Memorandum

Carlaw Park
12-16 Nicholls Lane, Parnell
Auckland 1010
PO Box 9806, Newmarket
Auckland 1149
New Zealand
T +64 9 928 5500

Subject	**Kaeo WWTP Performance Review**	**Project Name**	Kaeo WWTP Performance Review
Attention	Mandy Wilson	**Project No.**	IA266600
From	Grace Stumbles		
Date	13 December, 2021		
Copies to	**Melissa Parlane, Hayden Porter, Kate Simmonds, Becky Macdonald**		

1. Introduction

Far North District Council (FNDC) are applying for a new discharge consent to allow continued operation of the Kaeo Wastewater Treatment Plant (WWTP). The WWTP is located west of Kaeo township and South of the Kaeo River. The current discharge consent CON20100720501 allows for the discharge of treated wastewater into the Kaeo River which flows into the Whangaroa Harbour (Refer to Figure 1 for locations). The consent expires on the 31st of October 2022 (NRC, 2011).

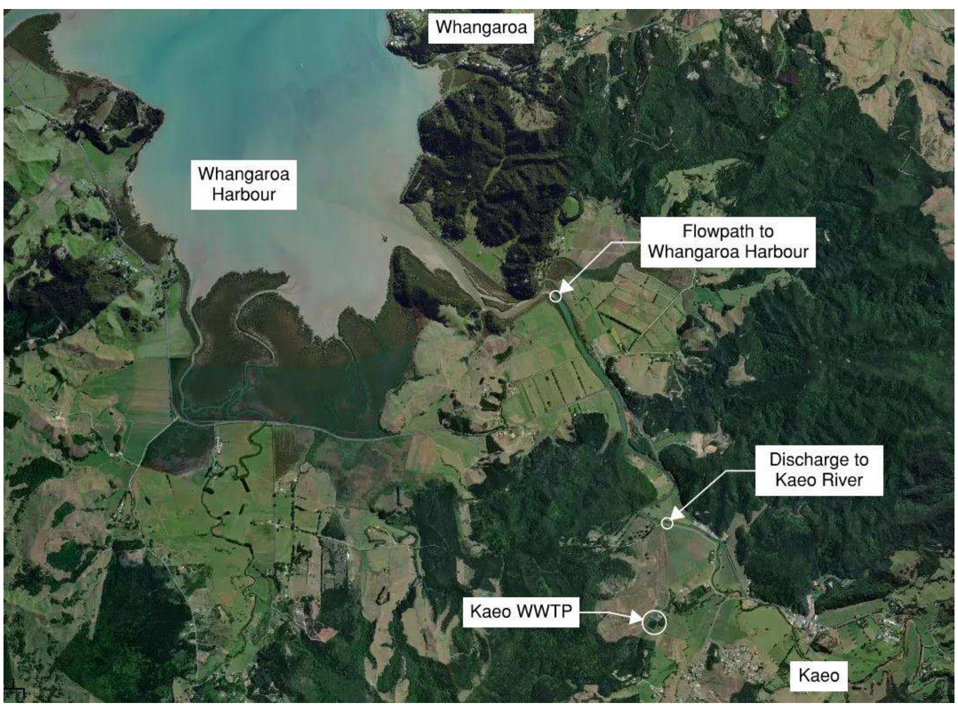


Figure 1: Kaeo WWTP Location and Whangaroa Harbour Discharge (Image sourced from LINZ Data Service and license for reuse under CC BY 4.0)

FNDC have commenced investigations to support the application of a new consent. According to the site logbook, the WWTP struggles to meet the existing discharge conditions specified under the current consent pertaining to a 4-log reduction of F-specific bacteriophage (57% of samples recorded are below this reduction limit). In line with the Proposed Regional Plan (PRP) by Northland Regional Council (NRC), it is expected that the new consent will include more stringent discharge conditions, but there may be an opportunity to meet interim requirements with a staged upgrade approach.

To support FNDC with their application, Jacobs were engaged to conduct a performance review of the Kaeo WWTP to identify areas of non-compliance, key performance issues, and to determine the quality of treated effluent that can be realistically achieved by the current design. The latter provides a starting point for the development of a basis of design for the WWTP and review of future treated wastewater discharge consent criteria dependent on the effluent disposal route.

This memorandum documents the review process and performance results. An initial review was conducted into historic operational issues and infrastructure upgrades. This aided the establishment of a design basis for the current WWTP performance review, which can be split into three key areas:

1. **Recent Consent Performance –** review of the WWTP effluent quality against the existing resource consent discharge conditions.

2. **Unit Process Performance –** review of WWTP treatment process in terms of pollutant removal plant-wide and for each treatment stage. This review was enabled by a two-week sampling programme carried out by FNDC whereby samples of wastewater were collected upstream and downstream of each treatment unit and tested for key pollutant concentrations. The performance indicated by sample data is subsequently compared to the theoretical design performance for each unit in the spreadsheet model.

3. **Overall WWTP Performance –** review of the overall WWTP treatment process performance as indicated by FNDC logbook data and sample data. This is compared to the theoretical design performance indicated by a spreadsheet model of the Kaeo WWTP that was developed for this study.

The available pathways forward for the plant are identified herein for consultation and development through the consenting process. As has been seen with recent consent applications in the region, it is expected that a working group may be established to develop the upgrade pathway and consent for the plant.

2. Kaeo Background

The following is the understanding of the plant based on information provided by FNDC and discussions with FNDC and Ventia staff.

2.1 Original WWTP System

The Kaeo WWTP was constructed in the mid-1980s and originally consisted of two waste-stabilisation (facultative and maturation) ponds and a surface flow constructed wetland. The ponds were conventional facultative ponds with concrete wavebands and no mechanical aeration (FNDC, 2006). A 3 mm inlet step screen was installed in December 2005 (MWH, 2007).

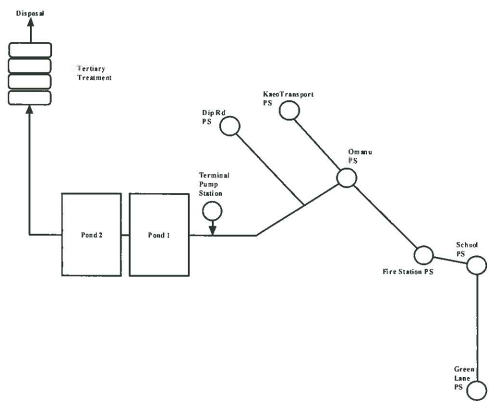


Figure 2: Original Kaeo WWTP process flow diagram (FNDC, 2006).

2.2 2006 Consent and Upgrade Investigations

In December 2006 the WWTP was granted a resource consent for effluent discharge to the Kaeo River based on the condition that it would be upgraded to achieve a 4-log reduction in F-specific bacteriophage. To support the reconsenting and upgrade process, FNDC engaged MWH (now Stantec), who reported the following:

- Concern was expressed about the scientific basis on which F-specific bacteriophage had been selected for monitoring due to inconclusive literature around viral resistance to pond treatment mechanism (MWH, 2007).
- It was identified that UV disinfection was required, but that pond-based systems cannot guarantee the clear effluent required for UV treatment due to the presence of algae.
- MWH recommended that FNDC install a biological trickling filer (BTF), humus tank, tertiary filter and UV disinfection to meet the new discharge consent requirements, as well as conversion of the existing ponds to storm and sludge storage (MWH, 2007).
- In the interest of retaining the pond-based system, FNDC requested further investigation into algae removal from pond effluent to enable UV treatment. MWH identified that a micro screen drum filter could possibly provide adequate UV pre-treatment, but presented this as a higher-risk alternative to the BTF solution. It was recommended that FNDC proceed with converting the pond to storage and installing another biological treatment solution that does not produce algae (MWH, 2007).

2.3 2011 Consent Update and Implemented Upgrades

In September 2011 a new resource consent was issued to FNDC with an update to condition 5. The 2006 consent stipulated a WWTP upgrade consisting of a secondary treatment process, filtration unit and tertiary disinfection system, however the updated consent was less specific. In the 2011 consent, condition 5 stipulated that an upgrade be commissioned to achieve at least a four order of magnitude reduction (4-log) in the concentration of F-specific bacteriophage. This is the current consent that the Kaeo WWTP is operating under, which expires in October next 2022.

The new consent allowed FNDC more flexibility in their upgrade. As discussed in Section 2.2, FNDC was eager to retain the existing pond-based system and was therefore likely to require additional UV disinfection to achieve 4-log F-specific bacteriophage reduction. Consequently, an upstream algae removal system was also required to produce clear effluent suitable for UV operation. FNDC installed a vermifiltration process.

The vermifiltration process is similar to that of a BTF – i.e. wastewater passes through the rock bed and pollutants are removed by biological mechanism due to the presence of a biofilm that grows on the media surface. However, in a vermifilter composting worms are added to digest organic solids (such as algae) and excrete microbial-rich worm castings. Worm burrows also reduced clogging potential and aid in aeration (Chow, 2016).

