Memorandum

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Subject	**Kaikohe WWTP Performance Assessment**	**Project Name**	Kaikohe WWTP Review
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Date	August 11, 2021		
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1. Introduction

Far North District Council (FNDC) are applying for a new discharge consent to allow continued operation of the Kaikohe Wastewater Treatment Plant (WWTP). The current discharge consent CON20100241701 allows for the discharge of treated wastewater into the Wairoro Stream for final discharge into the Hokianga Harbour (Refer Figure 1 for locations). The consent expires in November this year (NRC, 2010). In line with Northland Regional Council's (NRC) Proposed Regional Plan (PRP), it is expected that the new consent will include more stringent effluent discharge conditions.

Figure 1: Kaikohe WWTP Location and Hokianga Harbour Discharge Point (Image sourced from ArcGIS® software by Esri)

The Kaikohe WWTP will require a significant upgrade in the future to meet the discharge conditions outlined in the PRP. A review of the options to meet the expected conditions has been undertaken by others. Implementation of an IDAL treatment process within the existing ponds, and addition of UV disinfection, has been identified as the preferred approach (Harrison Grierson, 2020). Detailed design, construction and commissioning of the full upgrade will take a period of time to complete. In the interim, there are a number of improvements that can be implemented, relatively quickly, to improve the treatment performance of the existing WWTP; many of which could be incorporated into the final upgraded WWTP. These improvements require the new consent to include interim conditions that can be met by these upgrades. Jacobs has been engaged by FNDC to support their application to this effect.

The objective of this scope of work is to develop a set of recommended interim discharge conditions for the consent application and to identify options which can support the WWTP in meeting those interim conditions. The scope is being delivered in two stages:

1) The first stage is a performance assessment of the WWTP, as detailed in this document.
2) The second stage is an assessment of improvements that can be implemented at the Kaikohe WWTP, to support the development of interim consent conditions.

Jacobs have reviewed the Kaikohe WWTP's current performance (including a two-week period of interstage sampling) and developed a model to compare the sampling data with the expected performance of the WWTP as designed. This technical memorandum summarises this work.

2. WWTP Overview

2.1 Flow Basis

The Kaikohe WWTP is located near Cumber Road, adjacent to the Wairoro Stream. It receives wastewater from 8 local pump stations and septage trucks. In addition to Kaikohe and Ngawha townships, the WWTP also services the Northland Regional Corrections Facility (NRCF).

The most recent NZ census reports a population for Kaikohe (including nearby Ngawha) of 4,437 in 2018. This value is higher than the assumed 2020 population reported by Harrison Grierson in their Options Assessment, 4,371, which was based on .id projections (Harrison Grierson, 2020). The NRCF has approximately 600 residents and 100 staff members on site. Outside of the Kaikohe meshblock, it is estimated that an additional 70 to 100 connections to the network exist. For this assessment, a population of 5,210 was assumed.

Flow from the pump stations is measured by an inlet flowmeter immediately upstream of the Anaerobic Pond. Septage trucks connect to the pond separately. A flowmeter is available to measure the volume of septage received, however this is currently not being used while the inlet screen is away for repair. Instead, truck drivers are required to manually report unloading volumes to the WWTP operators.

A summary of the flow basis for the performance assessment is given in Table 1. Data from the site's logbook was used to characterise the inlet and outlet flows for the two-year period between May 2018 to April 2020). Septage data was provided by FNDC for each truck unload between January 2020 and February 2021. According to this data, no septage was received by the Kaikohe WWTP for 6 out of the 14 months. The average monthly volume reported in the table below considers only months where septage was received.

Table 1: Influent flow summary for the Kaikohe WWTP.

Basis	Unit	Value
Population Serviced[1]	No.	5,210
Influent Flow		
Average	m^3/day	1,662
Median	m^3/day	1,339
90th Percentile	m^3/day	2,718
Maximum	m^3/day	9,235
Septage Volumes		
Monthly Average[2]	m^3/month	588
Average Dry Weather Discharge[3]	m^3/day	1,871

1. Census population of Kaikohe in 2018 (NZ Census, 2018) plus assumed additional connections, NRFC residents and staff.
2. Monthly average calculated considering only months where septage was received (Jan, Feb, Jun, Aug, Sep, Nov, Dec 2020).
3. A “dry weather discharge day” is defined any day on which there is less than 1 mm of rainfall, occurring after three consecutive days each with no or less than 1 mm of rainfall.

The total volume of septage received by the WWTP in 2020 was 4,711. This is less than 1% of the total annual influent volume based on an average flow of 1,662 m^3/day. However, despite the small volumetric contribution of these flows, the attributed contaminant loading is high and requires consideration. The estimated influent loading to the WWTP based on these flows is discussed in Section 3.2.

2.2 Process Overview

The Kaikohe WWTP process treatment consists of an anaerobic pond, an oxidation pond, a maturation pond, a series of constructed surface flow wetlands (CWL) and a natural wetland (NWL). A sludge lagoon exists which receives high solids septage that is too thick to pump into the Anaerobic Pond. A screening device is usually installed to remove debris from influent wastewater; however, at the time of this review this had been removed for repair and a new screen is on order. The screen will be reinstalled once repaired/replaced. Treated effluent is discharged to the adjacent Wairoro Stream via a notched weir in the last CWL. A process flow diagram of the WWTP is shown in Figure 2.

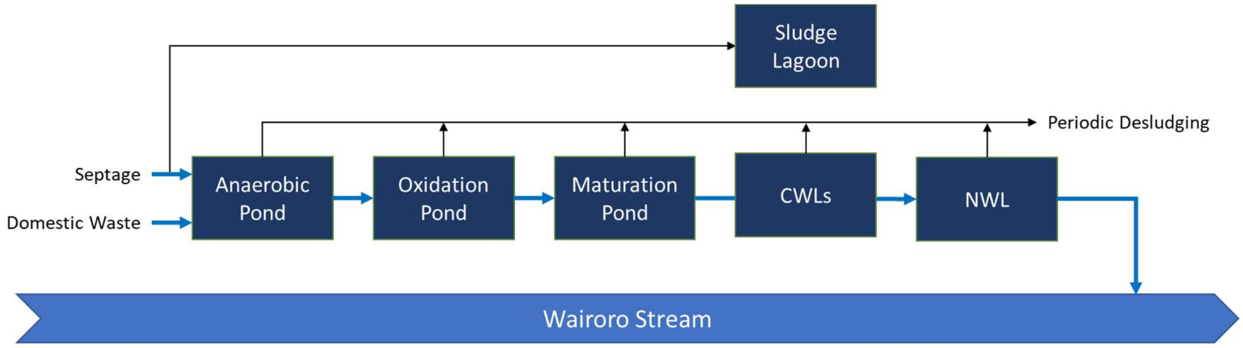

Figure 2: Process flow diagram of Kaikohe WWTP.

