Performance of a constructed wetland receiving drainage water on a Lichfield dairy farm

2019 drainage year

Prepared for DairyNZ

October 2020

Prepared by:
James Sukias
Stephan Heubeck

For any information regarding this report please contact:

James Sukias
Scientist
Aquatic Pollution
+64-7-856 1715
james.sukias@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

NIWA CLIENT REPORT No: 2020295HN
Report date: October 2020
NIWA Project: DNZ19204

Quality Assurance Statement		
	Reviewed by:	Neale Hudson
	Formatting checked by:	Carole Evans
	Approved for release by:	Scott Larned

Contents

Tables

Figures

Executive summary

In 2016, NIWA was engaged by DairyNZ to monitor the constructed wetland complex at Baldwin's farm, Lichfield, during the 2017 drainage year. The monitoring included hydrology, water quality and wetland vegetation. The results of that monitoring programme were previously reported (Sukias et al. 2018). In 2018, NIWA was engaged to monitor the wetland complex over the 2019 drainage season. This report summarises the results of the second monitoring period, making references to and comparisons with results from the first monitoring period as necessary.

The Baldwins "constructed wetland" is actually a series of five discrete wetland cells. Three primary inflows to the wetland complex exist: 1) natural surface water drainage from a catchment that has several natural wetlands, 2) runoff from farm laneways, and 3) groundwater that upwells in the wetland complex. During the 2017 assessment period, it was noted that groundwater was a substantial component of the wetland inflow, particularly in summer. Four shallow groundwater monitoring wells were installed prior to the start of the 2019 drainage year to improve estimates of contaminant loads transported in groundwater.

Meteorological conditions were very different during the two drainage years. The monitoring results provided insights regarding the agricultural contaminant attenuation performance of a constructed wetland complex under different hydrological conditions. Key meteorological and hydrological characteristics are summarised in Table i:

Table i: Comparison of meteorological and hydrological characteristics, 2017 and 2019 drainage years.

Metric	Drainage year	
	2017	2019
Precipitation (mm)	1 756	1 242
Number of rainfall events	25	7
Runoff (mm)	989	467
Total wetland outflow (m^3)	96 500	10 500

Precipitation in the 2017 drainage year was the highest since 2000, whereas the 2019 rainfall was the forth lowest recorded since 2000. In addition, the 2018 drainage year was also very dry. The combined effect of two dry years resulted in the lowest recorded runoff in 2019 since 2000. The total outflow volume recorded in 2019 was approximately nine times less than the total outflow volume recorded in the 2017 drainage year.

Contaminant removal performance or efficacy of a treatment device such as a constructed wetland is best quantified by comparing the total inflow and outflow contaminant mass over a period (e.g., annually). Several methods were trialled to identify suitable load estimation techniques. Traditional regression-based approaches (which rely on consistent relationships between concentration and discharge), proved unsuitable.

The RiverLoad software provides seven different methods (including regression techniques and flow-weighted concentration techniques). The flow-weighted concentration techniques provided plausible annual estimates of surface water contaminant loads.

The RiverLoad procedures were not suitable for providing estimates of groundwater loads. A stratified, "event-by-event" method was used to provide estimates of groundwater contaminant loads, as well as independent estimates of surface water inflow and outflow loads. Performance data for the two drainage years are summarised in Table ii:

Table ii: Comparison of annual loads and removal efficacies, 2017 and 2019 drainage years. The 2019 annual inflow and outflow load estimates are the median value derived from four RiverLoad methods (surface inputs) plus groundwater estimates based on the stratified "event-by-event" method. The 2017 annual estimates do not account for mass loads introduced by groundwater as comprehensively as do the 2019 estimates (especially relevant for nitrate-N). Negative values indicate that the wetland was a nett source of contaminants during that year. For *E. coli*, MPN = most probable number.

Variable	2017				2019			
	Annual load			Removal efficacy (%)	Annual load			Removal efficacy (%)
	In	Out	Removal		In	Out	Removal	
Nitrate-N (kg)	86.1	158.6	-72.5	-84%	48.9	15.1	33.8	69%
Ammonia-N (kg)	36.8	8.4	28.4	77%	5.11	2.78	2.33	46%
Organic-N (kg)	446.1	117.9	328.2	74%	51.3	25.4	25.9	50%
TN (kg)	569.0	284.9	284.1	50%	113.4	43.4	70.0	62%
DRP (kg)	8.0	8.4	-0.4	-6%	2.58	1.59	0.99	38%
TP (kg)	122	18	104	85%	20.3	7.0	13.3	66%
TSS (kg)	30 980	6 280	24 700	80%	3 940	1 360	2 580	65%
E. coli (MPN)	1.60×10^{12}	2.44×10^{11}	1.36×10^{12}	85%	3.78×10^{13}	1.33×10^{13}	2.45×10^{13}	65%

With the exception of dissolved reactive phosphorus (38%), the wetland complex reduced the inflow contaminant load of other contaminants during the 2019 drainage year by at least 50%.

From the available data, the wetland complex appeared to be a nett source of nitrate-N during the 2017 drainage year. It must be noted that the inflow estimates do not fully account for the load introduced through groundwater, because the groundwater wells did not exist at that time. The total inflow mass estimate is likely therefore to be smaller than the actual inflow mass, which makes the apparent mass load removal and removal efficacy smaller than the likely actual values. Apparent removal of nitrate-N by the wetland in 2017 was therefore likely to be low due to several compounding factors, including: relatively low concentrations of nitrate-N in surface water inflows, a relatively large (but essentially unknown) load of nitrate-N in upwelling groundwater, generally shorter residence time in the wetland (providing less opportunity for microbes to assimilate nitrate-N), and low dissolved organic carbon concentration (required for microbial denitrification). Smaller surface and groundwater inflows in 2019 than in 2017 created conditions more favourable for denitrification, and the nitrate-N load in 2019 was reduced by 70%. Upwelling groundwater enters the wetland complex downstream of the surface water inflow to the wetland, effectively short-circuiting the wetland, reducing the potential for treatment.

