

Appendix N: **WWTP Virus Reduction & Disinfection Performance**

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File: Porirua WWTP Outfall Discharge Consent
Application

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Porirua Wastewater Treatment Plant – Virus Reduction and Disinfection Performance

INTRODUCTION

BACKGROUND

A Quantitative Microbial Risk Assessment (QMRA) has been prepared by Streamlined Environmental Ltd to help determine the public health risks of the discharge of treated wastewater from the Porirua Wastewater Treatment Plant (WWTP) through the shoreline outfall located at Rukutane Point¹.

The QMRA assessed the health risks from the discharge at nearby “exposure sites” along the shoreline associated with both contact recreation (such as swimming and walking near the outfall) as well as consuming shellfish gathered at several sites within Porirua Harbour. Viruses including norovirus and enterovirus (enteric illness) and adenovirus (respiratory illness) were modelled - which is consistent with other QMRAs prepared in New Zealand.

The QMRA provided the results based on a 1, 2, 3 and 4 log reduction of norovirus and enterovirus, and 1, 1.5, 2, 3, and 4 log reduction of adenovirus concentrations through the WWTP.

PURPOSE OF THIS MEMO

The purpose of this memo is to assess the likely norovirus, enterovirus and adenovirus reduction through the WWTP (including through the secondary and UV disinfection processes), using available relevant information including the results of studies from similar secondary processes, and by calculating the dose and inactivation of viruses through the UV disinfection process. The expected virus log removals can be compared with the QMRA results to establish the likely risks to users at selected locations in the vicinity of the outfall.

The UV disinfection equipment at the WWTP is currently being upgraded with a new DURON UV system. The derivation of the design basis and UV dose for the new DURON UV system was based on receiving water enterococci values which are identified in the Proposed Natural Resources Plan. However, enterococci removal is not an input to the QMRA (which is focused on viruses) and therefore we have not reiterated this information in this memo.

¹ Streamlined Environmental Ltd (2020) *A Quantitative Microbial Risk Assessment of the Porirua WWTP Discharge and Receiving Environment*; Report DHI1901 prepared for Stantec by DHI and SEL January 2020

PATHOGENS IN RAW SEWAGE

Raw sewage can contain a number of pathogenic microorganisms that can cause illness in humans. These pathogens include protozoa, which can cause diseases including giardiasis, and cryptosporidiosis, viruses which can cause gastrointestinal as well as upper respiratory infections and bacteria which cause gastrointestinal diseases such as dysentery and salmonella.

The actual presence of pathogens is dependent on their prevalence and incidence in the local population. The Porirua community health profile can be considered typical from a demographic perspective of many New Zealand communities. There may also be seasonal influences on the prevalence of infectious diseases in the community with overseas tourists, and visitors from within New Zealand, visiting the area during holiday periods.

Literature suggests that the greatest public health risk from contact with wastewater is from viruses (eg Courault et al. 2017²). For receiving waters impacted by treated wastewater, the reference pathogens typically considered for human risk assessment are norovirus, enterovirus and adenovirus (e.g. McBride 2016³). These viruses have been used as representative viruses for previous QMRA studies in New Zealand.

Norovirus and enterovirus are principal causes of viral gastroenteritis in humans. In particular, human norovirus is identified as a major contributor to gastrointestinal illness in New Zealand and overseas. Siebenga (2009)⁴ reported that human norovirus is the most common cause of outbreaks of epidemic gastroenteritis worldwide. Norovirus is classified into five genotypes (GI to GV). The GI, GII and GIV strains can infect humans. The GI and GII strains are highly infectious for a proportion of the population and spread easily by person to person contact.

International literature (e.g. Soller et al, 2010⁵) has also recognised norovirus as the likely primary potential risk of infection for swimmers, surfers or consumers of raw shellfish.

Respiratory viruses, particularly Human Adenovirus (Types 2, 3 and 4) are generally adopted as the key risk indicators for recreational users particularly surfers. Respiratory infections caused by adenoviruses can result from inhalation of spray droplets, or aerosols, generated from wastewater-contaminated waters.

² Coulrault. D et al. (2017) *Assessment and risk modelling of airborne enteric viruses emitted from wastewater reused for irrigation*; Science of the total environment 592 512-526; cited in the SEL (2020) Porirua WWTP QMRA report

³ McBride, G (2016a) *Quantitative Microbial Risk Assessment for the discharge of treated wastewater: Warkworth Wastewater Treatment Plant*; Report prepared by NIWA for Watercare Services Ltd HAM2016 037; cited in the SEL (2020) Porirua WWTP QMRA report.

⁴ Siebenga J J (2009) *Norovirus illness is a global problem: emergence and spread of Norovirus G11.4 variants; 2001-2007*; Jnl of Infectious Diseases 200: 802-812.

⁵ Soller J A, Bartrand T, Ashbolt N J, Ravenscroft J, and Wade T J; *Estimating the primary etiologic agents in recreational freshwaters impacted by human sources of fecal contamination*; Water Research 44(16): 4736-4747.

WWTP TREATMENT AND DISINFECTION

OVERVIEW

The Porirua WWTP treats raw sewage from Porirua City and the northern Wellington City catchments. The WWTP provides screening to remove incoming solids (<2mm), secondary treatment (removal of organic and nitrogen based pollutants in an activated sludge single “carousel style” aeration basin and further separation of suspended solids in three clarifiers) and disinfection (UV irradiation for inactivation of pathogenic and indicator organisms). The TAK UV system, which was installed in 2003, consists of two banks of horizontal lights, through which the wastewater passes before discharge to the outfall.

The plant has been progressively upgraded over the past six years to improve wastewater quality. Ongoing improvements at the plant will include upgrading of the secondary treatment and UV processes to allow all incoming flows up to 1500 L/s to be fully treated. Currently, about 1000 L/s can be fully treated and approximately 930 L/s disinfected which means that higher flows, during wet weather, do not receive the same level of treatment before discharge. Figure 1 shows these treatment processes as wastewater progresses through the plant.