In June 2012 the maturation pond was divided to create a storm water storage pond and vermifilter system. The design involved pumping primary treated wastewater from the oxidation pond and distributing this on top of the vermifilter through four sprinkler lanes. Drainage coils at the bottom of the vermifilter collect the filtrate and four mechanical blowers were installed to suck air via these drainage coils and provide sufficient oxygen for the vermifiltration process (FNDC, 2012).

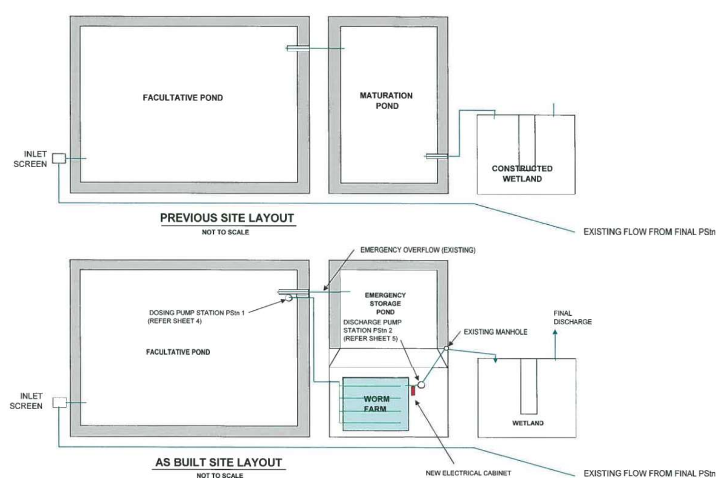


Figure 3: Addition of vermifilter (or worm farm) to the Kaeo WWTP (Transfield, 2012)

2.4 2012 to Current Operation

2.4.1 Changes to Process

A process flow diagram for the current WWTP is provided in Section 3.2.

As expected, compliance with the 4-log reduction condition was not met by addition of the vermifilter alone and a Trojan UV3000 disinfection system was installed downstream in September 2014. This unit was relocated from the Awanui WWTP.

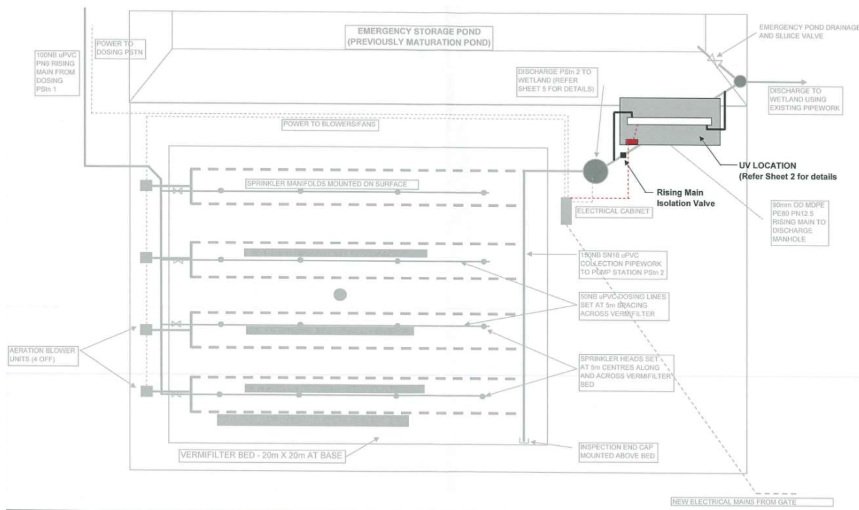


Figure 4: Addition of UV disinfection to Kaeo WWTP (Transfield, 2014)

Worms have washed out over time and have not been replenished in the vermifilter as the castings resulted in a similar solids loading and they attracted birds.. The vermifilter has therefore not operated as such for an extended period of time and now acts as a trickling filter with non-typical design (typical design is discussed in Section 5.3). This vermifilter unit is herein referred to as the biofilter or filter.

Other changes to the biofilter system since it was first installed include the addition of a rotating distribution arm and upstream break tank, the hydraulic head of which limits the flow of water through the filter and UV. One of the original sprinkler lane manifolds has been retained with a manual isolation valve to allow additional flow to the filter in high rain events. The maximum flow rate through both the distribution arm and then manifold is estimated to be 550 m^3/day. Operations staff report that the mechanical blowers are energy intensive and do not appear to significantly improve performance. They have not been operated since May 2019 (FNDC, 2021). FNDC reported that there may have also been a noise complaint by a neighbour due to the blowers.

Treated effluent is currently discharged directly to the Kaeo River after UV disinfection, bypassing the constructed wetland. At present, the wetland planting is in poor condition. Multiple efforts have been made to by Transfield Community Groups and BroadSpectrum to replant the wetland over the last 10 years, but none have been successful.

2.4.2 Desludging

In 2012 when the maturation pond was converted into a storm pond and filter, sludge was removed and transferred to the first oxidation pond. This was subsequently surveyed by Conhur in 2013 and it was estimated that 104 tonnes of dry solids (tDS) were contained within the pond (Conhur, 2013). In 2018, the oxidation pond was again desludged by Conhur in 2018 and an estimated 115 tDS was removed.

According to the 2013 sludge survey, the average solids content of the sludge in the Kaeo oxidation pond is 4.3% (Conhur, 2013). This equates to an estimated volume of 2,420 m^3 of sludge contained within the pond in 2013. Given that the estimated sludge accumulation rate for the Kaeo oxidation pond is 43 m^3 p.a. (CH2M Beca, 2017), the total volume of sludge within the pond would have been approximately 2,680 by 2018. Using the same average solids content, an estimated volume of 2,680 m^3 of sludge was removed from the pond in 2018, indicating that most of the sludge was removed at this time. As of November 2021, it is estimated that the current volume of sludge within the pond is 150 m^3.

3. Current Design Basis

3.1 Flow Basis

The Kaeo WWTP services the Kaeo urban drainage area and a public sewer network in Whangaroa. Wastewater from Kaeo is pumped to the WWTP by 6 main pumpstations located within the township and a 7th final pump station located immediately upstream of the WWTP (FNDC, 2006). Wastewater from Whangaroa collects in a holding tank prior to being trucked to Kaeo where it is discharged into a manhole in the network. Both Kaeo and Whangaroa communities have a mix of residential and commercial properties.

According to the 2018 Census, Kaeo has an area population of 1,191 though this area is much larger than that serviced by the WWTP. FNDC stated in their 2012 O&M Management Plan for all WWTPs that the Kaeo WWTP serviced a winter population of 443 people from 161 connections (FNDC, 2012). FNDC also supplied an estimate of the residential population based on the .ID population forecasts in the area, this predicted a base residential population of 324 people in 2021. At present, the WWTP services 250 free wastewater connections in Kaeo including the Whangaroa Health Services Trust Hospital which has a GP clinic, oral health clinic and the Kauri Lodge Rest Home. The Whangaroa College and Kaeo Primary School are also connected to the Kaeo WWTP, each with a roll of approximately 130 and 150, respectively. For the purpose of this review, it has been assumed that the WWTP services an equivalent population of 500 people. Pumped wastewater from the Kaeo township is measured by an inlet flowmeter immediately downstream of the final pump station.

The FNDC public sewer network in Whangaroa has 26 free connections. This includes the Whangaroa Big Game fishing club and a vacuum system connected to the marina. Sewage is trucked to the WWTP when the holding tank reaches alarm level, but there is no monitoring data for this process. The average rate of sewage transfer to the Kaeo WWTP is reportedly twice per week and each transfer is approximately 20 m^3.

A summary of the flow basis for the Kaeo WWTP is given in Table 1. Data from the site's logbook was used to characterize the Kaeo influent and effluent flows for the three-year period between September 2018 and September 2021.

Table 1: Flow basis for the Kaeo WWTP (FNDC, 2021).

Basis	Unit	Value
Population Serviced	No.	500
Influent Flow		
Average	m^3/day	111
Median	m^3/day	82
Peak (90th Percentile)	m^3/day	212
Maximum	m^3/day	2,061
Average Dry Weather Flow (ADWF)	m^3/day	70
Average Wet Weather Flow (AWWF)	m^3/day	144
Peak (90th Percentile) Wet Weather Flow (PWWF)	m^3/day	259
Tankered Sewage		
Average[1]	m^3/day	6
Effluent Flow		
Average	m^3/day	149
Median	m^3/day	76
90th Percentile	m^3/day	428
Maximum	m^3/day	3,855
Average Dry Weather Discharge[2]	m^3/day	49
Average 30-day Dry Weather Discharge[2]	m^3/day	41

1. Based on 2 x 20 m^3 deliveries per week.
2. 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.

3.2 Process Overview

A piping and instrumentation diagram for the Kaeo WWTP is shown in Figure 5 (the full drawing is provided in Appendix A). The treatment process consists of an influent step screen, primary oxidation pond, secondary biofilter and tertiary UV disinfection.