A summary of each treatment pond is given provided in Table 2.

Table 2: Kaikohe WWTP pond details.

			Anaerobic Pond	Oxidation Pond	Maturation Pond	CWLs	NWL
Surface Area	A	m^2	1,500	43,000	8,100	5,000	10,000
Depth	d	m	2.00[1]	1.47[2]	1.10[1]	0.50[1]	0.50[1]
Volume	V	m^3	2,000	63,210	8,910	2,500	5,000
Retention Time	θ	days	1.2	38.0	5.4	1.5	3.0

1. Assumed depth based on 2001 plan (Thomson & King Ltd, 2001).
2. Assumed depth based on 2018 oxidation pond sludge survey (Conhur, 2018).

2.3 Current Monitoring

A flowmeter is installed on the inlet pipeline to the anaerobic pond. BOD and TSS loading is measured annually during February-March. A combination of in-situ parameters (temperature, pH and Dissolved Oxygen (DO)) are measured at different points through the WWTP process, as shown in Table 3 below. The current discharge consent specifies four locations to monitor discharge (treated effluent) and receiving (Wairoro Stream) water flows and is summarized in Table 3:

- **CWL:** Outlet of the CWL
- **NWL:** Outlet of NWL (30 m U/S of entry into Wairoro Stream)
- **U/S:** Upstream of discharge point, in Wairoro Stream (25 m U/S)
- **D/S:** Downstream of discharge point, in Wairoro Stream (80 m D/S)

Table 3: Consent Monitoring Sampling Summary

Parameter	Anaerobic Pond	Oxidation Pond	CWL	NWL	U/S	D/S
Temperature	✓	✓	✓		✓	✓
pH	✓	✓	✓		✓	✓
Dissolved Oxygen (DO)		✓	✓		✓	✓
5-day Biological Oxygen Demand (BOD_5)			✓			
Total Suspended Solids (TSS)			✓			
Total Ammoniacal Nitrogen (NH_4^+N)			✓		✓	✓
Dissolved Inorganic Nitrogen (DIN)			✓		✓	✓
Total Nitrogen (TN)			✓			
Dissolved Reactive Phosphorous (DRP)			✓		✓	✓
Total Phosphorous (TP)			✓			
E. coli			✓		✓	✓
Hue					✓	✓
Microcystin-LR and blue-green algae					✓	✓

A schematic showing the physical layout of the WWTP and monitoring locations is shown in Figure 3. The current discharge standards are provided in Table 9 in Section 3.5.

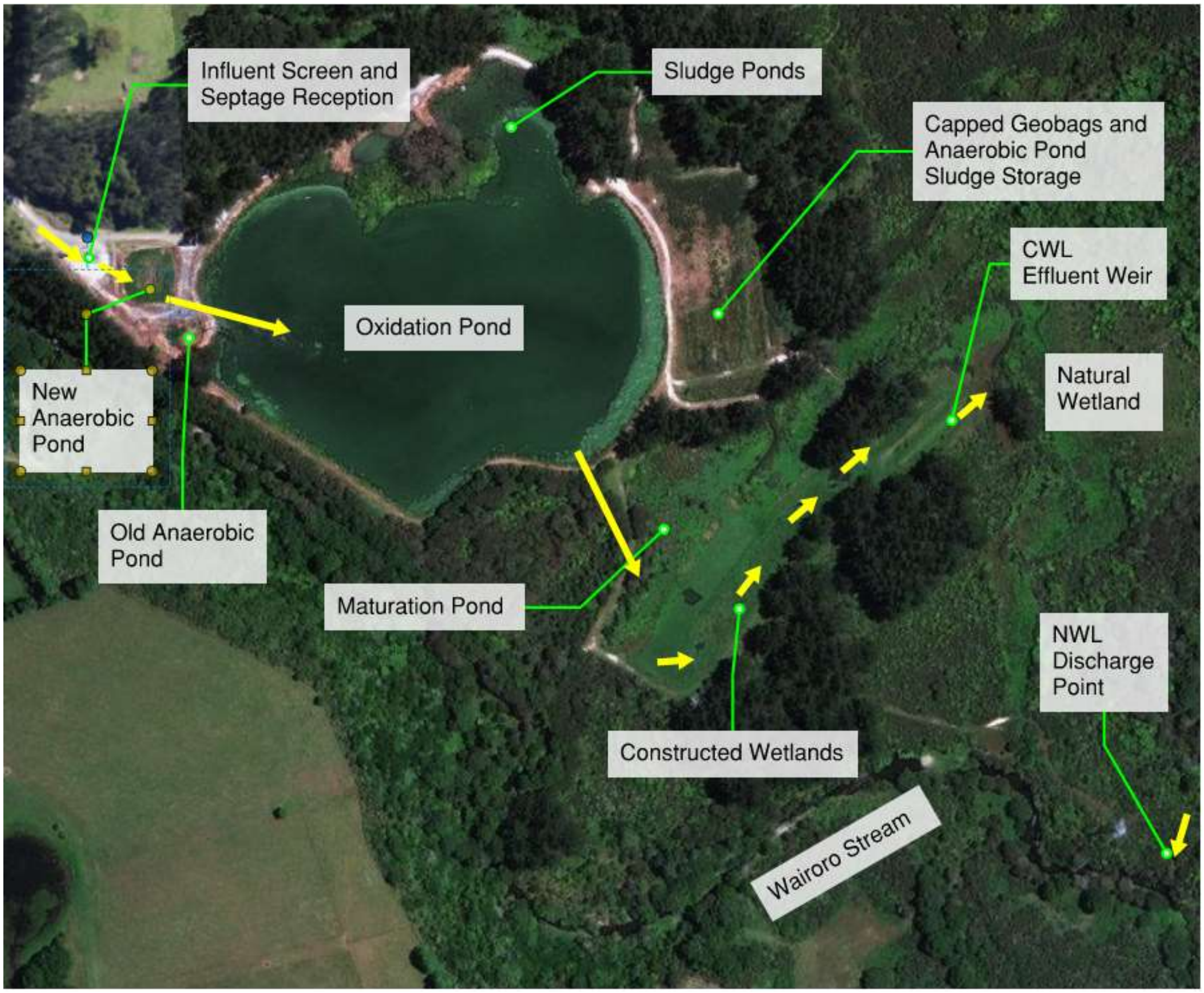

Figure 3: Kaikohe WWTP Overview (Image sourced from ArcGIS® software by Esri).