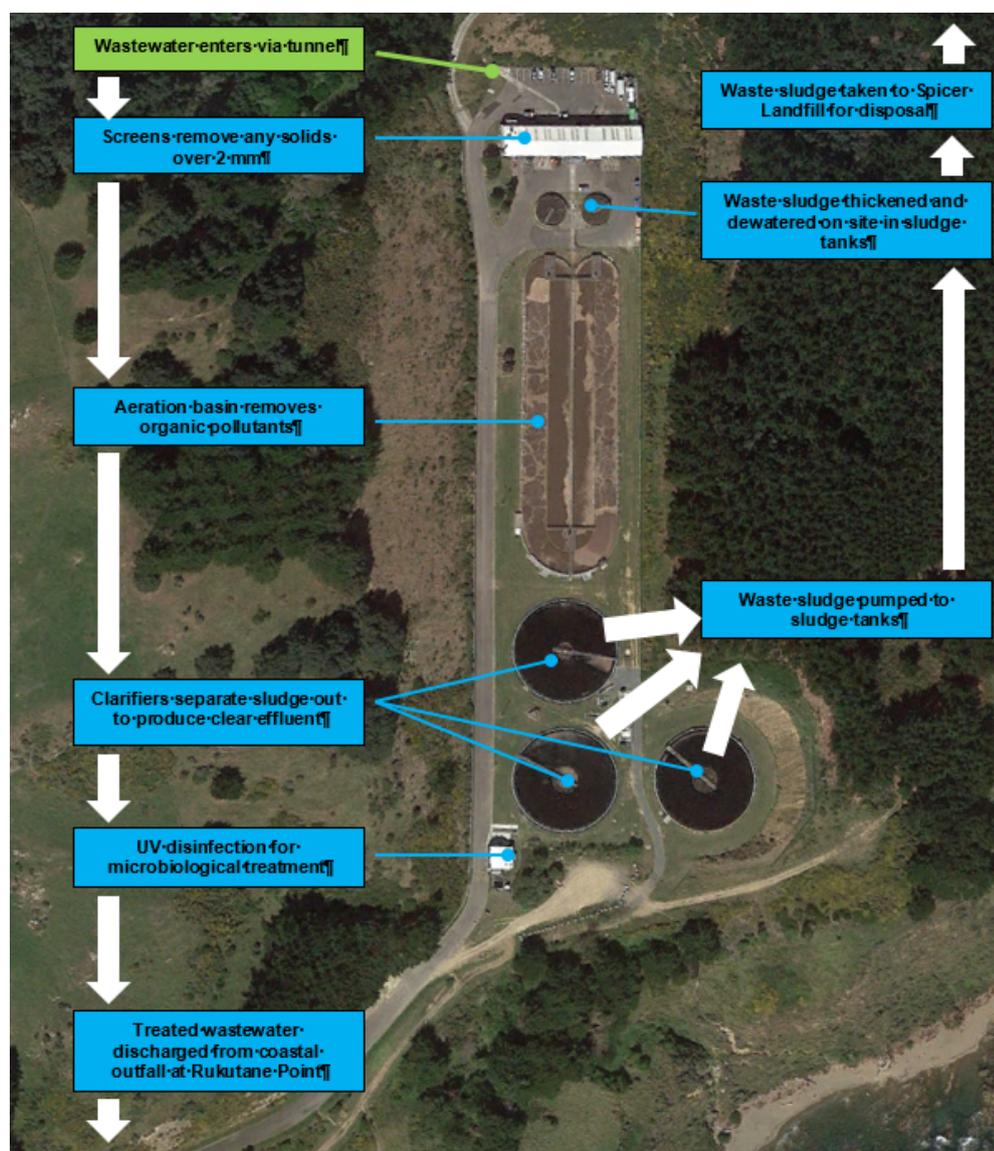


Figure 1: Porirua WWTP treatment processes

WASTEWATER QUALITY PRIOR TO UV DISINFECTION AT WWTP

The role of the primary and secondary treatment components at the WWTP is to reduce solids and organic material. However, these processes also facilitate the removal of a portion of the microbiological load that is associated with the removal of solids and predation within the bioreactor. These microorganisms (protozoa, bacteria and viruses) are removed with the sludge from the plant.

The secondary treatment process at the WWTP provides a relatively clear wastewater which is an important requirement for good UV performance. The transmission of UV light⁶ through the wastewater ensures that an appropriate dose of UV light is delivered to the target microorganism and that the “shielding” effects from other suspended particles are minimised. Total suspended solids (TSS) can also absorb UV radiation reducing the effectiveness of the disinfection process. A TSS concentration of less than 30g/m³ with a UV transmissivity greater than 60% (i.e. unfiltered secondary wastewater) are considered good target parameters for UV systems at WWTPs.

Results of monitoring at the WWTP between June 2017 and June 2018 show the plant achieves relatively low TSS concentrations and a relatively high UV transmissivity before discharge to the UV disinfection system. The results are consistent with target parameters and conducive to effective UV disinfection.

UV DISINFECTION

UV disinfection systems typically use monochromatic light at a wavelength close to the adsorption peak for nucleic acid⁷ (i.e. 254nm) to inactivate microorganisms by altering their genetic code to prevent reproduction. UV is an effective mechanism for inactivation of bacteria, protozoa and viruses (dependent upon the type of virus) with a relatively short “contact” time (approximately 20-30 seconds). UV also has the advantage of not forming any chemical byproducts or toxic residuals (as is the case with other methods such as chlorine).

However, some microorganisms are more resistant to UV disinfection than others. For example, more complex organisms such as bacteria are relatively susceptible to UV light. However, viruses that are more genetically simple, can be relatively more resistant to UV. For example, adenoviruses (a double stranded virus) that can cause respiratory infections are considered to be more resistant than enterovirus (a single stranded virus, responsible for gastrointestinal infections).