The efficacy of total nitrogen removal increased from 50% in 2017 to 62% in 2019. This was most likely related to the increased nitrate-N removal efficacy in 2019 – nitrate-N represented approximately 43% of total nitrogen during 2019.

The proportion of total suspended sediment and total phosphorus removed during the 2019 drainage year was lower than in the 2017 drainage year. This may have resulted from the legacy effect of the large sediment load input to the wetland during the 2017 year, which reduced the capacity of the initial three cells to store particulate material.

Runoff from the laneways was a significant source of *Escherichia coli*, a faecal indicator bacterium. During the 2019 drainage year:

- Rainfall events contributed 86% of the annual *E. coli* load, with much of this load mobilised from the farm laneways. During rainfall events:
  - median laneway inflow concentrations ranged from 198 400 to 956 375 MPN 100 mL^{-1}
  - median seepage wetland inflow concentrations were much lower, ranging from 200 to 4 352 MPN 100 mL^{-1}.
- On an annual basis, the wetland complex reduced the total number of *E. coli* by 65% during the 2019 drainage year.

Our results indicate that well-maintained wetland designs that facilitate retention of total suspended sediment are likely to remove particulate N and P effectively as well. Periodic removal of deposited sediment from wetland cells (particularly the initial cells in a multi-cell wetland complex) appears necessary to maintain the capacity of these cells to capture particulate contaminants.

Achieving consistently high removal of nitrate-N is more complex, because it is primarily transported through groundwater. Nitrate-N removal is impaired during periods of high flow because the mass of nitrate-N entering the wetland as groundwater is likely to increase, the residence time of the nitrate-N in the wetland is likely to be shortened, and other conditions necessary for denitrification are likely to be less favourable.

If maximising nitrate-N removal is a desired feature of a constructed wetland, the surface hydrology and hydrogeology of the proposed wetland construction site should be considered. The design should attempt to maximise water retention time, minimise ingress of groundwater, and the wetland substrate should provide an adequate supply of organic carbon as an energy source for microbial denitrification.

Analysis of standing plant biomass suggested that uptake (“removal”) of dissolved forms of N and P as biomass was relatively minor. Assimilation of N and P in biomass should also be regarded as temporary storage – the assimilated N and P may subsequently be released from dead plant material as a consequence of natural wetland biogeochemical processes.

1 Introduction

In 2015 a multi-cell, surface flow wetland was constructed on a 267ha Lichfield dairy farm, owned and operated by the Baldwin Family Trust. The wetland was designed to remediate runoff from farm laneways, as well as water originating from natural seepage wetlands. After treatment in the constructed wetland complex, water flows into the Ngutuwera Stream which ultimately flows into the Waikato River via the Pokaiwhenua Stream.

The constructed wetland project (comprising design, construction and monitoring phases) was undertaken as a partnership involving DairyNZ, Baldwin Family Trust, Opus International Consultants (Hamilton) and Hill Laboratories, with additional support from Waikato Regional Council and NIWA. Monitoring of the wetland (undertaken by NIWA) was intended to improve knowledge regarding wetland design, performance and management for landowners and other stakeholders. The monitoring component of the case study was intended to estimate the removal efficacy of the wetland for four main contaminants – suspended sediment, nitrogen, phosphorus and faecal indicator bacteria (FIB).

Previously we reported the results from the 2017 drainage year (Sukias et al. 2018). Key findings included:

- Total flow volume through the wetland was approximately 96 500 m^3.
- Annual attenuation of key contaminants (the difference between inflow and outflow mass loads) were approximately:
  - 24 700 kg of total suspended solids
  - 284 kg of TN
  - 104 kg of TP.
- During base flow conditions, concentrations of the faecal indicator bacterium, *E. coli*, were reduced by ~85%.
- During high intensity rain events (when large amounts of faecal matter were mobilised from the laneways), *E. coli* attenuation ranged from 81% up to 99.97% (c. 10,000-fold reduction).
- It was established that groundwater inflow into the constructed wetland was a substantial proportion of total flow volumes during baseflow conditions, available infrastructure allowed only crude estimation of the groundwater component of the total inflow load.

Prior to undertaking a second year of monitoring (the 2019 calendar year), steps were taken to enable groundwater inflows to be more accurately quantified, and the design of the monitoring programme gave greater emphasis to collecting samples over several rain events.

2 The brief for monitoring the 2019 drainage year

NIWA was engaged to deliver the following services through four separate but inter-related contracts:

A. Monitoring of the 2017 drainage year:

- DairyNZ Ref: 2017.064, 13 March 2017 (NIWA project DNZ17202).

B. Monitoring of the 2019 drainage year, including assessment of groundwater contributions to contaminant loads:

- DairyNZ Ref: 2019.105, executed 10 May 2019
- DairyNZ Ref: 2019.105a, executed 4 October 2019 (a variation to above agreement)
- DairyNZ Ref: 2019.0550, executed 19 December 2019.

The work identified in A) above was previously reported (Sukias et al. 2018).