3. Current WWTP Performance

The Kaikohe WWTP is a pond-based system that primarily targets BOD and solids removal. Natural disinfection (E. coli removal) and nutrient removal (nitrogen and phosphorous) occur in the oxidation pond, maturation pond and wetlands. Treatment performance is measured by the effectiveness of these removal processes and compliance with consent discharge conditions.

3.1 Discharge Conditions

The current discharge consent for the WWTP was issued in August 2005 and will expire in November this year. It originally stipulated a disinfection plant to be installed within two years to achieve a 4-log reduction in F-specific bacteriophage (a viral indicator organism), following which the WWTP could cease monitoring the median E. coli concentration. However, this plant was never installed, and in April 2011, the condition was deleted from the consent.

The consent allows the Kaikohe WWTP to discharge treated wastewater to the Wairoro Steam subject to conditions that specify monitoring and reporting requirements in addition to discharge limits. As discussed in Section 2.3, monitoring occurs at four locations, as specified in Section 2.3 (CWL, NWL, U/S and D/S). Specific discharge limits apply to the WWTP effluent and the effect on the receiving Wairoro Stream. A description of these limits and their compliance monitoring locations are given in Table 4.

Table 4: Specific limits in the Kaikohe WWTP discharge consent relating to treated wastewater.

Condition No.	Parameter	Specified Limit	Location
1	Discharge volume	Shall not exceed 1,710 m^3/day (based on a 30-day rolling average of dry weather discharges)[1]	CWL
7(a)	Temperature	Shall not change by more than 3 °C	U/S and D/S
7(b)	pH	Shall remain with the range 6.5 to 9.0.	D/S
7(c)	DO	Shall not be reduced by more than 20% (based on daily minimum concentration)	U/S and D/S
7(d)	Hue	Shall not be changed by more than 10 Munsell units	U/S and D/S
7(g)	Microcystin-LR	Shall not exceed 2.3 µg/mL	D/S
7(g)	Blue-green algae	Shall not increase by more than 50 cells/100mL.	U/S and D/S
7(h)	E. coli	Median cell concentration shall all not increase by more than 50 per 100mL	U/S and D/S
7(i)	Ammoniacal Nitrogen	Shall not exceed the limits specified within the consent[2]	D/S

1. A “dry weather discharge day” is defined any day on which there is less than 1 mm of rainfall, occurring after three consecutive days each with no or less than 1 mm of rainfall.
2. The consent provides a table of acceptable concentrations for pH values between 6.0 to 9.0.

3.2 Influent Loading

The influent flow to the Kaikohe WWTP is measured continuously by a flowmeter fitted to the anaerobic pond inlet. As required by the discharge consent, BOD_5 and TSS is measured annually during February-March on a minimum of four consecutive days under dry weather discharge conditions. The influent sampling uses 24-hour composite samples, however there is a risk that septage received during the sampling period is not captured in these samples.

Jacobs have calculated the contribution to the WWTP load from septage using the monthly septage data provided. We have assumed typical domestic septage concentrations per the US EPA design guide for domestic sewage Table 11-1 (US EPA, 1995). Our approach to estimation of the WWTP influent load differs from that used by Harrison Grierson in their options assessment report (Harrison Grierson, 2020), therefore our calculated influent loads differ to those used in their review. Harrison Grierson's influent BOD_5 and TSS load were calculated based on the average concentration of the influent samples multiplied by the average flow to provide an estimated load. Nutrients loads were calculated on a per capita basis, which is similar to our calculation for the load from the sewer network but do not appear to have accounted for the septage load. Hence the loads calculated in this report are higher as the septage load has been assed to the per capita loading to get our influent loads.

For the reticulated sewer network, average concentrations, and daily loads of BOD_5 and TSS entering the WWTP between May 2018 and April 2021 were determined from logbook data. Loads for TN, NH_3 and TP were also determined for later comparison with the WWTP effluent load. These were calculated on a per capita basis using typical New Zealand domestic wastewater values sourced from AS/NZS 1546.3. The corresponding concentration was estimated an average influent flow of 1,662 m^3/day (as per logbook data for the two-year period between May 2018 to April 2020).

The total estimated load to the WWTP includes the contribution of the reticulated sewer network and septage and is summarized in Table 5.

Table 5: Average influent load to the Kaikohe WWTP based on logbook data between May 2018 and April 2020 and per capita estimates.

Parameter	Average influent Concentration (g/m^3)	Domestic Load (kg/day)	Septage Load (kg/day)[3]	Total Load (kg/day)
BOD_5	271	328	127	455
TSS	453	516	251	767
TN[2]	56[1]	94	12	105
NH_4-N[2]	50[1]	83	10[4]	83
TP[2]	9[1]	16	4	20

1. Based on the average influent flow rate of 1,662 m^3/day between May 2018 and April 2020.
2. Based on typical New Zealand production values (Standards New Zealand, 2008):
   i. TN – 18 g/capita/day
   ii. TP – 3 g/capita/day
   iii. NH_3N – 16 g/capita/day
3. Based on US EPA Design Guide for Domestic Sewage Table 11-1 and septage flow data.
4. 90% of predicted influent TKN associated with septage has been converted to NH4-N for the purposes of this loading table to reflect conversion which takes place in the treatment process to provide an accurate comparison with the effluent.

3.3 Effluent Loading

Treated wastewater is discharged from the Kaikohe CWL via a v-notch weir and flow is measured using a laser flow meter. As required by the discharge consent, BOD_5, TSS, NH_4^+N, TN, DIN, TP, DRP and DO concentrations are determined fortnightly from November to April, and monthly for the rest of the year.

Average concentrations and daily loadings of contaminants exiting the WWTP between May 2018 and April 2021 were determined using logbook data. The results are provided in Table 6.

Table 6: Average effluent load from the Kaikohe WWTP based on logbook data between May 2018 and April 2021.

Parameter	Average Concentration (g/m^3)	Average Load (kg/day)
BOD	19	31
TSS	54	81
DIN	51	76
TN	38	74
NH_4^+N	36	63
DRP	4	8
TP	6	11
DO	4	7

3.4 Overall Removal Efficiency

Table 7 provides a comparison (where possible) of the influent and effluent loads. The removal percentage of key contaminants by the Kaikohe WWTP is shown as an indication of current WWTP performance. Note: As we have accounted for the influent load of the septage received at the WWTP the performance in terms of nutrient removal is higher than presented in the Harrison Grierson Options Assessment Report (Harrison Grierson, 2020).

Table 7: Kaikohe WWTP loadings and overall removal efficiency based on logbook data between May 2018 and April 2020.