The existing TAK UV disinfection system, consisting of two banks of horizontal Low Pressure High Output (LPHO) monochromatic lamps, was installed at the WWTP in 2003. The process guarantee provided by the equipment suppliers (Wedeco), was based on achievement of a treated wastewater concentration of faecal coliforms of 1000 organisms/100mL (90-day geometric mean).

The UV dose is typically selected by the UV manufacturer based on the supplied wastewater parameters including TSS and UVT and the target effluent bacterial indicator organisms to be achieved. Because the design parameters are based on a near worst case for both TSS (95th percentile) and UVT (5th percentile), a high level of compliance will be achieved. The manufacturer carries out a validation process for each design of UV reactor which requires a knowledge of the dose response to UV light of the pathogens of relevance and the challenge organisms used to represent them.

⁶ The amount of UV light at a wavelength of 254 nm that passes through a certain path length of water compared with the amount that passes through the same path length of distilled water.

⁷ Nucleic acid is the name for DNA and RNA which carry the genetic blueprint of the cell

Wellington Water is upgrading the WWTP to include new technology DURON UV equipment (programmed to be completed June 2021). This new system will be installed alongside the existing TAK system to allow disinfection of all flows up to 1500 L/s. While the upgraded plant will have the flexibility to operate in a 50:50 flow split mode, the new DURON system will be used as the duty (i.e. taking most of the flow – 930 L/s). The new DURON system has more modern lamp technology, a more efficient lamp cleaning system, and lower labour requirements for cleaning than the TAK system. The TAK system will only operate when flows in excess of 930L/s are received at the WWTP. The system specification is based on achieving a treated wastewater concentration of the target indicator bacteria (enterococci) of 1000 organisms/100 mL (95%ile).

The disinfection performance for the TAK system was designed for a geometric mean of 1000 faecal coliforms/100ml at a flow of 928 L/s. The disinfection performance for the DURON system was designed for a 95 percentile of 1000 enterococci/100ml at a flow of 930 L/s. The maximum design flow for the WWTP is 1500 L/s, so the combined capacity of the TAK and DURON systems (>1,800 l/s) easily exceeds the design flow. Currently flows of 1300 L/s can be delivered to the WWTP but it is expected that pump stations will be upgraded over the life of the proposed consent to deliver to the maximum capacity (1,500 l/s) of the WWTP. A frequency distribution analysis of wastewater flows for the years 2016 to 2020 (PCC data at 1 hour intervals) shows that flows exceeded 1000 L/s for less than 1% of the time and exceeded 1200 L/s less than 0.1% of the time (<9 hours per year), indicating that peak flows are rare short-term events.

A target effluent virus concentration was not required to be specified by Wedeco for either the existing TAK or proposed DURON UV systems, as the performance standards are based on the target effluent bacterial indicator organisms relevant to the receiving water standard set out in the Proposed Natural Resources Plan.

MONITORING OF FAECAL INDICATORS AND VIRUSES AT THE WWTP

FAECAL INDICATOR ORGANISMS

Viral pathogens are not routinely measured in the WWTP wastewater as they are difficult and expensive to detect and enumerate. As with other WWTPs in New Zealand, it is common practice to monitor faecal indicator organisms, such as faecal coliforms or enterococci, which are found in large numbers in the gut of warm-blooded animals including humans.

The current consent requires the regular monitoring of faecal coliforms to help assess plant disinfection performance and to meet consent requirements. However, as noted above, enterococci is the preferred bacterial indicator organism in marine recreational areas. The Proposed Natural Resources Plan includes a receiving water enterococci limit of <500 cfu/100mL (95%ile).

Municipal raw sewage typically contains between 10^6 and 10^7 (i.e. 1 million to 10 million) faecal coliforms CFU per 100mL. Analysis of wastewater monitoring data between 2011 and 2019 (see Section 2 of the AEE) shows that the WWTP performs well, reducing the faecal coliforms concentrations in the secondary treated and UV disinfected flows by between 99.99 and 99.999% (i.e. 4-5 log) before discharge.

Wellington Water does not routinely monitor enterococci concentrations in the Porirua WWTP discharge. However, some enterococci monitoring was carried between May and July 2018, to assess the requirements for upgrading the UV system. These results show that the plant provides good disinfection of enterococci with the average concentrations being reduced by at least a 4 log (99.99%) before discharge, compared with the concentrations of enterococci in raw sewage that enter the plant.

VIRUSES

The limitations associated with the use of bacterial indicator microorganisms as indicators for viruses are well documented (e.g. USEPA 2015⁸). Furthermore, as most standard wastewater treatment and disinfection processes vary in their efficiency in eliminating viruses, treated wastewater may still contain concentrations of enteric viruses that present a public health risk (eg Lodder et al⁹). If there is an outbreak of a viral disease in the community, the increased concentration of virus in the wastewater may not be reflected by an increase in the concentration of faecal indicator organisms which generally occur at fairly consistent concentrations¹⁰.

A limited (three sample) virus influent (raw sewage) and treated wastewater monitoring programme was carried out at the Porirua WWTP by Wellington Water in September 2019 under dry weather conditions. The results indicate that the WWTP influent virus concentrations could be as high i.e. 10^7 genome copies¹¹ per litre for Norovirus GII on 9th September (see Table 1 reproduced from Table 3 of the Streamlined Environmental 2020 QMRA report). However, this is a snapshot sampling and does not adequately reflect the year-round variabilities in influent virus concentrations. Notwithstanding this, the monitoring data fall within the range of concentrations reported in previous New Zealand studies (e.g. McBride 2016). Norovirus influent sampling was carried out on seven dry weather occasions in 2013 at Wellington City's Moa Point WWTP. The results show a smaller range for Norovirus GI and II of between 2.1×10^4 and 3.5×10^5 .

