Manaaki Whenua
Landcare Research

Lake Areare floating wetland monitoring 2019–2020

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Summary

Project and Client

- The treatment efficiency of the Lake Areare floating wetland was monitored from June 2019 to June 2020 in a joint project between Manaaki Whenua – Landcare Research (MWLR) and Living Water. The Lake Areare floating wetland had previously been monitored by MWLR from July 2016 to July 2017 and this work indicated that the floating wetland had a variable impact on nitrogen removal but showed some promise for reducing phosphorus and sediment entering the lake. The interactions between plant-mediated processes, season, and changes in flow regimes were not assessed during previous research.

Objectives

- Determine the treatment efficiency of the Lake Areare floating wetland
- Seasonally assess plant (*Carex secta, Carex virgata,* and *Cyperus ustalus*) nutrient concentrations, assessment of plant biomass above and below the raft, and particulates entrapped by root mass
- Determine sediment accumulation rates up- and down-stream of the floating wetland
- Determine the size of the catchment contributing to this drain.

Methods

- Sub-catchment area of the floating wetland drain determined by delineating a digital elevation model (DEM) from Light Detection and Ranging (LiDAR) data
- Continuous measurement of water depth using an in situ pressure transducer water level logger
- Approximately monthly discrete measurements of flow velocities, discharge, and water chemistry were undertaken from June 2019 to May 2020.
- In situ measurements of water temperature, dissolved oxygen (DO), electrical conductivity, pH and water depth were taken at most sampling events
- Water quality determined from analyses for total and dissolved forms of nitrogen (N; total N (TN), ammonium (NH_4-N), nitrate (NO_3-N), total organic N (TON), particulate organic N (PON)), phosphorus (P; total P (TP), particulate P (PP) and dissolved reactive phosphorus (DRP)), and suspended solids (SS; total suspended solids (TSS), volatile SS (VSS) and non-volatile SS)
- Hydraulic residence time (HRT) was measured via a sodium chloride tracer test
- Areal yields and mass loads of TN, TP, and TSS were calculated from discharge and concentrations of constituents
- Treatment efficiency was calculated as the proportional difference in loads from upstream to downstream of the floating wetland
- Biomass of each plant species on the floating wetland was determined in June 2019 and leaf and root parameters assessed
- Plant leaf and root samples (*n*=6/species) were taken in June, September, and December 2019, and March 2020. Leaf and root material were analysed for TN and TP

- Sediment entrapment in the root material was also assessed on the four plant sampling dates across the monitoring period. Root samples were washed, and the sediment captured analysed for TSS, VSS, TN, and TP
- Sediment accumulation in the drain up- and down-stream of the floating wetland was determined by assessing sediment depth, TN and TP on four transects across the drain.

Results

- The sub-catchment area of the floating wetland drain is 149 ha
- Water levels fluctuated by 1.0 m over the 12-month monitoring period
- Discharge ranged between 0 and 0.071 m^3/s, with no flow from January to late March 2020 and peak flows of 6,132 m^3/day
- Daily influent areal yields varied widely for TN, TP, and TSS reflecting fluctuating concentrations, water levels, and discharge
- Annual areal yields were 8.6–23 kg/ha/yr TN, 2–10 kg/ha/yr NO_3-N, 0.47–1.07 kg/ha/yr TP, and 0.11–0.26 kg/ha/yr DRP
- Analogous mass loads were also highly variable and ranged between 0.3 and 50 kg/day TN, 0.02 and 2.7 kg/day TP, and 0.6 and 32 kg/day TSS
- HRT was ~9 hours at mean water level depth and was 2.4–4.0 times theoretical HRT
- TN, NH_4-N, NO_3-N, TON, PON, TP, and DRP concentrations varied considerably over the monitoring period and were not reduced by the floating wetland; PP significantly increased downstream of the floating wetland
- TSS, VSS, and non-volatile SS were highly variable and increased with lower water levels, warmer temperatures, and anoxic DO levels, and were not significantly reduced by the floating wetland
- The floating wetland showed decreases and increases of parameters over time
- *Carex secta* had the largest biomass of the three species. All plant species invested more in producing root biomass over leaf biomass
- Leaf and root N contents varied seasonally
- Leaf TP contents (%) decreased in all species over time; root TP peaked in September 2019; leaf and root TP concentrations (mg/g) were higher in *Carex secta*
- Root entrapment of particulates varied widely: from 0 to 1200 mg/g for TSS and 0 to 500 mg/g for VSS. Roots of all species extended ~1 m depth to sediment on the drain bed
- There was a decreasing trend in TN and TP contents (%) of root entrapped sediment over time and concentrations (mg/g) peaked in September 2019.
- Sediment depths were not significantly reduced by the floating wetland.

Discussion

- The mature 60-m^2 Lake Areare floating wetland exhibits variable and poor performance, consistent with previous assessments undertaken at this site
- Despite small annual decreases in NO_4-N and PP, the floating wetland is not facilitating this drain to meet water quality guidelines in the Waikato

- It is likely the performance of this wetland is limited by its small size and short HRT. Increasing the wetland's size to 800 m^2 would increase HRT to 5 days, and catchment area ratio to 0.05%, which should enhance performance
- Inorganic N was more variable than organic N but in general fluctuations in water levels, discharge, and pollutant concentrations varied widely
- Research has shown accumulation of trace elements (copper and zinc) within the floating wetland; sediments under the wetland may contain elevated trace element concentrations
- Intraspecies competition resulted in high plant mortality and degrading plant material would contribute nutrients to the water column. Mortality may be linked to a high planting density and/or lack of foliar/plant harvesting
- Translocation of TN and TP from leaf to root storage occurred in Autumn; hence harvesting wetland foliage in late summer may improve treatment efficiency but may add nutrients to the water column due to root die off from foliar harvest
- Replacement of all plants annually, in line with international recommendations, may increase treatment efficiency, but would likely to be minor compared to increasing the size of the floating wetland
- Control of weeds on the floating wetland, and its banks, may increase treatment efficiency
- Accumulation of leaf litter and humic material on the floating wetland delivers nutrients back into the water column, contributing to the variability of wetland performance and accumulates copper and zinc
- Root lengths of nearly 1 metre reflected a large plant investment, all plant species had the same capacity for particulate entrapment regardless of species-specific biomass
- Particulates trapped by *Carex* species had greater TN and TP contents. This may be because they entrap particulates of a size class that has greater TN and TP concentrations and may be a factor of root size distributions rather than total biomass.

Recommendations

- Increase performance by increasing wetland size to 800 m^2 and therefore increasing hydraulic residence time to 5 days
- Increase performance by undertaking maintenance of the floating wetland. Actions should include:
    - Annual removal of leaf litter and fresh humus material on the floating wetland to reduce delivery of nutrients back into the water column
    - Harvesting leaves in late summer or replacing all plants annually
    - Weed control on the floating wetland and banks adjacent to the wetland
    - Removing sediment from the drain
- Measure heavy metal concentrations in sediment below the floating wetland
- Root size fractionation would be useful to determine plants with root structures most beneficial for use on floating wetlands.

1 Introduction

Lake Areare is located 6 km south-east of Ngāruawāhia and is the largest (33 ha) of the Kainui Bog peat lakes (Reeves & Mazzieri 2012). Much of the land surrounding the lake is used for grazing livestock, both dairy and non-dairy production (Reeves & Mazzieri 2012; Living Water 2014) which has contributed to a decrease of the water quality in the lake (Dean 2015).

A floating wetland was installed in a drain between the Waikato Expressway, a dairy farm, and Lake Areare in December 2015 (Fig. 1) to mitigate suspended solids and nutrient contributions from adjacent grazed land and to provide habitat for birds and aquatic organisms.

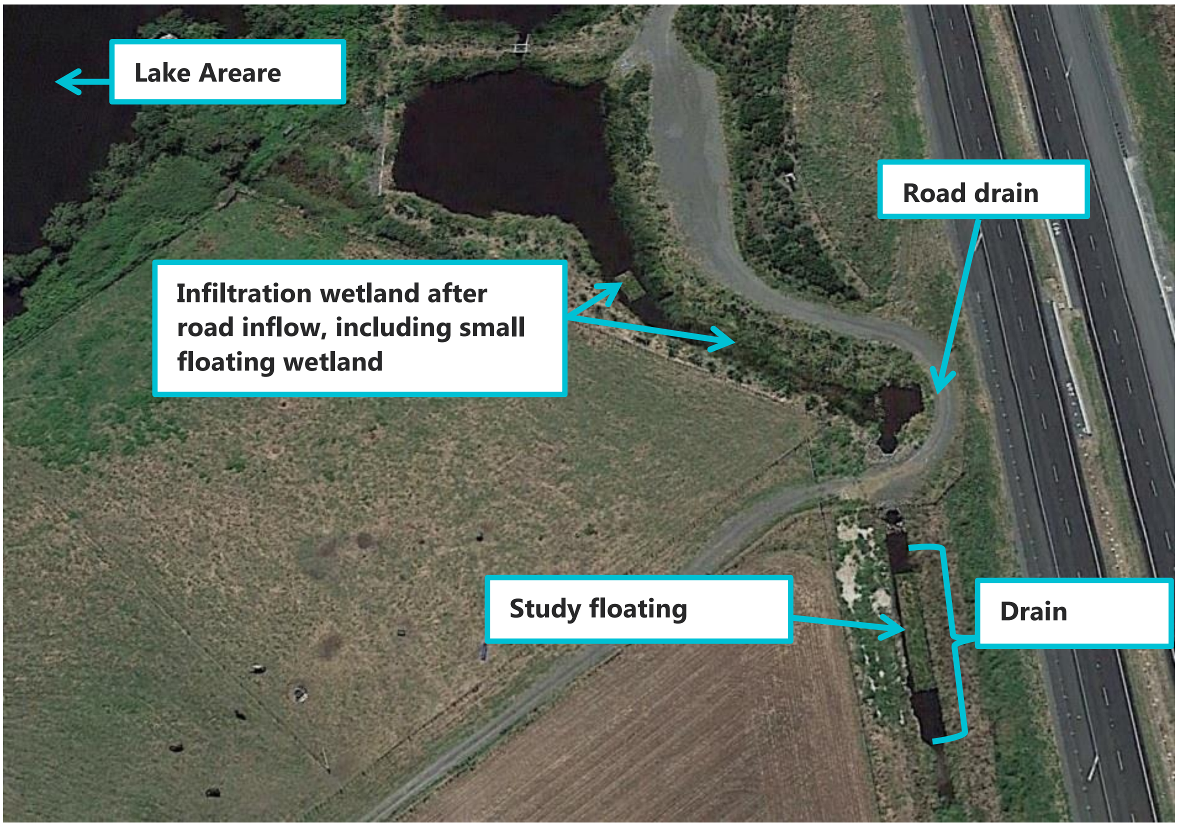

Figure 1. The study floating wetland and infiltration wetland at the south-eastern inflow into Lake Areare, Waikato.

The drain was artificially widened and deepened to slow water flow before floating wetland installation (Fig. 2). The wetland is a series of interconnected plastic rafts, each 1.2 × 1.0 m, with a total of 45 rafts covering 60 m^2 (Fig. 2). Each raft was originally planted with 13 plants (planting density of approx. 10 plants/m^2) for a total of 585 plants. Three plant species are used: *Carex virgata* (pūkio), *Carex secta* (pūrei) and *Cyperus ustulatus* (giant umbrella sedge). The floating wetland is anchored to the bank sides to stop the system migrating downstream. Baffles were also installed on the upstream end of the floating wetland to direct water through the wetland and to reduce water bypassing the wetland system.

Figure 2. Floating wetland in south-eastern drain inflow to Lake Areare; farmland to the right, State Highway 1 to the left, March 2016, 4 months after establishment.

Floating wetland systems can remove nutrient and suspended solids from slowly moving water columns via plant uptake and root entrapment (Stewart et al. 2008; Tanner & Headley 2011; Borne et al. 2013b; Nichols et al. 2016). However, a previous assessment of the performance of the Lake Areare floating wetland for nutrient and sediment attenuation showed variable effectiveness over time (Lambie 2017). The floating wetland had no consistent effects on N concentrations, which were consistently above the 0.5 mg/L water quality standards set by the Waikato Regional Council at both inflow and outflow. The floating wetland removed up to 50% of suspended solids and there was an increasing trend of P removal. However, these data were not assessed for flow rate in the drain.

2 Objectives

The objectives of this work were to determine the treatment efficiency of the Lake Areare floating wetland, to assess seasonal plant nutrient concentrations and plant biomass above and below the wetland, as well as particulates associated with the root mass. Further, assessment of sediment accumulation rates up- and down-stream of the wetland and the size of the catchment were undertaken.

3 Methods

3.1 Sub-catchment characteristics

The Lake Areare catchment comprises flat to rolling lowland hills ~60 m above sea level. Annual rainfall ranges from 900 mm to 1175 mm (Appendix 1 contains rainfall over the monitoring period). The catchment land use is almost entirely intensive dairy production.

The sub-catchment area of the drain in which the floating wetland is installed was calculated using QGIS 3.14.0-Pi software (QGIS 2020, Geographic Information System, Open Source Geospatial Foundation Project). The area was delineated from a digital elevation model (DEM) created from Light Detection and Ranging (LiDAR) data provided by the Waikato Regional Council. Two LiDAR datasets were used, one from the 2007/08 survey and the other from 2019. Unfortunately, the more recent and more accurate 2019 LiDAR raster tiles only covered a third of the lake's catchment area (Figure 3) therefore both LiDAR datasets were combined for the DEM analyses.

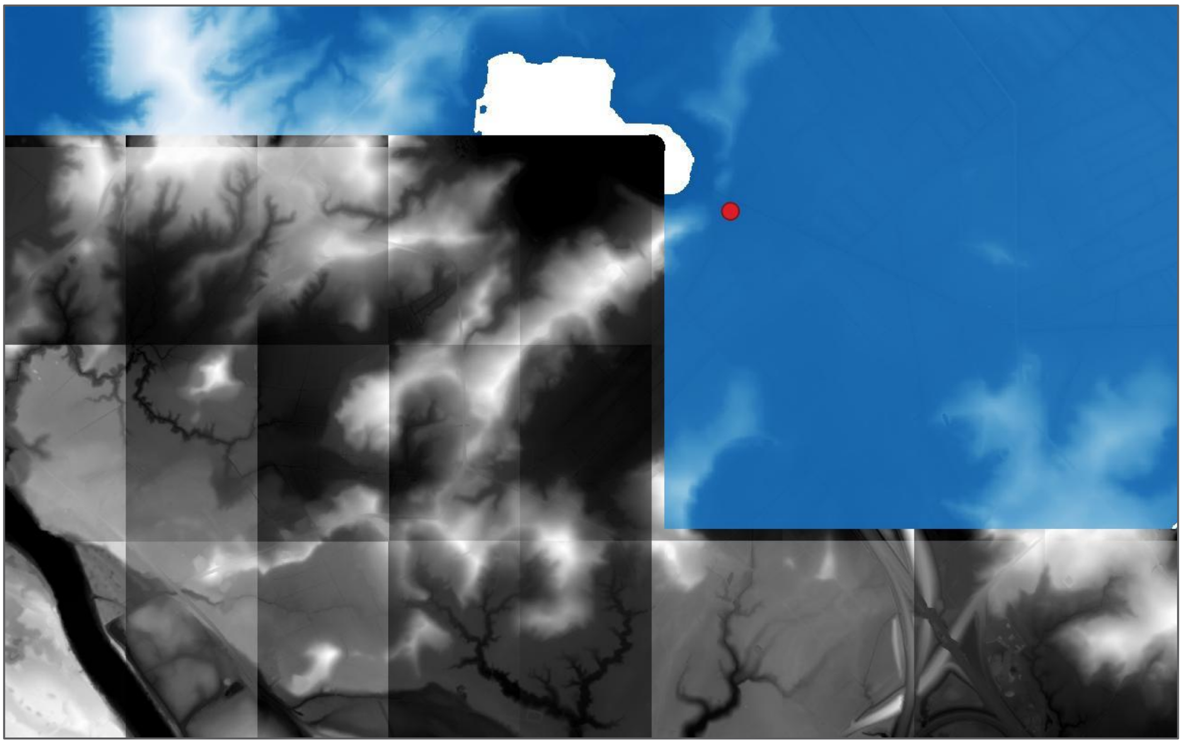

Figure 3. Extent of 2019 (black & white) and 2007/08 (blue & white) LiDAR datasets. The location of the Lake Areare floating wetland is shown by the red circle.

3.2 Water quality assessment

3.2.1 Water levels & discharge

A 'Solinst Levelogger Edge' pressure sensor and temperature datalogger was installed on 26 June 2019 to record water level fluctuations in the drain over the study period (Figure 4). A Barologger Edge was simultaneously installed to compensate the Levelogger Edge data for atmospheric pressure fluctuations. This was installed at a nearby outdoor lean-to adjoining a farm shed, ensuring the logger was in the open-air while being protected from the weather. The loggers measured water level (meters), temperature (°C), and atmospheric pressure (kPa) every 5 minutes with an accuracy of 0.05% FS.

Data were downloaded from the loggers to a laptop using the Solinst Levelogger Software 4.4.0 on 9 July 2019, 29 October 2019, 24 February 2020, and 22 June 2020. The 'Data Wizard' function of the Solinst Levelogger Software was used to compensate the raw water level data for atmospheric pressure fluctuations. Finally, the 'water pressure' water levels were calibrated with 16 physical water depth measurements made at least monthly since installation of the loggers.

Figure 4. Levelogger Edge installed on the true left edge of the drain, 9 m upstream of the floating wetland (26 June 2019).

Flow rates and discharge of the floating wetland drain were measured using a SonTek Flowtracker® (2006 Handheld ADV®, SonTek/YSI, San Diego, USA) using the 'Mid-Section Discharge Method' (SonTek/YSI 2009) on 16 dates from June 2019 to June 2020, in conjunction with sample collection for water quality analyses.

3.2.2 Hydraulic residence time

Tracers are frequently used to investigate aspects of hydrological systems such as flow pathways, velocities, and travel times (Flury & Wai 2003). Hydraulic tracer tests are used in constructed treatment wetlands to measure detention, or residence, times, i.e. the average time water spends in the wetland (Kadlec & Wallace 2008). The residence time can be related to the treatment efficiency of the wetland, and subsequently inform adjustments, maintenance, or improvements to the design to enhance treatment performance. The hydraulic residence time (HRT) of the floating wetland was measured on 29 October 2019 using the 'salt pulse' method (Chazarenc et al. 2003; Kadlec & Wallace 2008). High concentrations of sodium chloride solution were added to the floating wetland drain 15-m upstream of the wetland, and its movement through/below the wetland was indicated by measuring specific conductivity immediately up- and down-stream of the wetland using two YSI Professional Plus handheld multiparameter meters (Yellow Springs Instruments, Ohio, USA).

For comparison, theoretical HRT (HRT_t) was calculated as HRT_t V/Q, where V=width*length*depth of water beneath the floating wetland, and Q=velocity*cross-sectional area of flow at time t.

3.2.3 Water quality sampling

Water samples were collected using a 1-L measuring jug attached to a 2-m pole, water was stored in 500-mL opaque plastic pottles and 1-L semi-opaque bottles, and placed on ice in the field before laboratory analysis of nutrient and suspended solid concentrations (Figure 5). Samples were taken from the flowing channel upstream (U/S) of the floating wetland immediately above the widened and deepened channel excavated for the installation of the wetland. This ensured the samples were representative of influent surface water and not the ponded water above the wetland. Downstream (D/S) samples were collected 1 m downstream of the wetland.

Water temperature, dissolved oxygen (DO), specific conductivity, and pH were measured concurrently with most of the water sample collection events, using a YSI Professional Plus handheld multiparameter meter (Yellow Springs Instruments, Ohio, USA).

Figure 5. Upstream sampling location above the floating wetland and the widened and deepened channel (5 May 2020).

Water samples were collected from June 2019 to May 2020 in either triplicate or as a single replicate (Table 1).

Table 1. Date and replication of grab water samples taken from Lake Areare floating wetland between June 2019 and May 2020

Date sampled	Replicate
6 June 2019	3
9 July 2019	3
13 July 2019	1
8 August 2019	1
12 September 2019	3
29 October 2019	1
20 November 2019	1
10 December 2019	1
13 January 2020	1
24 March 2020	1
5 May 2020	1
26 May 2020	1

Ammonium (NH_4-N), nitrate (NO_3-N), and dissolved reactive phosphorus (DRP) were analysed on samples filtered to 0.45 µm (methods 4500 NH3-F (Modified), 4110 B, 4500-P E; APHA (2017); Central Environmental Laboratories). Total nitrogen (TN) and total phosphorus (TP) were analysed on unfiltered samples (methods 4500-P J, 4500-NO2 B, 4500-P J,E; APHA (2017); Central Environmental Laboratories). Total organic nitrogen (TON) concentrations were calculated by subtracting the sum of total inorganic nitrogen (i.e. NH_4-N, NO_3-N) from TN. Particulate P concentrations were calculated by subtracting DRP from TP. Limits of detection were 0.005 mg/L for NH_4-N, NO_3–N, and DRP, 0.05 mg/L for TN, and 0.01 mg/L for TP.

Total particulate organic N (PON) was assessed as described by Huang et al. (2018) by filtering 25–200 mL sub-samples of each water sample through pre-combusted 0.45-µm-pore-diameter glass filter papers. The filter paper and any particulate matter were dried at 60°C and enclosed in pre-combusted aluminium foil before analysis for total N by combustion furnace (Environmental Chemistry Laboratory 2019a).

Total suspended solids (TSS) and volatile SS (VSS), and pH were also measured (methods 2540 D, 2540 E and 4500-H+ B; APHA 1992; APHA (2017); Central Environmental Laboratories). Non-volatile SS were calculated by subtracting VSS from TSS. Detection limits for TSS and VSS were 1 mg/L.

3.2.4 Yields and mass loads of nutrients and sediments

Areal water yields for the floating wetland drain were calculated using measured instantaneous discharge for each sampling event divided by the sub-catchment area (ha) and extrapolated to give daily water yields (expressed as m^3/ha/d). Water yields were then multiplied by measured nutrient concentrations to give daily nutrient yields (kg/ha/d) for NH_4-N, NO_3–N, TON, TN, DRP, PP and TP.

Daily instantaneous mass loads were calculated by multiplying the daily discharge (m^3/d) by measured nutrient concentrations (g/m^3) to give nutrient loads (kg/d) for NH_4-N, NO_3-N, TON, TN, DRP, PP and TP for upstream (U/S) and downstream (D/S). Estimated mass load reductions associated with the floating treatment wetland were calculated by subtracting D/S loads from U/S.

3.3 Plant uptake

3.3.1 Plant biomass

Fifteen plants were removed from the floating wetland, intact where possible, on 6 June 2019: six plant samples of *Carex virgata* and *Cypurus ustulus,* and three of *Carex secta.* Fewer *C. secta* were taken as these plants were much larger than the other species and there were often only 1 or 2 *C. secta* plants on each of the rafts. Any removal of more *C. secta* plants might therefore have compromised nutrient attenuation and negatively impacted the water quality data that were being collected concurrently. Maximum leaf and root length were measured on removed plants before partitioning into above- and below-raft components. The leaf material was trimmed as close to the potting-mix surface as possible and all biomass below this point was considered below-raft biomass. The leaf and root material were dried at 80°C for a minimum of 48 hours before weighing.

3.4 Sediment entrapment

Particulate entrapment was determined as described by McAndrew et al. (2016) using root material collected through the seasons. The root systems were washed until clean and the water captured, sieved through a 2-mm then 0.5-mm sieve to remove large and small non-sediment material, respectively. The volume of washing water was measured, and subsamples of the water analysed for TSS and VSS as per Hach Company (2015): 0.45-µm glass filter papers (Thermo Fisher Scientific New Zealand) were washed with 300 mL of ultra-pure water and pre-combusted at 550°C and weighed before filtration of 20–200 mL of washing water. The filter papers and sediment were then dried at 105°C for at least 1 hour and then reweighed to determine TSS. The filter papers were then combusted at 550°C for 15 minutes and reweighed to determine VSS.

TSS and VSS was calculated as mg of solids per litre of root washing water. TSS and VSS were also calculated as mg of solids per gram of root material washed, calculated by multiplying the mg/L of solids by the total amount of water collected during root washing and dividing by the dry weight of the root mass washed (dried to 80 °C). VSS was also calculated as a proportion of TSS to indicate the proportion of the suspended solids of biological origin. One litre of washing water from each plant root sample was dried at 80°C until the water evaporated, and the sediment bulked for the six (or three) samples from each plant species within each seasonal collection. The sediment isolated from the root washing was analysed for total N and P.

The N and P concentrations (mg/g) of the sediment in the root washings was estimated by multiplying the content (%) by the TSS contents as corrected for the biomass of root material washed (mg/g).