Parameter	Average Influent Load (kg/day)	Average Effluent Load (kg/day)[2]	Removal Efficiency
BOD	455	31	**93%**
TSS	767	81	**89%**
TN	105[1]	74	**29%**
NH_4^+N	94[1]	63	**33%**
TP	20[1]	11	**44%**

1. Based on the average influent flow rate of 1,662 m^3/day between May 2018 and April 2020.
2. Based on effluent load as reported in the logbook between May 2018 and April 2020

E. coli concentrations are determined at each of the four monitoring locations during October-November, February-March, and July-August. Results from the U/S and D/S samples measure the impact of the WWTP discharge to the receiving stream, as required by the consent. Results from the CWL and NWL samples can be used to determine the reduction in E. coli achieved by the final treatment stage. Table 8 shows the average median cell count of E. coli at the CWL and NWL monitoring locations for the period May 2018 to April 2021. A removal efficiency is provided for NWL.

Table 8: E. coli cell count at consent sampling points.

	After CWL	After NWL	NWL Removal Efficiency
Median cell count (MPN/100 mL)	7,701	2,078	< 1 log

Table 8 shows the removal efficiency of E. coli within the NWL but omits any treatment prior to this stage.

3.5 Compliance with Discharge Consent

Table 9 compares the WWTP performance against current consent standards over the three-year period from May 2018 to April 2021. Exceedances refer to events where the measurements are above or below the consented limit. The Frequency column presents the number of exceedance events as a percentage of the total number of measurements taken throughout the three-year period.

Table 9: Kaikohe WWTP discharge standards and recent water quality (2018 to 2021).

Parameter	Basis	Consent Limit	Exceedances	Frequency
Flow[1]	30 day rolling average of dry weather discharges at CWL	1,710 m^3/day	579	79%
Temperature	Change in temperature from U/S to D/S	< 3 °C	0	0%
pH	pH at D/S	6.5 to 9.0	2	4%
DO	Reduction in concentration from U/S to D/S	> 80%	6	12%
Toxicity	Microcystin-LR concentration at D/S	2.3 µg/L	0	0
Toxicity	Blue algae cell count at D/S	11,500 c/mL	0	0
E. coli	Increase in median E. coli concentration from U/S to D/S	50 MPN/100mL	5	50%
NH_4^+N	NH_4-N concentration at D/S	(as per consent)	28	52%

1. Data available until May 2020 only.

As shown in Table 9, the Kaikohe WWTP has breached consent conditions numerous times over the last three years. These breaches occur regularly for flow and ammonia limits. Flow data was only available to 2020, therefore only a two-year data period was considered and the 579-exceedance events account for 79% of this time. Operators report that incorrect readings from the CWL outlet ultrasonic flowmeter occur periodically due to surface weed growth from the ponds passing through the weir. However, given the average influent flow rate to the WWTP between May 2018 and April 2020 was 1,662 m3/day, coupled with the capacity of the WWTP to collect and retain rain water during wet weather conditions, it is likely the effluent leaving the WWTP exceeds the consented limit, especially in winter. Interim consent conditions should take the actual effluent flow rate into account. Jacobs recommends that an average and 95th percentile dry weather flow condition be pursued, rather than a maximum limit as in the current consent.

Ammoniacal nitrogen consent exceedances have occurred since the start of the logbook data in 2010. These exceedances typically occur in summer during low flows in the Wairoro stream. The period where the stream ammoniacal nitrogen measurements exceed the consent limits have expanded in recent years to include from November through to June. There has been an increasing trend in the effluent ammoniacal nitrogen concentration measured at the CWL and NWL discharge sampling points, indicating a decline in WWTP performance over time. When considering interim consent conditions an “end of pipe” effluent concentration is recommended as this removes the influence of environmental factors that cannot be controlled. For the long-term consent an end of pipe discharge condition will require review of the environmental impacts of that condition, however the interim conditions should be linked to the anticipated WWTP performance that can be achieved.

Several investigations have been conducted by FNDC in the past to understand the consequence of effluent ammonia levels on aquatic life in the river and possible ways to rectify these. Previously proposed upgrades to the WWTP include aeration (VK Consulting Environmental Engineers, 2000) and Floating Treatment Wetlands (Fog, 2010). These will be discussed in the options assessment as part of the next stage of this scope of work.

4. Interstage Sampling and Analysis

4.1 Interstage Sampling Programme

Grab sampling and testing at the Kaikohe WWTP was completed to support this assessment. A sampling programme was developed to provide more complete influent sampling data as well as to inform the performance of the individual unit processes. Of particular interest was the anaerobic pond effluent sampling for nitrogen species, as this captures the septage load which is not typically captured in influent sampling due to the intermittent nature of septage unloading. The water sampling regime recommended by Jacobs to FNDC for this activity is given in Table 10. The purpose of this sampling programme was to obtain results to validate the assumed current WWTP performance, discussed in Section 3, and the model used to represent the Kaikohe WWTP, discussed in Section 5

Table 10: Sampling regime for Kaikohe WWTP Review.

Location	In-Situ Parameters[1]	NH_3-N	BOD_5	TSS	TN	TKN	E. Coli
Influent	✓	✓	✓	✓	✓	✓	✓
Anaerobic Pond Effluent	✓	✓	✓	✓	✓	✓	
Oxidation Pond Effluent	✓	✓	✓	✓	✓	✓	✓
CWL NRC#100562 (constructed wetland effluent)	✓	✓	✓	✓	✓	✓	✓

1. In-situ parameters include pH, temperature, and DO.

4.2 Sample Results

Grab samples were taken daily (including weekends) for two weeks between 9am and 12pm from the 29th of June to the 11th of July 2021. The data was reviewed, and outliers omitted before the measured BOD_5 and nitrogen fraction concentrations were converted to loads (all loads are based on the influent flow). The average values of sample test results over the 14-day period are given in Table 11. In addition to the sample locations recommended in Table 10 above, a single grab sample was taken at the septage site on the 8th of July and grab samples were taken at the outlet of the maturation pond, immediately upstream of the first CWL cell for the last three days of sampling.

Table 11: Average values test results for the two-week interstage sampling programme.

Location	DO (mg/L)	pH -	T (°C)	NH_3-N (kg/d)	BOD_5 (kg/d)	TSS (kg/d)	TN (kg/d)	TKN (kg/d)	E. Coli (MPN/100 mL)
Septage[1]	0.85	7.68	12.70	342	217	418	434	5294	-
Influent	3.36	7.60	16.37	77	425	121	126	502	13,175,000
Anaerobic Pond	1.35	6.86	15.89	68	230	96	100	312	3,908,000
Oxidation Pond	7.24	7.24	11.29	46	48	59	57	78	433,000
Maturation Pond[2]	4.28	7.38	11.33	46	40	53	56	53	69,000
CWL	3.02	7.10	9.61	45	26	51	52	50	20,000

1. Results from a single sample only, taken 8th July 2021 at 9:45 am.
2. Results from three samples only, taken 8th, 10th, and 11th July 2021 between 9:15 am and 12:00 pm.