Table 1: WWTP Influent virus monitoring results, September 2019

| Sampling date | Virus | Influent (genomes per L) |
|---------------------|------------------------|---------------------------|
| 9th September 2019 | Norovirus Genogroup I | 4.80E+05 |
| | Norovirus Genogroup II | 1.00E+07 |
| | Enterovirus | 8.40E+04 |
| | Adenovirus | 3.30E+05 |
| 16th September 2019 | Norovirus Genogroup I | 8.20E+04 |
| | Norovirus Genogroup II | 4.90E+06 |
| | Enterovirus | 5.20E+04 |
| | Adenovirus | 2.30E+05 |
| 23rd September 2019 | Norovirus Genogroup I | 8.30E+04 |
| | Norovirus Genogroup II | 4.70E+06 |
| | Enterovirus | 1.50E+05 |
| | Adenovirus | 1.00E+06 |

Norovirus can only currently be enumerated using molecular methods which detects the viral nucleic acid and does not necessarily correlate to infectivity (hence does not distinguish between live or dead organisms). For the virus analysis at the Porirua WWTP ESR have used the molecular method, quantitative polymerase chain reaction (qPCR) analysis for all three viruses (norovirus and enterovirus using Reverse Transcription (RT qPCR), and adenovirus by qPCR) so this limits the assessment of virus inactivation from the UV disinfection process in the treatment plant.

⁸ USEPA (2015) *Review of coliphages as possible indicators of fecal contamination for ambient water quality*; 820 R 15-098; cited in the SEL (2020) Porirua WWTP QMRA report

⁹ Lodder WJ et al. (2010) *Presence of enteric viruses in source waters for drinking water production in the Netherlands*; Applied and Environmental Microbiology 76(17): 5965-5971

¹⁰ NZWERF/MFE (2002) *New Zealand Municipal Wastewater Monitoring Guidelines* (September 2002)

¹¹ A genome is an organism's genetic material encoded in DNA (or RNA for some viruses)

In effect, the method of analysis of the virus concentration will have over-estimated the actual infectivity by using the molecular qPCR method as it will be enumerating UV inactivated virus DNA.

The literature indicates that virus reductions in wastewater after secondary treatment and UV could be as low as “no reduction” (in the case of a complete treatment failure) to as high as 5-log reduction i.e. a 100,000-fold reduction) (McBride 2016). On the basis of virus monitoring data from other activated sludge treatment plants, and the molecular method of detection, the range of log reductions achieved at the Porirua WWTP is likely to be greater than was captured during the limited sampling.

REVIEW OF VIRUS REDUCTIONS IN SIMILAR TREATMENT PLANTS

OVERVIEW

There have been a number of studies to assess the reduction of viruses in secondary treatment plants with UV disinfection, such as occurs at Porirua.

A review of the literature suggests that size, repair enzymes and composition of the microorganism’s nucleic acid are important factors in determining resistance to UV. Viruses are typically more resistant to UV than either bacteria or protozoa. Studies show that adenovirus are more resistant to UV than other water-borne pathogens (e.g. IUVA, 2006)¹².

In some cases, genetic damage caused by UV can be reversed by microbial repair mechanisms. Exposure of some microorganisms, notably bacteria to visible light shortly after UV irradiation can activate enzymes that can reverse the damage created during the UV process (known as photoreactivation). While viruses cannot repair themselves, they may use enzymes in the host cells to undertake some repair. The ability to self-repair is a function of UV dose – with less repair being observed as doses increase.¹³

SECONDARY TREATMENT

No monitoring of virus concentrations after secondary treatment (i.e. prior to UV disinfection), has been carried out at the plant. However, results from studies of similar plants elsewhere provide an expected range of removal of viruses through the primary and secondary treatment processes. The range reflects factors such as differences in hydraulic retention time, solids retention time (SRT) and mixed liquor suspended solids (MLSS) and temperature etc. through these plants.

A study by Sidhu et al¹⁴ investigated the presence and removal of human adenovirus (HAdV), human polyomavirus (HPyV), human torque teno virus (HTtV) and somatic coliphage family Microviridae in three wastewater treatment plants in sub-tropical Brisbane, Australia. The main aim of this study was to determine the ability of the WWTPs to remove viruses (i.e., log₁₀ reduction) from the wastewater stream, and not just inactivate them. For this reason the analysis of enteric virus numbers was by the qPCR method. The author notes that this could lead to an overestimation of health risks posed by the treated effluent as the qPCR method identifies all viruses present and does not

¹² IUVA, (2006) *Biodosimetric charts for UV disinfection data*, IUVA News Volume 8.

¹³ Hu, X et al (2012) *Inactivation and photo repair of enteric pathogenic microorganisms with ultraviolet irradiation*; Environmental Engineering Science Vol 29, (6)

¹⁴ Sidhu J.P.S, Sena K, Hodgers L, Palmer A, Toze S, (2018) *Comparative enteric viruses and coliphage removal during wastewater treatment processes in a sub-tropical environment*, Science of the Total Environment 616–617 (2018) 669–677

differentiate between non-infectious and infectious virus. Sampling was during the summer (January to April) on four occasions.

All three WWTPs were biological nutrient removal (BNR) activated sludge plant configurations. The secondary biological step SRT's for the three WWTPs were; 13 days, 15 days and 18 – 19 days. Porirua WWTP currently operates with an SRT of 19 days, decreasing to 12 days with year 2043 loadings, so over the life of the proposed consent will operate with a similar long sludge age to those in the Australian study.

Table 2 summarises the results.

