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memorandum

TO	Tanvir Bamji	FROM	Oliver Hunt and Alan Pattle
	Watercare Services Ltd	DATE	2 April 2024
RE	Beachlands WWTP: Assessment of Overland Flow System Treatment Performance – Memorandum 2		

1.0 Background

Watercare Services Ltd (**Watercare**) is currently undertaking technical assessments to inform the resource consent application for the discharge of treated wastewater from the Beachlands Wastewater Treatment Plant (**WWTP**). The consent will provide for projected population growth and an increase in the capacity of the WWTP to 30,000PE. The Best Practicable Option ("**BPO**") for the discharge was identified as the continued use and expansion of the existing overland flow system which is used to create a diffuse discharge from the Beachlands WWTP to the Te Puru Stream.

Watercare has engaged PDP to provide advice on expansion of the existing overland flow system. PDP has previously completed a preliminary assessment of the design of the existing overland flow system to determine if the system can be expanded and has identified potential expansion areas for further investigation. This assessment concluded that the expansion of the overland flow system to service an increase in capacity to 30,000PE is feasible, and can be accommodated with land owned by Watercare at the Beachlands WWTP site as detailed in a memorandum dated 27 March 2024 (Memorandum 1).

This memorandum has been prepared to assess the treatment performance of the existing overland flow system, inform work to determine if the receiving environment water quality targets are likely to be met (by others), and identify areas of uncertainty in the system performance for further investigation.

2.0 Typical Overland Flow System Treatment Performance

This section has been prepared to review and summarise the typical performance of overland flow systems in literature. It is important to note that the Beachlands WWTP overland flow system is unique in that it is used to polish highly treated wastewater effluent. PDP are not aware of any other examples where an overland flow system receives such a high-quality effluent. Typically, overland flow systems have been used to treat wastewater ranging from screened raw sewage through to secondary treated effluent (e.g., pond, sand filter, simple package plant systems).

2.1 Treatment Processes

Overland flow can provide treatment to wastewater through a combination of physical, biological, and chemical processes (Wightman, George, Zirschky, Filip, & Sims, 1982). Total suspended solids (TSS) are largely removed by settling and filtration through the vegetation on the slope while carbonaceous biochemical oxygen demand (cBOD) is removed by biological growth/activity. For the purposes of the Beachlands system, the primary parameters of concern are nitrogen and phosphorus.

cBOD and TSS may also be important from a water quality/ecological perspective, however, the proposed MBR system will produce effluent with low levels of cBOD and TSS, with effluent concentrations expected to be < 7 mg/L for both parameters. It is unlikely that any form of overland flow system will provide any further removal of BOD and TSS. Furthermore, it is a possibility that the effluent leaving the overland flow system could contain higher levels of cBOD and TSS than the MBR effluent as organic matter is collected/dissolved into the wastewater stream from plant sources on the slope (Kemp, Filip, & George, 1978).

The removal mechanisms for nitrogen and phosphorus in an overland flow system are relatively complex and are heavily influenced by the nature of the wastewater applied, the flowrate/loading rate, and the soils present at the site. Nitrogen can be removed by a variety of methods including ammonia volatilisation, adsorption of ammonium ions, biological nitrification-denitrification, and plant uptake. The conditions which control which processes occur, and how effective they are, can be influenced in the design of the slope to promote greater aeration or to promote anoxic conditions. There is considerable uncertainty with a large range of removal rates reported throughout the literature (Overcash, 1978). In many instances it appears that variability in construction of the slope is a significant factor in the effectiveness of the treatment (Kemp, Filip, & George, 1978).

For phosphorus, the primary methods of removal are chemical precipitation, adsorption to near surface soils and plant uptake (Kemp, Filip, & George, 1978). Generally, plant uptake may account for a small percentage of phosphorus removal along the slope. Adsorption of phosphorus onto the soil matrix, as well as chemical precipitation of phosphorus compounds with $CaCO_3$ or iron and aluminium oxides, may provide a greater removal of phosphorus. However, by their nature, overland flow systems provide limited contact with soils as there is typically minimal movement of water through the soil itself. Soils also have a finite capacity to adsorb phosphorus and therefore removal may be reduced with system age dependent on the nature of the soils present at the overland flow site. For Beachlands, it is expected that the soils will have a high potential for phosphorus retention based on preliminary soil sampling results which indicate good anion storage capacity (ASC) and low Olsen P throughout the soil profile (PDP, 2024).