Flow data was obtained for the two-week sample period. Measurement of the influent flow generated data that was considered reliable. However, data collected on the effluent flow was found to be reliable due to issues with the measurement location and has been excluded from further review. A summary of the influent flow is given in Table 12.

Table 12: Influent flows at the Kaikohe WWTP during the two-week sample period.

	Influent Flow (m^3/day)
Minimum	1,718
Average	2,085
Maximum	2,442

4.3 Comparison with Current WWTP Performance

Table 12 shows the average influent and effluent flow at the Kaikohe WWTP between the 29th of June 2021 and the 11th of July 2021 was 1,976 m^3/day and 1,075 m^3/day, respectively. These values have been used to determine the average influent and effluent loads to the WWTP for the two-week sampling period. Table 13 and Table 14 give the average concentrations and total loads of the WWTP influent and effluent, based on sample data. This is compared to the estimated loads for the current WWTP performance as detailed in Section 3, which were calculated using logbook data and per capita values. An overall removal efficiency has also been assessed for the two-week sample period and compared to the original estimate, as shown in Table 15.

Table 13: Average influent load to the Kaikohe WWTP during the two-week sampling period compared to the original estimate based on logbook data between May 2018 and April 2020 and per capita values.

Parameter	May 2018 – April 2020 (see Table 5)		Interstage Sampling	
	Average influent Concentration (g/m^3)	Total Load (kg/day)[1]	Average influent Concentration (g/m^3)	Total Load (kg/day)
BOD_5	271	455	206	425
TSS	453	767	249	502
TN	56	105	62	126
NH_4-N	50	83	38	77
TP	9	20	-	-

1. Including septage loads which are not captured in the average influent concentration, see Table 5.

Table 14: Average effluent load from the Kaikohe WWTP during the two-week sampling period compared to the original estimate based on logbook data between May 2018 and April 2020.

Parameter	May 2018 – April 2020 (see Table 6)		Interstage Sampling	
	Average effluent Concentration (g/m^3)	Total Load (kg/day)	Average effluent Concentration (g/m^3)	Total Load (kg/day)
BOD	19	31	12	26
TSS	54	81	24	50
DIN	51	76	-	-
TN	38	74	25	52
NH_4^+N	36	63	22	45
DRP	4	8	-	-
TP	6	11	-	-
DO	4	-	3	-

Table 15: Kaikohe WWTP loadings and overall removal efficiency during the two-week sampling period compared to the original estimate based on logbook data and per capita values.

Parameter	May 2018 – April 2020			Interstage Sampling		
	Average Influent Load (kg/day)	Average Effluent Load (kg/day)	Removal Efficiency	Average Influent Load (kg/day)	Average Effluent Load (kg/day)	Removal Efficiency
BOD	455	31	**93%**	425	26	**94%**
TSS	767	81	**89%**	502	50	**90%**
TN	105	74	**29%**	126	52	**59%**
NH_4^+N	94	63	**33%**	77	45	**42%**
TP	20	11	**44%**	-	-	**-**

Based on the data obtained during the two-week sampling period, Table 15 indicates that the WWTP is operating in line with the long-term average for removal efficiencies of BOD and TSS. In the case of TN and NH_4N removal, the measured removal efficiencies are higher than the long term average. This may be caused by a number of seasonal or other factors including, temperature, BOD and Nitrogen loading rates which may not be indicative of long term performance. It should also be noted that this data considers only a small volume of the wastewater received and discharged by the WWTP over a short period. Grab samples are often inaccurate in representing the flow streams from which they are taken. Longer-term data is required to depict the removal efficiencies of the WWTP more accurately.

5. Model WWTP Performance

A model of the Kaikohe WWTP was developed using MS Excel to determine the theoretical performance of the WWTP. The model comprises of three different waste stabilization pond (WSP) types: anaerobic, facultative and maturation, each of which considers different treatment mechanisms for BOD, E. coli, and TN. The pond types are employed to represent the four treatment stages at the Kaikohe WWTP. The correlation between the WSP model and Kaikohe WWTP process is shown in Table 16.

BOD and E. coli reduction are well represented in literature by first order kinetic equations that have proven effective when predicting these biological mechanisms. However, modelling of TN is less defined. Test methods for ammonia are sensitive to a range of factors, meaning it is difficult to compare data sets between sources and therefore determine a numerical prediction method. For pond systems, the nitrification process is highly dependent on pH, temperature, HRT and BOD levels. Equations proposed by Pano and Middlebrooks (1982) for ammonia removal were used for comparative purposes only. TSS and TP are not considered in the model.

Table 16: Correlation of Kaikohe treatment stages to the WSP model.

Kaikohe WWTP Stage	Removal Mechanism	Primary Function	Model Pond Type
Anaerobic Pond	Anaerobic digestion, sedimentation	BOD removal	Anaerobic
Oxidation Pond	Oxidation, UV disinfection, nutrient removal, algal incorporation	BOD pathogen and nutrient reduction	Secondary Facultative
CWLs	UV disinfection, nutrient removal, algal incorporation	Pathogen and nutrient reduction	Maturation
NWL	UV disinfection, nutrient removal, algal incorporation	Pathogen and nutrient reduction	Maturation

Data inputs to describe the influent entering the model were determined using average values of logbook data obtained between May 2018 and April 2021, as shown in Table 5, Section 3.2.

5.1 Stage 1 – Anaerobic Treatment

The first stage of treatment is the 1,000 m^2 anaerobic pond (assumed depth is 2 m) which was constructed after 2006. The pond is intended to provide solids and BOD removal as well as anaerobic digestion of the settled sludge.

Retention times in anaerobic ponds are typically only one or two days, with most of the BOD removal occurring within the first 0.8 days (Mara, 2003). Nutrient removal and disinfection of the wastewater occurs in aerobic conditions (e.g. in facultative and maturation ponds) and is therefore not included in the WSP model at this stage. Assuming the retention time is at least 0.8 days (within which the majority of BOD removal is assumed to take place), the WSP model considers BOD removal as a factor of temperature only, as given by the design equations in Table 17 below.

Table 17: Design Values of Volumetric BOD Loadings and Percentage Removals for Anaerobic Ponds (Mara, 2003).

Temperature (°C)	Volumetric Loading ($g\ BOD_5/m^3/day$)	BOD Removal (%)
< 10	100[1]	40
10 - 20	20T - 100	2T + 20
20 - 25	10T + 100	2T + 20
> 25	350[2]	70

1. The recommended lower limit for design to maintain anaerobic conditions.
2. The recommended upper limit for design to provide an adequate margin of safety with respect to odour.