Table 2: Virus removal log reduction values for three Australian wastewater treatment plants

| Virus | Luggage Point | Oxley Creek | Bundamba | Average |
|--------------------------------|---------------|-------------|----------|---------|
| Adenovirus (HAdV) | 2.91 | 2.68 | 3.08 | 2.89 |
| Human polyomavirus (HPyV) | 3.64 | 3.48 | 4.00 | 3.71 |
| Human torque teno virus (HTtV) | 2.73 | 2.91 | 3.03 | 2.89 |
| Microviridae | 3.22 | 3.78 | 4.24 | 3.75 |

In a more recent study, comparable removal of HAdV (1.7–3.3 log₁₀) in wastewater treatment plants employing a Bardenpho process as secondary treatment step has been reported (Schmitz et al., 2016). Similarly, in comparison to HAdV, higher removal of HPyV in a conventional activated sludge process has also been reported from Japan (3.19 log₁₀) and Austria (2.50 log₁₀) (Hata et al., 2013; Mayer et al., 2016). The HTtV removal observed in Brisbane WWTPs (~3 log₁₀) is comparable to the values reported from Germany (2.6 log₁₀) and Japan (3.5 log₁₀) (Hamza et al., 2011; Haramoto et al., 2008)

The Mangere WWTP services the greater Auckland area and is an activated sludge process with UV disinfection. The consent conditions require the monitoring of viruses and UV disinfection performance. NIWA¹⁵ presents the virus concentrations in the influent and secondary effluent in the period from 2002 to 2016. Virus removal across the secondary process was a median of 3.66 log₁₀ for enteroviruses and a median of 3.23 log₁₀ for adenoviruses.

Ulbricht et al¹⁶ investigated virus retention with each step of an activated sludge treatment plant in Germany. The plant had an average sludge retention time of 11.5 days. Sampling and analysis of human adenoviruses was carried out during a one week period in the summer during which the average wastewater temperature was 18.9 C. Across the activated sludge process, adenoviruses were reduced by 2.32 log₁₀.

¹⁵ McBride G (2017), Bell Island Wastewater Treatment Plant, Quantitative Microbial Risk Assessment.

¹⁶ Ulbricht K, Selinka H, Wolter S, Rosenwinkel K, and Nogueira R, (2014) *A mass balance approach to the fate of viruses in a municipal wastewater treatment plant during summer and winter seasons*, IWA Publishing, Water Science & Technology 69.2, 2014.

Norovirus sampling was carried out at two activated sludge plants in the UK¹⁷ during the winter months (November to February). Samples were collected on two occasions from each treatment plant from the influent and secondary activated sludge process. In the high rate activate sludge plant norovirus was reduced by 1.38 log₁₀. In the low rate activated sludge plant with biological nutrient removal, norovirus was reduced by 2.57 log₁₀. In a Swedish study¹⁸, it was found that there was an average 1.5 log₁₀ reduction in wastewater norovirus concentrations in an activated sludge treatment process. Van den Berg H et al¹⁹ determined that reductions in noroviruses ranged from 1.0 to >2 log₁₀.

VIRUS REDUCTION BY UV DISINFECTION

UV VALIDATION PROCESS

UV reactor validation is carried out on the full-scale reactor according to standards including the International Ultraviolet Association (IUVA) protocol for secondary wastewater treatment, and USEPA *Ultraviolet Disinfection Guidance Manual* (UVDGM)²⁰. Wedeco have undertaken a validation process of both the TAK (120mm centreline) and the DURON reactors. The validation process establishes the performance of the reactor under a range of operating conditions (flow per lamp, UV transmittance, bank head loss, relative sensor output) for a number of challenge organisms (of varying sensitivity). The range of operating conditions define the “validation envelope” and establishes “boundary conditions” beyond which the predictive performance cannot be defined.

The performance of the reactor is established during the validation process in terms of a reduction equivalent dose (RED) and also a validated dose (VD). The RED is the UV dose in mJ/cm² for a specific challenge organism inactivation and specific to the full scale reactor. In establishing the validated dose, the RED is derated by a “validation factor” (VF) that accounts for the uncertainties associated with the validation process (interpolation, sensor output and dose-response). The VD equals the RED/VF.

The validation of the TAK reactor was conducted using two challenge organisms, Q-beta and T1 bacteriophage and focussed on a performance that was considered typical of conventional indicator organisms (faecal coliforms, E. coli and enterococci). The validation of the reactor was undertaken in 2009 and was based on “second generation” lamps, SLR32143HP. The SLR32143HP lamps have a nominal UV output of 150 watts. Wellington Water confirmed that that TAK reactor currently has a mixture of Philips TUV 260W XPT HO DIM UNP/20 and ECORAY SLR32143 VP (UV output of 125 watts). The predictive form of the validation algorithm provides a determination of RED as a function of flow per lamp, UV transmittance, relative sensor output, organism sensitivity and water depth. Furthermore, the validation algorithm was limited to a minimum RED of 8.75 mJ/cm². At the original nominated design flow of 930 L/s provided by Xylem, the flow per lamp exceeds the upper boundary of the validation envelope by approximately 30 percent (136.2 gpm/lamp vs. 104 gpm/lamp) and this results in a head loss per bank of more than 60 percent greater than acceptable levels (43 mm vs. 26 mm). The maximum permissible flow in which a dose (RED or validated) can be

¹⁷ Palfrey R, Harman M, Moore R (2011) *Impact of Waste Water Treatments on Removal of Noroviruses from Sewage*, R&D Technical Report WT0924/TR, Defra Water Availability and Quality R&D Programme, November 2011.

¹⁸ Nordgren J et al. (2008) *Prevalence of norovirus and factors influencing virus concentrations during one year in a full scale wastewater treatment plant*; Elsevier IWA Water Research publication.

¹⁹ Van den Berg H et al. (2005) *Genetic diversity of noroviruses in raw and treated sewage water*; Res Microbiology. 156 (4) 532-540

²⁰ USEPA 815-R-06-007 (2006) *Ultraviolet Disinfection Guidance Manual For The Final Long Term 2 Enhanced Surface Water Treatment Rule*

determined (i.e. within the upper boundary of the validation envelope) is approximately 710 L/s. Fortunately, this is above the peak flow of 570 L/s proposed in the future when the TAK system is to be operated in a wet weather mode.

