PROJECT TECHNICAL MEMORANDUM FOR THE NELSON CITY COUNCIL

2877 Nelson Wastewater Treatment Plant (NWWTP)

Date: 07/07/2023

To: Nelson City Council

For the Attention of: Warren Biggs and Lucy Clarke

Project: NWWTP Resource Consenting Project

Subject: Expected Virus Log Removal at NWWTP

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Expected Virus Log Removal At NWWTP

1.1 Introduction

The Nelson Wastewater Treatment Plant (NWWTP) currently discharges treated wastewater to Tasman Bay under a resource consent, which expires in 2024. In preparing a new resource consent application for the treated wastewater discharge, an assessment of public health effects is being carried out for current (2022) and forecasted future (2059) wastewater flows.

A quantitative microbiological risk assessment (QMRA) is being carried out to determine the potential risk of illness associated with recreational uses of the receiving water (Tasman Bay) and shellfish gathering. The QMRA considers various scenarios, including a range of theoretical virus log reduction values (LRV) for the WWTP (ie 1 to 6 log reduction). The LRV range enables the risk of illness to be assessed with no treatment, current level of treatment and a higher level of treatment to better inform the alternatives assessment.

The purpose of this memo is to provide an overview of the expected virus LRV through the current treatment process at NWWTP. The expected virus LRV at NWWTP will be compared to the results of the QMRA separately and is not considered in this memo.

It is noted that log reduction refers to the reduction in concentrations of pathogens through the treatment process – “log” being shorthand for logarithms, which in this case are to base 10 (ie. $\log_{10}$). Essentially the log number is the number of zeros in the reduction efficacy figures – for example a 1,000-fold reduction is referred to as “log 3” reduction. An alternative way of considering the same example is, if the concentration of virus in the wastewater entering NWWTP was 1,000,000 no/100mL and the concentration leaving NWWTP was 1,000 no/100mL, the concentration would have been reduced by 1,000 or log 3 (or 99.9 percent).

1.2 NWWTP

The NWWTP receives primarily residential wastewater from the northern catchment of Nelson City. The wastewater is treated using an oxidation-pond based treatment system and then discharged via an ocean outfall to Tasman Bay.

The treatment process at NWWTP comprises:

- Preliminary treatment – grit trap and step screen, used to remove gross solids
- Flow buffering – flow buffer pond, used intermittently store high wet weather flows. The downstream ponds and wetlands are also used to buffer flows by increasing the operating water level
- Pre-treatment – clarifier and trickling filter, used intermittently to reduce organic and solids loading on the facultative pond.
- Pond-based treatment – facultative pond, maturation pond and wetland system, collectively used to reduce organics, solids and pathogens. Key features of each are:
    - facultative pond (or P1): single pond, surface area of 16 ha, average depth of 1.5m, four surface aerators positioned to minimise hydraulic short-circuiting.
    - maturation pond (or P2): single pond, surface area of 10 ha, average depth of 1.5, partitioned to promote plug-flow (and hence minimise hydraulic short-circuiting)
    - wetland system: two surface flow wetlands (Wetland 1 and Wetland 2), combined surface area of 13.5ha, each wetland has three ‘deep’ cells (60% area, 1m deep) and two ‘shallow’ cells (40% area, 0.3m deep). The shallow areas were originally planted but have all but died with the wetland essentially becoming an extension of the maturation pond. The deep areas were not planted but left as open water.

Typically wastewater is degritted, screened and then gravitates through the facultative pond, maturation pond and wetland system prior to discharge to Tasman Bay, with the pre-treatment bypassed.

Sludge gradually accumulates at the bottom of the ponds. Sludge levels across the pond system are monitored, with intermittent pond desludging occurring as required to maintain an adequate pond clear water depth for algae and to maximise hydraulic retention time. The facultative pond was desludged in 2014. The latest sludge survey, carried out by Southwater in March 2022, showed a high apparent sludge volume in both the facultative pond (32% of normal volume) and maturation pond (36% of normal volume). The wetlands were not surveyed. If the results of the sludge survey are accurate, desludging should be urgently considered.

The pre-treatment system (clarifier and trickling filter) is only used as required for pond health, while the flow buffer pond is only used to treat flows above 33,000 m^3/day. Primary sludge is either thickened on-site, digested at Bell Island WWTP and applied to land or discharged into the facultative pond. The Nelson City Council should consider only off-site primary sludge disposal until pond desludging occurs.