The work identified in B) was intended to provide estimates of wetland performance in a second drainage year, and to better quantify groundwater inflows and associated contaminant loads. Tasks included:

1. Install four piezometers around the wetland cells to intercept incoming groundwater.
2. Continue monitoring surface water inflows and outflow (creating a continuous record from the start of the first drainage year[1]), and measure contaminant concentrations (suspended sediment, nutrients (several forms of N and P) and faecal indicator bacteria) between 1 of October 2019 and 30 of April 2020[2] as follows:
   - Monthly baseflow sampling (up to 11 samples per month for six months, dependent on actual flow conditions):
     - wetland surface water inflows (seepage input and laneway input in this report)
     - four monitoring wells (numbered 1 to 4), and surface outflows from individual wetland cells (five locations – cells numbered 1 to 5) (refer to Figure 1).
   - Sampling between three and five storm events, at four locations:
     - two surface inflows (seepage input and laneway input)
     - two outflows (cell 1 and cell 5)
     - for each event, 10 to 15 samples were to be collected from each location.

[1] All flows occurred in the 2019 calendar year, this we have used the terminology 2019 drainage year for clarity.
[2] Sampling earlier in the year had been conducted under a separate contract.

3. Submit samples to a laboratory for analysis of several water quality variables, including:

    - turbidity
    - total and volatile suspended sediment concentrations
    - total coliform and *E. coli* concentrations
    - total and dissolved reactive phosphorus concentrations
    - total nitrogen, ammoniacal-nitrogen, and nitrate plus nitrite nitrogen concentrations.

4. Measure dissolved oxygen, temperature, electrical conductivity and pH at each sampling location during each baseflow sampling visit using hand-held meters.

5. Utilise drone images of the wetland to assess plant cover, density and species composition on one occasion at the height of the growing season.

6. Analyse the data and report the results of monitoring to the end of April 2020.

7. Organise a half-day workshop involving NIWA researchers and relevant DairyNZ staff to discuss the results of monitoring to date, and to determine whether further monitoring is required.

Results from the second monitoring period would be used to assess the efficacy of contaminant removal, as well as to determine the relative contribution of the groundwater contaminant load. The impact of the groundwater inflow on overall performance of the wetland would also be discussed.

The deliverable from these assessments was described as a "draft addendum that will be added to the latest report summarising results from the additional sampling and discussing the relative contribution of groundwater load and how that affects the overall performance of the Baldwins wetland". It was impractical to meet the reporting requirements through inclusion of an addendum, and a separate report was prepared for the 2019 drainage year.

Following review of the draft report of the second drainage year, DairyNZ requested that the scope of the deliverable be expanded to include a comparison of the results of the two drainage years.

3 Site description

The site was previously described in detail (Sukias et al. 2018). Briefly, the wetland complex was constructed in a valley as a series of five unlined cells separated by earthen bunds (Figure 1). The major surface inflow to the wetland in terms of volume ("seepage input") was itself the drainage from a series of un-monitored wetlands.

The first three cells had smaller surface areas and were slightly deeper than the two downstream cells, with less permanent vegetation cover. These deeper cells functioned primarily as settling ponds. Cells 4 and 5 were shallower, had much larger surface areas and were almost completely vegetated.

Other minor wetland cells were constructed to treat drainage flows downstream of the five-cell constructed wetland – these wetlands were not monitored as part of this programme.

To better estimate groundwater inflows (and associated contaminant loads), four groundwater sampling wells were installed around the edge of the constructed wetland prior to the 2019 drainage year. Detailed descriptions of the wells are provided in Section 4.1.3.

Vegetation of the constructed wetland comprised an assemblage of native species including *Carex virgata* (swamp sedge/pukio), *Juncus pallidus* (giant rush), *Juncus sarophorus* (broom rush), *Cyperus ustulatus* (Giant umbrella sedge), and *Machaerina articulata* (jointed twig rush, previously *Baumea articulata*). Non-native adventive[3] weeds have also established populations in the wetland, including Yorkshire fog (*Holcus lanatus*) and lotus (*Lotus pedunculatus*).

Table 1: Monitored constructed wetland cell areas. Total areas supplied by Opus (MacGibbon 2015).

Wetland cell	Total area (m^2)	Vegetated area (%)	Permanently open water areas (m^2)	Proportion of cell area permanently open water (%)
Cell 1	419	66%	232	55%
Cell 2	367	63%	367	100%
Cell 3	153	50%	153	100%
Cell 4	1 719	90%	158	9%
Cell 5	765	88%	112	15%
Total	3 423	83%	1 022	30%

The primary catchment area for the constructed wetland is 45.9ha of farmland. During rain events, the lower side laneway and side drain (Figure 1) intercept surface runoff from an additional 6.5 ha of farmland, this runoff and runoff generated on the laneway is directed into the wetland via the laneway input (total of 52.4ha) (Sukias et al. 2018). Previously we noted that this laneway input was heavily contaminated with faecal material (Sukias et al. 2018), and was a major source of contaminant load to the wetland.

[3] Adventive = self-introduced.