The validation of the DURON reactor was more comprehensive utilising four challenge organisms (T7, T1, MS2 and *Bacillus pumilis*) and provides a validation that covers a wide range of sensitivities. The predictive form of the validation algorithm provides a determination of log inactivation (rather than RED only for the TAK) as a function of flow per lamp, UV transmittance, relative sensor output, organism sensitivity and the number of modules in series. RED is determined as the product of the log inactivation and organism sensitivity.

SENSITIVITY OF VIRUSES

It is generally acknowledged that adenoviruses are one of the most resistant organisms of waterborne pathogens (this is one of the primary reasons for their selection in the QMRA – as stated in Appendices to the QMRA report). Previous research has demonstrated that most types (1, 2, 3, 4, 5, 6, 15, 40 and 41) of adenovirus exhibit a similar dose-response relationship. Nwachuku et al ²¹ undertook an evaluation of various UV inactivation's at a UV dose of 90 mWs/cm². Figure 2 shows that the variations in sensitivity to UV irradiation (at 253.7 nm) of the various serotypes 1, 3, 4, 5 and 6 of adenovirus are similar.

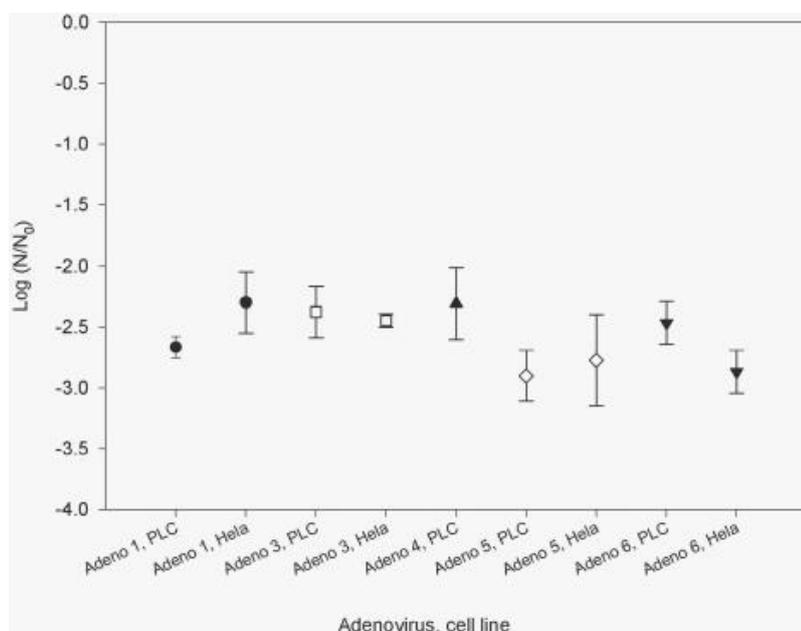


Figure 2: UV inactivation of adenoviruses at a dose of 90 mWs/cm²

The approach used by USEPA to set UV virus inactivation requirements was to identify the most UV-resistant group of viruses currently known, i.e., the adenoviruses. The adenoviruses were then used as the benchmark for all waterborne pathogenic microorganisms, even though many microorganisms, such as hepatitis A virus, rotavirus, and the enteroviruses, are significantly more sensitive to UV than are adenoviruses. Figure 3 from Yates et al²² illustrates the dose response for various adenovirus serotypes which are utilised in the derivation of the guidance described in the

²¹ Nwachuku N, Gerba C. P, Oswald A, and Mashadi F. D. (2005) *Comparative Inactivation of Adenovirus Serotypes by UV Light Disinfection*, Applied Environmental Microbiology

²² Yates M. V, Malley J, Rochelle P, and Hoffman R, (2006) Article in Journal - American Water Works Association, *Effect of adenovirus resistance on UV disinfection requirements: A report on the state of adenovirus science*

UVDGM. The graph indicates that Adenovirus type 41 is the most resistant type which is supported by other literature including Ding et al²³ which showed that a dose of 98 mJ/cm² was required for 1 log₁₀ removal, and IUVA²⁴ (2016) which provides 62 mJ/cm² for 1 log₁₀ removal (based on Baxter et al. 2007). IUVA (2016) is an update on IUVA (2006)²⁵.