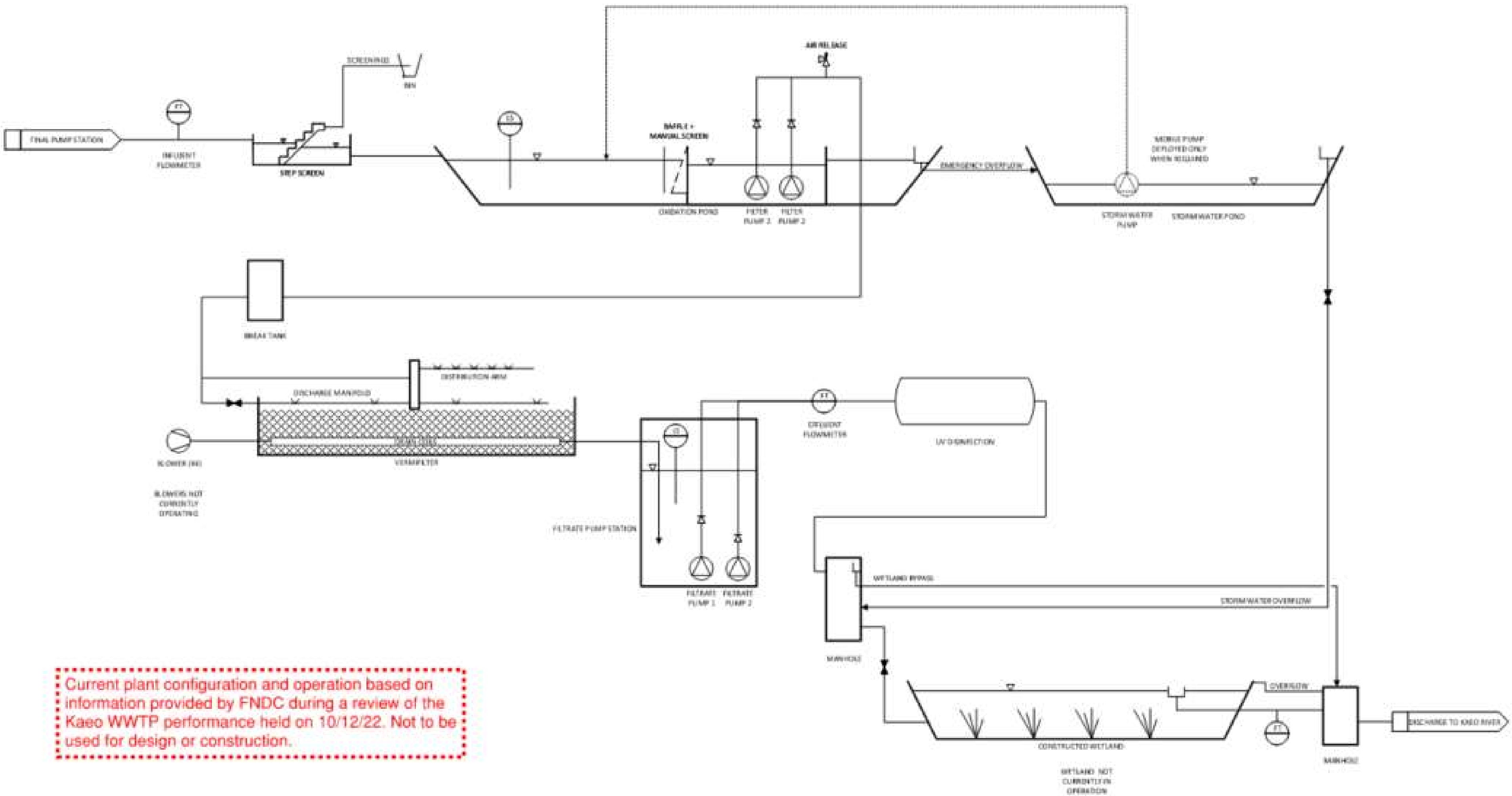


Figure 5: P&ID of Kaeo WWTP.

The oxidation pond has a surface area of 7,225 m^2 and is normally 1.2 m deep with an additional 0.5 m of buffer depth (freeboard) (FNDC, 2006). In 2018 Conhur estimated the total volume of the pond was 7,610. Accounting for the 150 m^3 of sludge accumulated since 2018 (refer to Section 2.4.2), the total working volume of the pond is assumed to be 7,460 m^3. This equates to a retention time of 64 days at an average influent flow rate of 111 m^3/day, which is much larger than the original design retention time of 40 days (FNDC, 2006). The retention time will decrease over time as sludge accumulates within the pond, which has a direct impact to performance.

Wastewater from the oxidation pond is pumped to a break tank by two ABS submerged pumps (duty/standby) controlled by pond level. Wastewater is then gravity fed from the break tank to the filter distribution arm. Flow to the filter is limited by the hydraulic head in the tank and a separate discharge manifold is opened to increase the flow when required. Filtrate is collected in the coils at the bottom of the filter and drains to the filtrate sump. The filtrate is then pumped to the UV system by two submerged pumps (duty/standby) which run off the sump water level.

During high-flows when the influent to the pond exceeds the pumped flow to the filter the pond will fill and eventually overflow to the stormwater storage pond. Once the capacity of the stormwater pond is reached it will bypass flow directly to the plant discharge, this flow rate is not monitored. When there is not sufficient time for the pond level to recover between rain events this can exacerbate this problem. This overflow is not consented. It is worth noting that such events are caused by high rainfall and therefore the concurrent wastewater influent is significantly diluted.

The UV system operates intermittently according to flow from the filtrate pumps. Disinfected treated wastewater is then discharged directly to the Kaeo river, bypassing the constructed wetland. More details about the current WWTP operation are provided in Section 2.

3.2.1 Reported Operational Issues

A number of issues with the current operational of the Kaeo WWTP have been reported by FNDC and Ventia. These are listed as follows:

- The application rate of wastewater to the filter bed media is not equally distributed as there are some issues with the distributor arm infrastructure.
- There is no permanent set-up to remove overflow contents from the storm pond. The design intent was that a mobile pump be used to achieve this, but this has not happened in recent years. The only outlet from the pond is the overflow to the discharge downstream of the UV system which flows directly to the Kaeo River. Untreated wastewater is discharged to the Kaeo River during wet weather events, this flow is not monitored so the frequency and volume of this unconsented bypass is not known.
- Algae blooms in the oxidation pond during summer months cause high solids content in the wastewater and poor hydraulic flow.
- The oxidation pond level transducer is located near the pier, around the inlet where the sludge levels are high and interfere with the readings. There is a risk of running the pond dry due to false high-level readings.
- The step screen installation causes operational issues for the screen handling equipment. The channels are designed to run in linear fashion with bar steps in the screen, but the wastewater enters the screen at a 90 degree angle. This creates a high amount of turbulence and causes grit to be lifted up, which can enter the screen an impact the auger. This situation has happened in the past and a critical spare was transported from Awanui.

- Access to the site is rudimentary and the road is often lost in high rain events, leaving only foot access.
- There are no amenities on site for visiting operators. This is an issue due to the remote nature of the site.

3.3 Monitoring

An influent flowmeter is installed on the inlet pipeline between the final pump station and the oxidation pond inlet. An effluent flowmeter is installed immediately upstream of the UV system. The effluent flow is required to be continuously monitored to determine the average daily dry weather discharge volume from the WWTP.

Resource consent monitoring requirements are mostly focused on the impact to the receiving water quality. Samples are required to be collected from NRC monitoring locations 10 m upstream (U/S) and 15 m downstream (D/s) of the WWTP discharge point within the Kaeo River. There are two sampling points located within the WWTP, one prior to the inlet screen and one on the outlet pipeline. Samples taken at these points are tested for F-specific bacteriophage concentration to determine the overall reduction through the WWTP process. A summary of monitoring undertaken at Kaeo WWTP is given in Table 2.

Table 2: Kaeo WWTP monitoring summary.

Parameter	Influent	Effluent	U/S	D/S
Flow	✓	✓		
Temperature		✓	✓	✓
pH		✓	✓	✓
Dissolved Oxygen (DO)		✓	✓	✓
5-day Biological Oxygen Demand (BOD_5)		✓		
Total Suspended Solids (TSS)		✓		
Total Ammoniacal Nitrogen (NH_4-N)		✓	✓	✓
Faecal Coliforms		✓	✓	✓
E. coli		✓	✓	✓
F-specific Bacteriophage	✓	✓		

4. Performance Review

The Kaeo WWTP primarily targets BOD_5, TSS and pathogen removal from raw domestic wastewater. It also achieves ammoniacal nitrogen reduction. WWTP performance has been measured by compliance with consent discharge conditions and the effectiveness of pollutant removal processes.