1.3 Expected Virus Log Reduction Value

1.3.1. Background

The key treatment processes that reduce viruses at NWWTP are the facultative pond, maturation pond and wetland system, with the wetland essentially operating as an extension of the maturation pond (ie three ponds in series). The pre-treatment system (clarifier and trickling filter) could provide further virus reduction, however, it is only operated intermittently so was not considered in this assessment.

The primary mechanism for virus reduction in pond-based systems is attributed to sun-mediated mechanisms as well as other mechanisms such as grazing by protozoans and invertebrates, and settlement through virus adsorption onto solids.

Factors[1] that influence virus reduction in pond-based systems include greater sunlight exposure (solar irradiation intensity and day light hours), warmer wastewater temperature, longer hydraulic retention time, shallower pond depth, the number of ponds in series, minimised hydraulic short circuiting, and operating ponds to manage pond organic loading, wastewater turbidity, and pond sludge levels. These factors are considered in NWWTP upgrades as well as day-to-day operations.

Globally, various researchers have reviewed the observed virus reduction through pond-based systems, with some providing typical virus LRV[2] and others deriving models to predict virus LRV based on the observed performance of a variety of pond configurations. Vannoy (2016)[3] presents a first-order plug flow model equation for predicting virus LRV in a pond based on hydraulic retention time and ambient air temperature; the LRV for each pond in series can be summed to yield the total LRV for the pond system.

The Pond Management Plan defines an operating strategy that ensures the overall health of the pond-based system. The Plan includes guideline monthly areal organic loading rates based on typical wastewater temperature, with higher loading rates during summer months. The loading rates are used as a guideline but at any time the actual pond conditions, microbiological heath and performance paired with current and forecasted climatic conditions (temperature, sunshine, wind, rainfall) are the prime consideration. This approach aims to ensure that the actual day-to-day pond loading is within an acceptable range that does not compromise the pond health and performance.

The day-to-day operation of the ponds is overseen by a Pond Management Team. Mitigation measures are deployed as required to maintain pond health and hence performance. These measures include de-loading the facultative pond by operating the pre-treatment system, algal seeding of affected pond from unaffected ponds, and sodium nitrate dosing.

Based on the consistent treated wastewater quality, particularly in terms of soluble Biochemical Oxygen Demand (sBOD), the pond-based system at NWWTP is an optimally functioning and well-maintained system.

Current influent loads to NWWTP are such that the pond loading rate is generally less than the guideline value throughout the year and so the pre-treatment system (clarifier and trickling filter) is seldom used. If influent loads increase as projected, the pre-treatment system will be operated in future to manage pond loading and hence pond health and performance.

1.3.2. Seasonal Variability in Plant Inflow and Ambient Air Temperature

A Process Capability Assessment (PCA) was carried out for NWWTP that considered current (2022) and future (2059) design inflows and loads. However, the assessment was primarily prepared to assess the treatment capacity in terms of flow and removal of solids and organics not virus removal.

Historic variations in NWWTP daily inflows and ambient air temperatures have been reviewed from 2012 to 2022 to understand their seasonal variability and to identify appropriate values to use to provide a conservative of typical virus LRV through the pond system. The following data is summarised in Appendix A:

- temporal variation in daily, 30-day rolling average and 1-year rolling average NWWTP inflows shown in Figure 1 alongside daily rainfall from the Nelson Airport Weather Station. The typical “wet winter”, extreme “wet winter” and typical “drier summer” inflows adopted for the LRV assessment for 2022 are also shown using horizontal blue lines. The extreme flooding event in August 2022 was used as the basis for prolonged inflows during an extreme “wet winter” event, while prolonged high flow events seen in 2017 and 2021 used as the basis for prolonged inflows during typical wet winter events. Drier summer inflows provide a less conservative estimate

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[1] Verbyla, M., von Sperling, M., and Maiga, Y. 2017. Waste Stabilisation Ponds. In: Rose, J.B. and Jimene-Cisneros, B (eds) Global Water Pathogen Project, Part Four, Management of Risk from Excreta and Wastewater

[2] *ibid*.

[3] *Vannoy, KJ, 'Modelling the Extent of Virus Removal in Waste Stabilization Ponds to Support Reuse of Wastewater' (2016). MSc thesis, University of South Florida.*

due to higher hydraulic retention time and higher temperature both positively contributing to higher virus LRV through the pond system.

- Monthly average NWWTP inflows for each year in Table 1
- Monthly average ambient air temperatures from Nelson Airport Weather Station in Table 2.