3.4.1 Plant nutrients

Leaf and root material were harvested on 6 June 2019, 12 September 2019, 10 December 2019, and 24 March 2020. Leaf and root material collected in Section 3.3.1 (Plant biomass) were also subsampled for nutrient analysis. After June 2019, no further entire plant destructive harvesting occurred due to the likely impact on the wetlands' integrity and water treatment. Instead, foliage and root material subsamples were harvested from the wetland for analysis from randomly selected plants, and a section of foliage (3 whole leaves per plant) and root material (3 whole roots) removed. Samples from six different plants of each species were taken, bulked within plant species, and dried to 80 °C.

The leaf matter from each species was ground to <1 mm for TN and TP analysis by Kjeldahl digestion (Environmental Chemistry Laboratory 2019). This was repeated for the root material after determination of sediment entrapment (Section 3.4).

Plant N and P concentrations (mg/g) were estimated using the average biomass of the plants harvested in June 2019, multiplied by the N and P contents (%) over time. While, it would have been preferable to use the average biomass for each species at each of the times leaf and root material was gathered, it was not possible due to the abundance of dead plants on the floating wetland.

3.5 Sediment accumulation

Sediment accumulated up- and down-stream of the floating wetland was assessed on 10 December 2019. Sediment depths were measured at five points across four transects, two upstream and two downstream of the wetland (Figs 6 & 7).

Figure 6. Transects 1 and 2, downstream of the floating wetland, December 2019.

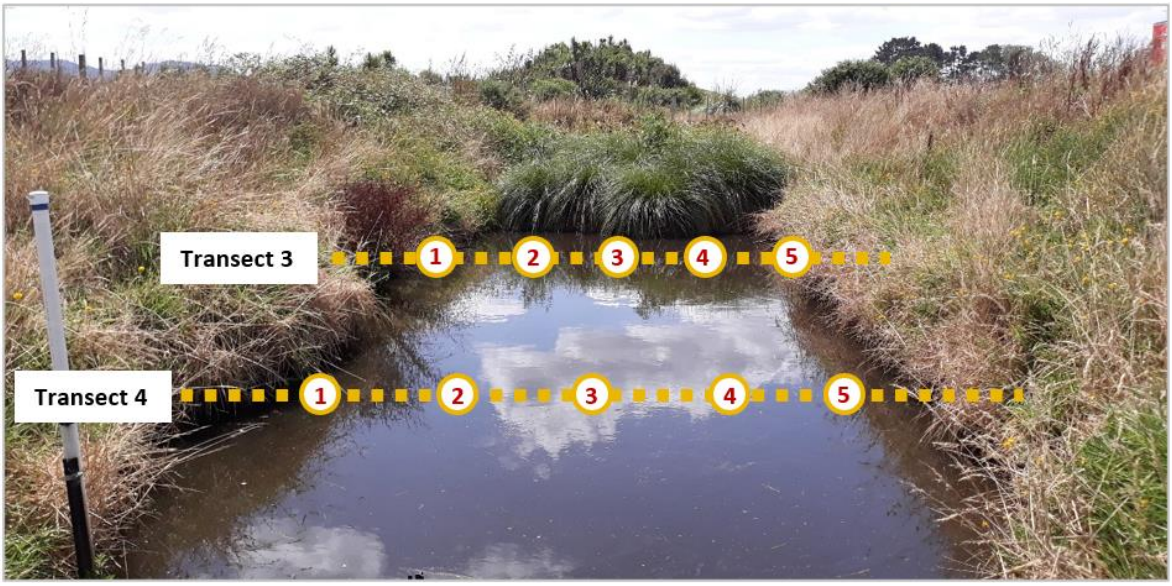

Figure 7. Transects 3 and 4, upstream of the floating wetland, December 2019.

Sediment depth was determined by first measuring water depth using a 1.8-m aluminium survey staff, then the depth of the sediment and water column after forcefully pushing the measuring staff down into the sediment until hitting the firm bed of the (excavated) drain. The differences between accumulation rates up- and down-stream were considered indicative of sediment accumulation beneath the floating wetland.

A single sediment core was collected from each transect using a 1-m long, 73-mm clear Perspex tube attached to an 850-mm long, 50-mm diameter PVC pipe fitted with a ball-value tap to create vacuum seal (Fig. 8). The rate of sediment accumulation was estimated by dividing the depth of sediment by 4, the years since wetland installation. The sediment/water slurry was dried at 80°C to evaporate the water and a subsample ground to <1 mm and analysed for TN and TP using Kjeldahl digestion (Environmental Chemistry Laboratory 2019a).

Figure 8. Sediment core taken upstream of the floating wetland, December 2019.

3.6 Statistical analysis

Water quality data, including water chemistry parameters, nutrient, and suspended solids concentrations from upstream (U/S) and downstream (D/S), were tested for normality using the Anderson-Darling Test (Anderson & Darling 1954). Differences between U/S and D/S data that met assumptions of normality were investigated using two-tailed, paired-sample t-test (Zar 1999). Differences between non-normally distributed data were assessed using the non-parametric Wilcoxon Signed Rank Test (also known as Mann-Whitney Test; Hollander & Wolfe 1999). Tests were conducted using R Statistical Software (R Core Team 2020).

Biomass parameters (e.g. leaf length, root biomass) were assessed using unbalanced ANOVA (Genstat 18, VSN International, UK) where the average least significant difference was used to determine significant differences between species. Differences between plant species and seasons for N and P contents of root washings, and leaf and root nutrients, were assessed using two-way ANOVA with post hoc Student-Newman-Keuls analysis.

Differences in sediment depths at each of the transects within and across measurement dates was assessed using two-way ANOVA (Genstat 18, VSN International, UK) where a post hoc Student Newman-Keuls was used to assign statistical differences between the transects.

All statistical analyses were considered significant if $P<0.05$.

4 Results

4.1 Floating wetland hydrology

4.1.1 Sub-catchment characteristics

The sub-catchment area of the drain in which the floating wetland is installed was 149 ha (Figure 9). The eastern and southern boundary of the catchment may be slightly inaccurate due to the age of the LiDAR data used to generate the DEM for this portion of the catchment (see Figure 3). After 2007/08, considerable earthworks were undertaken for the construction of the SH1 motorway, which now dissects the catchment of the drain roughly in half. The drainage network was significantly modified, with construction to run water from the eastern area of the catchment alongside the motorway and through two culverts under the road to the south west. It is likely these modifications have artificially increased the area of the catchment draining to the floating wetland drain and the magnitude of the effect on catchment size is not known.

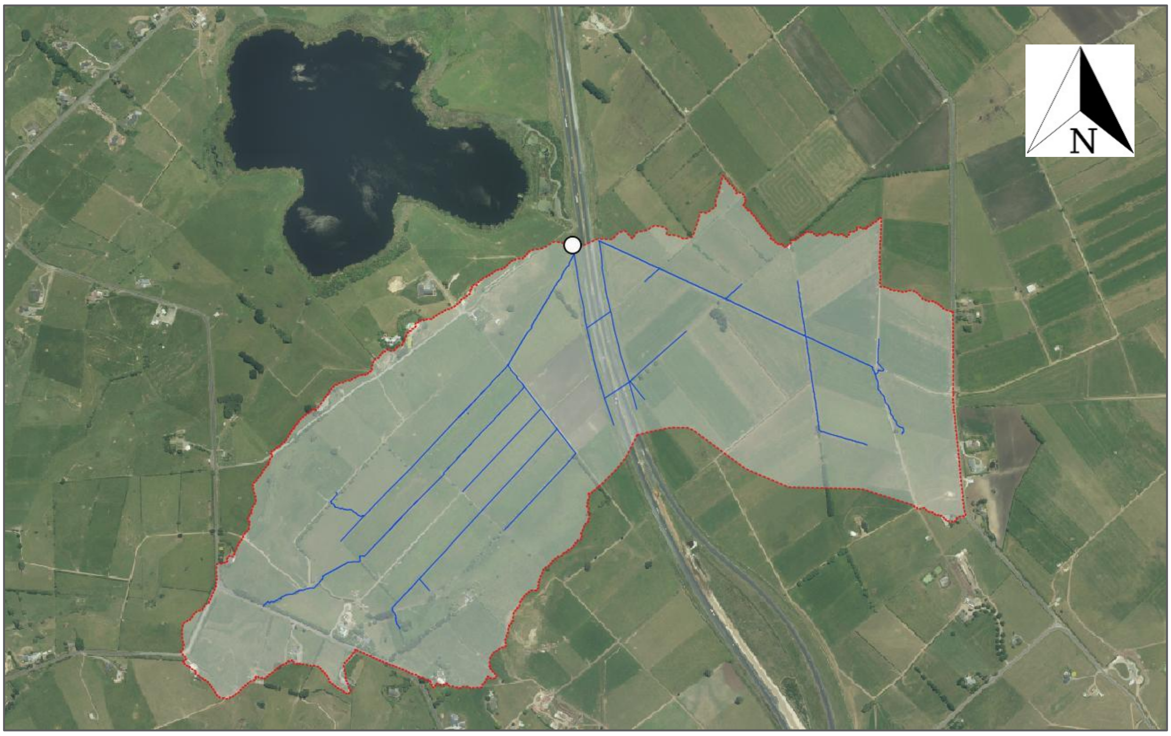

Figure 9. Sub-catchment boundary and approximate drainage network for the floating wetland drain, Lake Areare.

4.1.2 Water levels & discharge

Water levels were monitored from June 2019 to May 2020 and ceased to flow from mid-January to late March 2020; the logger, however, kept recording due to its location in the deepened channel excavated for the wetland (Figure 10). Water levels fluctuated from 0.13 to 1.13 m over the 12 months of monitoring (mean 0.40 ± 0.13 m; Figure 11). A comparison between the annual rainfall for 2019–2020 compared with the average since 2015 showed both greater than average and less than average rainfall distributed through the monitoring period (Appendix 1).

Figure 10. Floating wetland drain 24 February 2020 showing a) Levelogger, b) the dry channel immediately upstream.

Flow velocities ranged between 0–0.093 m/s (mean 0.024 ±0.025; median 0.019 m/s) and corresponding discharge volume of 0–0.071 m^3/s (mean 0.014 ± 0.018; median 0.009 m^3/s), equivalent to up to 6,132 m^3/day (mean 1,171 ± 1,554; median 772 m^3/day; Figure 12). The positive relationship between water levels/depths and discharge volume was highly statistically significant (R^2=0.82, P<0.0001).

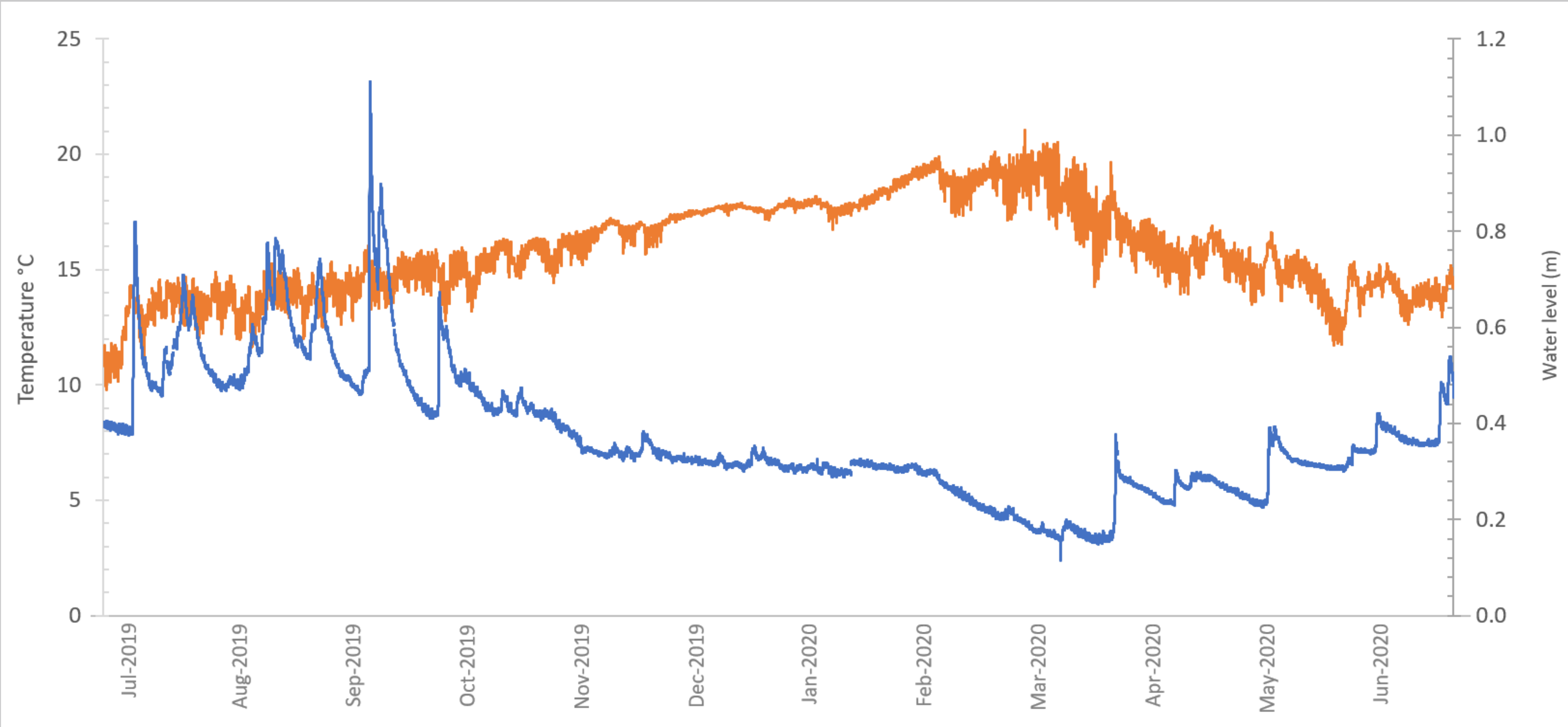

Figure 11. Water levels (blue line: m) and temperature (orange line: °C) in the floating wetland drain from July 2019 to June 2020.

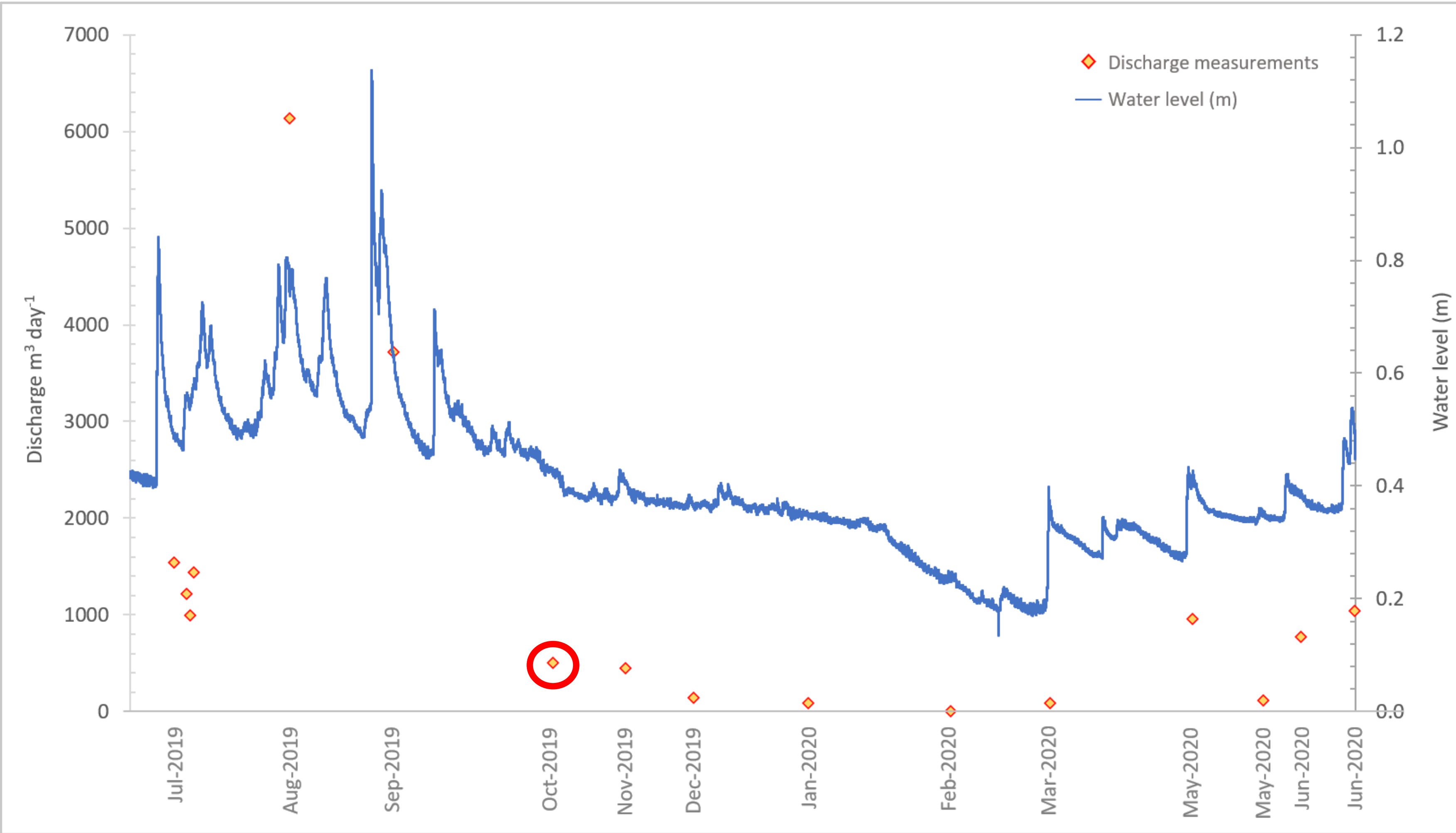

Figure 12. Water levels (m) and spot discharge measurements (m^3/day) taken approximately monthly from June 2019 to June 2020. The red circle indicates when hydraulic residence time was assessed.

4.1.3 Hydraulic residence time

Theoretical HRTs were calculated based on four different depth estimates (Table 2). Before the installation of the floating wetland, the channel was excavated to an approximately 1.2 m; however, the depth is expected to have reduced over the past 4 years due to accumulating sediments. Depth estimates used for the theoretical HRTs were derived from the mean water depths measured across transects 1, 2, and 3 at the time of the sediment accumulation measurements taken on 10 December 2019, plus 0.054 m to account for the higher water levels (as measured at the downstream outlet culvert) at the time when the tracer test was carried out.

Table 2. Theoretical hydraulic residence time (HRT_t) for the 60 m^2 floating wetland, 29 October 2019, derived from four depth estimates. Q=discharge

Depth estimate	Depth m	Volume m^3	Q m^3/s	Q m^3/hr	HRT_t mins	HRT_t hr
1	1.30	78.2	0.006	21.1	222	3.71
2	1.25	75.2	0.006	21.1	214	3.56
3	1.05	63.2	0.006	21.1	180	3.00
4	0.80	48.2	0.006	21.1	137	2.28

The HRT_t decreased from 222 to 137 minutes as estimated depths declined from 1.30 to 0.80 m (Table 2).

The sodium chloride tracer moved through the floating wetland over a 9+ hour period (Figure-13). Measurements of specific conductivity (µS/cm) downstream of the floating wetland during the tracer testing study, 29 October 2019. Red lines indicate the beginning of the elevation in conductivity, and the 'peak' of the initial sodium chloride pulse). The first detection of an increase in specific conductivity below the wetland occurred 65 minutes after the corresponding change immediately upstream of the wetland. The 'peak' of the pulse occurred 101 minutes after the corresponding peak upstream, aligning most closely with HRT_{t-d} (depth, d). The 'tail' of the sodium chloride trace was measurable until monitoring stopped at 8:00 pm (Fig. 13), suggesting the true HRT of the floating wetland is at least 9 hours (540 mins), 2.4–4.0 times longer than the theoretical HRT (Table 2).

The rapidity of the initial tracer 'peak' can be attributed to the sudden increase in 'discharge' due to instantaneously adding the volume of sodium chloride tracer to the drain. The tracer transit time following the primary peak is considered a more accurate representation of the true HRT of the system (Kadlec & Wallace 2008).

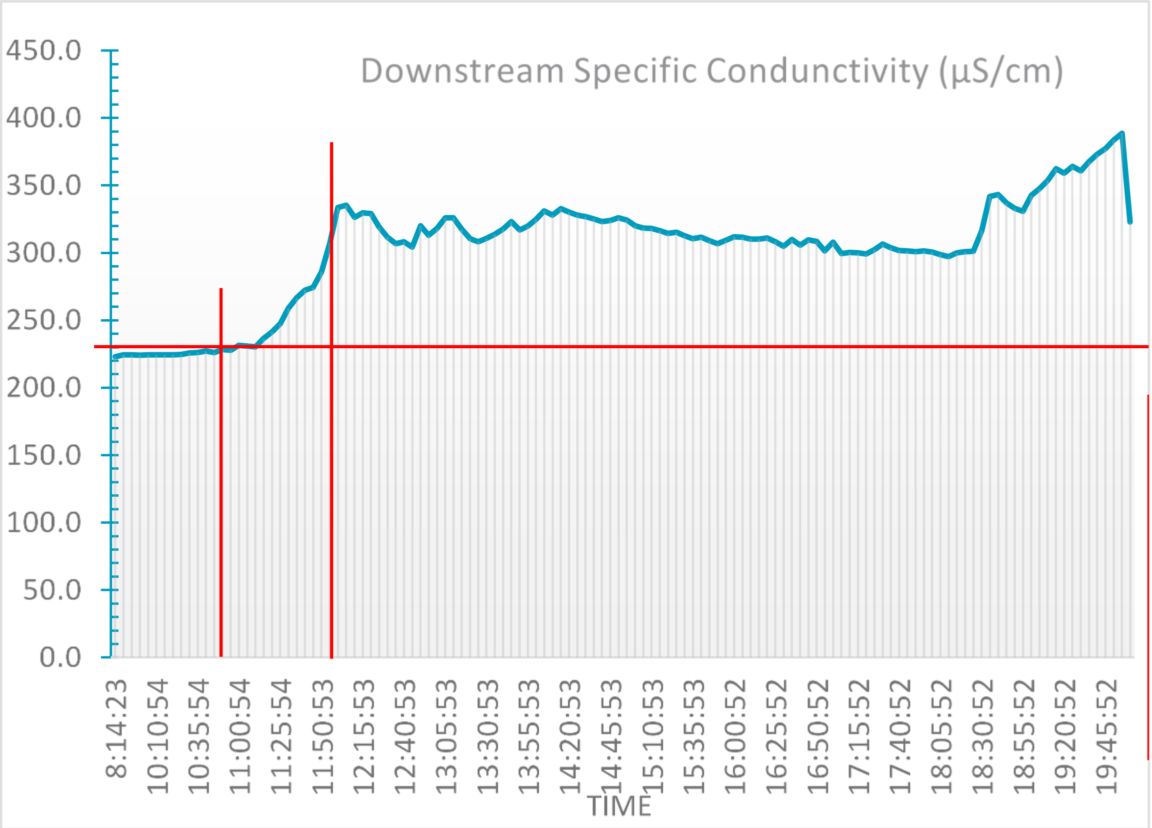

Figure 13. Measurements of specific conductivity (µS/cm) downstream of the floating wetland during the tracer testing study, 29 October 2019. Red lines indicate the beginning of the elevation in conductivity, and the 'peak' of the initial sodium chloride pulse.

4.2 Water quality treatment

4.2.1 Nitrogen

TN concentrations in water varied considerably over the monitoring period (3.0–10.8 mg/L), being generally higher during the cooler, wetter months of winter and early spring 2019, and lower during the dry, hot months of summer and autumn 2020 (Figure 14). During winter and spring 2019, the relative proportions of NH_4-N, NO_3-N, and TON comprising TN were uniformly consistent; however, from October 2019 to January 2020, NO_3-N was virtually absent. Overall, TN concentrations declined from upstream (U/S) to downstream (D/S) of the floating wetland; however, the difference was not significant due to high variability in the data.