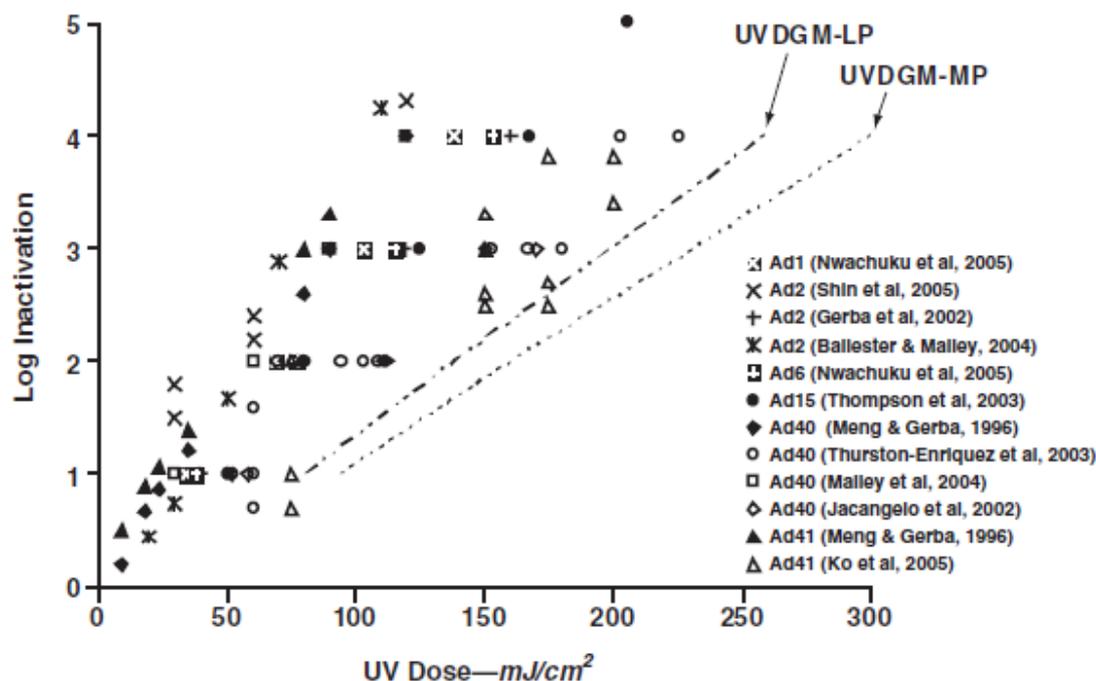


Figure 3: UV inactivation of adenoviruses

For Cryptosporidium, Giardia, and viruses, the USEPA developed UV dose requirements for their inactivation as shown in Table 3 (reproduced from Table 1.4, UVDGM). The virus dose in Table 1.4 is based on adenoviruses as this is, as noted above, the most UV-resistant group of viruses. This dose-response relationship should be adopted as a basis for determining the efficacy of inactivation of adenovirus.

²³ Ding N, Craik S. A, Pang X, Lee B, Neumann N. F. (2017) *Assessing UV inactivation for Adenovirus 41 using integrated cell culture real time qPCR-RT*. Water Environment Research, 89 (4) p323-329.

²⁴ Malayeri A H, Mohseni M, Cairns G and Bolton, J R (2016) *Fluence (UV dose) required to achieve incremental log inactivation of bacteria, protozoa, viruses and algae*.

²⁵ IUVA, (2006) *Biodosimetric charts for UV disinfection data*, IUVA News Volume 8.

Table 3: Table 1.4 from UVDGM

Table 1.4. UV Dose Requirements – millijoules per centimeter squared (mJ/cm²)¹

| Target Pathogens | Log Inactivation | | | | | | | |
|------------------------|------------------|-----|-----|-----|-----|-----|-----|-----|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
| <i>Cryptosporidium</i> | 1.6 | 2.5 | 3.9 | 5.8 | 8.5 | 12 | 15 | 22 |
| <i>Giardia</i> | 1.5 | 2.1 | 3.0 | 5.2 | 7.7 | 11 | 15 | 22 |
| Virus | 39 | 58 | 79 | 100 | 121 | 143 | 163 | 186 |

¹ 40 CFR 141.720(d)(1)

Norovirus and enteroviruses are more sensitive than adenovirus so greater log removals will be obtained with UV disinfection than adenovirus.

Enteroviruses are a group of single stranded RNA viruses that include poliovirus, Coxsackie A and B and echovirus²⁶.

Table 4 provides the published UV doses for 1 log inactivation of norovirus (Wedeco²⁷) and enterovirus (Malayeri et al., 2016).

Table 4: UV dose sensitivity for norovirus and enterovirus

| Virus/type | Dose for 1 log removal (mJ/cm ²) |
|-------------|---|
| Norovirus | 7.6 |
| Enterovirus | 8 (Coxsackievirus B3) 6.9 & 9.8 (Coxsackievirus B5) 8 (Echovirus I) 7 (Echovirus II) |

A dose sensitivity of 9mJ/cm² per log reduction value (LRV) was adopted by Wedeco for the design of the reactor to achieve the designated performance for enterococci reduction from 100,000 to 1,000 cfu/100mL (2 LRV at a dose sensitivity of 9 mJ/cm² provides a RED of 18 mJ/cm²). A comparison with sensitivity values presented in Table 4 also illustrates that a sensitivity of 9 mJ/cm² per LRV is similar (slightly conservative) to that expected for single stranded viruses (norovirus and the various enteroviruses). For the TAK system the disinfection performance was based on

²⁶ IUVA, (2006) *Biodosimetric charts for UV disinfection data*, IUVA News Volume 8.

²⁷ Steve Warne email 20.12.2019 quoting Wedeco for 1 log inactivation of norovirus

faecal coliforms with a dose-sensitivity of approximately 5 mJ/cm² per LRV based on the T1 challenge organism and therefore more sensitive than enterococci.

The dose delivery of the UV reactors have been presented in terms of reduction equivalent dose (and validated dose) as a function of the sensitivity of the target organisms.

For the DURON system the sensitivities of the target organism (D_L) used are based on:

- USEPA UVDGM Table 1.4 dose-response for adenovirus
- An organism having a sensitivity of 9 mJ/cm² per LRV, i.e. for norovirus, various enteroviruses and enterococci, and
- A standard challenge organism, MS2

For the TAK system the sensitivities of the target organism (D_L) used are based on:

- A standard challenge organism, T1
- An organism having a sensitivity of 9 mJ/cm² per LRV, i.e. for norovirus, various enteroviruses and enterococci, and
- A standard challenge organism, Q Beta

The dose response data has been used to assess the potential log inactivation for the new DURON UV disinfection installation at dry weather flows and the DURON and TAK for peak flows, for each of the three viruses modelled in the QMRA.

DURON UV AT AVERAGE FLOWS

As the DURON UV system will be used as the duty UV for flows up to its maximum capacity of 930 L/s, the validated dose, dose sensitivity, reduction equivalent dose, and log reduction values (based on validated dose) for the two average daily flows used in the QMRA of 306 L/s (year 2018) and 440 L/s (year 2043) are provided in Tables 5 and 6.

The design basis UV transmittance values of 60% (5 percentile) was used.

Data is presented for lamps in an end of lamp life (EOLL) condition having a combined ageing and fouling factor of both 0.853.