1.3.3. Range of Predicted Virus LRV

The first-order plug flow model equations developed by Vannoy (2016)[4] were used to predict the virus LRV for the pond system under a range of scenarios. The relevant equations are presented below:

$$K_{v,\,PFM} = \exp\,(0.034902 \cdot T - 0.03656 \cdot t - 1.89011)$$

$$C_e = C_i e^{-K_v \cdot t}$$

Where $K_{v,PFM}$ = virus removal rate coefficient (days^{-1})

T = air temperature (^{o}C)

t = hydraulic retention time, or HRT (days)

C_i = influent virus concentration (viruses/L), and

C_e = effluent virus concentration (viruses/L).

The above equations were used to calculate the virus LRV for each pond in series, which were then summed to yield the total LRV for the NWWTP pond system.

The following scenarios were considered to understand the range in predicted virus LRV:

- Base (2022) and future (2059)“drier” summer flows, assuming 35% population growth (from PCA report). The normal operating water levels were used to estimate ‘summer’ hydraulic capacity.
- Base (2022 and future (2059) typical and extreme “wet” winter flows, assuming wet weather flow is the sum of the “drier” summer flow for the projected year plus the inflow and infiltration seen in the “base” year (2022) increased by 10%. This is a nominal allowance only. The “high” operating water levels were used to estimate ‘winter’ hydraulic capacity during high inflows.
- Base (2022) and future (2059) winter and summer ambient air temperatures, assuming a nominal 1 degree increase in temperature.
- No accumulation and 20% accumulation of sludge across the pond-system, based on normal operating water depths. The recent sludge survey showed a high apparent sludge volume in both the facultative pond (32%) and maturation pond (36%); the wetlands were not surveyed.

The adopted input parameters and predicted virus LRV’s under each scenario are shown in Table 3 in Appendix A. As expected, a lower LRV is predicted for greater inflows, lower air temperatures and greater sludge accumulation. For current (2022) flows with and without 20% sludge accumulation, the predicted virus LRV range for the NWWTP pond system is about 2.3-2.4 in winter and about 3.0-3.2 in summer, with the lower values being with 20% sludge accumulation. For future (2059) flows, the predicted virus LRV range reduces to about 2.1-2.3 in winter and about 2.7-3.0 in summer, with lower values being with 20% sludge accumulation or for extreme wet winter flows. The predicted virus LRV ranges are generally consistent with that presented by others for pond-based systems (see Verbyla (2017), Section 1.3.1).

The period of high wet-weather related inflows during the colder winter months at NWWTP can be prolonged for 1-2 months. This period also coincides with the highest expected seasonal virus bioaccumulation in shellfish. Hence, a conservative estimate of typical minimum virus LRV through the NWWTP pond system for the purpose of assessing public health risks associated with contact recreation (in Tasman Bay) and shellfish gathering is 2.3-2.4 (2022) and 2.1-2.3 (2059), with lower LRV values being with 20% sludge accumulation. The LRV range is based on adopted inflows and ambient air temperatures and assumes that the pond system continues to be well managed and operated optimally, including utilising the flow buffer pond and pond-based system to buffer high inflows as well as monitoring sludge levels across the pond system, with intermittent pond desludging as required.

1.4 Conclusion

The predicted virus LRV for the NWWTP pond-based system for the purpose of assessing public health risks associated with contact recreation (in Tasman Bay) and shellfish gathering is 2.3-2.4 (2022) and 2.1-2.3 (2059), with lower LRV values being with 20% pond sludge accumulation.

The recent pond sludge survey at NWWTP (March 2022) showed a high apparent sludge volume in both the facultative pond (32%) and maturation pond (36%); the wetlands were not surveyed.

It is an estimate of the typical virus LRV expected during periods of high wet-weather related inflows during colder winter months that can be prolonged for 1-2 months at NWWTP. The winter period also coincides with the highest expected seasonal virus bioaccumulation in shellfish which have been observed during cooler seawater temperatures. Higher virus LRV (in the order of 3) is expected during drier, warmer summer months, with intermittent LRV expected during shoulder

[4] *ibid.*

seasons and summer cyclone events. However, the governing period at NWWTP in terms of public health risk are the winter months.

The predicted virus LRV presented above is based on adopted inflows and ambient air temperatures and assumes that the pond system continues to be well managed and operated optimally, including utilising plant flow buffering capacity and actively managing pond sludge levels.