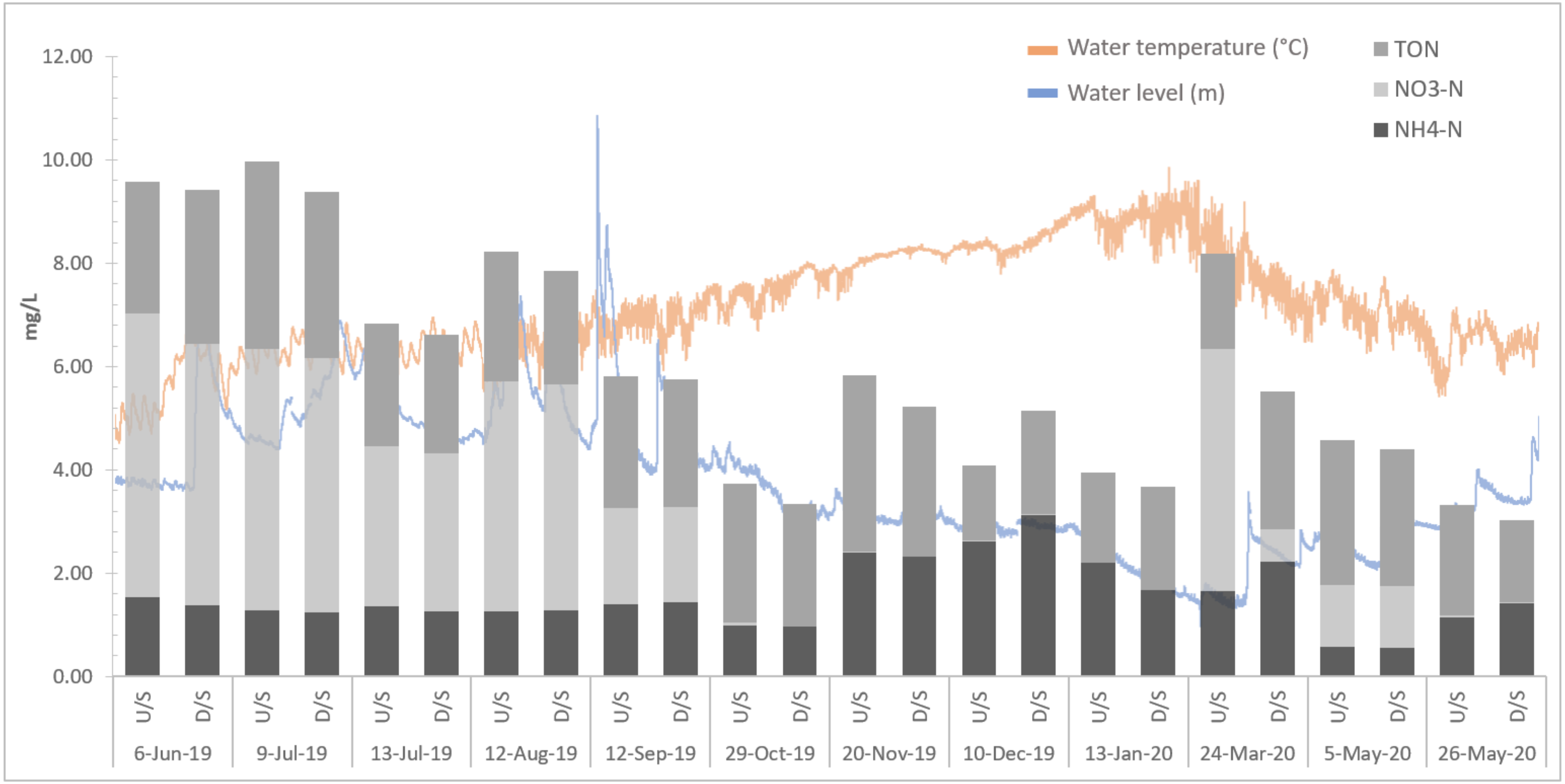

Figure 14. Concentrations (mg/L) of total nitrogen (TN), comprised of ammonium-N (NH_4-N), nitrate-N (NO_3-N), and total organic N (TON), upstream (U/S) and downstream (D/S) of the floating wetland during the monitoring period, June 2019 to May 2020. Relative water levels (blue line) and water temperatures (orange line) are provided for context of corresponding environmental conditions.

U/S NO_3-N concentration rose sharply on 24 March 2020 following a 23-mm heavy rain event on 23 March (Fig. 14), which may be due to higher fluxes of NO_3-N from the drought affected catchment, or contamination of the sample. NO_3-N concentrations decreased by 87% on 24 March 2020 between U/S and D/S, which seems highly unlikely if water flows were higher due to a rainfall event and suggests the floating wetland had very high proficiency for NO_3-N removal at higher flows. It is more likely that the U/S sample was contaminated.

NH_4-N concentrations were generally higher in the warmer months between November 2019 and March 2020, corresponding to an increase in water temperature and pH, and a decrease in dissolved oxygen (Fig. 15).

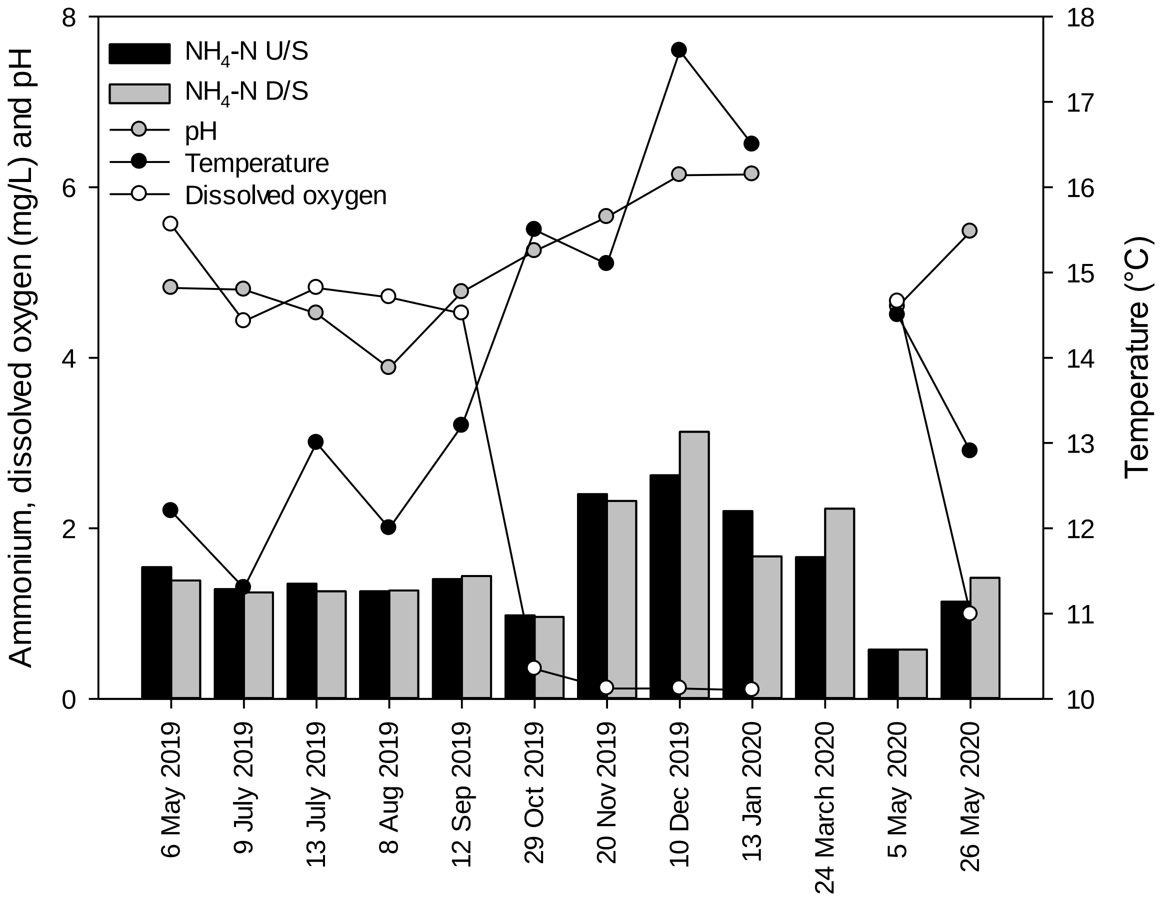

Figure 15. Ammonium-N (NH_4-N) concentrations upstream (U/S) and downstream (D/S) of the floating wetland and dissolved oxygen, water pH, and water temperature during the monitoring period, June 2019 to May 2020.

TON showed a slight reducing trend from U/S to D/S of the floating wetland, however TON increased markedly during 4 sampling events (June 2019, December 2019, January 2020, and March 2020; Fig. 16). As a result of this variability, there was no statistically significant change between U/S and D/S. PON patterns were more variable than TON (Fig. 16) and similarly showed no significant difference from U/S to D/S of the wetland. Finally, no obvious patterns were evident between concentrations of TON and PON (Fig. 16), suggesting dissolved organic N is contributing most of the TON.

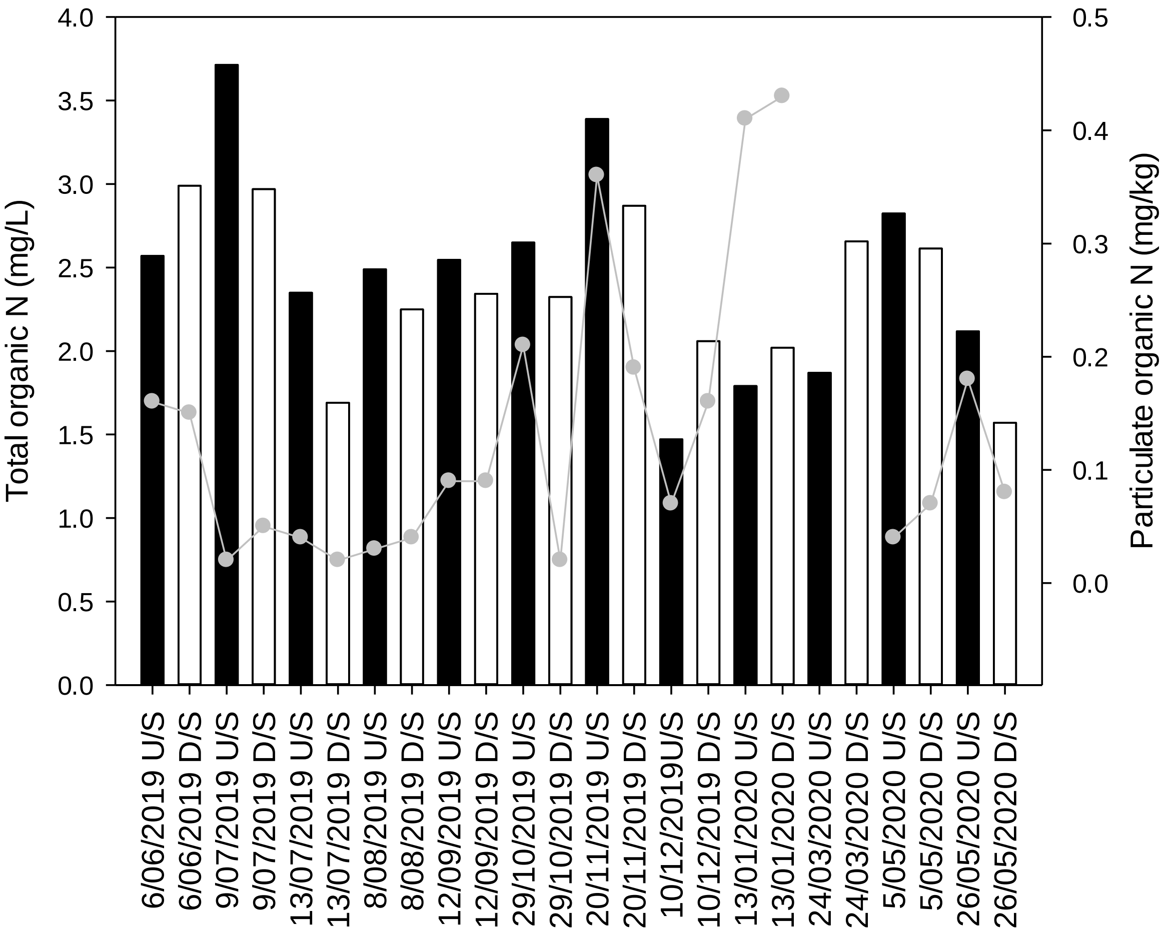

Figure 16. Total organic nitrogen and particulate organic nitrogen upstream (U/S) and downstream (D/S) of the floating wetland during the monitoring period, June 2019 to May 2020. No PON determinations were undertaken on samples collected in March 2020.

4.2.2 Phosphorus

TP concentrations were highly variable over the monitoring period (0.059–0.454 mg/L) with PP comprising the majority of TP, except in November 2019 (Fig. 17). No obvious patterns were evident between TP and changing water levels or temperature, and concentrations decreased D/S of the wetland as frequently as they increased, therefore no significant difference was found. DRP was generally lower D/S than U/S although the difference was not significant due to high variability in the data.

The annual average of PP concentrations U/S and D/S of the floating wetland are summarised (Fig. 18). Mean values are shown by the x, medians by the horizontal line, the 25^{th} to 75^{th} percentiles by the lower and upper extent of the boxes, the maximum by the upper 'T', and the minimum by the lower inverted 'T'. The D/S PP concentrations were slightly significantly greater than U/S (*P*=0.044) indicating a net increase in PP by the wetland over the monitoring period.

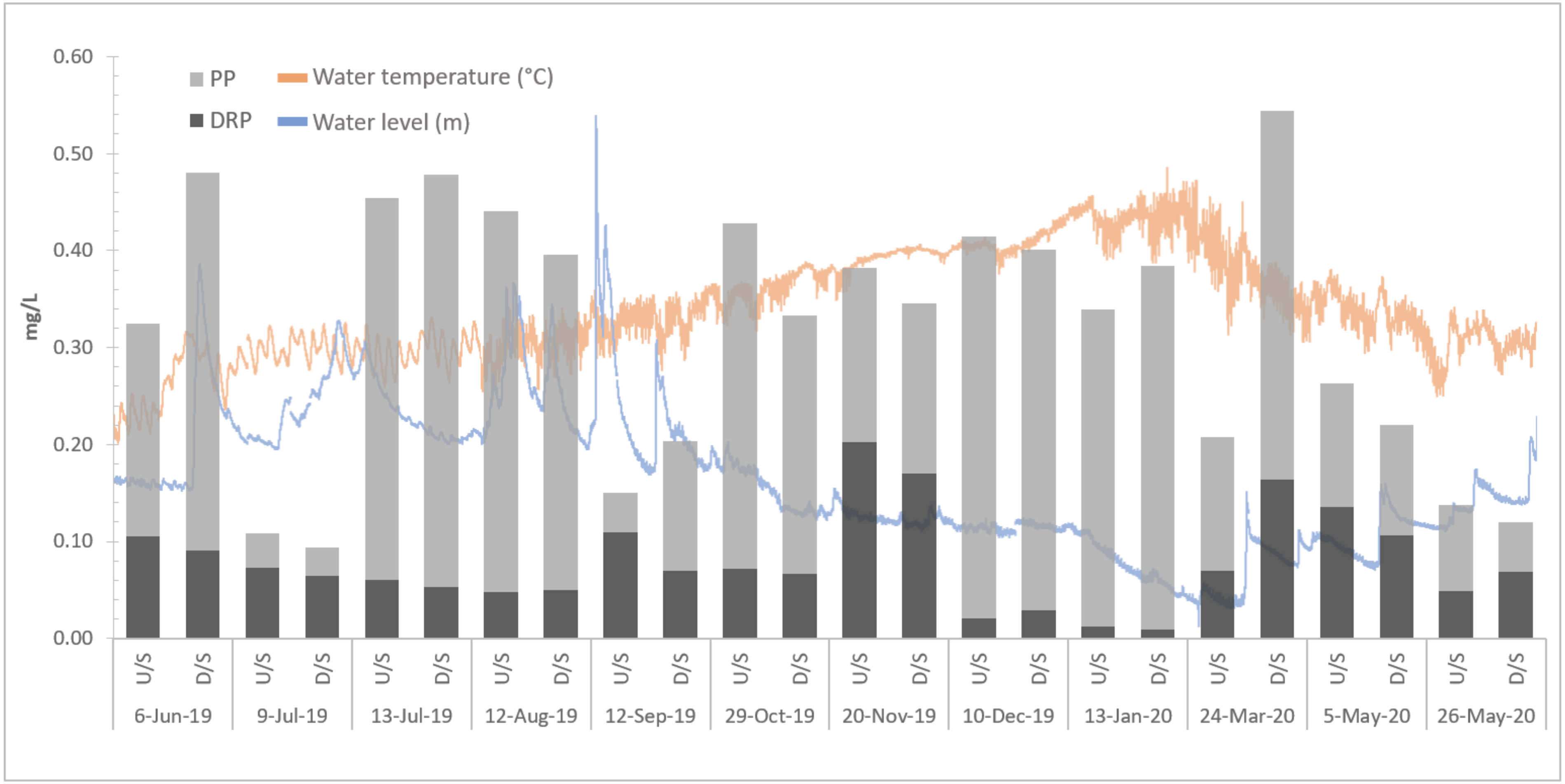

Figure 17. Concentrations of total phosphorus (TP), comprised of dissolved reactive P (DRP) and particulate P (PP), upstream (U/S) and downstream (D/S) of the floating wetland during the monitoring period, June 2019 to May 2020. Relative water levels (blue line) and water temperatures (orange line) are provided for context of corresponding environmental conditions.

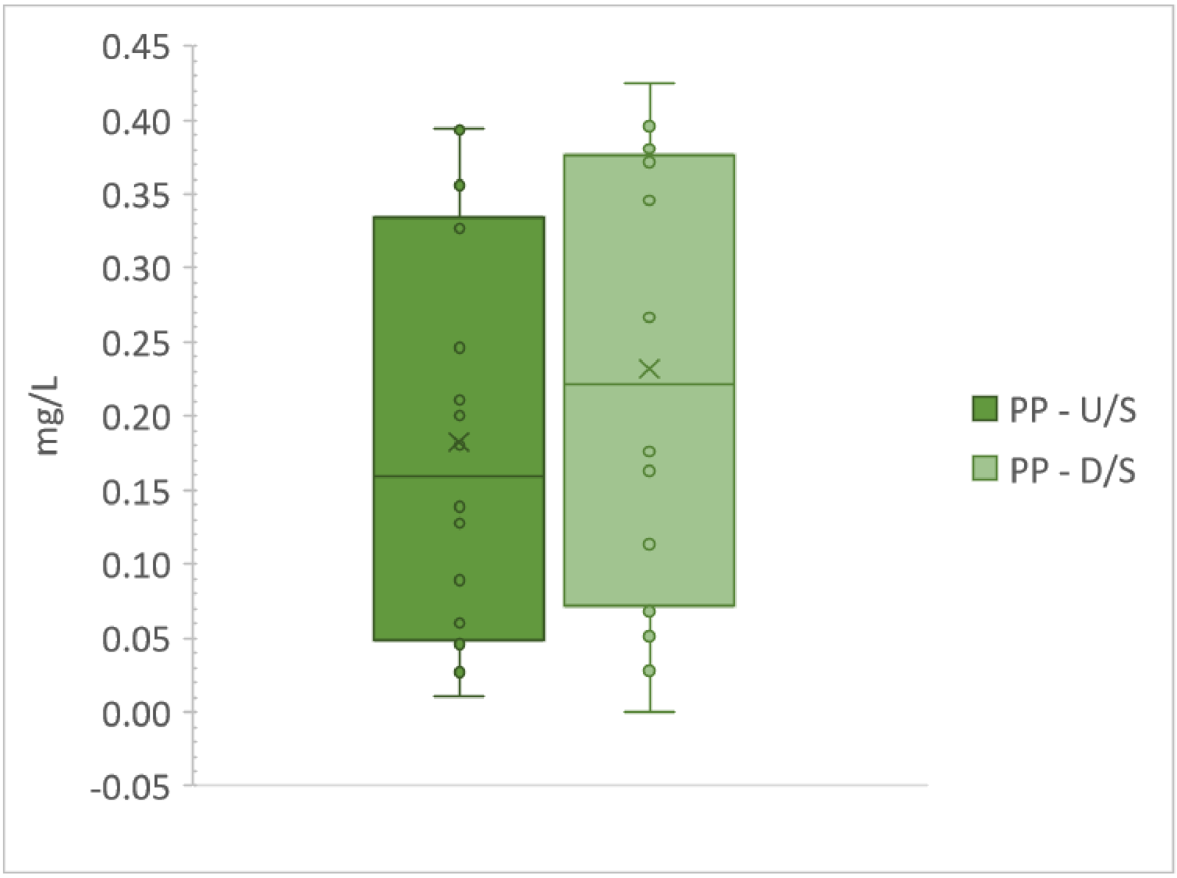

Figure 18. Maximum, minimum, 25th and 75th percentile range, mean (x), and median (-) particulate phosphorus (PP) concentrations upstream (U/S) and downstream (D/S) of the floating wetland.

4.2.3 Suspended solids

TSS concentrations were lower in winter and early spring 2019, when water levels were highest, and higher in warmer, drier months from late October 2019 to late March 2020 (Fig. 19). Like NH_4-N, the increases in TSS concentrations coincided with reduced DO concentrations in the water column, low flows, and higher temperatures (Figure 19). There were no significant differences between concentrations of TSS, VSS, or non-VSS from U/S to D/S of the floating wetland.

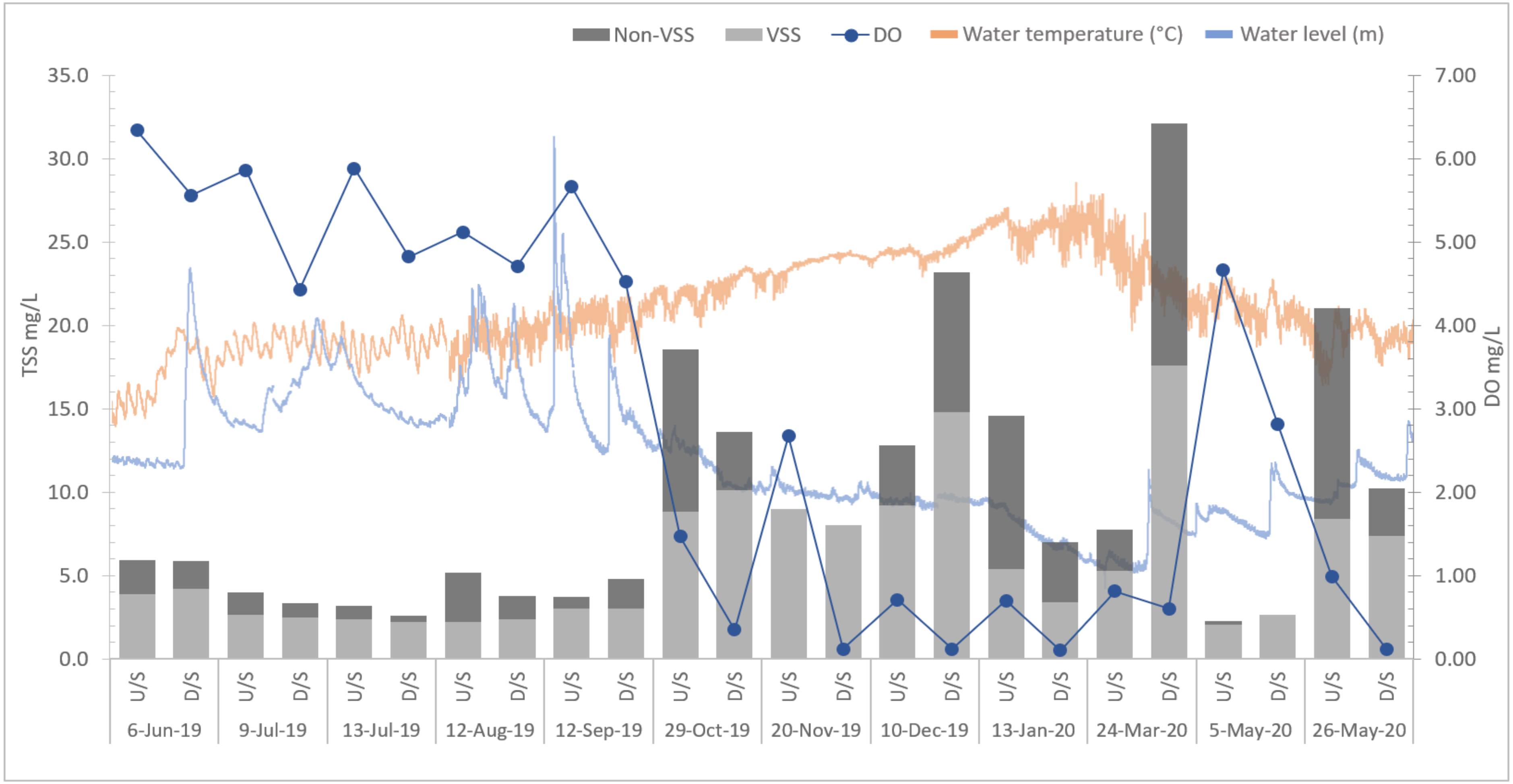

Figure 19. Concentrations (mg/L) of total suspended solids (TSS), comprised of volatile (VSS) and non-volatile (non-VSS) particulates, upstream (U/S) and downstream (D/S) of the floating wetland during the monitoring period, June 2019 to May 2020. Dissolved oxygen (DO) concentrations (mg/L) at each sampling occsaasion are shown by the dark blue dots. Relative water levels (blue line) and water temperatures (orange line) are provided for context of corresponding environmental conditions.

Annual averages of DO (*P*=0.001), electrical conductivity (*P*=0.03), and pH (*P*=0.01) were significantly different between U/S to D/S of the floating wetland (Table 3). DO levels declined most D/S during the drought period, October 2019–April 2020.