4.1 Resource Consent Performance

The current Kaeo WWTP discharge consent allows the discharge of treated wastewater to the Kaeo River subject to the limits shown in Table 3 below. This section measures the performance of the Kaeo WWTP in terms of non-compliance with these limits.

Table 3: Specific limits in the Kaeo WWTP discharge consent (FNDC, 2012).

Parameter	Limits Imposed by Consent	Sample Location
30-day Average Dry Weather Discharge[1]	< 360 m^3/day	Effluent
Cyanotoxins	< 2 µg/L	D/S
Blue-Green Algae	< 11,500 c/mL	D/S
F-Specific Bacteriophage	> 4 -log reduction	Influent and Effluent
D/S pH	6.5 – 9.0	D/S
D/S:U/S Dissolved Oxygen	< 0.80 mg/L	U/S and D/S
D/S:U/S Faecal Coliform	> 1.0 log increase	U/S and D/S
D/S:U/S *E. coli*	> 1.0 log increase	U/S and D/S
D/S NH_4-N (g/m^3)	> 1.2	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. Note that blue-green algae is not measured unless a cyanotoxins measurement more than 8 µg/L is first obtained.

Table 5 shows the minimum, average, 90th percentile and maximum values for each consent-limited parameter. Data was sourced from the FNDC Kaeo logbook which had measurements available from 2010 to 2021, however only data from 2018 onwards was considered to capture current and recent WWTP performance.

Table 4: Kaeo WWTP consented parameters from 2018 to 2021.

Parameter		Minimum	Average	90th percentile	Maximum
30-day Average Dry Weather Discharge[1,2]	m^3/day	4	41	41	127
Cyanotoxins	µg/L	Insufficient data			
Blue-Green Algae[3]	c/mL	11	11,000	22,000	29,000
F-Specific Bacteriophage	log	1.74	4.41	5.37	6.78
D/S pH		5.88	6.85	7.34	7.65
D/S:U/S Dissolved Oxygen		0.87	4.56	1.06	22.94
D/S:U/S Faecal Coliform	log	-0.78	0.01	0.36	1.18
D/S:U/S *E. coli*	log	-1.19	-0.07	0.17	0.38
D/S NH_4-N	g/m^3	0.01	0.25	0.51	1.80

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. Note that blue-green algae is not measured unless a cyanotoxins measurement more than 8 µg/L is first obtained. There were only 3 data points available in the logbook for blue-green algae cell count between 2018 and 2021. This was measured sporadically during the summer of 2020.

Table 5 summarises the historic performance of the Kaeo WWTP in terms of non-compliance with resource consent. 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 3-year period.

Table 5: Kaeo WWTP performance in terms of consent non-compliance from 2018 to 2021.

Parameter	Consent Limits	Exceedances	Frequency
30-day Average Dry Weather Discharge[1,2]	< 360 m^3/day	0	0%
Cyanotoxins	< 2 µg/L	Insufficient data	
Blue-Green Algae[3]	< 11,500 c/mL	3	N/A
F-Specific Bacteriophage	> 4 -log reduction	12	35%
D/S pH	6.5 – 9.0	6	15%
D/S:U/S Dissolved Oxygen	< 0.80	0	0%
D/S:U/S Faecal Coliform	> 1.0 log increase	1	3%
D/S:U/S *E. coli*	> 1.0 log increase	0	0%
D/S NH_4-N (g/m^3)	> 1.2	2	5%

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. Flow data considered from 2018 to 2021 only.
3. Note that blue-green algae is not measured unless a cyanotoxins measurement more than 8 µg/L is first obtained. There were only 3 data points available in the logbook for blue-green algae cell count between 2018 and 2021. This was measured sporadically during the summer of 2020.

Table 5 shows that the Kaeo WWTP struggles to comply with the F-specific bacteria reduction requirements and blue-green algae limits imposed by the current resource consent. It should be noted that, due to the nature of the consent conditions, this review is not an accurate representation of the overall WWTP performance. Key performance parameters that are not considered here include:

- **Wet weather discharges –** as shown in Table 1, the peak daily discharge from the WWTP exceeds 360 m^3 in wet-weather periods and has reached 3,855 m^3/day in the past, even with the storm water storage pond. Jacobs recommends that an average and peak dry weather flow condition be pursued, rather than a maximum limit as specified in the current consent.
- **Effectiveness of treatment process –** the current consent is focused on impacts to the receiving water quality. While this is the most important aspect of WWTP discharge, it does not give insight into the level of treatment occurring within the WWTP (with the exception of F-specific bacteriophage). 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 an assessment of the environmental impacts of that condition, however any interim conditions should be linked to the anticipated WWTP performance that can be achieved.
- **Ammonia discharge –** the current consent requires ammoniacal nitrogen to be measured downstream of the discharge point to determine the impact of the WWTP discharge to aquatic life in the river. As detailed above, this condition does not clearly indicate the WWTP's ability to treat nutrient dense influent. Higher levels of nitrogen treatment are anticipated for domestic WWTP's in the future. It is therefore likely that the new consent for Kaeo will include more stringent conditions to this effect and it is important to understand the WWTP's capacity to handle this.

4.2 Unit Process Performance

4.2.1 Interstage Sampling Programme

Grab sampling and testing at the Kaeo WWTP was completed to support this review. A sampling programme was developed to provide more complete influent and effluent data as well as to inform the performance of the individual unit processes. Of particular interest was the biofilter effluent sampling to determine whether this system was achieving any significant BOD_5 and NH_4-N removal. The water sampling regime recommended by Jacobs to FNDC for this activity is summarised in Table 6.

Table 6: Sampling regime for the Kaeo WWTP Performance Review.

Location	Frequency	In-Situ Parameters[1]	BOD_5	TSS	TN	TKN	NH_4-N	F-Specific Bacteriophage	E. Coli	Faecal Coliforms	UVT
Influent	Daily	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Pond 1 effluent	Daily (when operating)	✓	✓	✓	✓	✓	✓				
Biofilter effluent	Daily (when operating)	✓	✓	✓	✓	✓	✓	✓	✓	✓	
UV effluent[2]	Daily (when operating)							✓	✓	✓	✓
Whangaroa Sewage	2 samples over 2 weeks	✓	✓	✓	✓	✓	✓		✓		

[1] In-situ parameters are pH, temperature, and DO.

[2] To be taken during UV pump operation after the first flush has passed through the UV system.

4.2.2 Sample Results

Grab samples were taken daily (including weekends) for two weeks between the 26th of October and the 9th of November 2021. There was a WWTP outage from the 4th of November onwards during which the UV reactor was not operating, and flow data was not recorded. There were also high levels of rain during this time.

The average values of sample test results over the 14-day period are given in Table 7. These are also shown graphically in Figure 6 and Figure 7. The removal rate of contaminants for each treatment process is shown in Table 8.

Table 7: Average values of wastewater data obtained during the 14-day sampling period.

		Whangaroa Influent	Kaeo Influent	Combined Influent[1]	Ex. Pond	Ex. Biofilter	Ex. UV[2]
Flow	m^3/day	6[3]	142	148			
BOD_5	mg/L	236	139	143	24	14	-
E. coli	cfu/ 100mL	10^7	10^6	10^6	-	10^3	10^3
Faecal Coliforms	cfu/ 100mL	-	10^6	10^6	-	10^4	10^3
NH_4-N	g/m^3	19	25	25	8	5	
F-Specific Bacteriophage	pfu/L	-	10^7	10^7	-	10^4	10^3
TSS	g/m^3	49	113	110	47	36	-
TKN	g/m^3	38	41	41	14	10	-
TN	g/m^3	51	42	43	14	13	-
DO	g/m^3	3	1	1	4	4	4
UVT	%	-	-	-	-	-	40

1. Average composition of combined influent is determined by summing the multiples of each streams concentration by its contribution to the overall flow rate for the sampling period.
2. UV performance was impacted by unit failure from the 4th of November onwards. Samples exiting the UV after this date have not been considered.
3. Based on the assumption that two 20 m^3 truck loads are delivered per week.

Table 8: Unit treatment process performance.

	Oxidation Pond	Biofilter	UV[2]	Overall
BOD_5	83%	40%		90%
E. coli	3.10 log[1]		0.12 log	3.24 log
Faecal Coliforms	2.67 log[1]		0.57 log	3.25 log
NH_4-N	68%	39%		81%
F-Specific Bacteriophage	2.90 log[1]		0.43 log	3.31 log
TSS	57%	24%		67%
TKN	66%	28%		75%
TN	68%	3%		69%

1. Total log reduction of *E. coli*, faecal coliforms and F-specific bacteria across both the oxidation pond and the biofilter units.
2. UV performance was impacted by unit failure from the 4th of November onwards. Samples exiting the UV after this date have not been considered.