2.2 Typical Treatment Performance

In the literature, overland flow systems have been used to treat a wide range of influent quality. Table 2 provides several examples of overland flow treatment performance including several systems that treat oxidation pond effluent. PDP are not aware of any existing overland flow systems which are designed to provide further treatment to WWTP effluent of the proposed long-term treatment quality of the Beachlands WWTP.

As shown in Table 2, the current median effluent concentrations from the Beachlands WWTP are approximately at or below the maximum performance of an overland flow system. This issue will be accentuated with the further reduction in effluent nutrient concentrations from the proposed MBR plant. There may be some further reduction of nutrients over the slope however, this is difficult to quantify due to the absence of any research on treated of high-quality wastewater effluent by overland flow.

It should also be noted, that in some instances, there may be potential for the concentrations to increase over the overland flow system, including BOD, *E. Coli*/faecal coliforms from non-human sources, and TSS. This is shown in Utah Water example in Table 2. Concentrations of BOD and TSS in the slope runoff exceeded the influent concentrations in all trials.

Table 1: Overland Flow Effluent Quality compared to Beachlands WWTP Effluent Quality

Parameter	BOD (Applied)	TSS (Applied)	NH4-N (Applied)	NO3-N(Applied)	Total Nitrogen (Applied)	DRP (Applied)	Total Phosphorus (Applied)
Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Current WWTP Effluent Median[1]	6.16	8.07	0.08	4.60	6.02	0.80	1.02
Proposed MBR Effluent Median[6]	≤ 5	≤ 5	≤ 0.5	≤ 2			
USEPA Overland Flow System Maximum Performance[2]	10	15	1	5			
USACE Test Site (Summer, Secondary Effluent)[3]	5 (45)	3 (47)	4 (21.7)	6.2 (7.1)	13.6 (38.7)	1.1 (5.7)	3.3 (6.1)
Cheviot, Canterbury (Pond Effluent)[4]		39 (63)	0.37 (13)	0.2 (0.5)	5.1 (19.1)	1.1 (5.7)	2 (7.6)
Utah Water Research Lab (Pond Effluent, three application rates)[5]	8 – 10.2 (7.8)	11.8 – 15.4 (11.2)	0.14 – 0.59 (2.33)	0.04-0.12 (0.07)	2.2 - 2.9 (4.6)	1.2-1.5 (1.9)	1.5 – 1.9 (2.3)

Notes:

1. *Provided by Watercare for the period Sep 2023 – Feb 2024, n=62.*
2. *Obtained from USEPA Design Manual Section 9.1.3* (USEPA, 2006)
3. (Martel, Jenkins, & Palazzo, 1980)
4. (PDP, 2014)
5. (Kemp, Filip, & George, 1978)
6. *Provided by Aquatic Environmental Services Ltd*
7. *Concentrations in brackets are the concentration of wastewater applied to the top of the slope.*

3.0 Existing Performance Information

PDP has provided a summary of the design and construction of the overland flow system in the Memorandum 1, dated 22 March 2024. We are not currently aware of any previous work to quantify treatment provided by the overland flow system. However, the performance of the system is currently non-critical as further treatment past the point of discharge to the top of the overland flow system is not required to meet current consent limits.

PDP inspected the overland flow system on 19/03/2024. PDP observed poor dispersion of wastewater and rapid concentration/ channelisation of flows down the slope which are commonly reported as leading to poor treatment performance in experiments described in the literature. However, it is important to recognise following:

- Additional attenuation of contaminants in the overland flow system is not required to meet the existing consent limits.
- Watercare has commenced the process of renewing the existing system, however, this has been placed on hold until the new consent is finalised. We anticipate that as part of the detailed design of the expansion upgrades will also be made to the existing system so both the existing and new systems operate is a similar manner and with similar efficiency. It is expected that these improvements will improve the performance noted by PDP during the site visit.

3.1 Qualitative Review of Water Quality Data

As a proxy for information on the performance of the overland flow slope, PDP has reviewed the water quality information available for the WWTP outlet, the farm pond (Site B, sampled at outlet) and Site 15 (downstream of the first tributary confluence) as shown in Figure 1. The average concentration of key parameters as a percentage of the treated wastewater concentration is provided in Table 2.