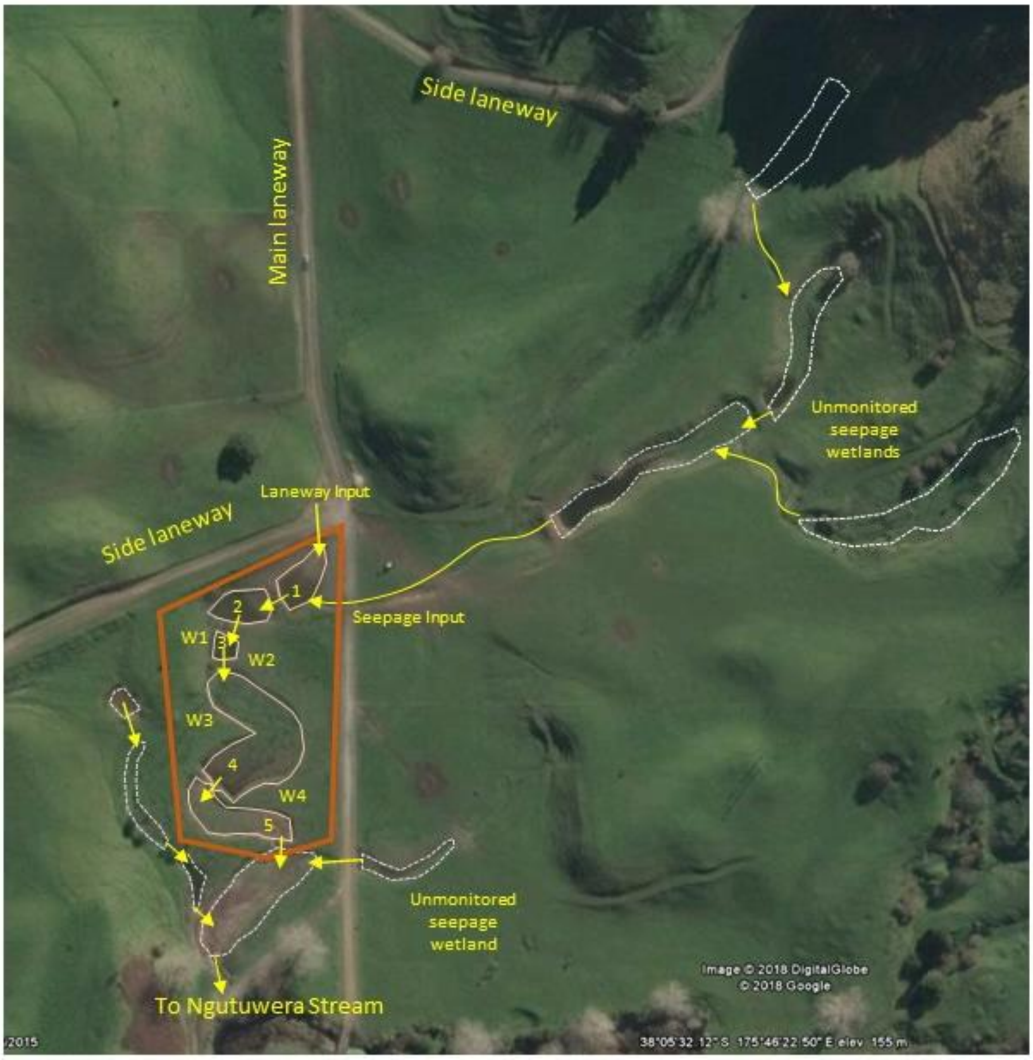


Figure 1: Layout of constructed wetland along with major inlets and outlets. The five monitored constructed wetland cells are defined with pink unbroken lines and have been enclosed within an orange boundary. Unmonitored wetland cells (constructed and natural seepage) are outlined in broken white lines. Laneways that contribute to the laneway input are identified. W1-W4 are the groundwater sampling wells.

4 Methods

4.1 Wetland hydrology and volume measurement

Continuous flow monitoring stations (float and counter weight attached to an encoder housed in a stilling well) were established prior to the 2017 drainage year at the outflow from cell 1, and the outflow of cell 5 (sampling locations 1 and 5 respectively in Figure 1). Flow from the cells exited though standard v-notch weirs. These were described in detail in Sukias et al. (2018). Flow data from cell 1 and cell 5 were used (in part) to create a water balance for the constructed wetland.

Referring to Figure 1 and the schematic in Figure 2, we describe the hydrological and contaminant pathways as follows:

- The flow volumes measured at cell 1 were a combination of inflow from the seepage wetlands (S) and runoff from the laneways (L). Groundwater also enters cell 1 at times, but this could not be separated from the dominant surface water input.
- Rainfall enters the wetland directly during rain events (measured at a nearby electronic weather station (Lichfield EWS), 4 km to the east).
- Evapotranspiration is the combination of evaporation[4] and transpiration[5]; estimates were obtained from the nearest station that measures evapotranspiration (Waikeria EWS, 33 km to the west). Evapotranspiration is negligible during rain events (0-2mm).
- Groundwater enters the wetland continuously across a wide (but unknown) spatial extent, through its base.
- The surface discharge from the wetland complex (C5 discharge) is the nett discharge:

$$Cell\ 5\ discharge = Cell\ 1\ discharge + Rainfall + Groundwater\ inflow - ET$$

Although the seepage inflow was not measured directly, it may be estimated as follows:

$$S = Cell\ 1\ discharge - \ L$$

The laneway inflow was transient, and only occurred during rainfall events. During the 2019 draingae year, bypass flow occurred once. Under baseflow conditions (the bulk of the 2019 drainage year), the laneway inflow was zero, and the seepage inflow was the same as the cell 1 discharge.

As Figure 2 indicates, under very heavy rainfall conditions a minor proportion of the laneway inflow bypassed the monitoring point (L) as well as cell 1, and entered the wetland complex downstream of the cell 1 discharge monitoring point. We describe how the volume of “laneway bypass” flow was estimated in Section 4.3.

[4] Direct water losses from a water surface.
[5] Water losses through plant leaves.