Table 5: Dose and LRV for viruses at 306 L/s

| Virus | Adenovirus | Norovirus / Enterovirus | MS2 |
|---|------------|-------------------------|------|
| Validated dose (mJ/cm ²) | 63.3 | 44.5 | 53.6 |
| Dose sensitivity (D _L) (mJ/cm ² per LRV) | 53.5 | 9 | 20.9 |
| Reduction equivalent dose (RED) (mJ/cm ²) | 76.1 | 47.0 | 59.0 |
| Log reduction value (LRV) | 1.2 | 4.9 | 2.6 |

Table 6: Dose and LRV for viruses at 440 L/s

| Virus | Adenovirus | Norovirus / Enterovirus / Enterococci | MS2 |
|---|------------|---------------------------------------|------|
| Validated dose (mJ/cm ²) | 46.2 | 34.3 | 40.4 |
| Dose sensitivity (D _L) (mJ/cm ² per LRV) | 57.4 | 9 | 19.8 |
| Reduction equivalent dose (RED) (mJ/cm ²) | 60.6 | 36.7 | 45.5 |
| Log reduction value (LRV) | 0.8 | 3.8 | 2.0 |

DISINFECTION DURING STORM FLOWS

As noted earlier, the upgrading of the WWTP consists of:

- UV disinfection to increase the capacity from 930 L/s to 1500 L/s – proposed June 2021
- Hydraulic upgrade to increase the capacity of the secondary treatment from 1000 L/s to 1500 L/s – proposed June 2023

The new DURON UV system will be used as the duty channel up to its peak capacity of 930 L/s. Flows in excess of that will pass to the TAK UV system. Currently, the network pump capacity limits the flows to the WWTP to 1300 L/s.

Table 7 provides the validated doses for the TAK system at its proposed peak flow of 570 L/s and a reduced UVT of 55% to account for the poorer wastewater transmittance at peak flows. Data are presented for lamps in an EOLL condition.

Table 7: Validated doses for the TAK UV at 570 L/s at UVT of 55%

| Virus | T1 | Norovirus / Enterovirus / Enterococci | Q Beta |
|---|------|---------------------------------------|--------|
| Validated dose (mJ/cm ²) | 12.6 | 17.0 | 18.5 |
| Dose sensitivity (D _L) (mJ/cm ² per LRV) | 4.3 | 9 | 11.2 |
| Reduction equivalent dose (RED) (mJ/cm ²) | 15.1 | 19.1 | 20.4 |

Table 8 provides the validated doses for DURON reactor at its maximum flow of 930 L/s and at 55% UVT. Data are presented for lamps in an EOLL condition.

Table 8: Validated doses for the DURON UV at 930 L/s

| Virus | T1 | Adenovirus | Norovirus / Enterovirus / Enterococci | MS2 |
|--|-----------|-------------------|--|------------|
| Validated dose (mJ/cm ²) | 14.5 | 19.9 | 16.5 | 21.5 |
| Dose sensitivity (D _L) (mJ/cm ² per LRV) | 4.9 | 78 | 9 | 17.8 |
| Reduction equivalent dose (RED) (mJ/cm ²) | 15.7 | 34.5 | 18.7 | 22.7 |

Using T1 as a mechanism to compare the dose delivery of the two UV systems, it is evident that the DURON and TAK system have an equivalent validated dose of approximately 14 mJ/cm² as T1 at the operating conditions of 930 L/s and 570 L/s. Therefore the inactivation (validated LRV of the DURON) of adenovirus would be not expected to exceed more than 0.2 LRV.

Using a sensitivity of 9 mJ/cm² (i.e. associated with enterococci, norovirus and some enteroviruses) as a mechanism to compare the dose delivery of the two UV systems, the DURON and TAK system have an equivalent validated dose of approximately 17 mJ/cm² so the LRV would be 1.9.

SUMMARY

This memo reviews the likely norovirus, enterovirus and adenovirus reduction through the WWTP for the secondary plant and the upgraded UV plant (DURON system), using available relevant information.

Table 9 summarises the estimated log removal of norovirus, enterovirus and adenovirus in the WWTP based on available information during average and wet weather flows of 1500 L/s. These log reductions are based on limited sampling at the Porirua WWTP, literature from virus removal in other secondary activated sludge treatment plants, and the calculated validated doses for the TAK and DURON UV systems with the expected UV transmittance. The log reductions for UV disinfection for average flows are considered to be conservative given that the UV system is designed for the assumed worst case design parameter of UVT (5 percentile). For peak flows through the UV system the assessment uses an assumed UVT of 55% (3 percentile) at peak flows as the treatment plant does not currently receive 1500 L/s.

Table 9 Assumed log removals of norovirus, enterovirus and Adenovirus in the WWTP during average and at 1500 L/s flows

| | Norovirus | Enterovirus | Adenovirus |
|--|------------------|------------------|------------------|
| Secondary Treatment | 2.1 ¹ | 3.2 ² | 2.7 ³ |
| UV disinfection at 306 L/s & 440 L/s | 4.9 & 3.8 | 4.9 & 3.8 | 1.2 & 0.8 |
| Combined secondary and UV at 306 L/s & 440 L/s | >5.0 | >7.0 | >3.0 |
| UV disinfection at 1500 L/s | 1.9 | 1.9 | 0.2 |
| Combined secondary and UV at 1500 L/s | >4.0 | >5.0 | >2.5 |

Notes:

1. Median result obtained for Porirua WWTP, UK study with limited sampling provides results of log₁₀ 1.38 and log₁₀ 2.57, Swedish study provides 1.5 log₁₀ removal.
2. Median result obtained for the Porirua WWTP, Mangere WWTP data (2002 -2016) provides results of log₁₀ 3.66
3. Average result for the Oxley Creek, Brisbane WWTP, other Brisbane WWTP provided results of log₁₀ 2.91 and log₁₀ 3.08, and Mangere WWTP data (2002 -2016) provides results of log₁₀ 3.23.