Appendix A: Supporting Information

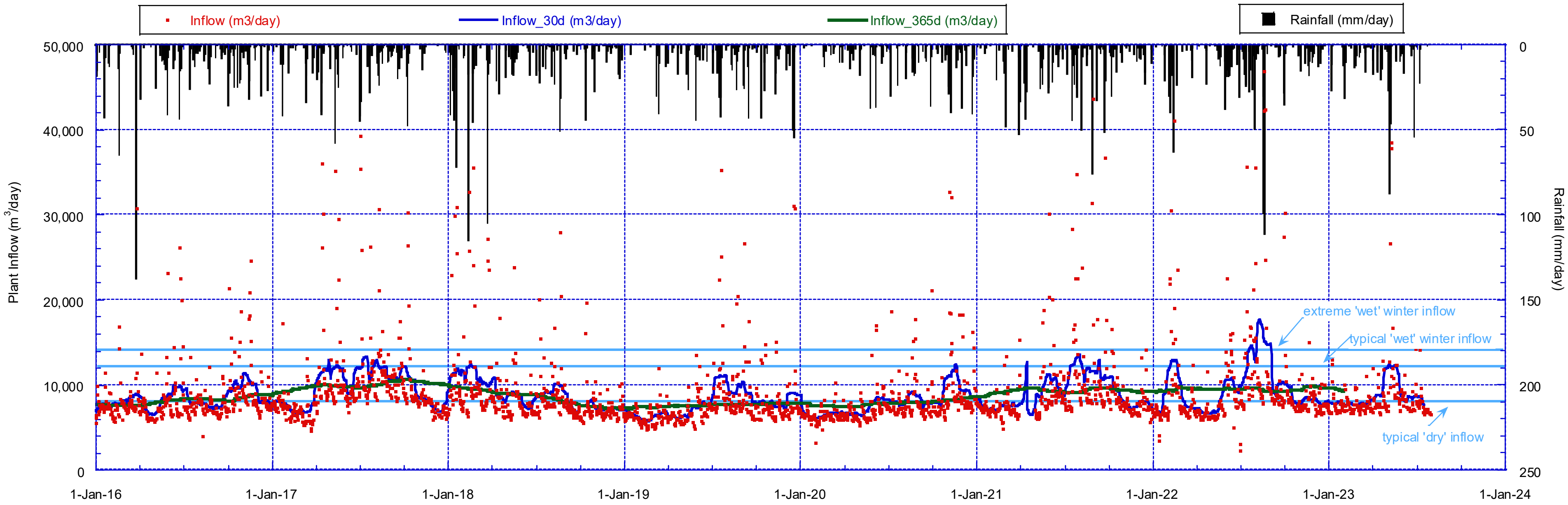

Figure 1 – Variation in NWWTP Daily Inflow and Daily Rainfall

Notes:

[1] Total daily Inflow – red dots; 30day rolling average inflow – blue line; 365day rolling average inflow – green line; rainfall – black bars.

[2] Typical 'dry' inflow, typical 'wet' winter inflow, and extreme 'wet' winter inflow adopted for 'base' (2022) year – light blue

[3] Rainfall from Nelson Airport Weather Station (#4241)

Table 1 – NWWTP Average Monthly Inflow by Year

Average of Plant Inflow, m3/d	Column Labels												
Row Labels	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
2012							8,574	10,909	10,405	8,956	7,586	6,780	8,765
2013	8,209	7,379	7,155	8,590	8,644	11,253	7,267	8,289	8,221	8,202	7,037	6,758	8,082
2014	7,593	6,906	7,298	10,514	8,097	9,703	8,216	7,262	7,624	7,642	7,121	7,710	7,974
2015	7,058	7,508	8,249	7,583	6,847	9,332	8,352	7,846	7,954	6,470	6,974	6,263	7,532
2016	7,756	7,693	8,591	6,926	8,266	9,745	7,745	7,647	7,293	10,343	10,405	7,973	8,366
2017	7,969	6,893	6,864	11,640	12,216	8,787	13,346	12,018	10,824	10,558	8,234	6,831	9,702
2018	11,421	12,631	10,263	8,540	9,075	7,176	8,877	10,126	7,168	7,781	7,124	7,160	8,931
2019	6,537	5,799	6,531	6,214	6,629	7,662	10,954	9,015	9,005	8,090	7,390	9,058	7,758
2020	6,364	6,332	6,657	6,509	6,870	8,402	8,006	9,033	7,789	7,402	11,805	9,287	7,871
2021	7,242	7,105	7,819		9,575	9,951	12,262	11,863	10,780	9,331	7,191	8,025	9,213
2022	6,702	13,488	7,332	6,767	7,041	10,621	12,679	16,468	9,198	9,132	8,455	7,593	9,601
2023	7,817	7,911	7,596	8,793	12,178	8,604	7,640						8,658
Grand Total	**7,697**	**8,142**	**7,669**	**8,208**	**8,676**	**9,203**	**9,501**	**10,020**	**8,751**	**8,537**	**8,120**	**7,585**	**8,517**

Notes: 2017, 2021 and 2022 considered 'wet' years, while 2014, 2015 and 2020 considered 'drier' years.