Table 3. Average temperature, dissolved oxygen, electrical conductivity, and pH (average ± standard deviation) taken upstream (U/S) and downstream (D/S) of the floating wetland from June 2019 to May 2020. * indicates significance difference (*P*<0.05). n.s. indicates no significant difference

	Upstream	Downstream	Significance
Temperature (°C)	13.8±1.8	14.2±2.2	n.s.
Dissolved oxygen (mg/L)	3.64±2.33	2.51±2.34	*
Conductivity (µS/m)	307.2±72.0	296.0±67.4	*
pH	5.04±0.70	5.15±0.73	*

4.2.4 Nutrient and sediment yields, mass loads, and treatment efficiency

Influent daily and annual nutrient and sediment yields for the floating wetland drain are summarised in Table 4. Daily influent yields varied widely across all constituents, reflecting the variability in water levels, discharge, and concentrations over the 12-month monitoring period. Daily yields of TN ranged between 0 and 0.34 kg/ha, TP between 0 and 0.018 kg/ha, and TSS between 0 and 0.22 kg/ha (Table 4-i). Annual yields based on the mean and median of the 12 daily yields, extrapolated to 365 days, are given in Table 4-ii. Median influent yields of TN were 8.6 kg/ha/yr, around a third of the mean (23±36 kg/ha/yr) and TP median annual yield 0.48 kg/ha/yr, which was less than half the mean (0.48 kg/ha/yr). There were similar differences for TSS, with mean annual yields 17±22 kg/ha/yr and the median 9.7 kg/ha/yr.

Due to the highly skewed distributions N, P, and SS discharge data, annual yield estimates were additionally calculated using four combinations of mean ($\bar{x}$) and median ($\tilde{x}$) values of discharge (Q) and constituent concentrations (conc.). These annual yield estimates are summarised in Table 4-iii. Overall, there is good agreement between yields calculated using mean Q and the mean yields in section ii (e.g. TN =18.7–19.8 compared with 23.3 kg/ha/yr), and similarly for yields calculated using median Q and median yields in section ii (e.g. TP=0.47–0.51 compared with 0.48 kg/ha/yr; Table 4-ii, iii).

Table 4. Daily and annual areal yield estimates for the floating wetland drain, Lake Areare, based on monitoring from June 2019 to May 2020. Q=discharge, conc.=concentration of constituent, $\bar{x}$=mean, $\tilde{x}$=median, SD=standard deviation

i. Daily influent yields, kg/ha/day								
Date	**TN**	**NH_4-N**	**NO_3-N**	**TON**	**TP**	**DRP**	**PP**	**TSS**
6-Jun-19	0.048	0.008	0.028	0.013	0.002	0.001	0.001	0.030
9-Jul-19	0.103	0.013	0.053	0.038	0.001	0.001	0.000	0.041
13-Jul-19	0.056	0.011	0.025	0.020	0.004	0.000	0.003	0.026
12-Aug-19	0.339	0.052	0.184	0.103	0.018	0.002	0.016	0.215
12-Sep-19	0.146	0.035	0.046	0.064	0.004	0.003	0.001	0.093
29-Oct-19	0.013	0.003	0.000	0.009	0.001	0.000	0.001	0.063
20-Nov-19	0.017	0.007	0.000	0.010	0.001	0.001	0.001	0.027
10-Dec-19	0.004	0.003	0.000	0.001	0.000	0.000	0.000	0.012
13-Jan-20	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.008
24-Mar-20	0.005	0.001	0.003	0.001	0.000	0.000	0.000	0.004
5-May-20	0.029	0.004	0.008	0.018	0.002	0.001	0.001	0.014
26-May-20	0.002	0.001	0.000	0.002	0.000	0.000	0.000	0.016
mean	**0.064**	**0.012**	**0.029**	**0.023**	**0.003**	**0.001**	**0.002**	**0.046**
SD	**0.098**	**0.016**	**0.052**	**0.031**	**0.005**	**0.001**	**0.005**	**0.059**
median	**0.023**	**0.005**	**0.005**	**0.012**	**0.001**	**0.001**	**0.001**	**0.027**
ii. Annual influent yields, kg/ha/year								
	TN	**NH_4-N**	**NO_3-N**	**TON**	**TP**	**DRP**	**PP**	**TSS**
mean	23.3	4.24	10.5	8.52	1.02	0.25	0.77	16.8
SD	35.7	5.80	19.1	11.4	1.83	0.31	1.65	21.5
median	8.57	1.99	1.90	4.23	0.48	0.19	0.25	9.71
iii. Annual influent yields, kg/ha/year								
	TN	**NH_4-N**	**NO_3-N**	**TON**	**TP**	**DRP**	**PP**	**TSS**
$\bar{x}$ Q, $\bar{x}$ conc.	19.8	4.93	6.96	7.96	0.98	0.26	0.72	28.9
$\bar{x}$ Q, $\tilde{x}$ conc.	18.7	4.43	4.91	8.13	1.07	0.23	0.64	22.0
$\tilde{x}$ Q, $\bar{x}$ conc.	9.54	2.37	3.34	3.83	0.47	0.12	0.35	13.9
$\tilde{x}$ Q, $\tilde{x}$ conc.	9.00	2.13	2.36	3.91	0.51	0.11	0.31	10.6

Daily instantaneous mass loads of nutrient and suspended sediment U/S and D/S of the floating wetland from June 2019 to May 2020 are summarised in Table 5. The differences between daily U/S and D/S loads, i.e. nutrient and SS removal (if positive) or addition (if negative), are given in Table 6. The large variability is attributable to infrequent peaks in NH_4-N, TON, and PON, and decreases in NO_3-N. Loads of TP were influenced by variable D/S concentrations of PP which were frequently higher than U/S values (Fig. 19). Changes in loads of suspended solids were also highly variable, with sediment export in some months.

Median values reduce the influence of outliers. Again, annual median TN removal was 78 kg, about half the mean, while median TP and TSS were similar to mean values, being 0.73 kg and 198 kg, respectively (Table 6).

Table 5. Daily instantaneous loads (kg/day) of TN, NH_4-N, NO_3–N, TON, TP, DRP, PP, and TSS measured upstream (U/S) and downstream (D/S) of the floating wetland

	TN kg/d		NH_4-N kg/d		NO_3-N kg/d		TON kg/d	
Date	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**
6-Jun-19	7.20	7.08	1.16	1.04	4.12	3.80	1.92	2.24
9-Jul-19	15.37	14.46	1.98	1.93	7.81	7.58	5.57	4.95
13-Jul-19	8.33	8.05	1.65	1.54	3.78	3.72	2.90	2.79
12-Aug-19	50.40	48.18	7.73	7.81	27.31	26.88	15.37	13.49
12-Sep-19	21.63	21.39	5.22	5.35	6.88	6.87	9.53	9.17
29-Oct-19	1.89	1.69	0.50	0.49	0.04	0.01	1.36	1.20
20-Nov-19	2.60	2.33	1.07	1.03	0.00	0.00	1.53	1.29
10-Dec-19	0.59	0.74	0.38	0.45	0.00	0.00	0.21	0.29
13-Jan-20	0.33	0.31	0.18	0.14	0.00	0.00	0.15	0.17
24-Mar-20	0.70	0.47	0.14	0.19	0.40	0.05	0.16	0.23
5-May-20	4.37	4.19	0.55	0.53	1.15	1.15	2.68	2.51
26-May-20	0.37	0.33	0.13	0.16	0.00	0.00	0.24	0.18

	TP kg/d		DRP kg/d		PP kg/d		TSS kg/d	
Date	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**	**U/S**	**D/S**
6-Jun-19	0.24	0.36	0.08	0.07	0.16	0.29	4.47	4.40
9-Jul-19	0.17	0.14	0.11	0.10	0.05	0.04	6.15	5.14
13-Jul-19	0.55	0.58	0.07	0.06	0.48	0.52	3.90	3.17
12-Aug-19	2.70	2.43	0.29	0.31	2.41	2.12	31.89	23.30
12-Sep-19	0.56	0.76	0.41	0.26	0.15	0.50	13.89	17.85
29-Oct-19	0.22	0.17	0.04	0.03	0.18	0.14	9.41	6.91
20-Nov-19	0.17	0.15	0.09	0.08	0.08	0.08	4.01	3.56
10-Dec-19	0.06	0.06	0.00	0.00	0.06	0.05	1.85	3.36
13-Jan-20	0.03	0.03	0.00	0.00	0.03	0.03	1.23	0.59
24-Mar-20	0.02	0.05	0.01	0.01	0.01	0.03	0.66	2.74
5-May-20	0.25	0.21	0.13	0.10	0.12	0.11	2.15	2.55
26-May-20	0.02	0.01	0.01	0.01	0.01	0.01	2.31	1.13

Table 6. Change in mass loads of TN, NH_4-N, NO_3-N, TON, TP, DRP, PP, and TSS attributable to the floating wetland. Daily loads (kg/day), annual loads (kg/year), and percentage (%) change in mass loads are presented. SD=standard deviation of the mean

	Daily loads, kg/d							
Date	**TN**	**NH_4-N**	**NO_3-N**	**TON**	**TP**	**DRP**	**PP**	**TSS**
6-Jun-19	0.12	0.12	0.32	-0.32	-0.117	0.011	-0.128	0.06
9-Jul-19	0.91	0.06	0.23	0.62	0.022	0.013	0.009	1.01
13-Jul-19	0.28	0.11	0.06	0.10	-0.029	0.009	-0.038	0.73
12-Aug-19	2.23	-0.08	0.42	1.88	0.276	-0.012	0.288	8.58
12-Sep-19	0.25	-0.13	0.01	0.36	-0.197	0.150	-0.347	-3.97
29-Oct-19	0.20	0.01	0.03	0.16	0.048	0.003	0.045	2.50
20-Nov-19	0.27	0.04	0.00	0.23	0.016	0.014	0.002	0.45
10-Dec-19	-0.16	-0.07	0.00	-0.08	0.002	-0.001	0.003	-1.50
13-Jan-20	0.02	0.04	0.00	-0.02	-0.004	0.000	-0.004	0.64
24-Mar-20	0.23	-0.05	0.35	-0.07	-0.029	-0.008	-0.021	-2.08
5-May-20	0.18	0.02	0.00	0.16	0.041	0.027	0.014	-0.40
26-May-20	0.03	-0.03	0.00	0.06	0.002	-0.002	0.004	1.19
mean	**0.38**	**0.003**	**0.12**	**0.26**	**0.003**	**0.017**	**-0.014**	**0.60**
SD	**0.63**	**0.076**	**0.16**	**0.56**	**0.111**	**0.043**	**0.142**	**3.04**
median	**0.21**	**0.014**	**0.02**	**0.13**	**0.002**	**0.006**	**0.003**	**0.54**
	Annual loads, kg/year							
mean	138.3	1.0	43.3	94.0	0.9	6.2	-5.3	219.4
SD	231.5	27.7	59.5	205.9	40.5	15.8	51.8	1109.6
median	77.6	5.3	7.0	48.2	0.7	2.1	0.9	197.9
	% treatment efficiency							
mean	5.3	-2.5	22.1	-2.0	-14.7	-7.0	-32.6	-19.9
SD	13.0	16.1	35.5	21.7	51.0	47.2	85.6	99.9
median	5.2	2.3	2.3	4.9	6.4	11.5	4.0	13.8

4.3 Plant uptake

4.3.1 Plant biomass

Leaf and root length were reasonably consistent for *C. virgata* and *C. ustalus* but *C. secta* were more variable, although based on fewer samples. Maximum plant leaf and root lengths were similar across the three species. The average maximum leaf length for all species ranged between 1.2 and 1.8 m (Table 7). The average maximum root length was between 0.9 and 0.95 m although longest root was 1.25 m (Appendix 3; Table 7). All plants that were destructively harvested had longer Leaves than roots (Appendix 3; Fig. 20).

Figure 20. Examples of a) *Carex virgata*, b) *Cyperus ustalus*, and c) *Carex secta* extracted from the Lake Areare floating wetland in June 2019.

Leaf and root biomass followed the following trend: *C. virgata*< *C. ustalus*< *C. secta*, although not statistically significant due to high variation in the leaf biomass of *C. secta* (Table 7). Root biomass was greater than leaf biomass for all plant species (Appendix 3 and Fig. 21).

Greater variability in *C. secta* biomass was due to very large size of some individuals which killed and suppressed growth of adjacent plants. The largest *C. secta* (and the largest of all harvested plants) was 11,1400 g, more than 20 times larger than the other sampled *C. secta* (Appendix 3).

Table 7. Leaf and root length and biomass for plants destructively harvested from the Lake Areare floating wetland on 6 June 2019. Values in brackets are the standard error of the mean. Values with a different letter in each row were significantly different

	Carex virgata (n=6)	*Cyperus ustalus (n=6)*	*Carex secta (n=3)*
Maximum leaf length (m)	1.42 (0.06)ab	1.77 (0.11)b	1.23 (0.35)a
Maximum root length (m)	0.90 (0.05)a	0.93 (0.05)a	0.95 (0.28)a
Total leaf biomass (g)	299 (146)a	590 (170)a	1427 (1393)a
Total root biomass (g)	423 (184)a	969 (157)a	2659 (2257)a

C. virgata had the highest root:shoot ratio (leaf/root biomass) and *C. secta* the lowest (Figure 21). A lower root:shoot ratio indicates a greater investment by the plant in root material compared with leaf material (Poorter & Nagel 2000). *C. secta* exhibited smaller root:shoot ratios in two of the harvested plants (Appendix 3) that were being shaded out by larger plants which may explain the shift towards reduced investment in leaf material.

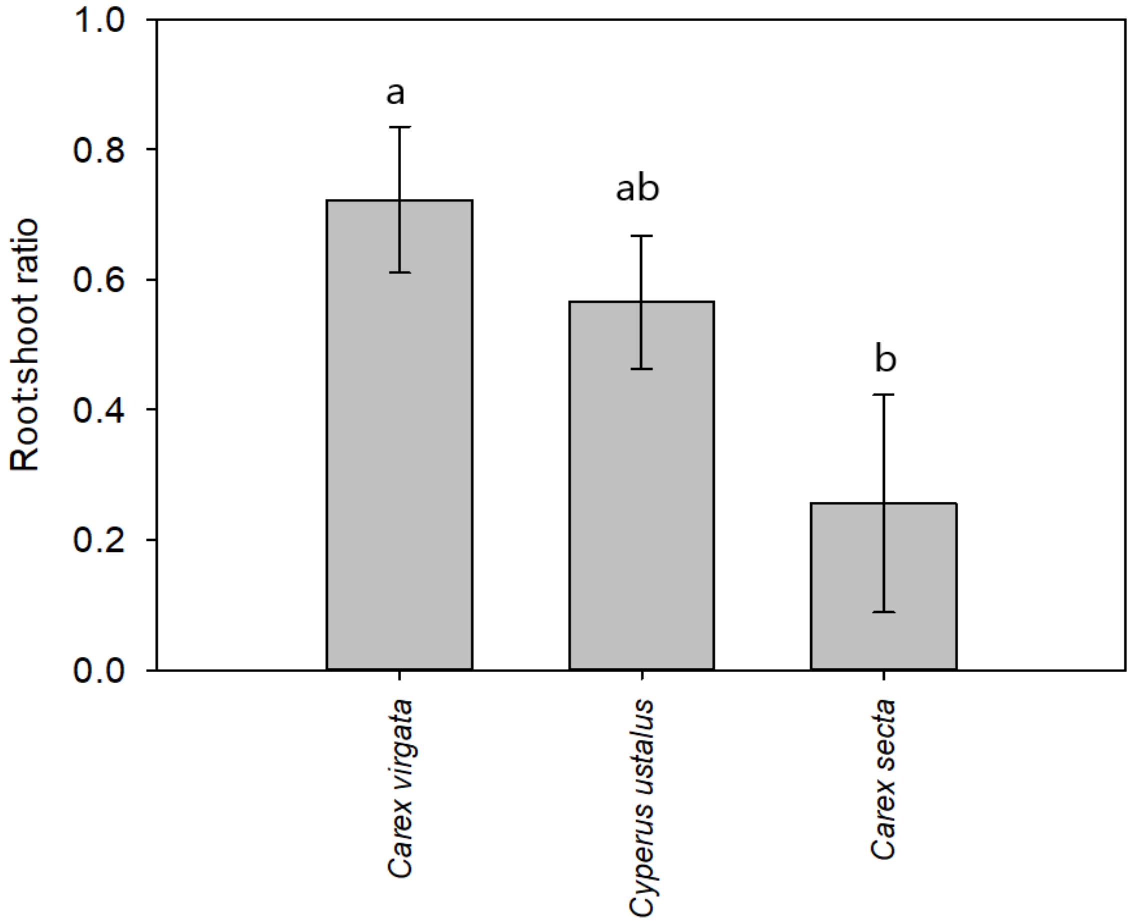

Figure 21. Root:shoot ratio for plants destructively harvested from the Lake Areare floating wetland in June 2019. Error bars represent the standard error of the mean. Bars with different letters were significantly different.

4.3.2 Plant nutrient concentrations

TN contents in leaf material increased between June and September 2019 and decreased from September 2019 to March 2020 (after the spring flush and during the drought). *C. virgata* consistently had higher TN content and *C. ustalus* the lowest TN (Fig. 22a). Interestingly, root TN contents showed a different pattern, with TN of *C. virgata* and *C. ustalus* increasing until December 2019, then decreasing to March 2020. However, *C. secta* showed a steadily increasing trend in root TN contents (Fig. 22b).

When assessing nutrient concentration with respect to the total leaf or root biomass (mg/g), there is a considerable flattening of changes in TN over time. There was still a peak in leaf TN concentration in September 2019, but little change in root TN over time (Fig. 22c,d). The larger biomass of *C. secta* meant it stored considerably more TN than the other two species. Root TN content of *C. secta* increased over time due to increasing TN content rather than changes in biomass.

The TP content of leaf material declined in *C. virgata* and *C. ustalus* over the sampling times (Fig. 23a). In contrast, leaf TP of *C. secta* increased between June 2019 and December 2019, then decreased by March 2020. Root TP contents increased between June and September 2019 but decreased from September 2019 to March 2020, except for *C. secta*, which increased between December 2019 and March 2020. (Fig. 23b). Separation between the plant species was variable across time, but *C. ustalus* generally had a higher root TP until March 2020 where it was equivalent to *C. secta* due to diverging patterns in root TP over time. When root TP data were combined within each species over time, there was significantly less root TP in *C. virgata* then in *C. ustalus*.

Leaf and root TP concentrations (mg/g) also reflected the much greater biomass of *C. secta* (Fig. 23c,d). *C. secta* exhibited a peak in leaf TP concentration in December 2019 and a peak in root TP in September 2019. The other two species had no marked pattern of TP over the monitoring period.

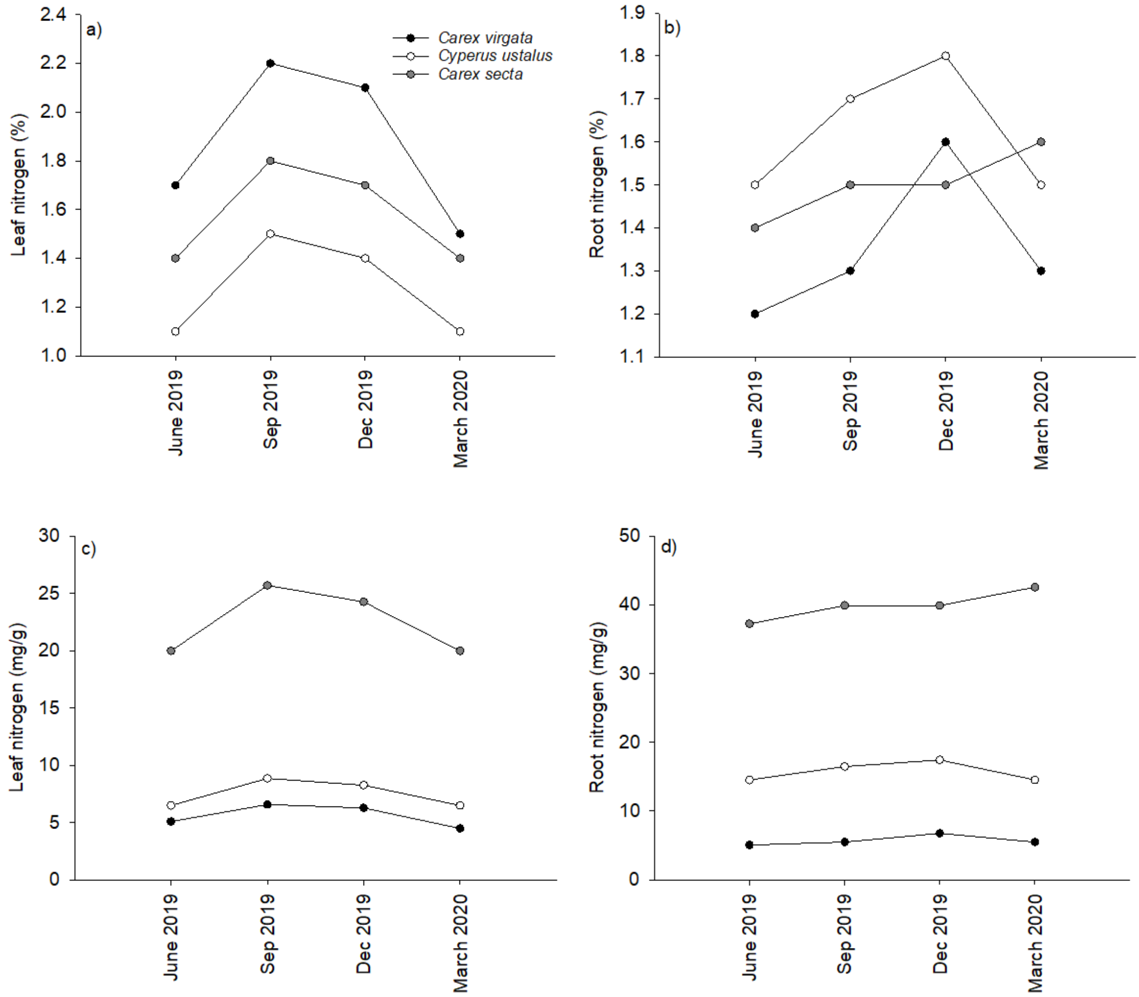

Figure 22. Leaf (a) and root (b) nitrogen contents *Carex virgata*, *Cyperus ustalus*, and *Carex secta* for samples taken between June 2019 and March 2020. Samples are composites of material collected from six different plants except for June 2019 where three samples of *Carex secta* were collected.

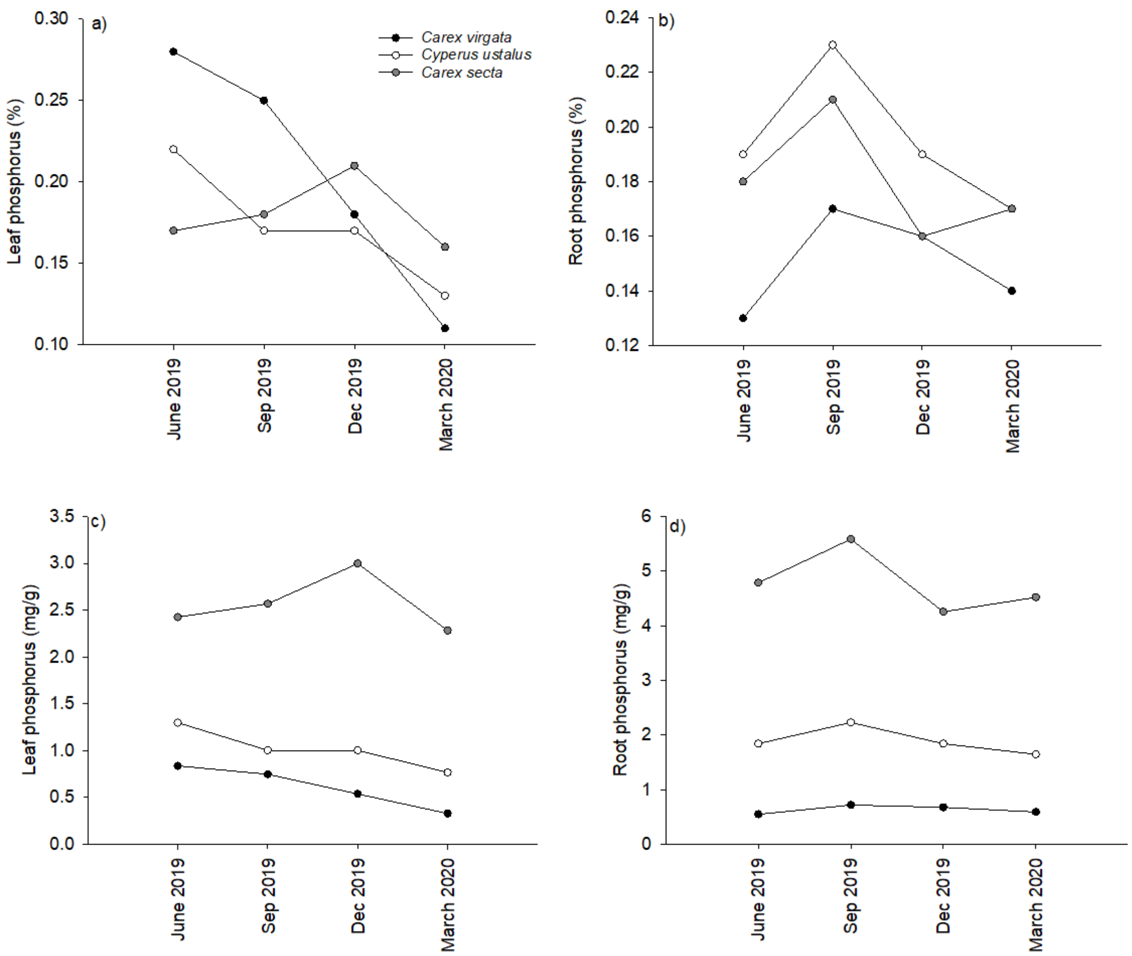

Figure 23. Leaf (a) and root (b) phosphorus contents *Carex virgata*, *Cyperus ustalus*, and *Carex secta* for samples taken between June 2019 and March 2020. Samples are composites of material collected from six different plants except for June 2019 where three samples of *Carex secta* were collected.