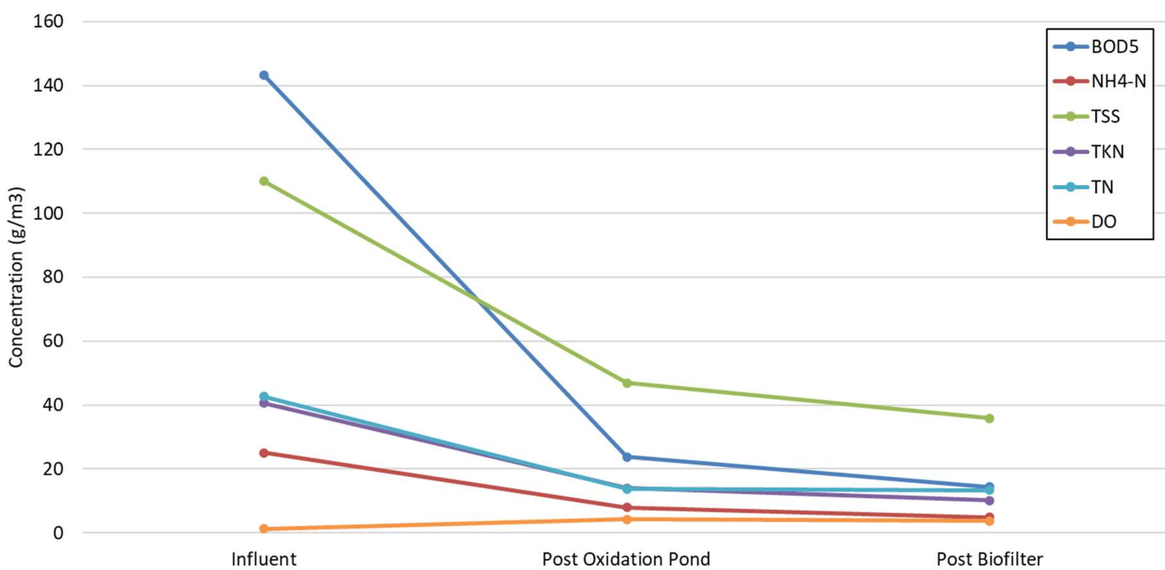


Figure 6: Average concentration of measured pollutants throughout the Kaeo WWTP process.

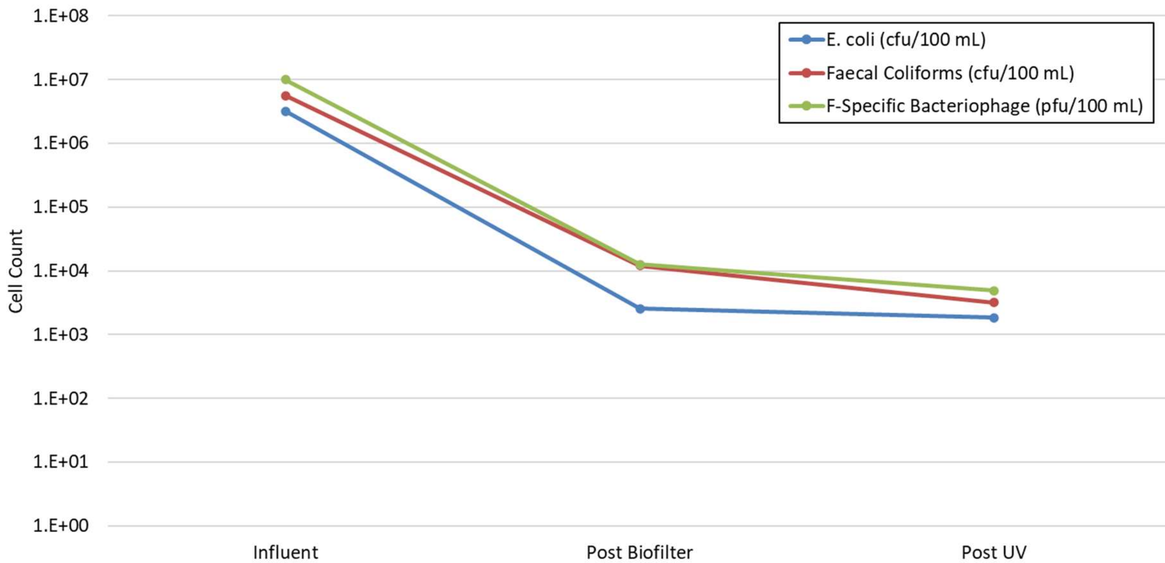


Figure 7: Average cell count of measured faecal indicators throughout the Kaeo WWTP process.

5. Model Development

A spreadsheet model has been developed to determine the theoretical design performance of the Kaeo WWTP. This provides a benchmark for comparison with the actual Kaeo WWTP process. The model consists of a primary facultative pond and biological trickling filter to represent the Kaeo oxidation pond and biofilter, respectively. It considers BOD_5, *E. coli* and ammoniacal nitrogen (NH_4-N) removal.

The use of F-specific bacteriophage as viral indicators of faecal contamination is not common and less widespread than the use of bacteria such as *E. coli*. Unlike *E. coli*, literature around viral indicators and their resistance to conventional wastewater treatment methods is sparsely available and mostly inconclusive. There are no theoretical and empirical formulas relating to their treatment mechanisms that are widely accepted throughout literature. Therefore, the Kaeo WWTP model considers the more commonly used *E. coli* removal rather than F-specific bacteriophage.

5.1 Influent Characterisation

As there is limited influent monitoring data at the Kaeo WWTP, the influent loading was determined using literature values for domestic wastewater where data was not available. Concentrations of influent pollutants have been validated by comparison to average values measured in the Kaikohe WWTP influent between 2018 and 2021 (Jacobs, 2021).

Table 9: Design influent loading for the Kaeo WWTP model (based on literature values for typical residential wastewater)

Parameter		Value	Basis	Source	*Ref: Kaikohe*
Average Influent Flow	m^3/day	117	FNDC Data	Table 1	
BOD	g/m^3	300	70 g per person per day	(Standards NZ, 2008)	*205*
E. coli	cfu/100 mL	10^7	10^6-10^8	(U.S.EPA, 1980)	
TSS	g/m^3	300	70 g per person per day	(Standards NZ, 2008)	*248*
NH_4-N	g/m^3	34	8 g per person per day	(MWH, 2007)	*38*
TN	g/m^3	64	15 g per person per day	(Standards NZ, 2008)	*62*
F-Specific Bacteriophage	pfu/100 mL	10^6	FNDC Data	FNDC Logbook	

5.2 Oxidation Pond

The Kaeo oxidation pond has been modelled as a primary facultative waste stabilisation pond. Equations for BOD_5 and *E. coli* removal in facultative ponds are well represented in literature by first order kinetic equations that have proven effective when predicting these biological mechanisms. However, modelling TN is less well defined. The mechanisms for nitrogen removal in are not certain and vary from pond to pond depending on the site location and climate. Nitrification is one potential mechanism. Autotrophic nitrifying bacteria is slow growing and therefore nitrification will only occur in pond systems provided there is sufficient retention time and DO to grow and feed this bacteria. The soluble BOD_5 concentration must also be low enough so that competition with heterotrophs is reduced.

It has been demonstrated that BOD_5 must be less than 30 g/m^3 to initiate nitrification (WEF, 2010). This is captured in the model by considering TN removal based on the remaining retention time in the pond after this BOD_5 limit has been achieved. To determine the effluent NH_4-N concentration exiting the pond, the equation for TN removal in facultative ponds proposed by Reed (1985) has been employed (Mara, 2003) and it has been assumed that 60% of TN is NH_4-N, based on the relative ratio observed by interstage sample data for this stream.

The input parameters used to model the Kaeo oxidation pond are given in Table 10.

Table 10: Model inputs for the Kaeo oxidation pond.

Parameter		Value
Pond Type	-	Primary Facultative
Surface Area	m^2	7,225
Volume	m^3	7,460
pH	-	9
Liquid Temperature	°C	20
Total Retention Time	days	64
Nitrification Retention Time[1]	days	34

1. Assuming that BOD_5 has to be less than 30 g/m^3 to initiate nitrification.

5.3 Biofilter

Given that the worms have been removed from the Kaeo WWTP biofilter, the system now operates similar to a BTF whereby water trickles over the biofilm surface attached to the carrier material. Air flow is either induced mechanically by the blowers when they are in use (refer to section 2) or by natural draft due to temperature differences between the air outside and within the BTF. However, there are key differences between the Kaeo biofilter design and that of a conventional BTF such as:

- BTF's typically employ effluent recirculation to achieve suitable hydraulic and organic loading rates for good performance
- BTF's typically have downstream liquids-solids separation (e.g. secondary sedimentation) to remove TSS (e.g. detached biofilm)
- BTF's are usually either 2 to 3 m deep circular tanks or deeper vertical towers. The Kaeo biofilter is a 20 m x 20 m square that is 1 m deep.