Temperature recordings for the anaerobic pond are available in the site logbook, the most recent taken in April this year. The recommended BOD loading capacity and resultant removal for the pond was assessed using the average temperature for the last three years (May 2018 to April 2021) and an assumed minimum temperature of 10 °C. The results are shown in Table 18 below.

Table 18: Model Values for Volumetric BOD Loading and Removal for the Kaikohe Anaerobic Pond.

	Temperature (°C)	Volumetric Loading ($g\ BOD_5/m^3/day$)	BOD Removal (%)
Average Temperature	20.9	308	62
Minimum Temperature	10.0	100	40
Interstage Sampling Period Temperature	15.0	200	50

Based on the table above, the Kaikohe anaerobic pond is expected to remove up to 62% of BOD_5 based on a volumetric loading rate of up to 308 g BOD_5/m^3/day during average temperatures. Based on logbook data from May 2018 to April 2021, the current average BOD loading for the anaerobic pond is 228 g BOD_5/m^3/day.

During the two-week sampling period, the anaerobic pond had an average temperature of approximately 15 °C. According to Table 17, at this temperature the pond is expected to remove up to 50% of BOD_5 based on a volumetric loading rate of up to 200 g BOD_5/m^3/day 200. Results obtained from grab samples during this period showed that the anaerobic pond was achieving an average BOD_5 removal rate of 47% at an average BOD loading of 200 g BOD_5/m^3/day. This indicates the pond can achieve design removal rates when appropriately loaded, however the grab samples do not give an accurate representation of the loading of the pond over time and do not necessarily account for septage. For the purpose of this review, these results validate the use of the design equations in Table 17 for the WSP model BOD_5 removal. However, it should be noted that the sample data also shows removal of E. coli and NH4N occurring in the anaerobic pond, which is not considered in the model for this treatment stage (see Section 5.5).

5.2 Stage 2 – Oxidation Pond

The Kaikohe oxidation pond originally had a total surface area of 4.8 ha (FNDC, 2006). However, some of the pond has been separated into two storage lagoons for high solids septage. The area of the pond left for oxidation purposes has been reduced to approximately 4.3 ha, based on measurement from FNDC GIS and accounting for the loss of pond area to the sludge storage lagoons. According to a sludge survey done in 2018, it has an average depth of 1.47 m (Conhur, 2018).

This pond has a high retention time of up to 38 days which allows for further BOD removal, some nutrient removal, and pathogen reduction through UV disinfection. Nutrient removal occurs by a number of mechanisms including the transformation of organic nitrogen into ammonia, the incorporation of ammonia into algal cells and volatilization (Mara, 2003). Ammonia is also removed via nitrification, provided there is sufficient retention time and DO to grow and feed the nitrifying bacteria and low enough soluble BOD concentration so that competition with heterotrophs is reduced. The impact of high BOD inhibiting ammonia reduction has been incorporated into the model by reducing the residence time allocated to nitrogen removal. The residence time for nitrogen removal has been allocated as the total residence time in the pond less the time required for the effluent to reach 30mg BOD_5/L. This threshold concentration has been selected to achieve a 10mg/L concentration of soluble BOD as referenced for nitrification in fixed film reactors (Metcalf & Eddy Inc., 2013) with the assumption that soluble BOD makes up around 30% of the total BOD in the pond effluent (Mara, 2003).

The WSP model approximates the removal of BOD and E. coli using first-order removal kinetics. Rate constants and equations for nitrogen removal in facultative and maturation ponds were sourced from literature. Table 19 shows the input values used to model the Kaikohe oxidation pond. Average temperature and pH values were determined from logbook data for oxidation pond measurements over the last three years (May 2018 to April 2021).

Table 19: Input variables for the Kaikohe oxidation pond (modelled as a facultative pond).

Stage 2 - Oxidation Pond				Ref.
Pond Type		Secondary Facultative		
Surface Area	A	m^2	43,000	FNDC GIS
Volume	V	m^3	63,210	Average depth from latest sludge survey (Conhur, 2018)
pH	pH	-	7.55	Site logbook
Liquid Temperature	T	°C	19.47	Site logbook

Table 20 gives the results for the approximated BOD and NH_4N removal and compares these to the average results obtained from interstage testing over the two-week sample period. Table 21 gives the log reduction value for E. coli obtained from both sample data and the WSP model.

Table 20: Results for BOD and NH_4N removal in the Kaikohe Oxidation Pond from sample data and the WSP model.

		Interstage Sampling			From WSP Model		
Contaminant	**Unit**	**Influent**	**Effluent**	**Removal**	**Influent**	**Effluent**	**Removal**
BOD	g/m^3	109	23	79%	105	22	79%
NH_4-N	g/m^3	33	22	33%	57	39	32%

Table 21: Results for E. coli removal in the Kaikohe Oxidation Pond from sample data and the WSP model.

	Interstage Sampling	From WSP Model
Contaminant	**Log Reduction**	**Log Reduction**
E. coli	1	2

5.3 Stage 3 – Maturation Pond & Constructed Wetlands

The oxidation pond is followed by one small maturation pond and four CWLs in series. The maturation pond has an approximate area of 8,100 m^2 and a depth of 1.1m based on the latest sludge survey (Conhur, 2018). The CWLs have a combined surface area of approximately 5,000 m^2 (FNDC, 2006). This stage of treatment has been modelled as one larger and four equally sized maturation ponds. The main function of maturation ponds is to reduce the number of excreted pathogens (e.g. E. coli). BOD and nutrient removal occur very slowly (Mara, 2003) but are still considered in the WSP model.

Table 22 shows the input values used to model the Kaikohe CWLs. Average temperature and pH values were determined from logbook data for CWL measurements taken over the last three years (May 2018 to April 2021) and assumed constant for each CW. Table 23 gives the results for the approximated BOD and NH_4N removal across the four CWLs and compares these to the average results obtained from interstage testing over the two-week sample period. Table 24 gives the log reduction value for E. coli obtained from both sample data and the WSP model.

Table 22: Input variables for the Kaikohe maturation pond & CWLs (modelled as maturation ponds).

Stage 3 - CWLs			**Maturation Pond**	**Cell 1**	**Cell 2**	**Cell 3**	**Cell 4**
Pond Type			Maturation				
Volume	V	m^3	8100	625	625	625	625
Surface Area	A	m^2	8,910	1,250	1,250	1,250	1,250
Retention Time	θ	days	5.36	0.34	0.34	0.34	0.34
pH	pH	-	7.34	7.34	7.34	7.34	7.34
Liquid Temperature	T	°C	19.76	19.76	19.76	19.76	19.76

Table 23: Results for total BOD and NH₄N removal in the Kaikohe maturation pond & CWLs from sample data and the WSP model.