Table 2 –Average Monthly Ambient Air Temperatures by Year at Nelson Airport Weather Station

Row Labels	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
Average of Tmean(C)													
2012	17.7	17.7	15.5	13.7	10.2	7.9	8.2	10.0	10.6	12.5	14.0	17.8	13.0
2013	17.7	17.8	17.4	14.6	11.2	10.9	8.2	10.3	11.3	13.4	16.2	17.8	14.1
2014	16.9	18.1	16.0	15.1	11.2	10.1	7.6	8.6	11.6	12.8	14.0	17.4	13.2
2015	19.1	17.8	17.5	14.5	10.7	8.8	7.5	8.5	10.3	13.8	14.2	16.8	13.3
2016	19.2	20.3	17.8	14.5	12.4	9.7	8.1	7.9	11.3	13.3	14.9	16.2	13.8
2017	17.4	18.3	17.5	14.4	10.5	8.8	8.2	9.6	11.3	13.8	15.4	19.4	13.7
2018	21.1	18.9	17.5	13.9	11.5	8.0	7.9	9.8	10.7	13.0	14.6	17.9	13.7
2019	20.8	18.6	18.0	13.8	12.3	8.3	8.8	8.5	10.5	12.3	15.3	16.6	13.6
2020	18.2	18.9	16.0	13.6	10.9	10.4	8.6	9.8	11.1	13.1	15.2	16.3	13.5
2021	17.8	17.6	16.2	14.4	11.6	10.4	8.3	9.7	10.5	13.2	15.9	18.6	13.7
2022	19.3	18.5	17.2	15.0	12.5	9.7	9.2	9.9	11.1	12.8	15.9	17.8	14.0
2023	19.2	19.3	16.8	14.7	13.3	10.2	8.9						15.1

Stantec

Table 3 – Estimated Virus LRV for Range of Scenarios with Predicted Flows in 2022 and 2059

			2022					2059				
Parameter Type	Parameter	Unit	typical "wet" winter	extreme "wet" winter	"dry" summer	"wet" winter, sludge	"dry" summer, sludge	typical "wet" winter	extreme "wet" winter	"dry" summer	"wet" winter, sludge	"dry" summer, sludge
Inputs	Inflow	m3/day	12,000	14,000	8000	12,000	8,000	15200	17400	10800	15,200	10,800
	Temp	^{0}C	10	10	17	10	17	11	11	18	11	18
Hydraulic Capacity	Facultative Pond	m3	288,000	288,000	240,000	240,000	192,000	288,000	288,000	240,000	240,000	192,000
	Maturation Pond	m3	180,000	180,000	150,000	150,000	120,000	180,000	180,000	150,000	150,000	120,000
	Wetlands	m3	137,700	137,700	97,200	118,260	77,760	137,700	137,700	97,200	118,260	77,760
Inputs	sludge vol. loss	%				20	20				20	20
	population growt	%						35	35	35	35	35
	I&I growth	%						10	10		10	
	Temp Increase	^{0}C						1	1	1	1	1
Hydraulic Retention Time	Facultative Pond	days	24	21	30	20	24	19	17	22	16	18
	Maturation Pond	days	15	13	19	13	15	12	10	14	10	11
	Wetlands	days	11	10	12	10	10	9	8	9	8	7
Virus LRV	Facultative Pond	(LRV)	0.93	0.90	1.19	0.90	1.19	0.91	0.87	1.21	0.85	1.14
	Maturation Pond	(LRV)	0.81	0.75	1.12	0.74	1.03	0.74	0.68	1.03	0.66	0.91
	Wetlands	(LRV)	0.70	0.64	0.93	0.64	0.81	0.63	0.57	0.80	0.56	0.68
	Total Pond Syster	(LRV)	2.4	2.3	3.2	2.3	3.0	2.3	2.1	3.0	2.1	2.7