For the purpose of this review, the Kaeo biofilter has been modelled as a single-pass BTF. Impacts to the biofilter performance due to these differences are discussed in section 7.3.

BTF's are classified by the intended mode of pollutant degradation (e.g. roughing, carbon oxidation, carbon oxidation and nitrification, or nitrification) and loading. The World Environment Federation's

Manual of Practice No. 8 (MOP8) for the design of water resource recovery facilities provides defining criteria for each operational mode. This is shown in Table 11.

Table 11: Trickling filter classification extracted from WEF's MOP8 (WEF, 2010).

Design Parameter		Roughing	Carbon Oxidising	Carbon Oxidising and Nitrifying	Nitrifying
Hydraulic Loading	$m^3/day.m^2$	53-179	14-88	14-88	35-88
BOD_5 Loading	$kg/m^3.day$	1.6-3.5	0.32-0.96	0.08-0.24	N/A
NH_4-N Loading	$kg/m^2.day$	N/A	N/A	0.2-1.0	0.5-2.4
Effluent Quality	g/m^3	40-70% BOD_5 conversion	15-30 BOD_5 and TSS	< 10 BOD_5 < 3 NH_4-N	0.5-3.0 NH_4-N

Input parameters used to model the BTF are given in Table 12. As the filter is run intermittently, two flow scenarios were considered; an average flow scenario based on the average annual flow of influent to the WWTP (refer to Table 1), and a maximum flow scenario of 550 m^3/h to match the reported pond filter capacity.

Table 12: Model inputs for the Kaeo biofilter.

Parameter		Average Flow	Maximum Flow
Filter Radius (Trickling Arm)	m	9	
Filter Surface Area	m^2	127	
Filter Depth	m	1	
Influent BOD_5[1]	g/m^3	22.23	
Influent NH_4-N[1]	g/m^3	6.42	
Influent Flow	m^3/day	117	550
Total Hydraulic Loading	$m^3/m^2.day$	0.9	4.3
BOD_5 Loading[1]	kg/day	1.7	6.9
	$kg/m^3.day$	0.0271	0.10
NH_4-N Loading[1]	kg/day	1.47	1.6
	$kg/m^2.day$	0.01	0.03

1. Based on BOD_5 and NH_4-N concentrations in the wastewater exiting the oxidation pond as determined by the primary facultative model (section 5).

The model hydraulic and contaminant loading values for the model BTF are much lower than the typical accepted design criteria. At maximum flow, the Kaeo BTF BOD_5 loading just reaches the design criteria for a carbon oxidizing and nitrifying BTF which suggest an effluent BOD_5 concentration of less than 10 g/m^3 may be achieved The National Research Council (NRC) Formula for BTF BOD_5 removal was used to calculate the effluent BOD_5 concentration. This empirical formula was founded on data for rock filters which typically accept primary treated wastewater, therefore a correction factor of 0.5 was applied to account for the relatively low strength nature of the influent.

In both flow scenarios, the NH_4-N loading is lower than the accepted design criteria for all types of BTF's. Carbon and nitrifying and nitrifying BTF types are have the lowest loading rates and are typically designed to achieve less than 3 g/m^3 of NH_4-N. However, it was thought that the design limitations of the Kaeo BTF, combined with the warm temperatures experienced in the Far North that limit NH_4-N removal, rendered this effluent NH_4-N concentration unrealistic. Instead, it was assumed that an appropriate 'best case scenario' for the Kaeo biofilter would achieve a 5 g/m^3 effluent NH_4-N concentration and this was specified in the model.

5.4 UV

The Kaeo WWTP has a Trojan Model UV3000Plus installed which was relocated from the Awanui WWTP in 2014. Details for this unit were sourced from Trojan directly. The unit was installed at the Awanui WWTP in 2006 and consists of 1 stainless steel channel with one bank, two modules (8 lamps per module) and automatic wipers.

The effectiveness of UV treatment is determined by the UV dose that the system is able to deliver. This in turn is dependent on the combined effects of UV light intensity (UVI), exposure time and UV transmissivity (UVT) of the water. UVI is determined by the size and type of lamps and power supply. The exposure time depends on the flow rate of the system. UVT is related to the quantity of organics and solids in the water which absorb and scatter UV light. If the UVT is of the water is too low, then UV light cannot penetrate the water and the effective UV dose is reduced.

The original design scope for the Kaeo UV unit is given in Table 13 alongside the actual value of design parameters experienced. It should be noted that bacteriophage resistance to UV disinfection is variable but generally higher than common faecal indicator bacteria (U.S. EPA, 2015). For the purpose of this review, it has been assumed that the model UV unit can provide at least 3-log reduction of *E. coli*.

Table 13: Trojan UV3000Plus design scope.

Parameter		Design Limit	Kaeo Performance
Performance		3-log reduction Faecal Coliform (Specific Bacteriophage)	1-log reduction of F-Specific Bacteriophage
Lamp Hours		12,000	11,955[1]
TSS			
Average	g/m^3	-	50
50th percentile	g/m^3	5	42
90th percentile	g/m^3	10	93
Flow			
Average	m^3/day	~112	117
Maximum	m^3/day	~650	550
UVT	%		
Minimum	%	34	1
Average	%	-	32

1. As of 23rd July 2021.

Table 13 shows that the flows observed by the Kaeo UV unit are similar to its design conditions. The average UVT appears acceptable, however Trojan has said that UV performance will be significantly impacted at all values less than this, especially when combined with the high TSS levels currently being seen by the unit. Furthermore, the lamp hours indicate that replacement is due. According to the unit's Filtec Service Technician, it was last serviced 18 to 24 months ago and maybe due for another. Other issues impacting performance could include failures of the lamps, wiper system, hydraulic pump, UVI sensor or fouling of sleeves.

The minimum, average, 90th percentile and maximum value of UVT and TSS recorded at the Kaeo WWTP is shown in Table 14.

Table 14: Kaeo WWTP typical UVT and TSS values from 2014 to 2021 (FNDC, 2021).

Parameter		Minimum	Average	90th percentile	Maximum
UVT	%	1	32	47	85
TSS	g/m^3	6	50	97	228

6. Comparison with Model

6.1 Interstage Sampling Data

A comparison of the assumed influent composition for the Kaeo WWTP model design (refer to section 3.1) and the actual influent composition observed at the WWTP during the 14-day period is provided in Table 15.

Table 15: Comparison of assumed design influent and average influent characteristics during the 14-day sampling period.

Influent Characteristic		Design Influent	Sample Data
Average Influent Flow	m^3/day	117	155[1]
BOD	g/m^3	300	143
E. coli	cfu/100mL	10^7	10^6
TSS	g/m^3	300	110
NH_4-N	g/m^3	34	25
TN	g/m^3	64	43

1. Average flow from the 26th of October to the 4th of November, as data was unavailable following this date due to a celcom outage.

Table 15 shows that the influent entering the Kaeo WWTP during the 14-day sampling period was higher than the WWTP's average flow and had significantly lower concentrations of key pollutants compared to the design basis. These discrepancies are likely due to the heavy rain experienced during this time, which would have increased the volume and diluted the influent stream. However, due to the large volume and long retention time of the oxidation pond, the influent entering the WWTP during this period is not necessarily representative of the wastewater composition within the pond or that passed through downstream processes. It was therefore assumed that the design influent, which is based on typical New Zealand domestic wastewater values, was still the most suitable basis on which to run the model.

Table 16 compares the measured performance of the WWTP during the 14-day sampling period and the estimated performance of each unit determined by the WWTP design model, which acts as a theoretical maximum for Kaeo process with a conventional BTF design.

Table 16: Comparison of actual performance of unit processes (in terms of effluent quality and overall removal of pollutants) during the 14-day sampling period and the theoretical maximum performance estimated by the model.

	Oxidation Pond (mg/L, cfu/100mL)		Biofilter (mg/L, cfu/100mL)		UV (mg/L, cfu/100mL)		Overall Pollutant Removal Rate	
	Sample Data	Model	Sample Data	Model	Sample Data	Model	Sample Data	Model
BOD_5	24	15	14	8	-	-	90%	99%
NH_4-N	8	10	5	5	-	-	81%	91%
E. coli	-	10^4	10^3	-	10^3	10^1	3.21 log	5.23 log

Table 16 shows that the majority of treatment occurs within the primary oxidation pond, but that the biofilter is currently providing some additional BOD_5 and NH_4-N removal. Though these removal rates are not as high as those anticipated by a conventional BTF as depicted by the model values, this is to be expected due to the current operational limitations of the biofilter design and warm weather experienced in Kaeo.