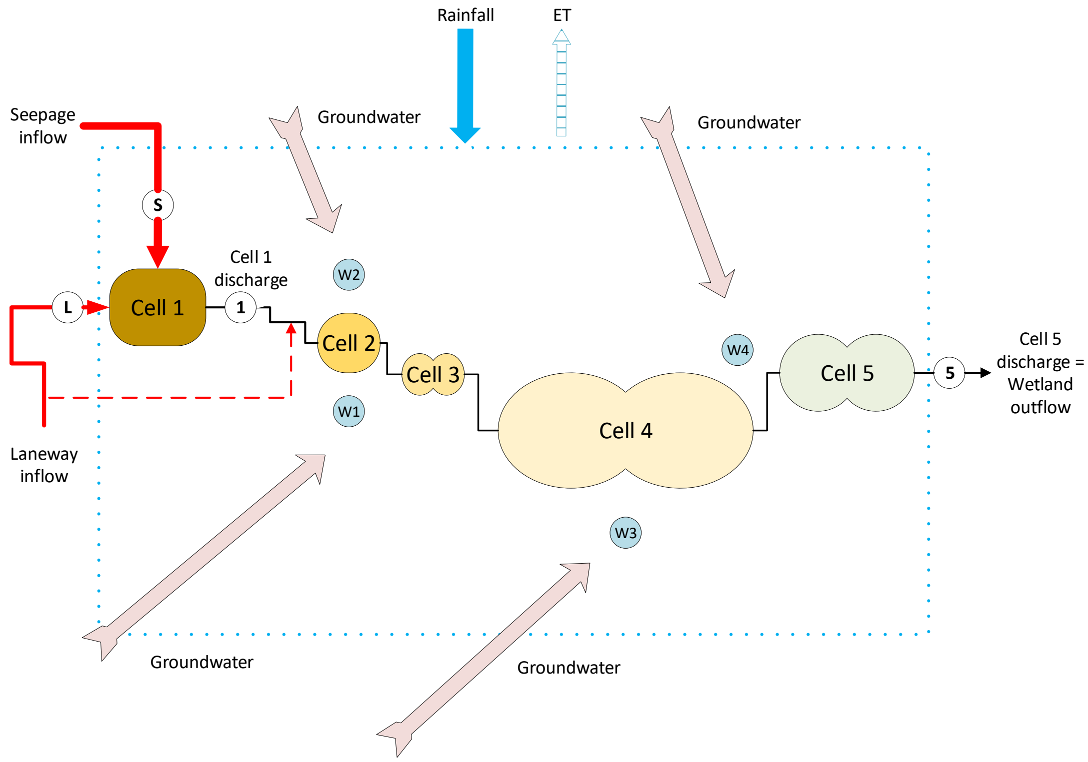


Figure 2: Hydrological and contaminant pathways in Baldwin's wetland complex. The stippled blue line defines the wetland complex. The route followed by runoff from the laneway that bypassed cell 1 is indicated by the broken red line. Groundwater flow (represented by the four groundwater "zones" defined by the four wells) is indicated by the pink arrows. Blue circles labelled W1, W2, W3 and W4 are groundwater monitoring wells. Not to scale.

4.1.1 Surface inflow volume measurement

Discharge (Q) entering wetland cell 1 from the farm laneways (via a culvert, L in Figure 2) was measured using an ES&S PumpPro 6150 at 2-minute intervals. The PumpPro estimates water depth using the hydrostatic pressure of water above a submersed bubbler tube fixed into the base of the culvert. Water depth data was stored on a NEON data logger and telemetered to a web-based data portal via a 3G cell phone network modem. Water depth was converted into discharge using the Manning formula[6] for flow in an open pipe as described by Bengtson (2000)[7] (Eq. 1):

$$Q = (1/n)A(Rh^{2/3})S^{1/2} \qquad \textbf{(1)}$$

Where:

- Q is the volumetric flow rate passing through the channel reach in $m^3 s^{-1}$.
- A is the cross-sectional area of flow normal to the flow direction in m^2.
- S is the bottom slope of the channel in $m m^{-1}$ (dimensionless).
- N is the Manning Roughness coefficient, an empirical constant (dimensionless).

[6] Note: this equation is used when a pipe is less than half full, as it was throughout the monitoring period. An alternative equation for pipes more than half full is available in Bengtson (2000).
[7] A graph of depth versus flow for the laneway input is shown in Appendix A.

- P is the wetted perimeter of the cross-sectional area of flow in m, from which the hydraulic radius (Rh) is calculated; Rh = A/P.

A Manning Roughness coefficient of 0.013 (appropriate for centrifugally spun concrete pipes) was used.

4.1.2 Estimate of laneway inflow when bypass flow was occurring

The seepage inflow is the dominant surface water inflow in terms of volume. During rainfall events, the laneway input becomes significant, as runoff mobilises and transports materials from the laneway into the wetland.

During one high intensity rainfall event, a proportion of the laneway runoff was observed to have bypassed cell 1 and entered the wetland downstream of the cell 1 wetland inflow monitoring point. Estimation of the total volume which would have been present at cell 1 was estimated based on total flows measured at cell 5 during this event, and comparison with a similarly sized event which occurred 11 days later where bypass flow did not occur. In the second event, the discharge volume at cell 1 was 92% of the discharge volume at cell 5 (Table 24). The difference between cell 1 and cell 5 (8%) was the groundwater ingress during this event. We adjusted the inflow during the event when pypass flow occurred so that it was 92% of the cell 5 discharge during the short period when bypass flow occurred. This provided an estimate of the total surface inflow during this “bypass flow event”, allowing total load estimation.

4.1.3 Estimation of groundwater inflow volume

The relative contribution of groundwater from the “groundwater catchment area” to surface water in the wetland was estimated as follows:

A. Under baseflow conditions, total groundwater inflow to the wetland complex was calculated as the difference between flow at cell 1 and cell 5.

B. During rainfall driven events, total groundwater inflow volume to the wetland complex was estimated as the difference in flow volumes between cell 1 and cell 5 minus direct rainfall.