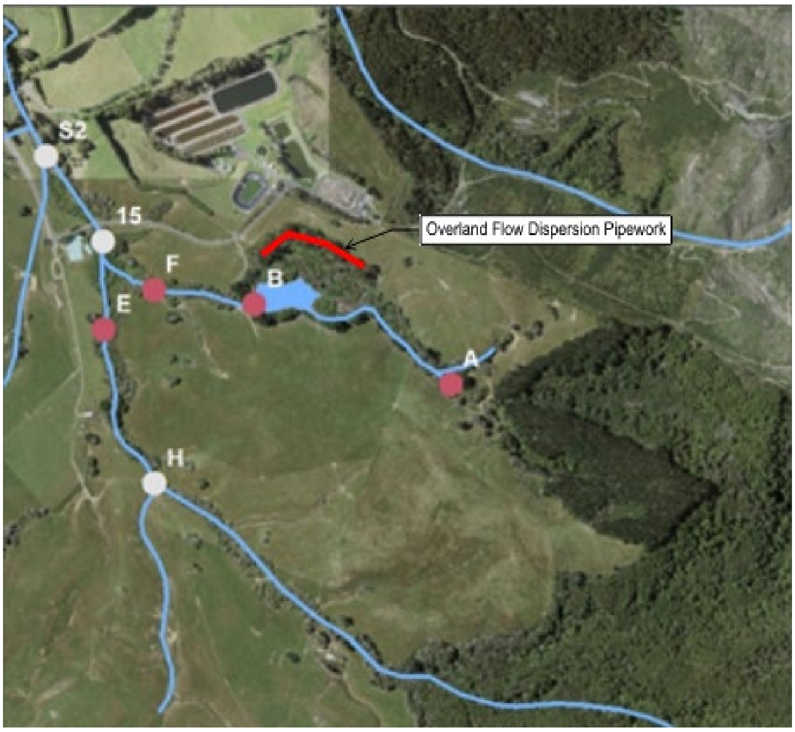

Figure 1: Beachlands WWTP Environmental Sampling Sites

Table 2: Average Residual Concentration as a Percentage of WWTP Effluent Concentrations

Parameter	Farm Pond	Site 15
Nitrate-N	59%	36%
Total Nitrogen	63%	36%
Ammoniacal-N[1]	581%	212%
Total Phosphorus	57%	32%
Dissolved Reactive Phosphorus	56%	28%
Conductivity	86%	53%

Notes:
1. *N=26 for ammoniacal nitrogen due to insufficient detection limits on WWTP samples prior to 4/12/23.*
2. *N = 62 for all other samples*

Based on this sampling data PDP have identified the following trends:

- Most nutrients are reduced by similar levels across the overland flow/pond combined system.
- Processes are occurring to produce ammoniacal nitrogen within the combined system, likely decomposition of organic matter within the pond.
- Key nutrients such as nitrate, total nitrogen, dissolved reactive phosphorus, and total phosphorus experience greater reduction in concentration relative to comparatively inert parameters such as electrical conductivity.

3.2 Quantitative Assessment of Overland Flow/Pond System Performance

To expand on these observations, PDP has completed a quantitative assessment of nutrient removal utilising sampling data over the wastewater disposal system collected between September 2023 and February 2024. In Table 3, the median concentrations across the system from the WWTP Outlet (Composite), through the farm pond and down to Site 15 are provided. The locations of the environmental sampling sites are provided in Figure 1. The median has been used in this instance as breakdown of the sampling results has revealed that some parameters can have significant short-term spikes in concentration, often associated with wet weather events.

To complete a qualitative assessment of the treatment processes, the conductivity of the wastewater/freshwater has been assumed to be unaffected by any processes other than dilution. There may be some effect of adsorption of ions within the overland flow system, however, this is expected to be negligible and is difficult to quantify. Using the median values and straightforward flow/mass balance approach the ratio of the various flow streams has been calculated with the WWTP flow assumed as 1 “flow unit”. These ratios are presented in Table 4 along with an extrapolation to the include the predicted three-fold increase in wastewater discharge as the Beachlands WWTP capacity increases to the predicted 30,000 PE proposed under the consent application.