It appears as though the oxidation pond is working relatively well. As the pond was desludged in 2018, it has a large effective volume and long retention time. The measured *E. coli* concentration exiting the biofilter is lower than the model prediction, indicating good pond conditions with no surface growth. There may also be additional *E. coli* removal occurring within the biofilter that is not captured in the model.

However, the UV unit is not currently achieving its design performance of a 3-log reduction of faecal indicators (stipulated as F-specific bacteriophage in the Trojan design scope, however it was assumed that this correlates to the same, if not higher, reduction of *E. coli* due to the high resistance of bacteriophage to disinfection). As discussed in 5.4, this is likely due to the high TSS contents in the effluent and perhaps the current condition of the unit (e.g. operation of lamps, wiper system, sleeve fouling, etc.).

6.2 Overall WWTP Performance

To determine the overall WWTP performance, the effluent composition produced by the model has been compared to the actual effluent composition produced at the Kaeo WWTP as indicated by long-term logbook data, and the effluent composition as measured during the 14-day sample period. The results are given in Table 17.

Table 17: Model, logbook and sample effluent quality.

		Model Effluent	Logbook Effluent	Sample Effluent
BOD_5	g/m^3	8.4	14.7	14.4
E. coli	cfu/ 100mL	10^1	10^3	10^3
NH_4-N	g/m^3	5.0	9.4	4.9
TSS[2]	g/m^3	-	50	36
F-Specific Bacteriophage[2]	pfu/L	-	10^3	10^3

1. Average logbook values recorded from 2018 to 2021.
2. The model does not calculate TSS and F-specific bacteriophage reduction, but these have been included in this table as there is long-term effluent data available for these pollutants.

The model estimates act as a theoretical maximum standard, or 'best case scenario', for the WWTP considering conventional BTF performance and unimpeded operation. Table 17 shows that the Kaeo WWTP is capable of achieving the model effluent NH_4-N concentration, as shown by the sample data, but that long-term trends indicate a higher effluent concentration is more typical. As previously discussed, performance is limited by the biofilter design and warm ambient temperatures. However, the sample effluent value indicates that significant NH_4-N removal is being achieved by the WWTP overall, and that some of this is attributed to the biofilter (refer to Table 16).

From this review, it can be assumed that the WWTP is capable of reducing NH_4-N concentration to below 10 g/m^3. BOD_5 and *E. coli* effluent concentration values are relatively consistent between the logbook and sample effluent streams. This indicates that the WWTP is consistently capable of achieving this effluent quality (less than 15 g/m^3 of BOD_5 and 4-log *E. coli* reduction) within its current infrastructure and operational limits.

The F-specific bacteriophage and *E. coli* concentrations in the logbook and sample effluent are significantly higher than the system is designed for. It appears that the WWTP process is struggling to achieve an additional 2-log reduction of these faecal indicators. Low performance of the UV unit may be attributed to the high solids content within the WWTP effluent, and the unit may need maintenance work. According to the U.S. EPA, UV disinfection with low-pressure lamps is not as effective for secondary effluent with TSS levels above 30 g/m^3 (EPA, 1999).

7. Conclusions

7.1 Operational Risks

A number of operational risks have been identified as part of the performance review process. These have direct impact to the performance of the WWTP and compliance with consent, and should be prioritised for rectification:

- Condition 2 of the current consent requires FNDC to minimise, as far as practicable, any increase in the quantity of wastewater discharged to the Kaeo River as a result of stormwater inflow and infiltration. At present, there is no permanent set-up to drain the storm pond and, in extreme weather events, the storm pond overflow discharges directly to the Kaeo River. To practically minimise this occurring, FNDC may wish to investigate a means of automatically emptying the storm pond to maximise the available storage. It is currently unclear when these overflows occur, and it is assumed that this usually occurs during period of wet weather when the wastewater is highly diluted but has been partially treated (screened and settled in the oxidation pond).
- There is a risk of running the pond dry due to the location of the level transducer.
- The step screen installation poses a risk to the auger due to turbulence caused by the wastewater entering the screen at a 90 degree angle.
- The site access road is in poor condition and is impacted by wet-weather. There are not any operator amenities on site.
- The UV unit is due to have the lamps replaced and for a service to be performed.

7.2 Consent Issues

The following issues have been identified with the current resource consent conditions and the WWTP's ability to meet these.

- Key compliance issues for the Kaeo WWTP under the current consent conditions are F-specific bacteriophage reduction and blue-green algae limits. Both of these issues are known to FNDC. Peak daily discharge from the WWTP exceeds 360 m^3 in wet-weather periods, though this is not currently captured as a non-compliance due to the definition of a 'dry weather discharge'.
- The current consent is focused on in-stream sampling with introduces factors that are outside of the control of the WWTP.
- The WWTP currently discharges partially treated flows from the storm pond directly to the Kaeo River during wet weather events. The risk is noted in Section 7.1, this may be a consent compliance issue.

7.3 Design Issues

As a result of the performance review presented in this document, the following conclusions have been reached in regard to the Kaeo WWTP design:

- The oxidation pond is thought to be operating as designed, with relatively low sludge contents and no permanent surface growth. However, pond-based systems are limited in their disinfection treatment ability and cannot guarantee low solids content in the effluent. Algae blooms are a known issue to FNDC during the summer months and impact downstream treatment processes
- The current biofilter is not being operated as per the original intent (vermifilter) and is instead acting as a non-standard BTF. As seen in the performance review, this unit is achieving some BOD_5 and NH_4-

N removal but not to the same extent as a conventionally designed BTF. Key design factors impacting the biofilter operation are:

- Issues with the distributor arm causes uneven distribution of wastewater to the filter bed media. The effective area and volume of the biofilter is therefore significantly reduced, as poor media wetting leads to dry media pockets and ineffective treatment zones.
- Natural ventilation can be inadequate aeration when neutral temperature gradients do not produce air movement. This is likely true for Kaeo, where ambient temperatures are often similar to the water temp (e.g. 20 deg). Aeration is crucial to maintain aerobic zones within the biofilter and allow heterotrophic and nitrifying bacteria digestion.
- There is no subsequent liquid-solid separation stage downstream of the biofilter. As such, detached biofilm and other entrained solids are not removed prior to UV treatment and impact performance.
- Loading of the biofilter is dependent on upstream factors as there is no effluent recycle system to balance out the influent. Low pollutant loading and high flow rates due to high rainfall may contribute to biofilm washout. High solids content in the pond effluent can contribute to plugging.

▪ The WWTP is currently struggling to achieve the required 4-log reduction of F-specific bacteriophage, likely due to the high solids content of secondary effluent entering the UV reactor, the current condition of the unit and the intermittent nature of operation. Viral faecal indicators such as bacteriophage are also more resistant to disinfection than more conventionally used indicators, such as *E. coli*.

8. Upgrade Pathway Progression

This document can be used as a basis of design for the WWTP and to review its ability to comply with possible future discharge consent criteria, which will be dependent on the effluent disposal route. The possible pathways forward for the WWTP have been identified below for consultation and development through the consenting process. These are focused on two discharge routes: to river (continuation of current process) or to land. The level of treatment required for each route differs depending on what the receiving environment can tolerate and what is acceptable to the community. Key differences are outlined below.

1. **Discharge to River**

   This upgrade pathway focuses on the treatment of pathogens to ensure public safety and nutrient removal to preserve aquatic life. In particular, consent conditions for river discharges focus on faecals, nitrogen and dissolved oxygen. It is envisaged that future conditions for river discharges in the Far North Region will be aligned to the NRC Proposed Regional Plan (PRP) and therefore more stringent than those currently imposed. Compliance with these conditions may be achieved by upgrades to the existing pond system or may require a new mechanical WWTP to be built.

   a. Upgrades to the existing pond-based system focused primarily on disinfection but also on improvements to meet more stringent discharge limits (e.g. nutrient removal). These may include:

      - UV maintenance
      - Installation of a solids separation stage between the biofilter and UV unit
      - Other biofilter upgrades, such as: reinstating mechanical aeration, improving the distribution arm to improve the effective filter area, replacing the filter media to enhance specific surface area, venting and reduce clogging potential, increase filter depth, etc.

   b. If the above upgrades cannot meet the new discharge consent criteria, a new mechanical WWTP process may be required.

2. **Discharge to Land**

   There is increasing pressure to discharge treated wastewater to land, instead of water ways, due to a wide range of cultural and sustainability drivers. Investigations into this alternative disposal route are likely to be required in the future, according to the PRP which states “an application for resource consent to discharge municipal, domestic, horticultural or farm wastewater to water will generally not be granted unless a discharge to land has been considered and found not to be environmentally, economically, or practicably viable” (NRC, 2021).

   FNDC have commenced investigations into land disposal options and identified numerous feasible options for land disposal within 5 km of the Kaeo WWTP. However, initial high-level cost estimates for this option are relatively high (approximately $6.2M), especially when considering the low number of ratepayers in the Kaeo wastewater scheme. This will be a significant factor when determining the economic viability of this disposal route (FNDC, 2021).