		Interstage Sampling			From WSP Model		
Contaminant	**Unit**	**Influent**	**Effluent**	**Removal**	**Influent**	**Effluent**	**Removal**
BOD	g/m^3	23	12	46%	22	16	27%
NH_4-N	g/m^3	22	21	2%	39	32	18%

Table 24: Results for E. coli removal in the Kaikohe maturation pond & CWLs from sample data and the WSP model.

	Interstage Sampling	From WSP Model
Contaminant	**Log Reduction**	**Log Reduction**
E. coli	< 1 log	> 1 log

5.4 Stage 4 – Natural Wetland

The outlet of the CWLs flows through approximately one hectare of natural marsh. This NWL has been modelled as a maturation pond with surface area of 10,000 m^2.

Table 25 shows the input values used to model the Kaikohe NWL. Average temperature and pH values were determined from logbook data for NWL measurements taken over the last three years (May 2018 to April 2021). Table 26 gives the results for the approximated BOD and NH₄N removal. Table 27 gives the log reduction value for E. coli. Note that the last location for grab sample was immediately downstream of the CWL and therefore this data does not consider the NWL treatment stage. As such, no comparison is given.

Table 25: Input variables for the Kaikohe NWL (modelled as a maturation pond).

Stage 4 - NWL			
Pond Type			Maturation
Volume	V	m^3	5,000
Surface Area	A	m^2	10,000
Retention Time	θ	days	2.69
pH	pH	-	7.37
Liquid Temperature	T	°C	18.18

Table 26: WSP model results for total BOD and NH₄N removal in the Kaikohe NWL.

Contaminant	**Unit**	**Influent**	**Effluent**	**Removal**
BOD	g/m^3	16	14	12%
NH_4-N	g/m^3	32	27	13%

Table 27: WSP model results for E. coli removal in the Kaikohe NWL.

Contaminant	Removal (%)	Log Reduction
E. coli	85%	< 1

5.5 Comparison with Sample WWTP Performance

Where appropriate throughout this section, WSP model results have been compared to the corresponding performance of the WWTP unit process(es) according to results obtained from the two-week sample period. In some cases, there is a misalignment between model and sample results which does not allow them to be directly compared. A summary of the BOD, NH_4N and E.coli removal performance for each stage of the WSP model is given in Table 28, these are mapped to the corresponding removal performance according to sample data.

Table 28: Summary of average BOD, NH4N and E. coli removal efficiency for each treatment stage in the WSP model, mapped to the corresponding results for obtained by sample data.

Contaminant	WSP Model Stage	WSP Model Removal	Interstage Sampling Removal
BOD	Anaerobic Pond	62%	47%
	Oxidation Pond	79%	79%
	Maturation Pond and CWL	27%	46%
	NWL	12%	NWL not sampled
NH_4N	Anaerobic Pond	Not considered	14%
	Oxidation Pond	32%	33%
	Maturation Pond and CWL	18%	2%
	NWL	13%	NWL not sampled
E. coli	Anaerobic Pond	Not considered	< 1 log
	Oxidation Pond	2 log	1 log
	Maturation Pond and CWL	> 2 log	< 1 log
	NWL	< 1 log	NWL not sampled

The interstage sampling results are discussed and compared with the current long-term performance of the Kaikohe WWTP and the modelled expected performance in Section 6.

6. Comparison of Current, Sample and Model Performance

As detailed in Section 3, the ‘current’ performance of the Kaikohe WWTP has been estimated using long-term logbook data and typical per capita values. Section **Error! Reference source not found.** details the performance of the WWTP during the ‘interstage sampling’ period, determined by grab samples taken over a two-week period. The ‘model’ performance of the WWTP, detailed in Section 5, gives an indication of the expected overall performance under ideal conditions, which may be interpreted as the removal efficiency the WWTP could achieve if it was operating to its theoretical full potential. A comparison of the current, interstage sampling and model overall performance values is given in Table 29. The final effluent concentrations based on the model performance are also given. These will serve as a starting point for defining the recommended end-of-pipe interim consent conditions discussed in Section 3.5, to be developed in the next stage of work.

Table 29: Kaikohe WWTP current, sample and model performance, and baseline effluent concentrations according to model performance.

Parameter	Current Removal Efficiency	Interstage Sampling Removal Efficiency	Model Removal Efficiency	Model Effluent Concentrations
BOD_5	93%	94%	95%	14 g/m^3
NH_4-N	33%	59%	52%	24 g/m^3
E. coli	< 1 log[1]	> 2 log[2]	> 4 log	65 CFU/100mL

1. Removal between the CWL and NWL only.
2. Removal between influent and CWL (not considering the NWL).

6.1 BOD Removal

Table 29 shows the Kaikohe WWTP is performing reasonably well overall regarding BOD removal when compared to the model. However due to the first order kinetics of BOD removal the last few percentage points in removal take up a large portion of the treatment area. The previously discussed inhibition of ammonia removal is also impacted by this as the threshold for ammonia removal (assumed to be around 30 mg BOD_5/L as described in Section 5.2) means small changes in performance could have more significant impacts on ammonia removal.

The results of the interstage sampling confirms that the ponds are able to achieve the BOD reductions predicted in the model.

The main issues identified within the current WWTP, which could be contributing to the underperformance of some processes, includes the overloading of the Anaerobic Pond with septage influent that has high TSS and BOD levels. The pond is unable to effectively treat these high loads and passes them downstream, a cumulative effect that flows through the treatment system. Another cause for underperformance is likely the sludge accumulation in the primary and secondary treatment ponds. The accumulation of sludge in the anaerobic pond reduces the HRT so that there is too little time for anaerobic digestion to occur.

While the model predicted an average BOD removal rate of 62% in the anaerobic pond (based on an average pond temperature of 20 °C) the anaerobic pond may not be providing this level of treatment due to reduced hydraulic residence time caused by sludge build up. Insufficient BOD removal in the anaerobic pond will mean that the oxidation pond may be overloaded or at least not able to reduce BOD sufficiently to allow for ammonia removal.

An overloaded oxidation pond will be unable to achieve sufficient BOD, and therefore nitrogen, removal. Sludge accumulation in the oxidation pond reduces the effective volume of the pond, shortening the HRT and limiting the treatment capacity. This is due to the actual volume of sludge, and also the anaerobic and anoxic conditions above the sludge layer, which further decrease the aerobic volume of the pond. Removal downstream of the main pond may also be impacted by the lack of established wetland planting and wetland maintenance.