4.4 Root/biofilm entrapment

Root material was washed to determine the extent to which root/biofilm entrapment contributed to sediment and sediment associated TP and TN removal by the floating wetland. TSS analysis of the root washing water was considered a representative of the amount of sediment trapped by root material.

TSS (mg/L) exhibited a decreasing trend over our sampling period; but this was not statistically significant due to substantial variation within and between sampling times (Fig. 24a).

Volatile suspended solids (mg/L) also showed a decreasing trend over time and was less for all species in March 2020 than June 2019 (Fig. 24b). VSS (as a percentage of TSS) also exhibited a decreasing trend and VSS was significantly greater in June 2019 than December 2019 and March 2020 (Fig. 24c). This indicates TSS was composed of a greater amount of biological (e.g. plant material) in June which decreased over time leading to a greater proportion of non-biological material.

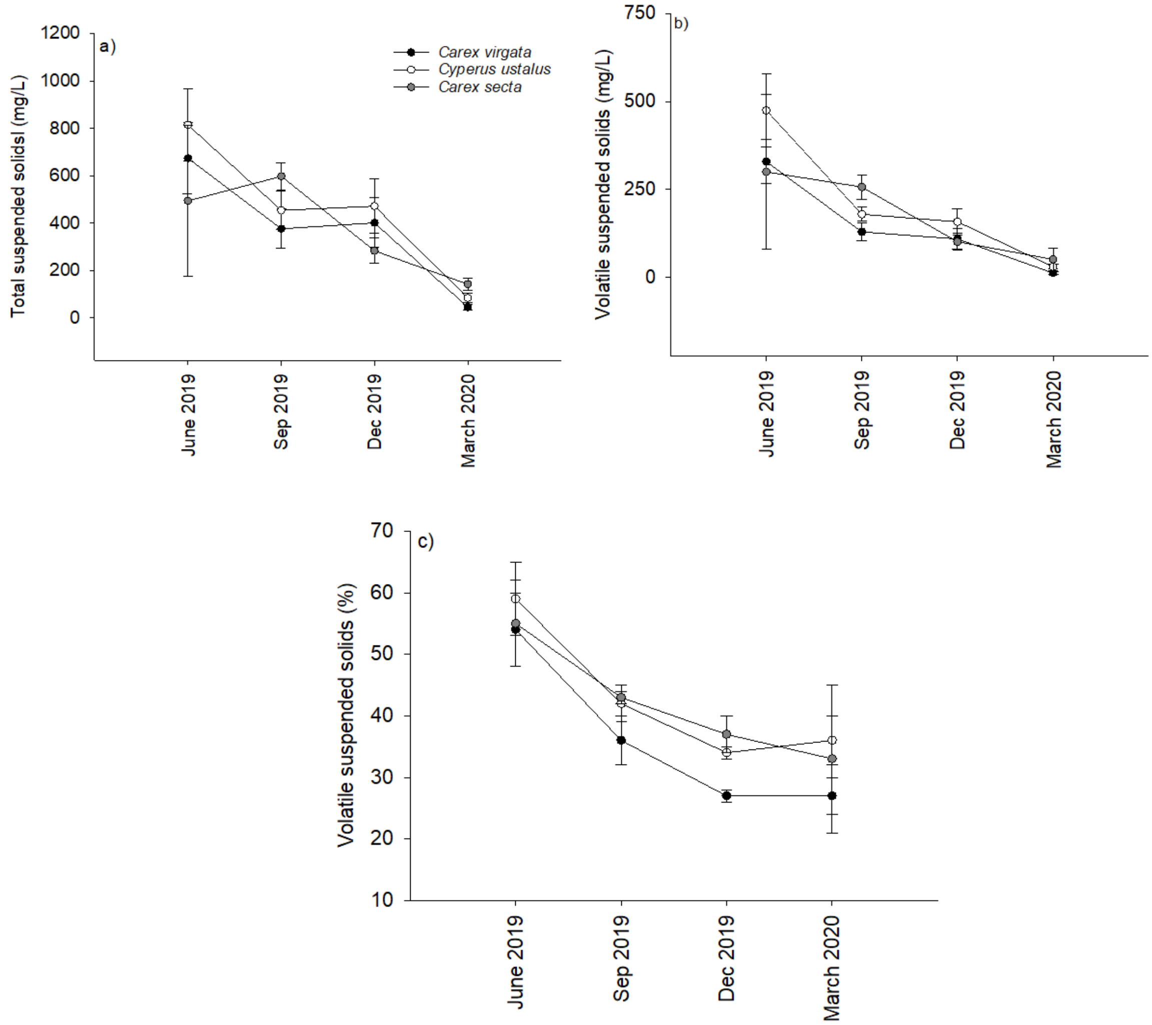

Figure 24. Total (a) and volatile (b) suspended solids (mg/L) contents of root washings captured by root material of *Carex virgata*, *Cyperus ustalus*, and *Carex secta* collected from Lake Areare floating wetland from June 2019 to March 2020. Volatile suspended also presented as a percentage of total suspended solids (c). Values are means with standard error (*n*=6) except for June 2019 where *Carex secta* (*n*=3).

TSS per gram of root biomass washed (mg/g) was significantly less for all plant species in June 2019 and March 2020 than in *C. secta* and *C. virgata* in September 2019; however, there were few statistically significant differences between the plant species and sampling dates due to high variability (Fig. 25a). VSS per gram of root biomass washed (mg/g) showed the same pattern as TSS and was the same for all plant species at all sampling times with exception of *C. secta* in September 2019 which was significantly greater than all remaining species at all time sampling points (Fig. 25b).

TN content (%) of sediment trapped by the root material declined between June 2019 and March 2020 and exhibited little difference between the plant species (Fig. 26a). TP content of the entrapped sediment increased between June 2019 and September 2019 but then decreased significantly by March 2020 (Fig. 26b). Differentiation between the plant species was minimal, except for *C. secta*, which appeared to have a higher TP content in the entrapped sediment in September 2019.

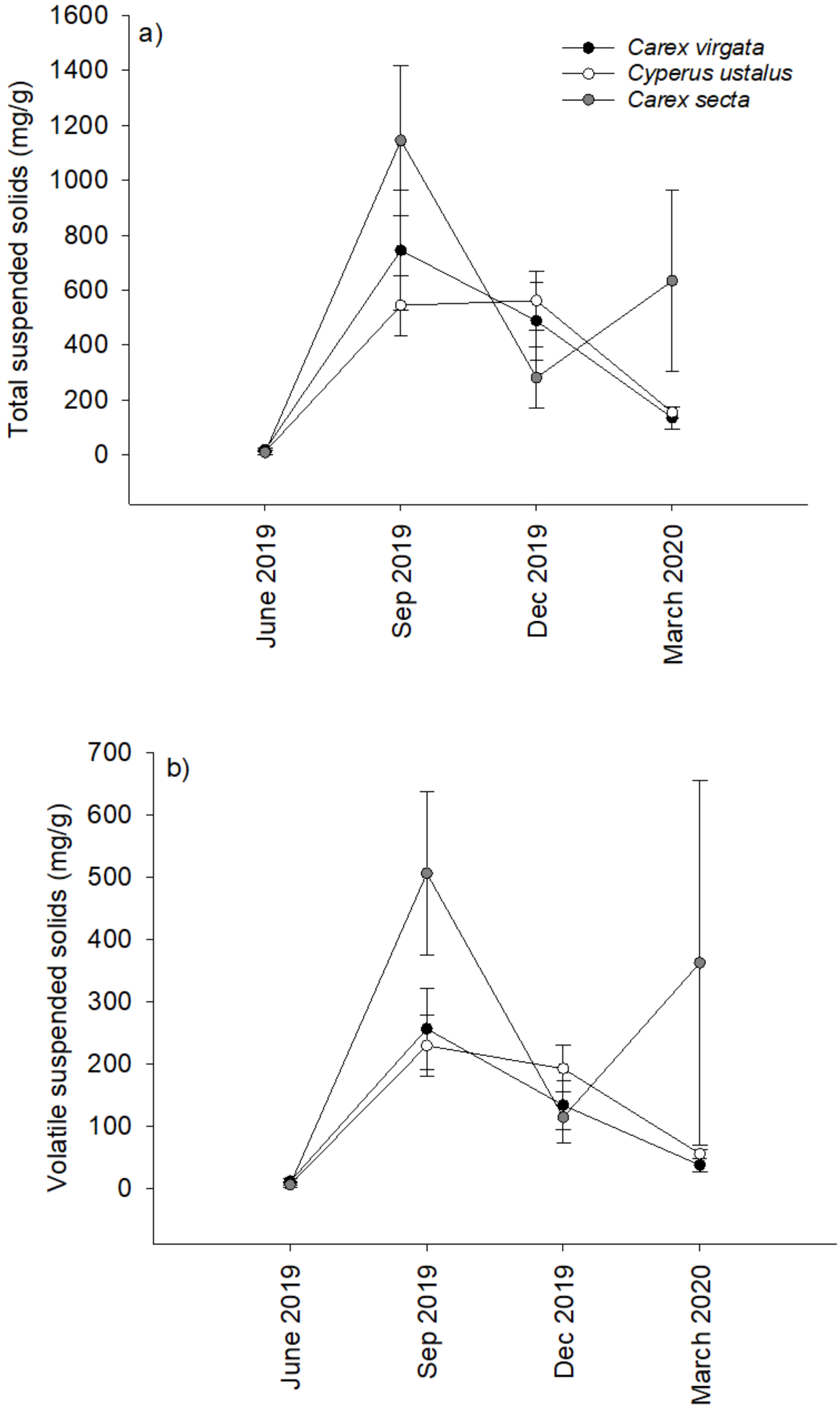

Figure 25. Total (a) and volatile (b) suspended solids (mg/g) contents of sediment captured by root material of *Carex virgata*, *Cyperus ustalus*, and *Carex secta* collected from the Areare floating wetland from June 2019 to March 2020. Values are means with standard error (*n*=6), except for June 2019 where *n*=3 for *Carex secta*.

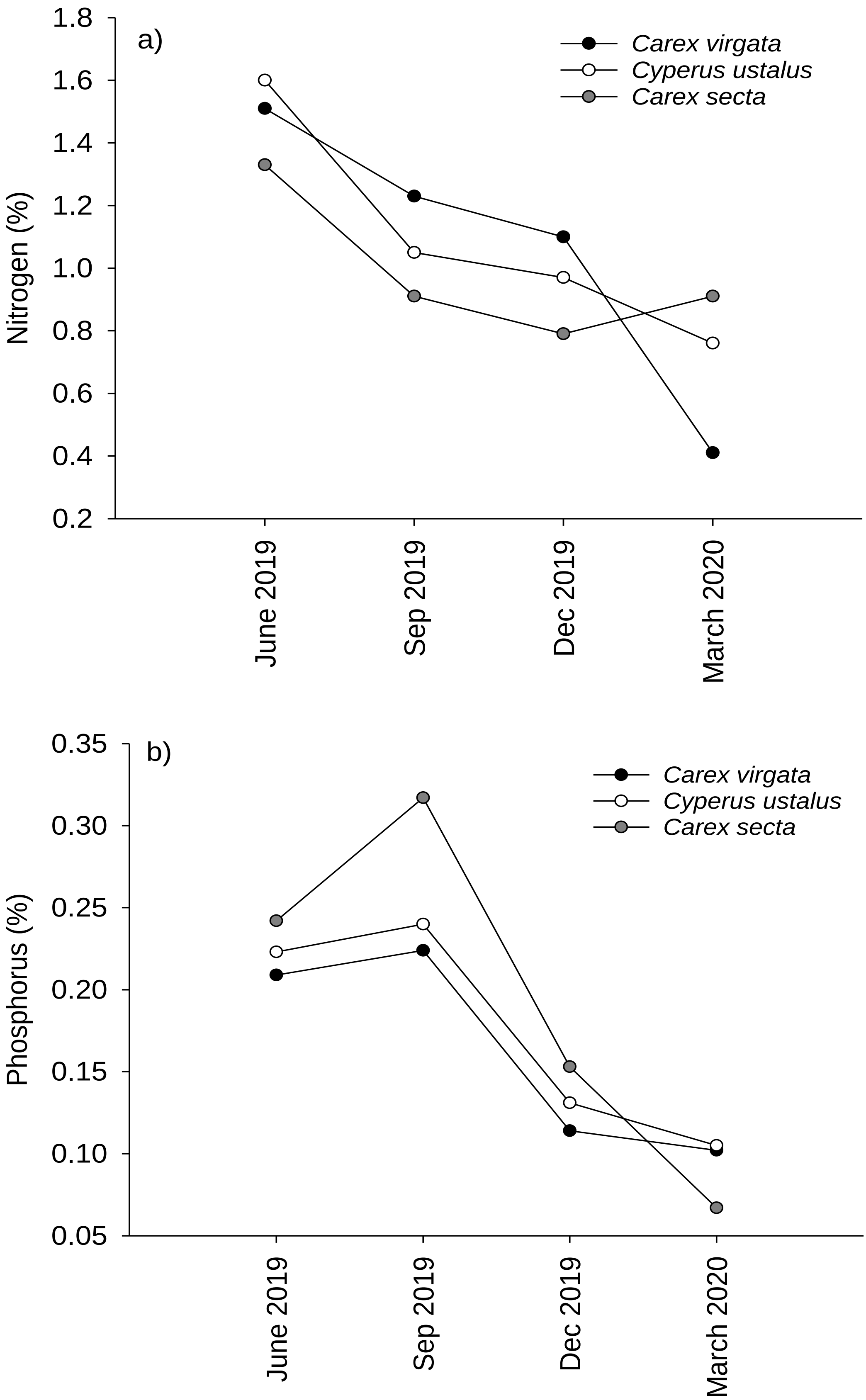

Figure 26. Nitrogen (a) and phosphorus (b) contents of sediment captured by root biomass of *Carex virgata*, *Cyperus ustalus*, and *Carex secta* for samples taken between June 2019 and March 2020. Samples are composites of material collected from six different plants, except for June 2019 where three samples of *Carex secta* were collected.

TN concentration (mg/g) of TSS from root washing per gram of root biomass increased between June and September 2019, but decreased from then until March 2020 with the exception of *C. virgata* which increased between December 2019 and March 2020 (Figure 27a). TN concentrations were comparable between the plant species at most of the sampling times, although *C. ustalus* appeared to have a lower TN concentration in September 2019 compared to the other plant species. TP concentration of TSS showed the same pattern as for TN (Figure 27b).

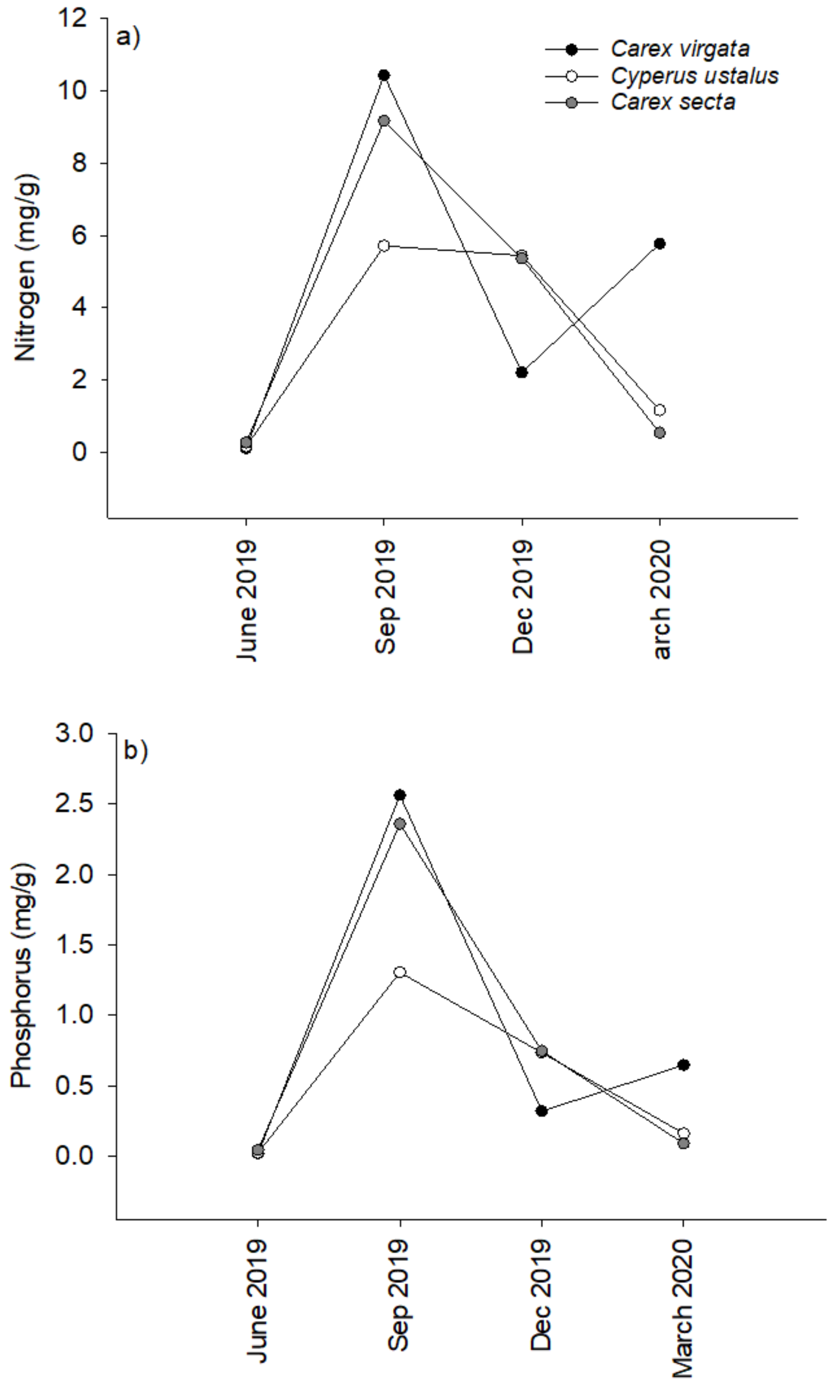

Figure 27. Nitrogen (a) and phosphorus (b) concentrations (mg/g) of sediment captured by root biomass of *Carex virgata*, *Cyperus ustalus*, and *Carex secta* for samples taken between June 2019 and March 2020. Samples are composites of material collected from six different plants except for June 2019 where three samples of *Carex secta* were collected.

4.5 Sediment accumulation

The average sediment depth was not statistically different between the four transects and ranged between 200 and 480 mm (Fig. 28). The rate of sediment accumulation (over the 4 years since the wetland installation) upstream of the wetland is 80–120 mm/year. Downstream of the wetland, sediment is accumulating at 50–60 mm/year, indicating sediment accumulation rates up- and down-stream of the wetland are similar.

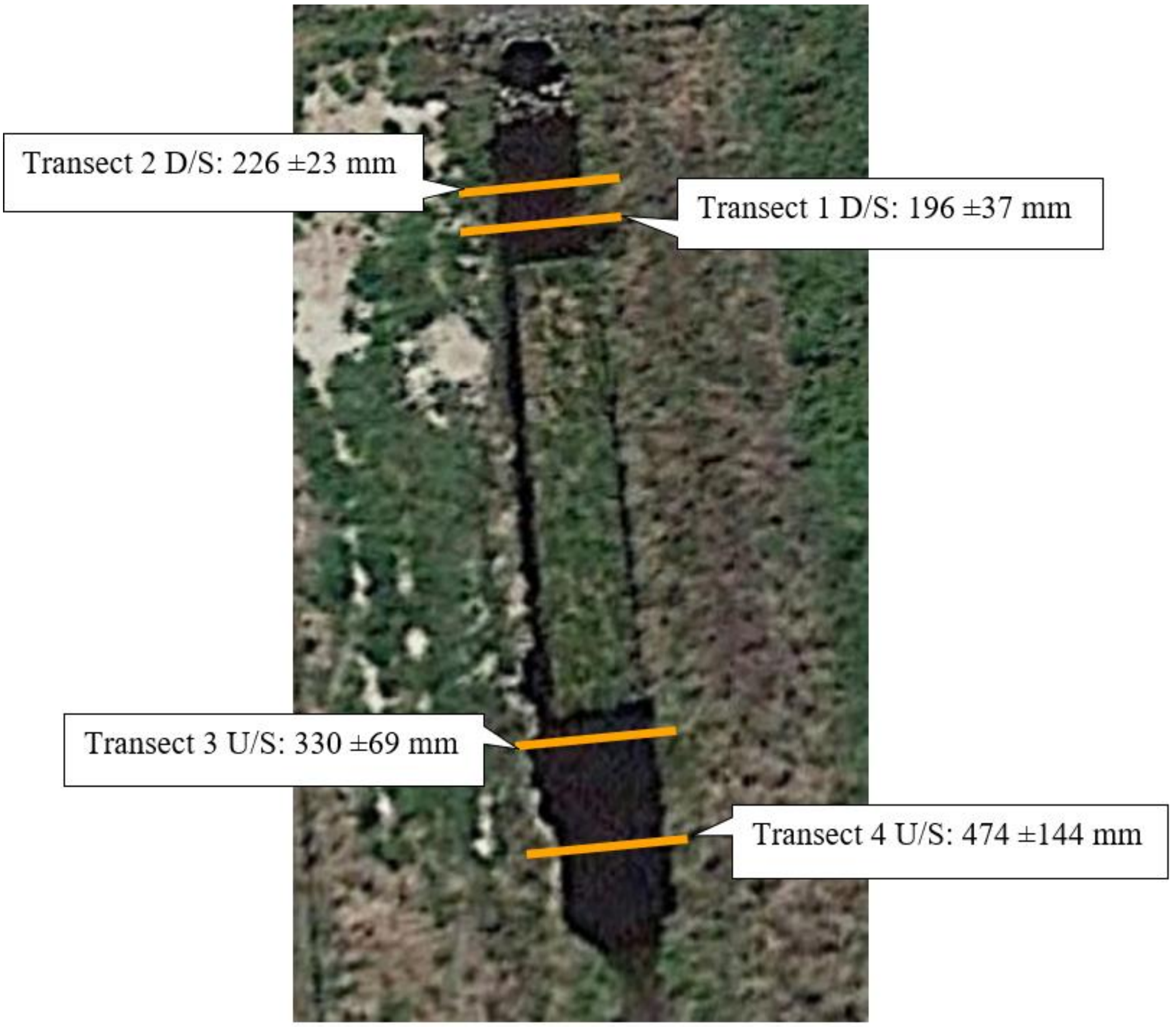

Figure 28. Mean sediment depth (mm) across four transects, 10 December 2019. Transects 1 and 2 were downstream (D/S) of floating wetland and transects 3 and 4 were upstream (U/S).

The TN content of sediment ranged between 0.18 and 0.34% and was higher in samples taken downstream of the wetland (Table 8). TP content ranged between 0.035 and 0.076% and again was higher in samples taken downstream of the wetland (Table 8).

Table 8. Nitrogen and phosphorus contents of sediment collected on 10 December 2019 up- and down-stream of the Lake Areare floating wetland

Sediment transect	Nitrogen (%)	Phosphorus (%)
1 (downstream)	0.34	0.076
2 (downstream)	0.34	0.069
3 (upstream)	0.24	0.046
4 (upstream)	0.18	0.035

5 Discussion

5.1 Water treatment efficiency

The mature floating wetland in the inlet drain to Lake Areare delivered overall negligible water quality benefits over the 12-month monitoring period. D/S concentrations were 7–20 times greater than guidelines for TN concentrations, 2–14 times greater for TP, 1.4–8.5 times greater for NH_4-N, and well below the guideline for dissolved oxygen (7–60%; Appendix 10) (Waikato Regional Council 2019). It is also highly unlikely that the study site's drain will meet water quality guidelines within the National Policy Statement for Freshwater Management. High variability of performance of the floating wetland is consistent with previous assessments of the Lake Areare floating wetland (Lambie et al. 2017).