   Treatment requirements for this disposal route are technically less than those for disposal to waterways due to the ability of the land to absorb nutrients. However, community perception often drives the need for additional wastewater treatment. If FNDC proceed with a consent to discharge to land, this may omit the need to upgrade the Kaeo WWTP for enhanced nutrient removal. However, it will be important that FNDC effectively communicate to their community the benefits of nutrients contained in wastewater to offset fertilizer demand.

If land disposal is deemed to be an economically viable option, the upgrade pathway will still require improved pathogen removal. It is therefore likely that upgrades mentioned for river disposal will also apply. However, the upgrade pathway will also focus on effective delivery. For example, the WWTP will need to achieve higher TSS removal to allow for wastewater transfer over long distances, and a solution to allow for high-velocity flushing (e.g. on-site holding tank) or chemical cleaning of the irrigation lines. Septicity management in the pipeline will also be required

References

CH2M Beca. (2017). *FNDC Sludge Strategy Options Review Report.*

Chow, L. (2016, April 23). *EcoWatch*. Retrieved from The Role of the Worm in Recycling Wastewater: https://www.ecowatch.com/the-role-of-the-worm-in-recycling-wastewater-1891122409.html

Conhur. (2013). *Kaeo Oxidation Pond Sludge Survey Report.* Conhur.

EPA. (1999). *Wastewater Technology Fact Sheet - Ultraviolet Disinfection.* Washington: United States Environmental Protection Agency.

FNDC. (2006). *Kaeo Wastewater Treatment Plant Operation and Maintenance Manual.* Kaikohe: Impact Services Ltd.

FNDC. (2006). *Kaeo Wastewater Treatment Plant Operation and Maintenance Manual.* Kaikohe: FNDC.

FNDC. (2012). *Kaeo STP O&M Manual.* Kaikohe: FNDC.

FNDC. (2012). *Operation and Maintenance Management Plan for all Wastewater Treatment Plants in the Far North District.* Kaikohe: FNDC.

FNDC. (2021). *Kaeo Land Disposal Options Report.*

FNDC. (2021). *Kaeo STP Logbook.* FNDC.

Jacobs. (2021). *Kaikohe WWTP Performance Assessment TM.* Auckland: Jacobs.

Malley, J., Bernardy, C., White, M., & Hidrovo, A. (2020, 05 03). *When Influent Water Percent UVT is Out of Range.* Retrieved from UVSolutions.

Mara, D. (2003). *Domestic Wastewater Treatment in Developing Countries.* London, UK: Earthscan.

MWH. (2007). *Algae Filtration Techniques Feasibility Study.* MWH.

MWH. (2007). *Kaeo Wastewater Treatment Plan Upgrade Feasibility Report.*

Nakova, S. (2021). *What Is UV Transmittance (UVT) And Why Is It Important To Know?* Retrieved from We UVCare: https://www.weuvcare.com/what-is-uv-transmittance-uvt-and-why-is-it-important-to-know/

NRC. (2010, November). CON20100241701 Replacement Document. *Resource Consent*. Northland: Northland Regional Council.

NRC. (2011, September 2). CON20100720501. Northland: Northland Regional Council. Retrieved November 2021

NRC. (2021). *Proposed Regional Plan for Northland - Updated Appeals Verion 3.*

Real Tech Inc. (2017, November 4). *The Importance of UV Transmittance for UV Disinfection Applications*. Retrieved from Real Tech Water: https://realtechwater.com/blog-post/the-importance-of-uv-transmittance-for-uv-disinfection-applications/

Standards NZ. (2008). *On-site domestic wastewater treatment units. Part 3: Aerated wastewater treatment (AS/NZS 1543:2008)*.

Transfield. (2012, June). Kaeo STP Vermifilter Former and As Built Site Layout.

Transfield. (2014, September). Kaeo Sewerage Treatment Plant UV System Installation Locaton Plan.

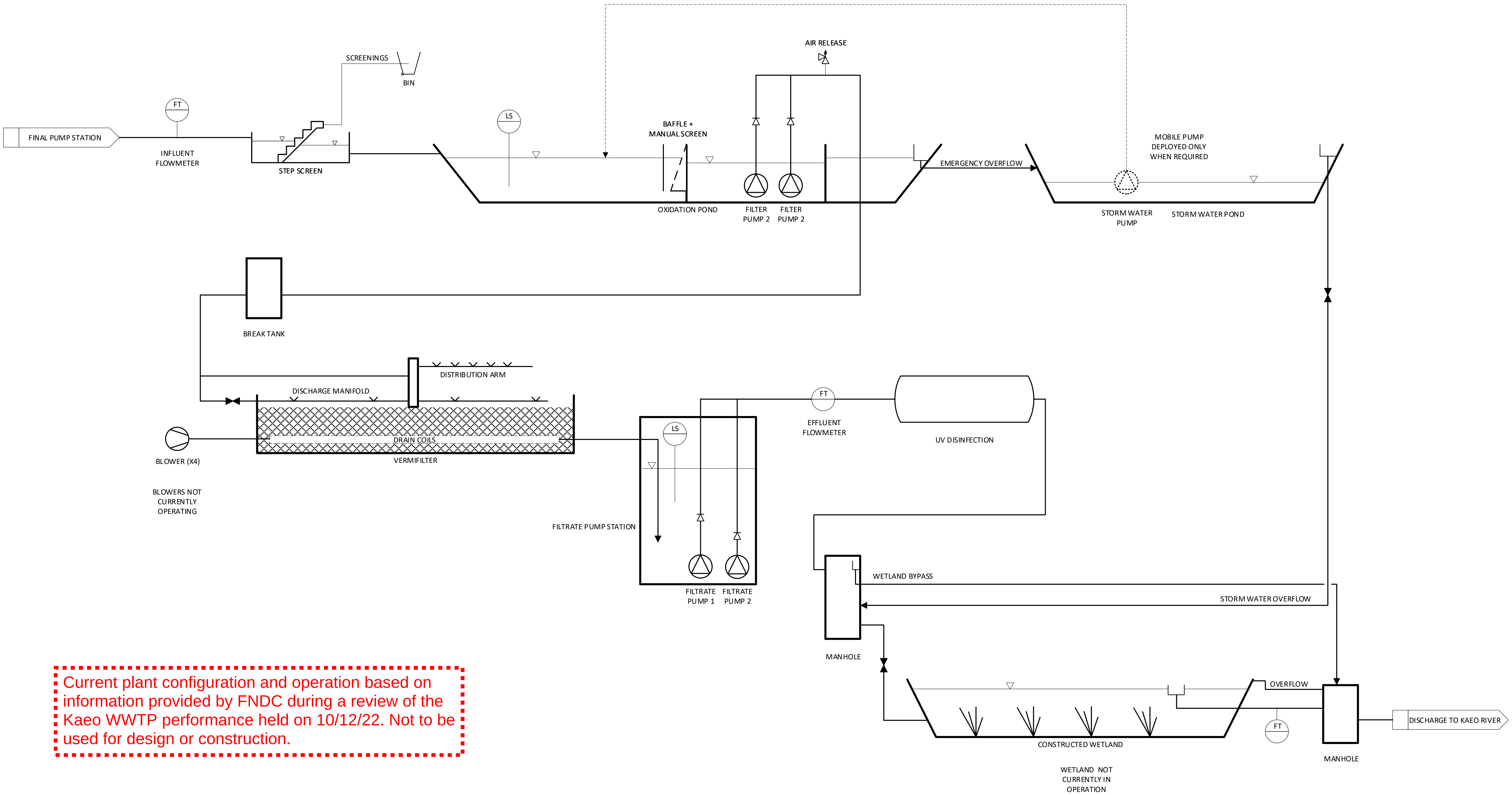
U.S. EPA. (2015). *Review of Coliphages as Possible Indicators of Fecal Contamination for Ambient Water Quality.* Washington: EPA Office of Water.

U.S.EPA. (1980). *Design Manual Onsite Wastewater Treatment and Disposal Systems (EPA 625/1-80-012)*.

WEF. (2010). Chapter 13 - Biofilm Reactor Technology and Design. *Design of Water Resource Recovery Facilities (MOP8).*

WEF. (2013, February 6). *Fundamentals of Disinfection.* Retrieved from Water Environment Federation: https://www.wefnet.org/fundamentalsofdisinfection/Fundamentals%20of%20Disinfection%20Webcast_color.pdf

Appendix A. Kaeo WWTP P&ID



Current plant configuration and operation based on information provided by FNDC during a review of the Kaeo WWTP performance held on 10/12/22. Not to be used for design or construction.

Jacobs

SITE	
KAEO WWTP	
SHEET TITLE	
PID	
SHEET NUMBER	DATE PRINTED
1 OF 1	12.11.21