6.2 E. coli Removal

The model indicates disinfection within the WWTP should be sufficient to achieve adequate effluent disinfection, however, there have been consent breaches which may be impacted by contamination from birds or due to poor disinfection performance. According to the model, the most significant removal of E. coli occurs in the oxidation pond. There isn't sufficient data to assess the long term performance of the stages of treatment at the Kaikohe WWTP however the interstage sampling does provide a snapshot of this performance. The sampling indicates that each stage of the treatment process is underperforming compared to the model. Disinfection is impacted by temperature and the penetration of light into the pond so a 2-week period in winter is likely not representative of the overall treatment performance of the ponds.

Disinfection occurs in the ponds due to UV light penetrating the surface. It is apparent that significant plant growth has taken over a large fraction of the pond surface in recent years. This will have contributed to reduced disinfection rates. Removal of this growth may significantly improve disinfection performance.

6.3 Nitrogen Removal

The key issue with the current Kaikohe WWTP – as mentioned earlier in Section 3.5 and confirmed in Table 29 – is its inability to effectively remove NH_4-N. As organic matter enters the WWTP, nitrogen is broken down and converted to NH_3 in the anaerobic pond. Some NH_3 removal takes place in facultative and maturation ponds by the incorporation of NH_3 into algal mass and volatilisation. However, removal of TN from the effluent is not achieved by the former unless the algae is removed prior to discharge. An evaluation of nitrogen removal through oxidation ponds in New Zealand also suggests that volatilisation does not occur according to literature models in ponds under New Zealand conditions, and that nitrification likely plays a more significant role (Ratsey, 2019).

For oxidation ponds in New Zealand conditions, it is instead suggested that NH_3 removal in the WWTP is more often attributed to the nitrification and denitrification process. In nitrification, NH_3 is oxidized to nitrite (NO_2^-) and subsequently nitrate (NO_3^-). Denitrification then converts NO_3^- to N_2 which is ultimately emitted to atmosphere. In WSP where nitrification occurs, denitrification rapidly follows due to the typically low DO concentrations in the lower depths of the pond. This results in low concentrations of nitrite and nitrates, attributing most of the effluent TN to NH_3 (Ratsey, 2019). Therefore, to achieve a higher TN removal, NH_3 removal should be targeted through nitrification.

Nitrifying bacteria grow a lot more slowly than the heterotrophic bacteria that aerobically break down BOD. Heterotrophic bacteria also utilize oxygen rapidly, meaning that only once the oxygen demand for BOD removal has been satisfied will nitrification occur. Therefore, a high retention time and sufficient DO is required to facilitate this removal mechanism. This will be a key area of focus for the next stage of this review.

The interstage sampling results for the removal of NH_4-N indicate that overall, the treatment processes in the Kaikohe WWTP are able to achieve the modelled results. Removal at the anaerobic pond is not included in the model but is seen in the testing results. The removal through the oxidation ponds align with the model results however the maturation pond and CWLs appear to be ineffective at removing NH4-NH_4-N. Improving the performance of the CWLs is considered in the next stage of this review.

7. Summary and Recommendations

7.1 Summary

The purpose of this review was to assess the current and expected performance of the Kaikohe WWTP. This was done by first assessing the performance under current consent conditions. This assessment showed a number of instances where the effluent NH_4N, disinfection, and flow was non-compliant, and determined the removal efficiencies of the WWTP in its current state for BOD, TSS, TN, NH_4-N and TP (Table 7).

A WSP model was developed to determine the design treatment capacity of the WWTP – that is, the possible BOD, NH_4-N and E. coli removal that can be achieved under ideal conditions. This showed that the WWTP is currently underperforming for all three contaminants studied, though most significantly for nitrogen removal, and that the WWTP could theoretically achieve improved treatment if operating to its full design potential (summarised in Table 22).

An interstage sampling and analysis programme was carried out to determine which processes within the Kaikohe WWTP were contributing to the underperformance. The sampling confirmed that the modelled removal rates for the parameters of concern appear to be appropriate. Sampled BOD removal and NH_4-N removal aligned with the overall model removal rates. Although, the maturation ponds and constructed wetlands appeared to be underperforming in terms of NH_4 -N removal. Disinfection performance was less effective than predicted by the model. The sampling results reflect a snapshot of the treatment system's performance and further interstage sampling programme's may be considered to provide a more comprehensive picture of performance (especially in summer).

This assessment confirms the significance of the issues around NH_4-N that FNDC have reported both recently and in the past, which have also been validated by documented consent breaches. The modelled BOD and E. coli effluent concentrations are at similar levels to recently obtained consents from similar process trains in the Far North District and nearby regions. This provides a basis for setting and meeting interim consent conditions. The NH_4-N effluent concentration is slightly higher than what has been recently consented (i.e. for East Coast WWTP), however, the receiving environment conditions differ and an AEE and dilution study (hydrodynamic and flow assessment) would be required to determine if this effluent concentration would be acceptable from an effects based assessment.

The interim consent conditions and improvement options for the WWTP will be investigated further as part of the stage 2 assessment.

7.2 Recommendations

Jacobs recommend the following be implemented to support the discharge consent renewal for the Kaikohe WWTP:

1) An average and 95th percentile dry weather flow condition be pursued, rather than the maximum limit per the current consent. In the two-year period we reviewed the average of the 30-day rolling average of the dry weather flow (as defined in the current consent) was 1,871 m^3/d and the 95th percentile flow was 2,388 m^3/d.

2) That the “dry day” is redefined in the new consent. In a climate like Kaikohe, 3 mm would be more appropriate than 1 mm.
3) That the load assessment presented in this memo should be used moving forward, as the loads in the Harrison and Grierson report are an underestimate due to not appearing to include septage loads (Harrison Grierson, 2020).
4) That end of pipe consent conditions be applied for, rather than U/S and D/S conditions.
5) That an AEE / hydrodynamic assessment be completed on the effluent concentration that can be achieved if the WWTP is operating per its original design intent as this may indicate that improvements in the treatment processes are not required.

Jacobs noted from the site visit several maintenance improvements that could be made to improve treatment performance to allow the WWTP to perform per its original design intent. These will be elaborated on further as part of the second stage technical memorandum.

A repetition of the interstage sampling programme during the summer is recommended to provide a more comprehensive understanding of the treatment process performance and of seasonal impacts on performance.

8. Next Steps

The next stage of this review is to develop the interim consent conditions, and the upgrade / improvement options for the WWTP that will enable these conditions to be complied with. It is important that these improvements consider the full treatment upgrade proposed by Harrison Grierson, as part of the reconsenting process, and that they support and complement the path toward this upgrade. These options will primarily target nitrogen removal, BOD and E. coli reduction. Possible solutions will be subject to a technical multi-criteria assessment (MCA) to determine the preferred outcome for FNDC. The outcomes of this next stage of the project will be presented in a technical memorandum.

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