Table 3: Median concentrations across the Overland Flow/Pond system

Parameter	WWTP Effluent	U/S Pond (Site A)[2]	Farm Pond (Site B)	Tributary (Site E)[2]	Site 15
Nitrate-N (mg/L)	5.02	0.0205	2.71	0.115	1.59
Total Nitrogen (mg/L)	6.25	0.18	3.70	0.27	2.10
Ammoniacal-N[1] (mg/L)	0.03	0.0277	0.28	0.02	0.07
Total Phosphorus (mg/L)	0.87	0.0305	0.47	0.028	0.26
Dissolved Reactive Phosphorus (mg/L)	0.73	0.014	0.38	0.015	0.18
Conductivity (µS/cm)	141	20	122	16	71

Notes:

1. *N=26 for ammoniacal nitrogen due to insufficient detection limits on WWTP samples prior to 4/12/23.*
2. *N = 20*
3. *N = 62 for all other samples*

Table 4: Beachlands WWTP Flow Ratios (Median)

Flow Stream	Ratio to WWTP Flow (Median Conditions)[1]	Extrapolation to Future WWTP Flows[2]
WWTP Effluent	1	3
U/S Pond	0.19	0.19
D/S Pond	1.19	3.19
Site 15 Tributary	1.10	1.10
D/S Site 15	2.29	4.29

Notes:

1. *Environmental flows calculated as a ratio of the WWTP flow stream using conductivity sampling presented in Table 3 and a mass/flow balance method.*
2. *Ratio of flows in future scenario based on a three-fold increase in WWTP flows and no change to base flows in the stream/tributaries.*

These flow ratios can then be used to determine the "fraction" of each parameter which has been "removed by treatment processes" vs. simple dilution. These results are provided in Table 5, however, it is important to note that these are an estimate only with significant limitations including the limited sampling range (n=62, Sep 2023 – Feb 2024). These should not be interpreted as the treatment performance of the system under all conditions.

Table 5: Concentration Reduction due to Processes other than Dilution

Parameter	WWTP Effluent -> Farm Pond[1]	Farm Pond -> Site 15[1]
Nitrate-N (mg/L)	1.81 (36%)	-0.24 (-9%)
Total Nitrogen (mg/L)	1.89 (30%)	-0.10 (-3%)
Ammoniacal-N (mg/L)	-0.29 (-874%)	0.17 (61%)
Total Phosphorus (mg/L)	0.32 (37%)	-0.003 (-1%)
Dissolved Reactive Phosphorus (mg/L)	0.28 (38%)	0.044 (11%)

Notes:

1. *Additional change in concentration after dilution has been accounted for.*
2. *Bracketed figure represents the percentage removal of upstream concentration by non-dilution processes.*
3. *Negative changes represent an increase in the concentration from the upstream site to the downstream site.*

These results quantify the change in concentrations within the current overland flow/farm pond system. Overall, (from the WWTP outlet to Site 15) the system is estimated to remove approximately 30 – 35% of both nitrogen and phosphorus. In addition, it is notable that:

- Natural processes are occurring to produce an increase in ammoniacal nitrogen, approximately 0.3 mg/L under median conditions. This is likely due to mineralisation (ammonification) of organic nitrogen within an anaerobic base layer in the pond.
- Under median conditions, approximately 40-50% of this ammoniacal nitrogen is nitrified as wastewater flows out of the pond and into the turbulent/well-aerated stream. Monitoring data indicates that nitrate increases slightly to Site 15, likely as a result of this process.

Overall dilution predictions, based on this dataset, for the current and future (three-fold increase) scenarios are summarised in Table 6:

Table 6: Beachlands WWTP Dilution to Site 15 by Scenario

Scenario	Wastewater to Site 15 Flow Ratio	Dilution
Current	1:2.29	56%
Future (three-fold increase)	3:4.29	30%

While the dilution effects have been quantified, it remains unclear what fractions of this reduction are attributable to the overland flow system vs. natural biological processes in the pond. Given the available information on the construction and operation of the overland flow system, it is unlikely that the overland flow slope is constructed in a way which promotes highly effective treatment. Based on studies of pilot scale overland flow systems, the careful preparation and maintenance of the overland flow slope is critical to maximising treatment performance (Kemp, Filip, & George, 1978). This could indicate that the pond is providing most of the treatment performance. Production of ammonia within the pond adds further evidence that there are significant processes occurring within the pond. As part of the detailed design phase of the process, PDP recommends that an investigation on the current performance of the system is completed to quantify the treatment performance of the overland flow system and inform the design of any future expansion.

Higher wastewater flows under the interim and Stage 2 scenarios will likely reduce the hydraulic retention time of the pond. If the pond is providing most of the observed nutrient removal this risks the expanded system providing reduced treatment performance if an expanded or additional pond is not provided.