In 2017 it was not possible to determine where the bulk of the groundwater entering the wetland originated, or whether the groundwater source area influenced the mass loads of contaminants entering the wetland complex substantially. To overcome this knowledge gap, four groundwater sampling wells were installed (W1-W4, Figure 1). Well placement was guided by best judgement regarding likely sources of groundwater, using areas with convergent topography as a guide. Each well was 1.7 m deep and located within 5 m of the outer edge of the wetland cell. The final 30 cm length of well casing was slotted (slots 0.5 mm) and covered with a fabric mesh (nominal pore size 0.2 mm) to create a screened section between 1.4 m and 1.7 m below ground level. Each well comprised a 50 mm diameter casing that was installed in an over-sized hole that was backfilled with quartz sand and sealed with bentonite to prevent surface water ingress around the casing. The well casings were covered with a loosely fitting plastic plug to prevent ingress of rain or contaminants.

These four wells were placed around the wetland to intercept and estimate groundwater inflow (relative discharge as well as quality). The relative contribution of the different groundwater flow areas (represented by each well) to the wetland was estimated on two occasions under baseflow conditions using a standard salt dilution technique (Lamontagne et al. 2002, Shafer et al. 2010).

Two litres of salt solution (diluted sea water) with a specific conductance of 5,000 µS cm^{-1} was added to each well, and a pre-calibrated YSI EXO1 data sonde (YSI Incorporated, Yellow Springs, Ohio, USA) was placed in the well to measure specific conductance at 5-minute intervals. Specific conductance was measured as a surrogate of the concentration of inert tracer salts in each well.[8]

The rate at which the salt concentration in the wells decreases is related to dilution and advection of tracer solution out of the well. The rate at which the tracer was diluted in each well was estimated using the method of Piccinini et al. (2016), a simple graphical solution may be used by plotting:

$$ln\left(\frac{C_t}{C_0}\right) vs\ t$$

where:

ln is the natural logarithm, C_t = concentration at time t, C_0 = starting concentration, and t = time.

If dilution of the tracer is caused only by water flowing through the screened section of the well casing (which must be the case for a "sealed" monitoring well), the logarithm of (C_t/C_0) is proportional to the groundwater velocity (Darcy velocity). Groundwater velocity is largest where specific conductance decreases most rapidly.

The total volume of groundwater entering the wetland complex was determined as the difference between the wetland outflow and the measured inflow (after adjusting for precipitation and evapotranspiration). Rainfall was measured at a nearby weather station (~4 km from the wetland). Direct input of surface water from rainfall for the 2019 calendar year was calculated to be 4 250 m^3 (based on wetland area and rainfall data from the Lichfield weather station), after accounting for evapotranspiration[9] (equivalent to a maximum loss of 2 790 m^3), a direct rainfall contribution to surface discharge of 1 460 m^3 was estimated.

We apportioned the total contribution of groundwater under different conditions (A and B above) according to the estimates of relative contribution derived from the four monitoring wells.

We acknowledge that the approach used to estimate the sources and relative contributions of groundwater is uncertain. Ideally, a hydrogeological survey would be undertaken using a larger number of groundwater monitoring wells. Data derived from the drilling, pump testing and subsequent groundwater level monitoring would then be used to construct a groundwater model. The project resources did not allow for a comprehensive approach of this nature. The approach used here provided some indication of the spatial variability of groundwater inflows, and information needed to weight contaminant load in terms of groundwater inflows.

[8] Only 3 wells could be measured during the first experiment as NIWA only had 3 EXO1 sondes which are small enough to fit into the piezometers.

[9] Measured at Waikeria electronic weather station, the nearest location where evapotranspiration (Pennman Potenital Evapo-Transpiration) was measured. This was 33 km from the wetland location. Note evapotranspiration is calculated from open-pan water troughs. As much of the wetland did not have permanent standing water, and for extended periods was completely dry, this estimate is likely to be an overestimate.

4.2 Surface and groundwater sampling

Water quality sampling was undertaken at the outflow of each cell, at each groundwater sampling well, and from the seepage input during "base-flow" periods (if flow was occurring)[10]. During the 2017 sampling campaign (Sukias et al. 2018), values below 3.0 L s^{-1} in the outflow of cell 5 were considered baseflow, and flows above this threshold were associated with rainfall events[11].

Baseflow sampling was intended to be approximately monthly, commencing as surface flow began (typically during May). However, the assessment period was unusually dry, and followed on from a relatively dry 2018 drainage year. Surface inflow to the wetland only commenced in early July 2019. Despite the occurrence of stormflow events between July and October, flow was intermittent, and periods of no flow also occurred during the drainage year. As a result, it was not possible to collect as many baseflow samples as anticipated. To supplement the baseflow record, some samples taken as part of storm event sampling (but collected before the hydrograph started to rise) were used in the baseflow data set. This was possible because "rain event" sampling intentionally bracketed the anticipated period of elevated flow – generally at least one sample was taken before flows started to increase. The start of sampling and interval between samples was decided based on weather forecasts for this region. Any samples taken prior to an event (i.e., before surface flows increased) were considered baseflow samples, and not used to calculate storm event loads.

During baseflow sample collection, temperature, pH and dissolved oxygen concentrations were measured on-site using hand-held water quality meters. Water quality samples were stored in ice-filled containers and returned to the laboratory where they were filtered and then stored frozen prior to analysis. Unfiltered *E. coli* samples were (as far as possible) analysed within 24 h of sampling. Details of water quality variables measured in the field and the laboratory are provided in Appendix B.

Groundwater samples were collected during baseflow sampling as well as prior to rain event sampling.

Event samples were collected using four ISCO programmable autosamplers (Teledyne ISCO, Lincoln Nebraska, USA) according to a fixed sampling interval (estimated according to the anticipated length of each event derived from weather predictions). The four autosamplers collected water samples from the outlet of cell 1 and cell 5, the seepage input and the laneway input (Figure 1).

