated on a monthly basis to ensure even wearing of units. This preventive maintenance procedure is undertaken by way of automatic inlet and outlet isolation valves around the UV units. The valves also allow for a duty/assist arrangements of the UV reactors (e.g. Rotorua Central and Reporoa Deep Creek). Other sites rely on manual intervention to alternate UV reactors duties.

4.3 SHUT DOWN

The duty UV reactor control was designed to automatically switch off when the reservoir reaches a high level or the reticulation reaches a sufficient pressure, depending on the supply, and signals a pump stop or by manual operator intervention. The supply pumps were interlocked to prevent pump start when the UV is turned off manually. A bypass valve was also included in the design in case of emergencies.

4.4 ALARMS

As the sites are unmanned and are only attended to for a short period of time each day, or twice a week only for the small sites, alarming of operational parameters is critical.

The design of the control systems allow for an operator to be able to acknowledge any alarm immediately and attend any critic event within 4 hours to carry out a diagnostic test on the UV unit and take appropriate action. This may be to replace lamps, conduct a clean-in-place (CIP) and/or switch the standby unit into duty mode.

Critical Alarms which could compromise compliance with DWSNZ (2005) include:

- Low UV Intensity (e.g. below specified values determined in the validation report for each individual UV reactor model)

- High Feedwater Turbidity (e.g. exceeds 2.0 NTU for the duration of any three-minute period exceeds or 1.0 NTU for more than 5% of the monitoring period)
- Low UV Transmissivity (e.g. less than 95% of the lowest UVT the reactor has been validated for more 5% of the monitoring period, or UVT less than 90% of the lowest UVT the reactor has been validated for more than 1% of the monitoring period, or UVT falls below 80 percent cm^{-1})
- High water flows (e.g. higher flowrate than what the UV reactor has been validated for)

5. CONCLUSIONS

The following conclusions are drawn:

- Rotorua's water supplies are well suited for UV technology, and this has proven to be a cost effective means to meet DWSNZ (2005)
- UV is now accepted as means to meet protozoa section of DWSNZ (2005) following overseas evidence regarding its efficacy
- Designs that used too conservative UV Transmissivity values could potentially increase the capital costs of UV Disinfection equipment substantially. This highlights the importance of the accurate determination of the UVT quality of the raw water, particularly for water supplies with productions of 10 ML/d or over.
- Each site had specific design challenges and these were met whilst balancing costs and maintainability issues
- Procurement of the UV systems was by means of a headline contract to a single UV supplier, giving economies of scale and commonality of spares, training and maintenance.

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