Subject to further investigations, in the event pond is found to be the primary treatment process, the overland flow system could be designed to provide for some form of pond/wetland/riparian planted area at the toe of the new overland flow slopes to mimic the existing system more closely. Wastewater would likely be dispersed overland through a riparian margin into the existing farm pond as final form of discharge.

It is noted that in Memo 1, PDP identified that there was sufficient area (up to 11.5 ha) to provide overland flow treatment systems, even at the lowest end of the application rate range specified by the USEPA, within the existing Watercare site. If the pond is found to be the primary treatment process, it is expected that an application rate at the upper end of the USEPA range could be used. This will reduce the overland flow area requirements and result in sufficient available area for the potential pond/wetland areas in addition to the proposed overland flow areas.

4.0 Summary

A review of available overland flow literature has indicated that in some settings, overland flow systems can provide additional removal of well-treated wastewater. However, there are no examples of an overland flow system which is used to provide additional treatment to wastewater which is similar in nature and quality to that of the predicted MBR effluent quality. In the literature, it is common that overland flow systems produce effluent which is of worse quality that predicted MBR effluent quality. In some systems, the overland flow system increased concentrations of BOD, and TSS.

For the Beachlands WWTP, PDP is not aware of any information on the treatment performance of the existing overland flow system. PDP have attempted to quantify the treatment performance using sampling data from Sep 2023 – Feb 2024 from the WWTP effluent and environmental sampling points. Based on this assessment, it is expected that under median conditions the current combination of overland flow and retention within the farm pond provides removal of approximately 30 – 40% of total phosphorus and total nitrogen. Additionally, it is noted that ammoniacal nitrogen is generated within the system, likely due to mineralisation of organic nitrogen within the pond and that a large portion of this ammoniacal nitrogen is nitrified in the stream immediately downstream of the pond.

However, it is not possible to separate the individual performance of the overland flow slope and the farm pond. Without quantification of the performance of the overland flow slope vs. the farm pond it is not possible to predict with certainty the treatment performance of the upgraded system.

Under the expanded overland flow systems increased volumes will reduce the hydraulic residence time of the pond and therefore likely reduce the treatment capacity. This poses a risk as additional attenuation of nutrients within the overland flow/pond/wetland system is required to meet the proposed receiving water quality limits (as assessed by others). To mitigate this risk, PDP suggest that Watercare proceed on the basis that, subject to the results of ongoing investigations to inform detailed design, the consent application provides for new pond/wetland areas at the toe of the overland flow slopes. This will allow closer replication of the existing system/performance in the event the pond is providing the majority of the additional treatment. PDP recommends that, as part of the detailed design phase of the process, that Watercare undertake further investigations to quantify the performance of the existing system components to inform the design of the expanded system. If further investigations suggest that, based on a more complete understanding of the performance of different components of the current system, it is not necessary to provide an additional pond/wetland area, that area can be removed from the application after lodgement.

5.0 References

Kemp, M. C., Filip, D. S., & George, D. B. (1978). *Evaluation and Comparison of Overland Flow and Slow Rate Systems to Upgrade Secondary Wastewater Lagoon Effluent.* Utah Water Research Laboratory.

Martel, C. J., Jenkins, T. F., & Palazzo, A. J. (1980). *Wastewater treatment in cold regions by overland flow.* Hanover: United States Army Corps of Engineers.

Overcash, M. R. (1978). Implications of overland flow for municipal waste management. *Journal Water Pollution Control Federation*, 2337-2347.

PDP. (2014). *Assessment of Environmental Effects for Treatment and Discharge of Municipal Wastewater: Cheviot Wastewater Treatment Plnat.* Christchurch.

PDP. (2024). *Beachlands Maraetai WWTP Options Assesment: Soil Sampling LA site – Factual Report.* Auckland.

USEPA. (2006). *Process Design Manual Land Treatnebt of Municipal Wastewater Effluents.* Cincinnati: U.S. Environmental Protection Agency.

Wightman, D., George, D. B., Zirschky, J. H., Filip, D. S., & Sims, J. (1982). *An Evaluation of the Performance of a Modified Overland Flow Wastewater Treatment System: Sloped Rock-Grass Filtration.* Utah Water Research Labaratory.

6.0 Limitations

This memorandum has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Watercare Services Ltd and others (not directly contracted by PDP for the work), including Aquatic Environmental Sciences Ltd. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the memorandum. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

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Yours faithfully

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