These negligible effects on pollutant loads are attributed to three factors: a very small wetland relative to the catchment area; and highly variable influent concentrations of N, P, and TSS; coupled with widely fluctuating water levels (±1.0 m) and flow rates (1,171±1,554 m^3/day). The catchment size for this drain is too large for the floating wetland, with a wetland:catchment area ratio of 0.00004 (<0.01%). For NO_3-N removal of 22±10%, Tanner et al. (2010) recommend the wetland treatment area should be 1% of the drainage catchment, which for this catchment would be 14,800m^2. However, Tanner et al.'s recommendations are for terrestrial subsurface-flow constructed wetlands, and floating wetlands are more effective per m^2 (Tanner et al. 2011).

The HRT of the wetland using a sodium chloride tracer was ~9 hrs. Although 2.4–4 times longer than the theoretical HRT, this is considerably shorter than for effective treatment wetlands for which HRTs are more commonly measured in 'days' (Kadlec & Wallace 2008). Headley and Tanner (2012) report effective removal of TN, TP, and/or TSS with HRTs between 1 and 16 days, with an average of 5 days.

To increase the HRT to 5 days, the Lake Areare floating wetland area would need to increase to 800 m^2, using an additional 12 floating wetlands of 60 m^2. While this will improve treatment performance it may not, however, ensure reaching clean water objectives, given the high loading rates in this catchment. Further widening of the channel may also facilitate slowing the water and decreasing HRT but would need to be in conjunction with widening the floating wetland to minimise by-pass flow. Sediment attenuation would also be improved by placing the new floating wetlands in a formation, with sufficient gap between rafts to allow for digger access to remove sediment every 1-2 years to extend the life of the wetlands.

The Waikato region experienced unusually prolonged drought conditions during the 12-month monitoring period, with record low rainfall from October 2019 to May 2020 (Appendix 1). The floating wetland drain ceased to flow from mid-January to late March 2020, resulting in low DO levels and extended periods of anoxia. During anoxic conditions (DO<2 mg/L; Appendix 10), NH_4-N concentrations increased by ~70% and TSS increased by almost 4-fold. Interestingly, TP was less affected by the anoxic conditions, which usually cause desorption of DRP from sediments (Borne 2014), although during March 2020 concentrations increased by 0.34 mg/L (162%) D/S of the floating wetland. Ammonia (NH_3-N) increases with increasing water pH and temperature, and it is possible that during the period of high NH_4-N, temperature, and pH, ammonia (NH_3-N) concentrations became toxic to fish (Richardson et al 1997). There was no evidence of aquatic toxicity on fish species at the Lake Areare floating wetland as in other streams in the Waikato during the drought (O'Dwyer 2020).

Total organic N displayed less variability than inorganic N (NH_4-N and NO_3-N) throughout the monitoring period, with concentrations 2.6±0.4 mg/L for more than half of samples collected, both U/S and D/S of the floating wetland. Kadlec and Wallace (2008) similarly report that for treatment wetlands there is little change in outlet concentrations of organic N when influent concentrations range between 0.5 and 2.5 mg/L, primarily due to background concentrations created by residuals and wetland return fluxes, such as organic matter release from roots (Borne et al. 2015).

Daily influent areal yields varied extensively, reflecting large fluctuations in water levels, discharge, and constituent concentrations over the 12-month monitoring period. Nevertheless, annual yields were within expectations for intensive dairy-farmed catchments in New Zealand (Elliott et al. 2005) and TN yields aligned well with recent national estimates for warm-climate, lowland catchments (Snelder et al. 2017).

The high influent yields translated to high mass nutrient and sediment loads to the floating wetland. These loading rates are >45 times the mean rates of TN, and >11 times the mean loads rates of TP (Headley & Tanner 2012). The excessively high loading rates to the Lake Areare floating wetland further highlight the inadequate size of the wetland treatment system.

5.2 Sediment acumulation

The drain area under the floating wetland was excavated to 1.2 m. The plants on the floating wetland have a rooting length of approximately 1 m (as of June 2019), therefore the root mass will be 'filling' much of the cross-sectional area of the channel beneath the wetland. This slows water, allowing more time for plant root uptake and filtration, increasing HRT.

Assuming sediment accumulation rates under the floating wetland are similar to those exhibited up- and down-stream of the floating wetland at a rate of ~60 mm/year, and a drain depth of 1.2 m, it would take 3–4 years for the sediment acumulation to reach 1 m below the floating wetland, which is the current rooting depth of the plants on the wetland, suggesting that the sediment build up under the floating wetland has therefore already reached the depth at which the plant roots could anchor. Although any rooting into the sediment will likely be broken as the floating wetland moves up and down with fluctuating water levels, sufficiently long periods of low water levels (e.g. during prolonged drought as experienced in early 2020) may allow for more permanent rooting into sediment and potentially inhibit the vertical movement of the floating wetland with changes in water level.

Lambie et al. (2019) found substantial amounts of copper and zinc in the potting mix and fresh humus material on the floating wetland. We recommend sediment samples be taken underneath the floating wetland and assessed for heavy metal contaminations (Borne et al. 2015). Further, plants used for floating wetlands should be grown in media with low Cu and Zn, and Cu fungicides should be used sparingly.

5.3 Plants

There are two main pathways for nutrient removal by floating wetlands: plant uptake and root/biofilm associated processes such as denitrification, root entrapment, and sedimentation.

Plant uptake was assessed seasonally over the 1-year monitoring period. While there were few statistical differences between the plant species, there were some interesting trends. Root and shoot biomass (and its variability between individual plants) were greatest by far in *C. secta* compared with the other two plant species. This exacerbated competition for light within the *C. secta*, leading to the eventual death of slower growing plants. Smaller plants on the floating wetland recovered after the initial plant harvest, probably due to decreased light competition, as nutrients were not limiting (Weiner 2004). While it has been firmly established that floating wetlands reduce light provision to waterborne algae, thus reducing the possibility of below-raft plants (e.g. Wanielista et al. 2012; Zhao et al. 2012; West et al. 2017), competition for light on the floating wetlands themselves has not previously been established; however, competition for light has been reported between wetland plants in terrestrial settings (Wetzel & van der Valk 1998).

Death of plants may indicate a design or maintenance flaw within the floating wetland system. The initial stocking rate of plants on the floating wetland was 10 plants/m^2; for large plants such as *C. secta,* 10 plants is too many to maintain 100% plant survival as the plants mature. Plant density rates in floating wetlands vary dramatically internationally ranging between 8 and 83 plant/m^2 (Wang et al. 2014). Borne et al. (2013a) monitored a floating wetland with a *C. virgata* plant density of ~17/m^2 and found that plants began to die 15 months after wetland establishment. They suggest that this may be due to low oxygenation levels under the wetland and toxicity impacts associated with anaerobic processes, and anoxic conditions were evident between October 2019 and March 2020 at the Lake Areare floating wetland. However, floating wetland systems are often only studied in the early stages after installation when the plants are small (Pavlineri et al. 2017), or in controlled laboratory/greenhouse conditions (Pavlineri et al. 2017), and are often harvested on an annual basis (Borne et al. 2013a). None of these conditions represent the mature Areare floating wetland (~4.5 years old), which has had no maintenance; only a small proportion of individual plants were removed (2.5% of total number planted, but if the number of dead plants was included, this would be closer to 20%) for monitoring purposes. Removing whole plants or harvesting plant leaves (dead and alive) would minimise competition. It might also maintain nutrient uptake by the plants due to enhanced growth and the reduced input of nutrients from leaf litter decomposition (Wang et al. 2015). While we recommend the continued use of *C. secta* for floating wetlands due to their large potential for TN uptake and entrapment of particulates with a higher concentration of TN and TP, we suggest that future plastic rafts be designed to accommodate greater plant biomass but fewer plants.

Removal of plants for the assessment of biomass increased opportunities for weeds to invade the floating wetland. In March 2020, the area exposed by removing the largest *C. secta* had been invaded by *Bidens frondosa* (Beggar's ticks), a few *Onopordum acanthuim* (Scotch thistle), and some pasture grasses species. *Rubus fruiticosus* (Blackberry) also spread from the bank into the leaves of the wetland plants. Poor maintenance of one of the banks alongside the floating wetland, between the wetland and the grazing land, facilitated weed invasion. *Bidens frondosa* has a high seed production rate and spreads aggressively. If the colonisation of the floating wetland by this species continues, these plants will compete directly with the planted species for light and potentially inhibit wetland performance over time unless control measures are instigated. Weed incursion has occurred in other floating wetland systems (e.g. Powell 2010; Garcia Chance & White 2018; Shahid et al. 2018) affecting performance.

The larger biomass of *C. secta* facilitated a greater uptake of both N and P despite having a lower N or P content (%) than *C. virgata.* All plant species exhibited a peak in leaf N concentration in spring (September 2019), but other species have exhibited peaks of nutrient concentrations in summer (Garcia Chance et al. 2019). *C. secta* also displayed an increasing trend in root N concentration over time, inferring that despite a static amount of biomass there was accumulation of N in the root mass that had not reached full capacity (Pavlineri et al. 2017) and did not appear to be linked to seasonality as for the other species. Plant P contents were steady across time in *C. virgata* and *C. ustalus.* These concentrations may reflect the much larger scale of concentration in *C. secta*, or 'luxury uptake' of P above that required for plant maintenance and therefore a stabilisation of P storage over time (Peeters et al. 2016). *C. secta* also exhibited translocation of both TN and TP from leaf matter into root matter in autumn (March 2020), which can occur in some floating wetland species (e.g. Wang et al. 2015). It has been suggested that harvesting of leaf material from floating wetlands should occur before this translocation to increase treatment efficiency, e.g. at the end of summer (Wang et al. 2015).

Plants that are left without harvest of foliar material can decay in phases. Dead plant material that accumulates on top of the plastic wetland raft can cause re-entry of nutrients into the water column (Pavlineri et al. 2017). At the Lake Areare floating wetland, 4.5 years after wetland installation and in combination with the death of some of the plants, a considerable amount of fresh humic material derived from litter degradation is present as are large amounts of leaf litter (Fig. 29). The humic material on the Lake Areare floating wetland contains very large amounts of carbon, TN, and some TP (Lambie et al. 2019). On submersion, for example during rainfall events, this humic material is likely to release TN,

NH_4-N, and TP (Pan et al. 2017). While humic material/leaf litter can contribute carbon for denitrification and conversion of nitrogen from solution to gaseous forms, this generally only occurs in waters with low eutrophication which are carbon limited (Van de Moortel et al. 2012; Pan et al. 2017). In the case of Lake Areare floating wetland, it is highly likely that the dead litter and fresh humus material contributed to the large variability in the performance of the wetland.

Figure 29. Litter and fresh humus material on top of the Lake Areare floating wetland system in October 2019.

The high carbon contents of the material on the floating wetland will have exacerbated heavy metal accumulation on the floating wetland (Lidman et al. 2014). The wetland potting mix and fresh humus had carbon contents of 30–40% (Lambie et al. 2019), and Fassman et al. (2013) recommend potting media with 10–20% carbon to reduce metal retention and nutrient leaching from the media as it breaks down.

Plant uptake of nutrients varies between species and is affected by many factors including nutrient uptake rate, storage location, and maximum accumulation capacity (Pavlineri et al. 2017; Garcia Chance et al. 2019). While the contribution of plants to treatment efficiency varies, the potential of this could be maximised with appropriate interventions, particularly by harvesting foliar material (Zhou & Wang 2010). Uptake of nutrients by floating wetland plants can also be enhanced by inoculation with arbuscular mycorrhizae, particularly where there is a high N:P ratio (Fraser & Feinstein 2005). This may be an option for NZ plant species, although has not yet been trialled here. We found that root material accumulated more N and P than leaf material in *C. secta* and *C. ustalus*, which is contrary to *Pontederia cordata* and *Juncus effusus* assessed by Garcia Chance et al. (2019) and contrasts with *C. virgata* in our current study.

The root length of the plant species was consistent, ranging between 0.9 and 0.95 m, which is considerably longer than reported by Borne et al. (2013a), who found maximal root length of *C. virgata* on a floating wetland was 0.37 m. The root:shoot ratio of the plant species was below 1, indicating a greater investment in root material compared with leaf material. The enhanced root growth on a floating wetland may be due to a lack of physical obstruction to root growth as would be experienced in soil (Bengough 2003, 2006). The root:shoot ratio was smallest in *C. secta*, indicating this species diverted energy nearly equally into shoot and root growth (Mokany et al. 2006). Despite the differences in root biomass, we found little differences between the amount of suspended solids that were captured by the different species. Root structure facilitates entrapment of sediment (i.e. the proportion of fine root material) rather than root biomass as a whole (Sanicola et al. 2019) and characterisation of root mass into size classes to reflect differing amounts of coarse versus fine root mass would be beneficial in the future.

Root biomass did appear to impact sediment entrapment under the wetland. There was little differentiation between the species with respect to TSS, VSS (mg/g) or the N and P content (%) of the sediment. This is contrary to McAndrew et al. (2016) who found considerable variation between the different species of plants on their wetland with the greatest entrapment by *C. stricta.* However, N and P concentration (mg/g) of the entrapped sediment differed between species, as was also found by McAndrew et al. (2016). The two *Carex* species captured more N- and P-rich sediment than *C. ustalus*. This suggests that the root structure of *Carex* and *Cyperus* differ sufficiently to trap different-sized particulates. Tanner and Headley (2011) found that root entrapment was effective for reducing the amount to fine suspended solids (97% <2 µm and 60% <0.4 µm) tested in a mesocosm study. Fractionation of root entrapped sediment and nutrient analysis of the various fractions have not been undertaken but may add to understanding of treatment efficiency processes.

Root entrapment of particulate pollutants is reduced by higher influent water velocity and volume (Borne et al. 2013a) as higher energy water strips sediment from roots and allows for more bypass flow to occur. However, our data showed greatest removal of TSS and VSS in September, when the velocity and volume of water in the drain was at its highest. This may reflect that even 'high' velocities had insufficient energy to strip sediment from roots and may even have mobilised coarser sediment onto and into the extensive root mass. Further, the wetland minimised bypass flow as the whole channel was filled, and this was not the case for Borne et al (2013).

6 Conclusions and recommendations

The Lake Areare floating wetland is not delivering treatment of influent water to meet water quality guidelines. This is not unexpected, given the wetland receives high nutrient yields of TN and TP, has inadequate hydraulic residence times, and is 50–100 times smaller than the 0.5 to 1% area recommended for treatment wetlands. Lack of harvesting or plant replacement has probably also contributed to lower performance as this allows dead leaves and humic material to add nutrients to the water column as they decompose. Performance of the floating wetland would be enhanced by greatly increasing the size of the system to extend hydraulic residence times to an average of 5 days. Given field-measured HRT in this system was 2.4 – 4-fold higher than modelled HRT, we estimate at least an additional 10-12 floating wetlands, each of similar size (60 m^2) would be needed to significantly reduce nutrient and sediment loads exported downstream to Lake Areare and improve water quality in the lake.

An increase in wetland area should be combined with annual harvesting in late summer (March) to reduce the mass of litter and fresh humus material on the floating wetland. This would reduce added nutrients and enhance removal of nutrients by plant uptake. However, harvesting needs to be done in combination with weed control on the floating wetland and its banks to prevent weed incursion that may decrease treatment efficiency. Inoculation with arbuscular mycorrhizae on establishment of a floating wetland system might also improve nutrient treatment efficiency. The impacts of litter and humic residues on the floating wetland on water treatment performance should be quantified.

We also recommend measurement of heavy metal concentrations, particularly copper and zinc, in sediments under the existing floating wetland as if they are in high concentrations they will likely move out of solution and therefore remain a potentially toxic pollutant going into the Lake. Further benefits may be achieved by designing new floating wetlands to facilitate efficient removal of accumulated sediment between rafts.

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Appendix 1 – Rainfall records, Taupiri, 2019-2020

2019	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2020	Jan	Feb	Mar	Apr	May	Jun
1	0	0	0	21.2	0	11	1.8	0	0.2	5.2	0	0.8	1	0	0	0	0	0	0.2
2	0	0	0	0.2	0	0.6	0.2	8.4	0	2.8	0	0	2	0	0	0	0	0.2	0.4
3	0.2	0	0	0	0	0	0.4	1.4	8	0	0	9.8	3	0.4	0	0	0	39.2	0.4
4	0	0	0	0	0.4	2.8	32.2	11.6	4.2	0.2	0	0	4	0	0.8	5.2	0	8.8	2.8
5	0	0	0	0	0.4	13.2	0.6	3.6	31.6	0.2	0	0	5	0	0	0	0	14.2	0
6	0	6.6	0	1.8	0.2	1.4	0	1.8	5.6	2	0	0	6	2.6	0	0	0	0	0.6
7	0	0.4	0.2	0	0.4	5.2	0.2	3.8	4.2	0	0	0	7	0.2	0	0	0	0	1
8	0	0	19.4	0	0	1.2	0.4	12.2	27.2	0	0	21.2	8	0	0.6	0	18.2	0	1.6
9	0	0	0.4	0	0	0	0.6	6.4	6.2	0	0	0	9	0	0	9.4	0.2	0	0.8
10	0	0	0	0	2.8	0.2	0.8	1.2	1	3.4	4	0	10	0	0	0.6	0	0	0
11	0	0	0	10.6	0.2	0.2	0	22.8	0	8.2	0.2	0	11	0	0	5.8	0	0	0.2
12	0	0.2	0	2.2	6	0.6	9.6	10.4	0	0.6	0.4	0	12	0	0	0	1.4	0	1.6
13	33.6	0	0	0	1.4	3.6	0	5.8	0.2	0	0	0	13	0.2	0.2	0	10.4	0	0
14	13.4	0	0	0	0	0.2	7.4	1.6	3.6	0.6	8	0.8	14	1.4	0	0	5.4	0	0
15	0	0.2	0	0	2.2	0	1	0.2	2.2	10.2	2	1.2	15	0	0	0	0.2	0	0
16	0.4	0	0	0	0.4	2.4	8	1.2	0	0	0	6.8	16	0	0	0	3.6	0	0
17	0	0	0	0	0	2.4	7.4	6.6	0.8	0	5.2	18	17	0	0	0.2	1.4	0	0
18	0.2	0	0	0	0	0.2	0.2	0.2	0	1.4	25	8.6	18	0	0	0	2.8	0	23.4
19	0	0	0.4	0	4.4	0	6.8	0	0	3	0	0	19	0	0	0.2	1.8	0	0
20	0.8	0	0	0	0	2	3.2	7.8	0	0	0	3.8	20	0	0	2.6	0.4	0	11.2
21	0	0	0	1.6	0	3.4	0.4	2.6	0	2	0	3	21	0	0	0	0	0	0.6
22	0	6.2	0.2	14.8	0	0.2	0	11.2	0	2.6	0	0	22	0	3.6	3.2	0.4	0	0
23	0	0.2	0.2	0	0.4	3.4	0.2	5	0	12.4	0	0	23	0	1.8	27	0	0	0
24	0.8	0.6	0	0.2	0.4	0.2	0.2	0.2	25	0.2	0	0	24	0	0	0.2	0	3.2	0.4
25	0	0	0	0.2	0	0	1.2	0.2	8.4	0	0	0	25	0	0	1.2	0	5.4	10.4
26	0	0	0	0	0.2	0	0.4	1.6	3.4	0	0	0	26	0	0	2	0	0.6	2.2
27	0	0	0.2	0.2	2.8	0.2	0.2	0.6	2.4	0	0	0	27	0	0	2.6	0	0	21
28	0	0	3.8	3.2	2.8	0	0.6	0.8	0.2	0.6	0	0.6	28	0	0	0	0.8	0	5.6
29	0		0	10	2.6	0.4	0.4	5.2	0.6	0.4	4.4	0	29	0	0	0	0	2.4	6.8
30	0		0	0.6	0.8	0	10.6	4.8	7.4	0	0.2	0.2	30	0.8		2.2	0	0	1
31	0		0		24.2		3.8	0.2		0.8		0	31	0		0		0.6	
Σ	49.4	14.4	24.8	66.8	53	55	98.8	139.4	142.4	56.8	49.4	74.8	Σ	5.6	7	62.4	47	74.6	92.2
Mean	1.6	0.5	0.8	2.2	1.7	1.8	3.2	4.5	4.7	1.8	1.6	2.4	Mean	0	0.2	2	1.6	2.4	3.1
Max.	33.6	6.6	19.4	21.2	24.2	13.2	32.2	22.8	31.6	12.4	25	21.2	Max.	2.6	3.6	27	18.2	39.2	23.4

Avg	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2020	0.0	0.2	2.0	1.6	2.4	3.1	2.6	2.5	* 1.3			
2019	1.6	0.5	0.8	2.2	1.7	1.8	3.2	4.5	4.7	1.8	1.6	2.4
2018	2.6	* 4.7	1.5	2.9	3.9	* 4.4	4.1	4.1	1.6	1.5	2.7	5.1
2017	1.5	2.5	7.2	5.8	3.1	1.7	4.1	2.9	* 4.5	4.3	0.9	0.3
2016	3.8	2.9	* 0.8	1.0	4.8	4.5	4.8	2.6	3.9	3.5	2.6	* 1.0
2015									3.7	1.8	3.8	0.9
Avg	1.9	* 2.2	* 2.4	2.7	3.2	* 3.1	3.7	3.3	* 3.3	2.6	2.3	* 1.9

Appendix 2 – Water analytical reports

Analytical reports for water samples taken between June 2019 and May 2020 (Central Environmental Laboratories).