Surface samples collected using the autosamplers and groundwater samples were analysed in the laboratory for the same set of variables as those collected during manual baseflow sampling. Autosampler samples were collected at the end of each sampled event, which extended for between 1 and 3 days (rainfall intensity- and duration-dependent). While analysis of *E. coli* after periods of prolonged storage (greater than 24 hours) is not ideal, the events occurred during cooler seasons, and the autosamplers were filled with ice to reduce excessive growth or die-off of faecal indicator bacteria (FIB) during storage. In addition, because samples at cell 1 were taken at the same time as those at cell 5, both sets of samples would have experienced the same delay prior to analysis – the relative difference in FIB concentrations would still be informative.

[10] Baseflow is the sustained low-water discharge between rain events. It is sometimes referred to as "fair weather flow" and was sampled during periods of fair weather. The laneway input did not flow during baseflow during this drainage year.

[11] Due to the dry conditions during the 2019 drainage year, some event peaks did not even reach this low value, but were still analysed as events due to the peak in the hydrograph as well as induced runoff from the laneways. In those instances, the period of autosampler "sampling" is considered as event data.

4.3 Estimating wetland complex contaminant inputs and losses

In order to estimate the efficacy of the Baldwin's wetland complex in reducing contaminant fluxes from the farmland to the downstream waterways, it was necessary to calculate the differences between the mass loads of contaminants entering and leaving the wetland complex. A load is the mass of material transported into or out of a treatment device in a time period, and may be expressed in several inter-related ways:

- Flux – (also known as instantaneous load) is the product of discharge and concentration, expressed as mass per unit time (e.g., g s^{-1}). These values may be integrated over a period of time (e.g., a day), to provide a mass per unit time.
- Load – this is the integrated flux of contaminant per unit time, expressed as mass; the period of integration is required, e.g., annual load.

We used a combination of two independent methods to estimate the performance of the wetland complex – the RiverLoad package, which provided annual estimates of surface inflow and outflow loads (Section 4.3.1), and a stratified load estimation method (Section 4.3.2). The stratified load estimation technique was used to calculate groundwater contributions to the total load to the wetland, because RiverLoad measures surface water loads only.

4.3.1 RiverLoad load estimation

RiverLoad includes averaging methods (methods 1–6), ratio estimators (Beale ratio) and regression methods (see Appendix C). Preliminary analysis steps in RiverLoad (which check for a relationship between discharge and concentration) showed that the regression methods were not suitable for the Baldwin's wetland datasets because the discharge-concentration correlations were low ($r<0.3$). Concentration–discharge relationships at Baldwin's wetland varied between events in both wetland inflow and outflow (as indicated in

Figure 3).