6 June 2019

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Analytical Report

COA No: 19/03274-1

Landcare Research
Private Bag 3127
Hamilton 3240
Attention: Suzanne Lambie

Date received: 07/06/2019 **Time received:** 08:00 **Sample date:** 06/06/2019 **Sample type:** Surface water

Sample	Sample ID	Test	Result	Units
19/03274-01	LA19 S1 In R1	Nitrogen - Ammonia	1.55	g/m³ NH3-N
		Nitrogen - Total	9.5	g/m³
		Nitrate	5.39	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.124	g/m³ PO4-P
		Phosphorus - Total	0.32	g/m³
		pH	5.0	
		Solids - Suspended	6	g/m³
		Solids - Volatile Suspended	4	g/m³
19/03274-02	LA19 S1 In R2	Nitrogen - Ammonia	1.54	g/m³ NH3-N
		Nitrogen - Total	9.6	g/m³
		Nitrate	5.45	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.108	g/m³ PO4-P
		Phosphorus - Total	0.32	g/m³
		pH	5.0	
		Solids - Suspended	6	g/m³
		Solids - Volatile Suspended	4	g/m³
19/03274-03	LA19 S1 In R3	Nitrogen - Ammonia	1.54	g/m³ NH3-N
		Nitrogen - Total	9.7	g/m³
		Nitrate	5.62	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.085	g/m³ PO4-P
		Phosphorus - Total	0.33	g/m³
		pH	4.9	
		Solids - Suspended	6	g/m³
		Solids - Volatile Suspended	4	g/m³
19/03274-04	LA19 S1 Out R1	Nitrogen - Ammonia	1.41	g/m³ NH3-N
		Nitrogen - Total	9.2	g/m³
		Nitrate	5.16	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.112	g/m³ PO4-P
		Phosphorus - Total	0.49	g/m³
		pH	5.0	
		Solids - Suspended	6	g/m³
		Solids - Volatile Suspended	4	g/m³
19/03274-05	LA19 S1 Out R2	Nitrogen - Ammonia	1.36	g/m³ NH3-N
		Nitrogen - Total	10	g/m³
		Nitrate	5.05	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.067	g/m³ PO4-P
		Phosphorus - Total	0.46	g/m³
		pH	5.0	
		Solids - Suspended	6	g/m³
		Solids - Volatile Suspended	4	g/m³
19/03274-06	LA19 S1 Out R3	Nitrogen - Ammonia	1.39	g/m³ NH3-N
		Nitrogen - Total	9.1	g/m³
		Nitrate	4.96	g/m³ NO3-N
		Phosphorus - Dissolved	0.094	g/m³ PO4-P

COA No.: 19/03274-1 1 of 2

Sample	Sample ID	Test	Result	Units
		Reactive		
		Phosphorus - Total	0.49	g/m^3
		pH	5.0	
		Solids - Suspended	6	g/m^3
		Solids - Volatile Suspended	4	g/m^3

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

Report released by **Johan Bosch** **Date: 19 June 2019**
Principal Analyst

Key Technical Person:

Carrie-Ann Leighton

Johan Bosch

Nishani Thennakoon

9 July 2019

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Analytical Report

COA No: 19/03902-1

Landcare Research
Private Bag 3127
Hamilton 3240

Attention: Suzanne Lamble

Date received: 11/07/2019 **Time received:** 11:17 **Sample date:** 09/07/2019 **Sample time:** 08:45

Sample type: Stormwater

Sample	Sample ID	Test	Result	Units
19/03902-01	LA19 S2 In R1	Nitrogen - Ammonia	1.31	g/m^3 NH3-N
		Nitrogen - Total	11	g/m^3
		Nitrate	5.11	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.077	g/m^3 PO4-P
		Phosphorus - Total	0.12	g/m^3
		pH	4.8	
		Solids - Suspended	4	g/m^3
		Solids - Volatile Suspended	3	g/m^3
19/03902-02	LA19 S2 In R2	Nitrogen - Ammonia	1.29	g/m^3 NH3-N
		Nitrogen - Total	9.8	g/m^3
		Nitrate	5.09	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.072	g/m^3 PO4-P
		Phosphorus - Total	0.10	g/m^3
		pH	4.7	
		Solids - Suspended	4	g/m^3
		Solids - Volatile Suspended	3	g/m^3
19/03902-03	LA19 S2 In R3	Nitrogen - Ammonia	1.26	g/m^3 NH3-N
		Nitrogen - Total	9.4	g/m^3
		Nitrate	5.00	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.071	g/m^3 PO4-P
		Phosphorus - Total	0.10	g/m^3
		pH	4.8	
		Solids - Suspended	4	g/m^3
		Solids - Volatile Suspended	3	g/m^3
Sample time: 09:00				
19/03902-04	LA19 S2 Out R1	Nitrogen - Ammonia	1.26	g/m^3 NH3-N
		Nitrogen - Total	9.1	g/m^3
		Nitrate	4.92	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.064	g/m^3 PO4-P
		Phosphorus - Total	0.09	g/m^3
		pH	4.8	
		Solids - Suspended	4	g/m^3
		Solids - Volatile Suspended	3	g/m^3
Sample time: 09:00				
19/03902-05	LA19 S2 Out R2	Nitrogen - Ammonia	1.20	g/m^3 NH3-N
		Nitrogen - Total	9.1	g/m^3
		Nitrate	4.91	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.063	g/m^3 PO4-P
		Phosphorus - Total	0.13	g/m^3
		pH	4.8	
		Solids - Suspended	3	g/m^3
		Solids - Volatile Suspended	2	g/m^3

Sample time: 09:00

Sample	Sample ID	Test	Result	Units
19/03902-06	LA19 S2 Out R3	Nitrogen - Ammonia	1.28	g/m^3 NH3-N
		Nitrogen - Total	9.9	g/m^3
		Nitrate	4.92	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.068	g/m^3 PO4-P
		Phosphorus - Total	0.06	g/m^3
		pH	4.8	
		Solids - Suspended	3	g/m^3
		Solids - Volatile Suspended	2	g/m^3

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

Report released by **Johan Bosch** **Date: 16 July 2019**

Principal Analyst

Key Technical Person:

Johan Bosch

IANZ

13 July 2019

CENTRAL ENVIRONMENTAL LABORATORIES

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Analytical Report

COA No: 19/03993-1

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Landcare Research
Private Bag 3127
Hamilton 3240

Attention: Suzanne Lambie

Date received: 17/07/2019 **Time received:** 08:00 **Sample date:** 13/07/2019

Sample	Sample ID	Test	Result	Units
19/03993-01	LA19 S3 In	Nitrogen - Ammonia	1.35	g/m^3 NH3-N
		Nitrogen - Total	6.8	g/m^3
		Nitrate	3.10	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.060	g/m^3 PO4-P
		Phosphorus - Total	0.45	g/m^3
		pH	4.8	
		Solids - Suspended	3	g/m^3
		Solids - Volatile Suspended	2	g/m^3
19/03993-02	LA19 S3 Out	Nitrogen - Ammonia	1.26	g/m^3 NH3-N
		Nitrogen - Total	6.6	g/m^3
		Nitrate	3.05	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.053	g/m^3 PO4-P
		Phosphorus - Total	0.48	g/m^3
		pH	4.8	
		Solids - Suspended	3	g/m^3
		Solids - Volatile Suspended	2	g/m^3

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

Report released by **Johan Bosch** **Date: 25 July 2019**
Principal Analyst

Key Technical Person:

Johan Bosch

12 August 2019

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Analytical Report

COA No: 19/04504-1

Landcare Research
Private Bag 3127
Hamilton 3240

Attention: Suzanne Lambie

Date received: 14/08/2019 **Time received:** 08:00 **Sample date:** 12/08/2019 **Sample type:** Surface water

Sample	Sample ID	Test	Result	Units
Sample time: 08:45				
19/04504-01	LA1984In	Nitrogen - Ammonia	1.26	g/m^3 NH3-N
		Nitrogen - Total	8.2	g/m^3
	Lake Areare	Nitrate	4.45	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.048	g/m^3 PO4-P
		Phosphorus - Total	0.44	g/m^3
		pH	4.5	
		Solids - Suspended	5	g/m^3
		Solids - Volatile Suspended	2	g/m^3
Sample time: 09:15				
19/04504-02	LA1983Out	Nitrogen - Ammonia	1.27	g/m^3 NH3-N
		Nitrogen - Total	7.9	g/m^3
	Lake Areare	Nitrate	4.38	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.050	g/m^3 PO4-P
		Phosphorus - Total	0.40	g/m^3
		pH	4.5	
		Solids - Suspended	4	g/m^3
		Solids - Volatile Suspended	2	g/m^3

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

Report released by **Johan Bosch** **Date: 22 August 2019**
Principal Analyst

Key Technical Person:

Johan Bosch

12 September 2019

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Analytical Report

COA No: 19/05120-1

Landcare Research
Private Bag 3127
Hamilton 3240
Attention: Suzanne Lamble

Date received: 17/09/2019 **Time received:** 08:00 **Sample date:** 12/09/2019 **Sample time:** 11:35

Sample type: Surface water

Sample	Sample ID	Test	Result	Units
19/05120-01	LA19S5In-R1	Nitrogen - Ammonia	1.38	g/m³ NH3-N
		Nitrogen - Total	5.6	g/m³
	Lake Areare	Nitrate	1.88	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.111	g/m³ PO4-P
		Phosphorus - Total	0.17	g/m³
		pH	4.8	
		Solids - Suspended	4	g/m³
		Solids - Volatile Suspended	3	g/m³
19/05120-02	LA19S5In-R2	Nitrogen - Ammonia	1.38	g/m³ NH3-N
		Nitrogen - Total	5.7	g/m³
	Lake Areare	Nitrate	1.83	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.102	g/m³ PO4-P
		Phosphorus - Total	0.11	g/m³
		pH	4.8	
		Solids - Suspended	4	g/m³
		Solids - Volatile Suspended	3	g/m³
19/05120-03	LA19S5In-R3	Nitrogen - Ammonia	1.45	g/m³ NH3-N
		Nitrogen - Total	6.1	g/m³
	Lake Areare	Nitrate	1.84	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.116	g/m³ PO4-P
		Phosphorus - Total	0.17	g/m³
		pH	4.8	
		Solids - Suspended	4	g/m³
		Solids - Volatile Suspended	3	g/m³
Sample time: 12:00				
19/05120-04	LA19S5Out-R1	Nitrogen - Ammonia	1.46	g/m³ NH3-N
		Nitrogen - Total	6.4	g/m³
	Lake Areare	Nitrate	1.85	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.071	g/m³ PO4-P
		Phosphorus - Total	0.14	g/m³
		pH	4.8	
		Solids - Suspended	4	g/m³
		Solids - Volatile Suspended	2	g/m³
Sample time: 12:00				
19/05120-05	LA19S5Out-R2	Nitrogen - Ammonia	1.41	g/m³ NH3-N
		Nitrogen - Total	5.3	g/m³
	Lake Areare	Nitrate	1.85	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.069	g/m³ PO4-P
		Phosphorus - Total	0.23	g/m³
		pH	4.8	
		Solids - Suspended	5	g/m³
		Solids - Volatile Suspended	3	g/m³

Sample time: 12:00

Sample	Sample ID	Test	Result	Units
19/05120-06	LA19S5Out-R3	Nitrogen - Ammonia	1.45	g/m³ NH3-N
		Nitrogen - Total	5.5	g/m³
	Lake Areare	Nitrate	1.85	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.068	g/m³ PO4-P
		Phosphorus - Total	0.23	g/m³
		pH	4.8	
		Solids - Suspended	6	g/m³
		Solids - Volatile Suspended	3	g/m³

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m³ NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m³
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m³ NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m³ PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m³
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m³
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m³

Report released by **Johan Bosch** **Date: 24 September 2019**

Principal Analyst

Key Technical Person:

Carrie-Ann Leighton

Johan Bosch

This Laboratory is accredited by International Accreditation New Zealand.
Tests and sampling procedures have been performed in accordance with the conditions of our accreditation.
Where not supplied test methods, detection limits and uncertainties are available on request.
When samples are collected by the client or an agent of the client, results reported apply only to samples as received at the Laboratory.
This report shall not be reproduced except in full, without the written approval of this laboratory.

IANZ ACCREDITED LABORATORY

29 October 2019

CENTRAL ENVIRONMENTAL LABORATORIES

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Analytical Report

COA No: 19/06019-1

Landcare Research
Private Bag 3127
Hamilton 3240
Attention: Suzanne Lambie

Date received: 01/11/2019 **Time received:** 08:00 **Sample date:** 29/10/2019 **Sample type:** Surface water

Sample	Sample ID	Test	Result	Units
Sample time: 09:00				
19/06019-01	LA19S6In	Nitrogen - Ammonia	0.979	g/m³ NH3-N
	Lake Areare	Nitrogen - Total	3.7	g/m³
		Nitrate	0.071	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.072	g/m³ PO4-P
		Phosphorus - Total	0.43	g/m³
		pH	5.4	
		Solids - Suspended	19	g/m³
		Solids - Volatile Suspended	9	g/m³
Sample time: 09:30				
19/06019-02	LA19S6Out	Nitrogen - Ammonia	0.961	g/m³ NH3-N
	Lake Areare	Nitrogen - Total	3.3	g/m³
		Nitrate	0.015	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.066	g/m³ PO4-P
		Phosphorus - Total	0.33	g/m³
		pH	5.4	
		Solids - Suspended	14	g/m³
		Solids - Volatile Suspended	10	g/m³

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m³ NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m³
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m³ NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m³ PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m³
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m³
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m³

Report released by **Johan Bosch** **Principal Analyst** **Date: 08 November 2019**

Key Technical Person:

Johan Bosch

20 November 2019

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Analytical Report

COA No: 19/06514-1

Landcare Research
Private Bag 3127
Hamilton 3240
Attention: Suzanne Lamble

Date received: 22/11/2019 **Time received:** 08:00 **Sample date:** 20/11/2019 **Sample type:** Surface water

Sample	Sample ID	Test	Result	Units
Sample time: 10:30				
19/06514-01	LA19S7In	Nitrogen - Ammonia	2.40	g/m³ NH3-N
		Nitrogen - Total	5.8	g/m³
	Lake Areare	Nitrate	0.011	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.202	g/m³ PO4-P
		Phosphorus - Total	0.38	g/m³
		pH	5.5	
		Solids - Suspended	9	g/m³
		Solids - Volatile Suspended	9	g/m³
Sample time: 10:45				
19/06514-02	LA19S7Out	Nitrogen - Ammonia	2.32	g/m³ NH3-N
		Nitrogen - Total	5.2	g/m³
	Lake Areare	Nitrate	< 0.010	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.170	g/m³ PO4-P
		Phosphorus - Total	0.35	g/m³
		pH	5.5	
		Solids - Suspended	8	g/m³
		Solids - Volatile Suspended	8	g/m³

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m³ NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m³
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m³ NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m³ PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m³
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m³
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m³

Report released by **Johan Bosch** **Principal Analyst** **Date: 06 December 2019**

Key Technical Person:

Carrie-Ann Leighton

10 December 2019

CENTRAL ENVIRONMENTAL LABORATORIES

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Analytical Report

COA No: 19/06957-1

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Landcare Research
Private Bag 3127
Hamilton 3240
Attention: Suzanne Lamble

Date received: 12/12/2019 **Time received:** 08:00 **Sample date:** 10/12/2019 **Sample time:** 09:00

Sample type: Surface water

Sample	Sample ID	Test	Result	Units
19/06957-01	LA19 S8 In Lake Areare Ngaruawahia	Nitrogen - Ammonia	2.62	g/m³ NH3-N
		Nitrogen - Total	4.1	g/m³
		Nitrate	< 0.010	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.020	g/m³ PO4-P
		Phosphorus - Total	0.42	g/m³
		pH	5.7	
		Solids - Suspended	13	g/m³
		Solids - Volatile Suspended	9	g/m³
19/06957-02	LA19 S8 Out Lake Areare Ngaruawahia	Nitrogen - Ammonia	3.13	g/m³ NH3-N
		Nitrogen - Total	5.2	g/m³
		Nitrate	< 0.010	g/m³ NO3-N
		Phosphorus - Dissolved Reactive	0.029	g/m³ PO4-P
		Phosphorus - Total	0.40	g/m³
		pH	5.7	
		Solids - Suspended	23	g/m³
		Solids - Volatile Suspended	15	g/m³

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m³ NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m³
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m³ NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m³ PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m³
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m³
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m³

Report released by **Johan Bosch** **Date: 24 December 2019**
Principal Analyst

Key Technical Person:
Carrie-Ann Leighton

13 January 2020

CENTRAL ENVIRONMENTAL LABORATORIES

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Analytical Report

COA No: 20/00246-1

Landcare Research
Private Bag 3127
Hamilton 3240
Attention: Suzanne Lambie

Date received: 15/01/2020 **Time received:** 08:00 **Sample date:** 13/01/2020 **Sample type:** Surface water

Sample	Sample ID	Test	Result	Units
20/00246-01	LA19 S9 In	Nitrogen - Ammonia	2.20	g/m^3 NH_3-N
		Nitrogen - Total	4.0	g/m^3
	Lake Areare	Nitrate	< 0.010	g/m^3 NO_3-N
		Phosphorus - Dissolved Reactive	0.012	g/m^3 PO_4-P
		Phosphorus - Total	0.34	g/m^3
		pH	5.9	
		Solids - Suspended	15	g/m^3
		Solids - Volatile Suspended	5	g/m^3
20/00246-02	LA19 S9 Out	Nitrogen - Ammonia	1.67	g/m^3 NH_3-N
		Nitrogen - Total	3.7	g/m^3
	Lake Areare	Nitrate	< 0.010	g/m^3 NO_3-N
		Phosphorus - Dissolved Reactive	0.009	g/m^3 PO_4-P
		Phosphorus - Total	0.38	g/m^3
		pH	5.9	
		Solids - Suspended	7	g/m^3
		Solids - Volatile Suspended	3	g/m^3

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH_3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO_3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO_4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

Report released by **Johan Bosch** **Date: 22 January 2020**

Principal Analyst

24 March 2020

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Analytical Report

COA No: 20/01690-1

Landcare Research
Private Bag 3127
Hamilton 3240

Attention: Suzanne Lambie

Date received: 25/03/2020 **Time received:** 08:00 **Sample date:** 24/03/2020 **Sample time:** 14:00

Sample type: Surface water

Sample	Sample ID	Test	Result	Units
20/01690-01	LA20 In Floating wetland Lake Areare	Nitrogen - Ammonia	1.66	g/m^3 NH3-N
		Nitrogen - Total	8.2	g/m^3
		Nitrate	4.67	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.069	g/m^3 PO4-P
		Phosphorus - Total	0.21	g/m^3
		pH	5.5	
		Solids - Suspended	8	g/m^3
		Solids - Volatile Suspended	5	g/m^3
20/01690-02	LA20 Out Floating wetland Lake Areare	Nitrogen - Ammonia	2.23	g/m^3 NH3-N
		Nitrogen - Total	5.5	g/m^3
		Nitrate	0.613	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.163	g/m^3 PO4-P
		Phosphorus - Total	0.54	g/m^3
		pH	6.0	
		Solids - Suspended	32	g/m^3
		Solids - Volatile Suspended	18	g/m^3

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

5 May 2020

CENTRAL ENVIRONMENTAL LABORATORIES

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Analytical Report

COA No: 20/02207-1

.andcare Research
'rivate Bag 3127
lamilton 3240
\ttention: Suzanne Lambie

)ate received: 07/05/2020 **Time received:** 08:00 **Sample date:** 05/05/2020 **Sample time:** 10:00

;ample type: Surface water

;ample	Sample ID	Test	Result	Units
0/02207-01	LA19 S11 In Lake Areare	Nitrogen - Ammonia	0.576	g/m^3 NH3-N
		Nitrogen - Total	4.6	g/m^3
		Nitrate	1.20	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.135	g/m^3 PO4-P
		Phosphorus - Total	0.26	g/m^3
		pH	4.8	
		Solids - Suspended	2	g/m^3
		Solids - Volatile Suspended	2	g/m^3
0/02207-02	LA19 S11 Out Lake Areare	Nitrogen - Ammonia	0.556	g/m^3 NH3-N
		Nitrogen - Total	4.4	g/m^3
		Nitrate	1.21	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.107	g/m^3 PO4-P
		Phosphorus - Total	0.22	g/m^3
		pH	5.0	
		Solids - Suspended	3	g/m^3
		Solids - Volatile Suspended	3	g/m^3

Notes:

'est Methodology:

Test	Methodology	Detection Limit
litrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH3-N
litrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
litrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO3-N
'hosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO4-P
'hosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
ιH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
;olids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
;olids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

Report released by **Johan Bosch** **Date: 12 May 2020**

Principal Analyst

(ey Technical Person:

ohan Bosch

26 May 2020

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Analytical Report

COA No: 20/02600-1

Landcare Research
Private Bag 3127
Hamilton 3240
Attention: Suzanne Lambie

Date received: 28/05/2020 **Time received:** 08:00 **Sample date:** 26/05/2020 **Sample type:** Surface water

Sample	Sample ID	Test	Result	Units
20/02600-01	LA19 S12 In	Nitrogen - Ammonia	1.14	g/m^3 NH3-N
		Nitrogen - Total	3.3	g/m^3
	Lake Areare	Nitrate	0.042	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.049	g/m^3 PO4-P
		Phosphorus - Total	0.14	g/m^3
		pH	5.5	
		Solids - Suspended	21	g/m^3
		Solids - Volatile Suspended	8	g/m^3
20/02600-02	LA19 S12 Out	Nitrogen - Ammonia	1.42	g/m^3 NH3-N
		Nitrogen - Total	3.0	g/m^3
	Lake Areare	Nitrate	< 0.010	g/m^3 NO3-N
		Phosphorus - Dissolved Reactive	0.069	g/m^3 PO4-P
		Phosphorus - Total	0.12	g/m^3
		pH	5.6	
		Solids - Suspended	10	g/m^3
		Solids - Volatile Suspended	7	g/m^3

Notes:

Test Methodology:

Test	Methodology	Detection Limit
Nitrogen - Ammonia	APHA 23rd Ed. 4500 NH3-F (Modified)	0.005 g/m^3 NH3-N
Nitrogen - Total	APHA 23rd Ed. 4500-P J and 4500-NO2 B	0.05 g/m^3
Nitrate	APHA 23rd Ed. 4110 B	0.005 g/m^3 NO3-N
Phosphorus - Dissolved Reactive	APHA 23rd Ed. 4500-P E, 0.45 micron filtered	0.005 g/m^3 PO4-P
Phosphorus - Total	APHA 23rd Ed. 4500-P J, E	0.01 g/m^3
pH	APHA 23rd Ed. 4500-H+ B. Note: It is not possible to perform pH on samples received in the laboratory within the 15 minutes APHA Recommended Storage Time.	
Solids - Suspended	APHA 23rd Ed. 2540 D	1 g/m^3
Solids - Volatile Suspended	APHA 23rd Ed. 2540 E	1 g/m^3

Report released by **Johan Bosch** **Date: 08 June 2020**
Principal Analyst

Key Technical Person:
Johan Bosch
Nishani Thennakoon

Appendix 3 – Leaf and root length and biomass hard data

Root and shoot length and biomass hard data, including the root: shoot ratio for all plants destructively harvested in June 2019.

Carex virgata

Rep	Leaf length (m)	Root length (m)	Leaf (g)	Root (g)	Total (g)	Root:shoot
1	1.5	0.81	90	156.3	246.3	0.58
2	1.7	1	1005.3	1223.4	2228.7	0.82
3	1.3	1.06	103.6	162.4	266	0.64
4	1.3	0.75	93.7	158.1	251.8	0.59
5	1.34	0.8	167.6	135.8	303.4	1.23
6	1.4	1	333.3	703.5	1036.8	0.47

Cyperus ustalus

Rep	Leaf length (m)	Root length (m)	Leaf (g)	Root (g)	Total (g)	Root:shoot
1	1.9	0.85	168.5	376.9	545.4	0.45
2	1.8	0.8	359.9	904.5	1264.4	0.40
3	2	1.05	1226.1	1186	2412.1	1.03
4	1.4	0.8	273.3	712.1	985.4	0.38
5	1.5	1	564	1203	1767	0.47
6	2	1.1	949.3	1431.6	2380.9	0.66

Carex secta

Rep	Leaf length (m)	Root length (m)	Leaf (g)	Root (g)	Total (g)	Root:shoot
1	1.3	1.1	45.8	352	397.8	0.30
2	0.6	0.5	22.5	453.5	476	0.05
3	1.8	1.25	4212	7172.8	11384.8	0.59

Appendix 4 – Water particulate organic nitrogen hard data

Environmental Chemistry Laboratory
Analytical Report – Soils

Manaaki Whenua – Landcare Research
Riddet Rd, Massey University Campus, Private Bag 11052, Palmerston North 4442
Phone: +64 6 353 4800

Manaaki Whenua
Landcare Research

Job number: LJ19035

Date received: 17th October 2019

Customer: Suzanne Lambie, Manaaki Whenua – Landcare Research
Private Bag 3127, Hamilton 3240

Date reported: 27th November 2019

Samples are water-borne particulates, captured and dried on filter papers and contained within aluminium foil.
The entire foil parcel was carefully folded and combusted in the LECO, using normal EC Lab conditions for soil or plant analysis.
The first two columns for Organic C and Total N are the output from the LECO Trumac analyser, with the weight set to 1g for every sample. The second two columns for Organic C and Total N are the adjusted values with the average blank reading subtracted and then corrected for the sediment weights supplied.

Client ID	Sample No.	Organic C (method 114) (%)	Total N (method 114) (%)	Sediment weight Client supplied (g)	Organic C (method 114) (mg/kg)	Total N (method 114) (mg/kg)	C/N ratio (calculation)
		1g weight used on LECO			Corrected for sediment wt and average blank		
Blank1	M19/1934	0.05	0.01				
Blank2	M19/1935	0.05	0.01				
AFW037	M19/1936	0.11	0.02	0.0024	1.5	0.16	9
AFW038	M19/1937	0.12	0.02	0.0020	1.3	0.16	8
AFW039	M19/1938	0.11	0.02	0.0021	1.3	0.16	8
AFW040	M19/1939	0.12	0.02	0.0022	1.6	0.15	11
AFW041	M19/1940	0.12	0.02	0.0021	1.5	0.18	8
AFW042	M19/1941	0.11	0.02	0.0021	1.3	0.13	10
AFW043	M19/1942	0.07	0.01	0.0012	0.3	0.03	9
AFW044	M19/1943	0.07	0.01	0.0010	0.2	0.02	13
AFW045	M19/1944	0.07	0.01	0.0009	0.2	0.01	14
AFW046	M19/1945	0.08	0.01	0.0011	0.3	0.04	7
AFW047	M19/1946	0.07	0.02	0.0009	0.2	0.06	3
AFW048	M19/1947	0.07	0.01	0.0011	0.2	0.04	6
AFW049	M19/1948	0.07	0.02	0.0007	0.1	0.04	4
AFW050	M19/1949	0.07	0.01	0.0008	0.2	0.02	11
AFW051	M19/1950	0.08	0.01	0.0011	0.3	0.03	9
AFW052	M19/1951	0.07	0.01	0.0013	0.3	0.04	8
AFW053	M19/1952	0.10	0.02	0.0015	0.7	0.08	8
AFW054	M19/1953	0.10	0.02	0.0014	0.6	0.10	6
AFW055	M19/1954	0.10	0.02	0.0015	0.8	0.09	8
AFW056	M19/1955	0.10	0.02	0.0016	0.8	0.08	10
AFW057	M19/1956	0.10	0.02	0.0013	0.6	0.11	6
AFW058	M19/1957	0.10	0.02	0.0016	0.8	0.08	9

N Foster

Ngaire Foster, Laboratory Manager

Results apply to the samples as received and are expressed on an oven-dry (105°C) basis. Details of method codes are available online at http://www.landcareresearch.co.nz/resources/laboratories/environmental-chemistry-laboratory/services. This report may not be reproduced, except in full, without the consent of the signatory.

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Interim Soil Analysis Results

Environmental Chemistry Laboratory, Landcare Research

The following results are interim data, they have not gone through our complete quality control checking process and are issued for information only.

Client: Suzanne Lambie **Date In: 7th August 2020**

Job No.: LJ20010 **Date Out: Interim data out 24th August 2020**

This spreadsheet is supplied for informational purposes only and does not constitute an official report

Client ID	Sample No.	Organic C (method 114) (%)	Total N (method 114) (%)	Sediment weight Client supplied (g)	Organic C (method 114) (mg/kg)	Total N (method 114) (mg/kg)	C/N ratio (calculation)*
		1g weight used on LECO			Corrected for sediment wt and average blank		
LA19 S6 In	M20/0238	0.13	0.02	0.0032	2.6	0.21	13
LA19 S6 Out	M20/0239	0.07	0.01	0.0008	0.2	0.02	11
LA19 S7 In	M20/0240	0.15	0.02	0.0027	2.8	0.36	8
LA19 S7 Out	M20/0241	0.13	0.02	0.0027	2.2	0.19	12
LA19 S8 In	M20/0242	0.08	0.01	0.0018	0.7	0.07	11
LA19 S8 Out	M20/0243	0.11	0.02	0.0025	1.7	0.16	10
LA19 S9 In	M20/0244	0.12	0.02	0.0063	4.9	0.41	12
LA19 S9 Out	M20/0245	0.14	0.02	0.0047	4.6	0.43	11
LA19 S11 In	M20/0246	0.08	0.01	0.0007	0.3	0.04	7
LA19 S11 Out	M20/0247	0.09	0.02	0.001	0.4	0.07	6
LA19 S12 In	M20/0248	0.10	0.01	0.0032	1.8	0.18	10
LA19 S12 Out	M20/0249	0.09	0.01	0.0019	0.8	0.08	10
Blank-1	M20/0250	0.04	0.01	0	0.0	0.00	
Blank-2	M20/0251	0.04	0.01	0	0.0	0.00	

Notes:

Samples were run through the LECO with a weight of 1g specified in the software.

Samples are particulates, captured and dried on filter papers and contained within aluminium foil.

The entire foil parcel was carefully folded and combusted in the LECO, using normal conditions for soil or plant analysis

Appendix 5 – Plant foliage and root nitrogen and phosphorus hard data

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AR-20-NU-024491-01 1 24

ANALYTICAL REPORT

REPORT CODE	AR-20-NU-024491-01	REPORT DATE	23/03/2020
		Landcare Research NZ Ltd Suzanne Lambie C/- Landcare Research Hamilton NEW ZEALAND +6478593795 lambies@landcareresearch.co.nz	
Contact for your orders:	Sarah Jones	Order code:	EUNZAU-00258479

Sample Name	Leaf CS June 2019		
Sample Code:	816-2020-00075863	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS	Units	Results
NU251 Nitrogen	%	1.4
NU268 Phosphorus	%	0.17

eurofins

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Sample Name	Leaf CU June 2019		
Sample Code:	816-2020-00075864	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS	Units	Results
NU251 Nitrogen	%	1.1
NU268 Phosphorus	%	0.22

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Sample Name	Leaf CV June 2019		
Sample Code:	816-2020-00075865	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS	Units	Results
NU251 Nitrogen	%	1.7
NU268 Phosphorus	%	0.28

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Sample Name	Leaf CS Sep 2019		
Sample Code:	816-2020-00075866	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS	Units	Results
NU251 Nitrogen	%	1.8
NU268 Phosphorus	%	0.18

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Sample Name	Leaf CU Sep 2019		
Sample Code:	816-2020-00075867	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.5
NU268	Phosphorus	%	0.17

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Sample Name	Leaf CV Sep 2019		
Sample Code:	816-2020-00075868	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	2.2
NU268	Phosphorus	%	0.25

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Sample Name	Leaf CS Dec 2019		
Sample Code:	816-2020-00075869	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.7
NU268	Phosphorus	%	0.21

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Sample Name	Leaf CU Dec 2019		
Sample Code:	816-2020-00075870	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.4
NU268	Phosphorus	%	0.17

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Sample Name	Leaf CV Dec 2019		
Sample Code:	816-2020-00075871	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	2.1
NU268	Phosphorus	%	0.18

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Sample Name	Leaf CS March 2020		
Sample Code:	816-2020-00075872	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.4
NU268	Phosphorus	%	0.16

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Sample Name	Leaf CU March 2020		
Sample Code:	816-2020-00075873	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.1
NU268	Phosphorus	%	0.13

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Sample Name	Leaf CV March 2020		
Sample Code:	816-2020-00075874	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.5
NU268	Phosphorus	%	0.11

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AR-20-NU-024491-01 13 24

Sample Name	Root CS June 2019		
Sample Code:	816-2020-00075875	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.4
NU268	Phosphorus	%	0.18

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Sample Name	Root CU June 2019		
Sample Code:	816-2020-00075876	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.5
NU268	Phosphorus	%	0.19

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Sample Name	Root CV June 2019		
Sample Code:	816-2020-00075877	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.2
NU268	Phosphorus	%	0.13

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Sample Name	Root CS Sep 2019		
Sample Code:	816-2020-00075878	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.5
NU268	Phosphorus	%	0.21

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Sample Name	Root CU Sep 2019		
Sample Code:	816-2020-00075879	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.7
NU268	Phosphorus	%	0.23

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Sample Name	Root CV Sep 2019		
Sample Code:	816-2020-00075880	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.3
NU268	Phosphorus	%	0.17

eurofins AR-20-NU-024491-01 19 24

Sample Name	Root CS Dec 2019		
Sample Code:	816-2020-00075881	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.5
NU268	Phosphorus	%	0.16

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Sample Name	Root CU Dec 2019		
Sample Code:	816-2020-00075882	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.8
NU268	Phosphorus	%	0.19

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Sample Name	Root CV Dec 2019		
Sample Code:	816-2020-00075883	Plant Type	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS		Units	Results
NU251	Nitrogen	%	1.6
NU268	Phosphorus	%	0.16

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Sample Name	Root CS March 2020		
Sample Code:	816-2020-00075884	**Plant Type**	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS	Units	Results
NU251 Nitrogen	%	1.6
NU268 Phosphorus	%	0.17

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Sample Name	Root CU March 2020		
Sample Code:	816-2020-00075885	**Plant Type**	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS	Units	Results
NU251 Nitrogen	%	1.5
NU268 Phosphorus	%	0.17

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AR-20-NU-024491-01 24 24

Sample Name	Root CV March 2020		
Sample Code:	816-2020-00075886	**Plant Type**	Miscellaneous
Reception Date:	18/03/2020		
Analysis Ending Date:	23/03/2020		

MACRO ELEMENTS	Units	Results
NU251 Nitrogen	%	1.3
NU268 Phosphorus	%	0.14

LIST OF METHODS

NU251 **Nitrogen:** Combustion elemental analyser: Thermal conductivity detection.

NU268 **Phosphorus:** Microwave digestion, ICP_OES determination

Signature

Brent Miller

Brent Miller Technical Manager

EXPLANATORY NOTE

- ◆ test is not accredited
- o test is subcontracted within Eurofins group and is accredited
- • test is subcontracted within Eurofins group and is not accredited
- □ test is subcontracted outside Eurofins group and is accredited
- ■ test is subcontracted outside Eurofins group and is not accredited

N/A means Not applicable
Not Detected means not detected at or above the Limit of Quantification (LOQ)
Accreditation does not apply to comments or graphical representations.
Eurofins General Terms and Conditions apply.
This document can only be reproduced in full; it only concerns the submitted sample.
Results have been obtained and reported in accordance with our general sales conditions available on request.
The tests are identified by a five-digit code, their description is available on request.

Unless otherwise stated, all tests in this analytical report (except for subcontracted tests) are performed at 35 O'Rorke Road, Penrose, Auckland, NEW ZEALAND.
References for desired levels can be supplied on request.

END OF REPORT

Appendix 6 – Sediment nitrogen and phosphorus hard data

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AR-20-NU-024428-01 2 4

SAMPLE CODE	816-2020-00076642			
Client Reference:				
Sample described as:	Root Wash CS Mar 20			
Reception Date & Time:	18/03/2020 16:56			
Analysis Start Date & Time	19/03/2020 06:30		Analysis Ending Date:	23/03/2020

SOIL TEST RESULTS	RESULTS		LOQ
NU362 Total Nitrogen			
Nitrogen	0.91	%	0.02
ANIONS	**RESULTS**		**LOQ**
◆ NU363 Total Recoverable Phosphorus			
Phosphorus	1020	mg/kg	1

SAMPLE CODE	816-2020-00076643			
Client Reference:				
Sample described as:	Root Wash CU Mar 20			
Reception Date & Time:	18/03/2020 16:56			
Analysis Start Date & Time	19/03/2020 06:30		Analysis Ending Date:	23/03/2020

SOIL TEST RESULTS	RESULTS		LOQ
NU362 Total Nitrogen			
Nitrogen	0.76	%	0.02
ANIONS	**RESULTS**		**LOQ**
◆ NU363 Total Recoverable Phosphorus			
Phosphorus	1050	mg/kg	1

SAMPLE CODE	816-2020-00076644			
Client Reference:				
Sample described as:	Root Wash CV Mar 20			
Reception Date & Time:	18/03/2020 16:56			
Analysis Start Date & Time	19/03/2020 06:30		Analysis Ending Date:	23/03/2020

SOIL TEST RESULTS	RESULTS		LOQ
NU362 Total Nitrogen			
Nitrogen	0.41	%	0.02
ANIONS	**RESULTS**		**LOQ**
◆ NU363 Total Recoverable Phosphorus			
Phosphorus	670	mg/kg	1

SAMPLE CODE	816-2020-00076645			
Client Reference:				
Sample described as:	Sediment Mansect 1			
Reception Date & Time:	18/03/2020 16:56			
Analysis Start Date & Time	19/03/2020 06:30		Analysis Ending Date:	23/03/2020

SOIL TEST RESULTS	RESULTS		LOQ
NU362 Total Nitrogen			
Nitrogen	0.34	%	0.02
ANIONS	**RESULTS**		**LOQ**
◆ NU363 Total Recoverable Phosphorus			
Phosphorus	756	mg/kg	1

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SAMPLE CODE	816-2020-00076646		
Client Reference:			
Sample described as:	Sediment Mansect 2		
Reception Date & Time:	18/03/2020 16:56		
Analysis Start Date & Time	19/03/2020 06:30	Analysis Ending Date:	23/03/2020

SOIL TEST RESULTS		RESULTS		LOQ
NU362	Total Nitrogen			
	Nitrogen	0.34	%	0.02

ANIONS		RESULTS		LOQ
◆ NU363	Total Recoverable Phosphorus			
	Phosphorus	690	mg/kg	1

SAMPLE CODE	816-2020-00076647		
Client Reference:			
Sample described as:	Sediment Mansect 3		
Reception Date & Time:	18/03/2020 16:56		
Analysis Start Date & Time	19/03/2020 06:30	Analysis Ending Date:	23/03/2020

SOIL TEST RESULTS		RESULTS		LOQ
NU362	Total Nitrogen			
	Nitrogen	0.24	%	0.02

ANIONS		RESULTS		LOQ
◆ NU363	Total Recoverable Phosphorus			
	Phosphorus	459	mg/kg	1

SAMPLE CODE	816-2020-00076648		
Client Reference:			
Sample described as:	Sediment Mansect 4		
Reception Date & Time:	18/03/2020 16:56		
Analysis Start Date & Time	19/03/2020 06:30	Analysis Ending Date:	23/03/2020

SOIL TEST RESULTS		RESULTS		LOQ
NU362	Total Nitrogen			
	Nitrogen	0.18	%	0.02

ANIONS		RESULTS		LOQ
◆ NU363	Total Recoverable Phosphorus			
	Phosphorus	352	mg/kg	1

LIST OF METHODS

NU362 **Total Nitrogen:** Combustion elemental analyser: Thermal conductivity detection.

NU363 **Total Recoverable Phosphorus:** EPA 200.2 digestion, ICP_OES determination

Signature

Brent Miller

Brent Miller Technical Manager

EXPLANATORY NOTE

N/A means Not applicable

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Appendix 7 – Root washing sediment total nitrogen and phosphorus hard data

Environmental Chemistry Laboratory

Analytical Report – Soils

Manaaki Whenua – Landcare Research
Riddet Rd, Massey University Campus, Private Bag 11052, Palmerston North 4442
Phone: +64 6 353 4800

Manaaki Whenua
Landcare Research

Job number: LJ19039

Date received: 22nd October 2019

Customer: Suzanne Lambie, Manaaki Whenua – Landcare Research
Private Bag 3127, Hamilton 3240

Date reported: 16th January 2020

The sediment samples were tested using the plant digestion method. This has additional steps compared to the soils method, to allow recovery of nitrates. The samples were dried at 80°C for at least 2 hours before weighing, as per the plants method, and results are presented on this basis.

Client ID	Sample No.	Nitrogen (method 206) (%)	Phosphorus (method 206) (%)
C0190150 AFW025 Root wash CS June 2019	M19/1975	1.33	0.209
C0190150 AFW026 Root wash CU June 2019	M19/1976	1.60	0.223
C0190150 AFW027 Root wash CV June 2019	M19/1977	1.51	0.242
C0190150 AFW028 Root wash CS Sep 2019	M19/1978	0.91	0.224
C0190150 AFW029 Root wash CU Sep 2019	M19/1979	1.05	0.240
C0190150 AFW030 Root wash CV Sep 2019	M19/1980	1.23	0.317

ANALYTICAL REPORT

REPORT CODE	AR-20-NU-024428-01	REPORT DATE	23/03/2020

For the attention of Landcare Research NZ Ltd
Suzanne Lambie
C/- Landcare Research
Hamilton
NEW ZEALAND
Phone +6478593795
Email lambies@landcareresearch.co.nz

Contact for your orders: Sarah Jones **Order code:** EUNZAU-00258683

SAMPLE CODE 816-2020-00076639

Client Reference:
Sample described as: Root Wash CS Dec 19
Reception Date & Time: 18/03/2020 16:56
Analysis Start Date & Time 19/03/2020 06:30 **Analysis Ending Date:** 23/03/2020

SOIL TEST RESULTS		RESULTS		LOQ
NU362	Total Nitrogen			
	Nitrogen	0.79	%	0.02
ANIONS		**RESULTS**		**LOQ**
◆ NU363	Total Recoverable Phosphorus			
	Phosphorus	1140	mg/kg	1

SAMPLE CODE 816-2020-00076640

Client Reference:
Sample described as: Root Wash CU Dec 19
Reception Date & Time: 18/03/2020 16:56
Analysis Start Date & Time 19/03/2020 06:30 **Analysis Ending Date:** 23/03/2020

SOIL TEST RESULTS		RESULTS		LOQ
NU362	Total Nitrogen			
	Nitrogen	0.97	%	0.02
ANIONS		**RESULTS**		**LOQ**
◆ NU363	Total Recoverable Phosphorus			
	Phosphorus	1310	mg/kg	1

SAMPLE CODE 816-2020-00076641

Client Reference:
Sample described as: Root Wash CV Dec 19
Reception Date & Time: 18/03/2020 16:56
Analysis Start Date & Time 19/03/2020 06:30 **Analysis Ending Date:** 23/03/2020

SOIL TEST RESULTS		RESULTS		LOQ
NU362	Total Nitrogen			
	Nitrogen	1.1	%	0.02
ANIONS		**RESULTS**		**LOQ**
◆ NU363	Total Recoverable Phosphorus			
	Phosphorus	1530	mg/kg	1

Appendix 8 – Flow data at times of water quality sampling collection

Site	Sample #	Date	Time NZST	Area of flow m^2	Velocity m/s	Discharge m^3/s	Discharge m^3/d
AFWL_DS	1	6/06/2019	11:35:00 AM	0.470	0.019	0.009	772
AFWL_DS	2	9/07/2019	10:00:00 AM	0.496	0.036	0.018	1542
AFWL_DS	3	13/07/2019	2:50:00 PM	0.542	0.026	0.014	1219
AFWL_DS	4	8/08/2019	9:15:00 AM	0.763	0.093	0.071	6132
AFWL_DS	5	12/09/2019	11:55:00 AM	0.606	0.071	0.043	3719
AFWL_DS	6	29/10/2019	8:30:00 AM	0.391	0.015	0.006	507
AFWL_DS	7	20/11/2019	11:23:00 AM	0.368	0.014	0.005	445
AFWL_DS	8	10/12/2019	8:15:00 AM	0.335	0.005	0.002	145
AFWL_DS	9	13/01/2020	8:30:00 AM	0.324	0.003	0.001	84
AFWL_DS	10	24/03/2020	13:30:00 PM	0.329	0.003	0.001	85
AFWL_DS	11	5/05/2020	9:55:00 AM	0.394	0.028	0.011	953
AFWL_DS	12	26/05/2020	9:30:00 AM	0.318	0.004	0.001	110

Appendix 9 – Salt tracer hard data 29 October 2019

Time	Up/Downstream	Specific Conductivity (µS/cm)
9:12	Upstream	213.9
9:30	Upstream	215
9:35	Upstream	214.4
9:40	Upstream	214.2
9:45	Upstream	213.9
9:50	Upstream	213.8
9:55	Upstream	218.5
10:00	Upstream	219.4
10:05	Upstream	232.6
10:10	Upstream	272.3
10:15	Upstream	291.2
10:20	Upstream	297.3
10:25	Upstream	306.4
10:30	Upstream	305.3
10:35	Upstream	304.4
10:40	Upstream	303
10:45	Upstream	299.9
10:50	Upstream	295.4
10:55	Upstream	290.9
11:00	Upstream	284.8
11:05	Upstream	283.1
11:10	Upstream	280.6
11:15	Upstream	280
11:20	Upstream	277.2
11:25	Upstream	275.4
11:30	Upstream	274.1
11:35	Upstream	270.4
11:40	Upstream	268.3
11:45	Upstream	266.3
11:50	Upstream	265.9
11:55	Upstream	263.8
12:00	Upstream	261.8
12:05	Upstream	261
8:21:47	Downstream	183.5
8:31:32	Downstream	183.3
10:00:54	Downstream	183.4

Time	Up/Downstream	Specific Conductivity (µS/cm)
10:05:54	Downstream	183.5
10:10:54	Downstream	183.6
10:15:54	Downstream	183.6
10:20:54	Downstream	183.7
10:25:54	Downstream	183.9
10:30:54	Downstream	184.8
10:35:54	Downstream	185.2
10:40:54	Downstream	185.9
10:45:54	Downstream	185.1
10:50:54	Downstream	187
10:55:54	Downstream	186.7
11:00:54	Downstream	189.5
11:05:54	Downstream	189.2
11:10:54	Downstream	188.8
11:15:54	Downstream	193.9
11:20:54	Downstream	197.9
11:25:54	Downstream	203
11:30:54	Downstream	212.5
11:35:54	Downstream	219.2
11:40:53	Downstream	224
11:45:53	Downstream	225.4
11:50:53	Downstream	235.3
11:55:53	Downstream	253.4
12:00:53	Downstream	275.4
12:05:53	Downstream	276.6
12:10:53	Downstream	268.8
12:15:53	Downstream	272.3
12:20:53	Downstream	271.3
12:25:53	Downstream	263.1
12:30:53	Downstream	256.7
12:35:53	Downstream	253.1
12:40:53	Downstream	253.8
12:45:53	Downstream	251.1
12:50:53	Downstream	264.1
12:55:53	Downstream	258.2
13:00:53	Downstream	262.7
13:05:53	Downstream	269.6
13:10:53	Downstream	269.6

Time	Up/Downstream	Specific Conductivity (μS/cm)
13:15:53	Downstream	262.2
13:20:53	Downstream	256.5
13:25:53	Downstream	254.8
13:30:53	Downstream	256.9
13:35:53	Downstream	259.8
13:40:53	Downstream	263.2
13:45:53	Downstream	267.8
13:50:53	Downstream	262.5
13:55:53	Downstream	265
14:00:53	Downstream	269.8
14:05:53	Downstream	274.9
14:10:53	Downstream	272.2
14:15:53	Downstream	276.4
14:20:53	Downstream	274.3
14:25:53	Downstream	272.6
14:30:53	Downstream	271.6
14:35:53	Downstream	270.4
14:40:53	Downstream	268.6
14:45:53	Downstream	269.6
14:50:53	Downstream	271.3
14:55:53	Downstream	270
15:00:53	Downstream	266.7
15:05:53	Downstream	265.4
15:10:53	Downstream	265.3
15:15:53	Downstream	263.9
15:20:53	Downstream	262.3
15:25:53	Downstream	263.2
15:30:53	Downstream	261.1
15:35:53	Downstream	259.5
15:40:53	Downstream	260.2
15:45:53	Downstream	258.3
15:50:53	Downstream	256.7
15:55:52	Downstream	259
16:00:52	Downstream	261.2
16:05:52	Downstream	261.1
16:10:52	Downstream	260.3
16:15:52	Downstream	260.2
16:20:52	Downstream	261

Time	Up/Downstream	Specific Conductivity (µS/cm)
16:25:52	Downstream	259.1
16:30:52	Downstream	256.1
16:35:52	Downstream	260.6
16:40:52	Downstream	257.1
16:45:52	Downstream	260.6
16:50:52	Downstream	259.2
16:55:52	Downstream	254.8
17:00:52	Downstream	259.7
17:05:52	Downstream	252.3
17:10:52	Downstream	253.2
17:15:52	Downstream	252.7
17:20:52	Downstream	252.2
17:25:52	Downstream	255.4
17:30:52	Downstream	258.6
17:35:52	Downstream	256.4
17:40:52	Downstream	254.8
17:45:52	Downstream	254.5
17:50:52	Downstream	254.3
17:55:52	Downstream	254.6
18:00:52	Downstream	253.9
18:05:52	Downstream	252.2
18:10:52	Downstream	251
18:15:52	Downstream	253.5
18:20:52	Downstream	254.2
18:25:52	Downstream	254.4
18:30:52	Downstream	267.7
18:35:52	Downstream	290
18:40:52	Downstream	290.9
18:45:52	Downstream	286.1
18:50:52	Downstream	282.5
18:55:52	Downstream	280.6
19:00:52	Downstream	291
19:05:52	Downstream	295
19:10:52	Downstream	300.7
19:15:52	Downstream	307.8
19:20:52	Downstream	304.5
19:25:52	Downstream	309.4
19:30:52	Downstream	306.2

Time	Up/Downstream	Specific Conductivity (µS/cm)
19:35:52	Downstream	312.1
19:40:52	Downstream	316.7
19:45:52	Downstream	320.2
19:50:51	Downstream	325.6
19:55:51	Downstream	329.8
20:00:51	Downstream	273.5

Appendix 10 – Up- and down-stream water data collected on-site at sampling dates

Upstream data

Date	Temp (°C)	DO (%)	DO (mg/L)	Specific cond. (μS^{SPC})	Specific cond. (μS^{C})	pH	Water depth (m)
6/06/2019	12	58.9	6.34	412.2	310.3	4.77	0.376
9/07/2019	11.2	53.4	5.86	361.7	266.3	4.78	
13/07/2019	13.1	56.1	5.88	340.9	263.6	4.3	
8/08/2019	12	47.5	5.12	301.2		3.88	
12/09/2019	13.4	54.2	5.66	65.7		4.76	
29/10/2019	15.8	14.8	1.47	223	183.7	5.18	0.4
20/11/2019	16.8	27.6	2.67	229.1	193.3	5.63	
10/12/2019	15.7	7.1	0.71	228.4	187.7	5.87	
13/01/2020	14.5	7	0.7	222.6	178.1	6.19	
24/03/2020							
5/05/2020	14.5	45.9	4.66	392.6	314	4.6	
26/05/2020	12.9	9.4	0.99	360.4	277.3	5.48	

Downstream data

Date	Temp (°C)	DO (%)	DO (mg/L)	Specific cond. (µS^SPC)	Specific cond. (µS^C)	pH	Water depth (m)
6/06/2019	12.2	52.2	5.56	408.2	304.3	4.82	0.305
9/07/2019	11.3	40.3	4.43	357.6	263.8	4.8	0.585
13/07/2019	13	45.7	4.82	338.7	260.8	4.52	0.63
8/08/2019	12	43.7	4.71	293.5		3.88	0.865
12/09/2019	13.2	43.1	4.52	42.2	32.7	4.77	0.69
29/10/2019	15.5	3.5	0.35	224.4	183.5	5.25	0.49
20/11/2019	15.1	1.2	0.12	228.4	185.4	5.65	0.46
10/12/2019	17.6	1.2	0.12	238.3	204.5	6.14	0.43
13/01/2020	16.5	1	0.1	208.7	174.7	6.15	0.42
24/03/2020							
5/05/2020	14.5	45.9	4.66	392.6	314	4.6	
26/05/2020	12.9	9.4	0.99	360.4	277.3	5.48	