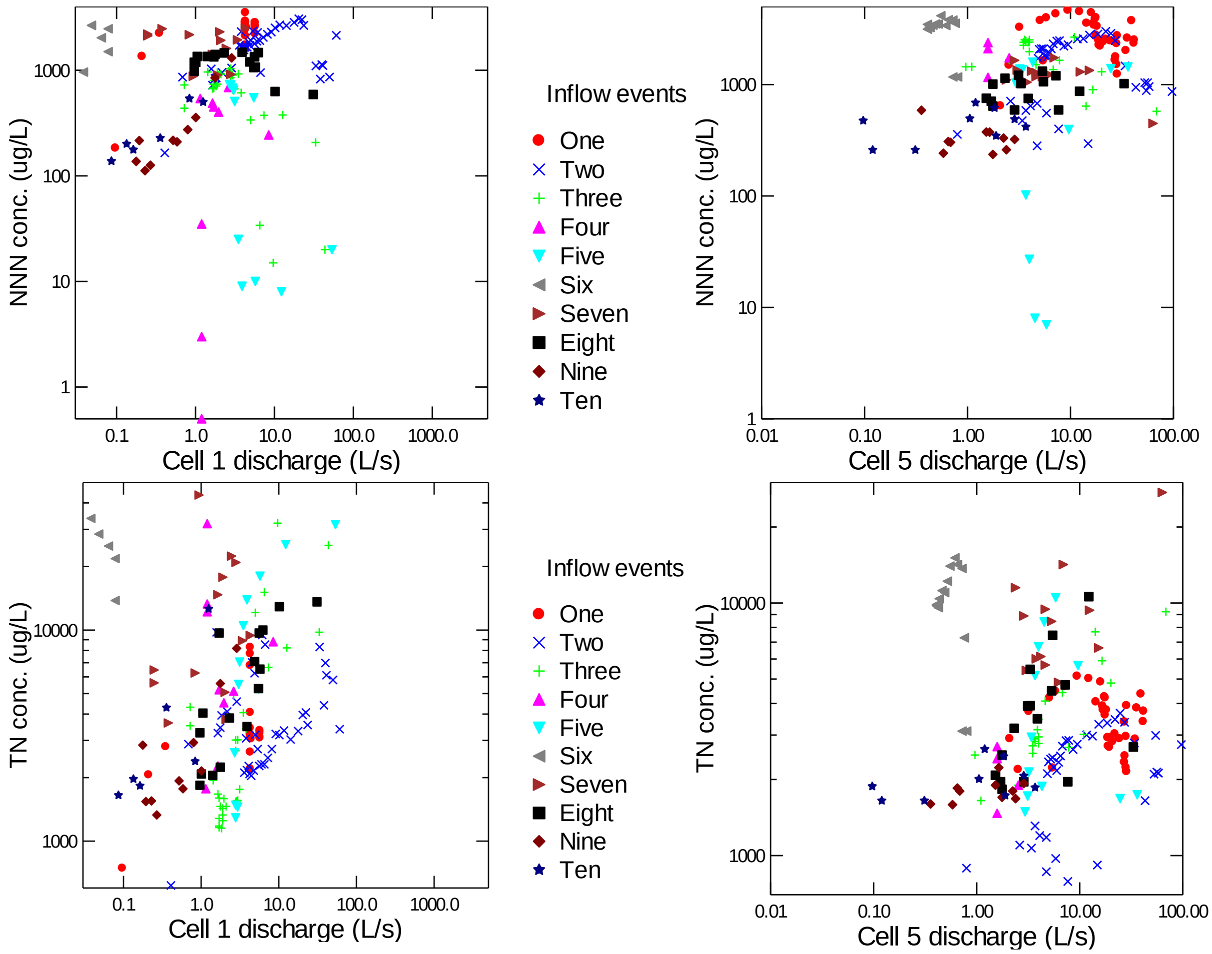


Figure 3: Contaminant concentration and discharge relationships in the Baldwin's wetland complex inflow (left) and outflow (right). These data represent ten separate events during the 2017 and 2019 drainage years. The relationships between nitrate-N and TN concentrations and discharge were highly variable, both within a single event, or between events.

4.3.2 Stratified load estimation method

The stratified load estimation method calculates loads on an event-by-event basis, as well as for intervening baseflow periods. It is described in detail in Appendix D. This has been used to provide the groundwater loads which RiverLoad is unable to calculate.

4.3.3 Estimating the nett removal or release of contaminants during the assessment period

The estimated total annual mass of contaminants in inflow to and outflow from the wetland complex are reported in Section 5.4.2 . The difference between these estimates is the mass retained (or released) by the wetland complex. We summarise the calculation process in Table 2.

Table 2: Contaminant load estimation method.

Wetland inflow		Wetland outflow	
Surface water inflow	**Base flow** mass (plus groundwater load)	Surface water outflow	**Base flow** mass
Surface water inflow	Sum of **event flow** mass for five monitored events (plus groundwater load)	Surface water outflow	Sum of **event flow** mass for five monitored events
Surface water inflow	Sum of estimated **event flow** mass for each of two un-monitored events (plus groundwater)	Surface water outflow	Sum of estimated **event flow** mass for each of two un-monitored events
Groundwater inflow	Sum of estimated mass represented by four **groundwater inflow** zones	Groundwater inflow	N/A
Annual total inflow mass	**Sum of all inflow mass estimates**	**Annual total outflow mass**	**Sum of all outflow mass estimates**

These estimates were used to calculate contaminant removal efficacy in terms of the proportion of inflow mass removed:

$$Contaminant\ removal\ efficacy\ (\%) = \frac{Annual\ inflow\ mass - annual\ outflow\ mass}{Annual\ inflow\ mass} \times 100$$

5 Results

5.1 Weather and drainage flow volumes

Rainfall during the 2019 drainage year[12] (1242 mm) was 87% of the average annual rainfall (1 422 mm) for the period 2000-2019 (Appendix E). Rainfall in the 2019 drainage year was the forth lowest recorded during the 20-year period. The calculated runoff for this period[13] (467 mm) (Figure 4) was the lowest estimated over the 20 years of record.

As a result of generally dry conditions, outflow from the first wetland cell was intermittent between 5 July 2019 and 25 October 2019. The longest period of continuous outflow from cell 1 during this period was 40 days. Discharge occurred from cell 1 over the equivalent of 69.5 days during the 2019 drainage year.

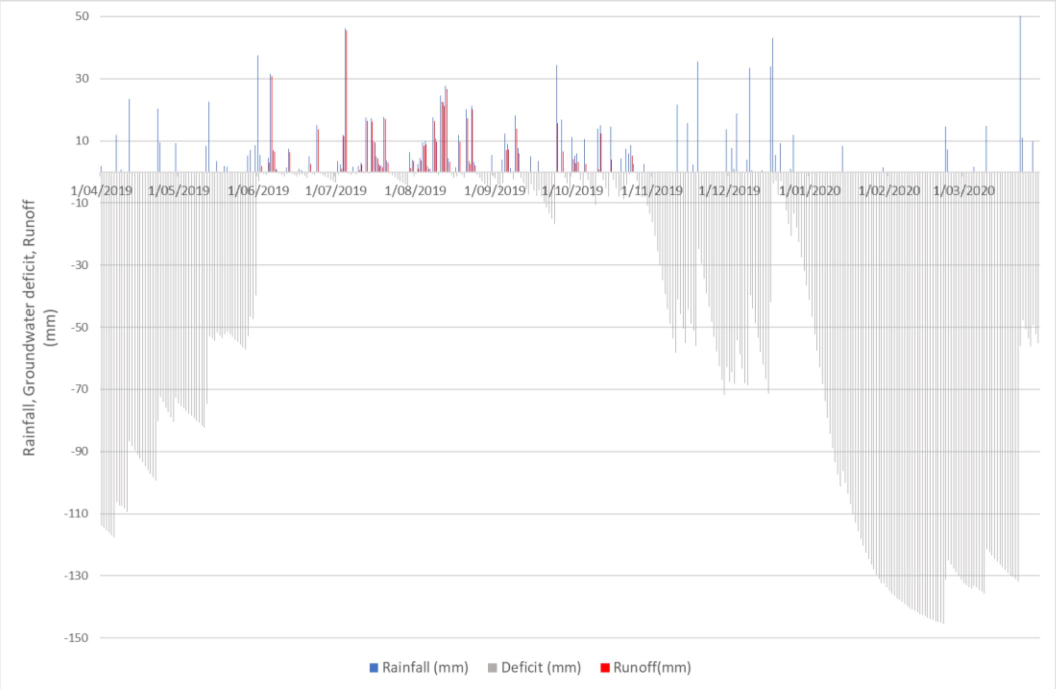


Figure 4: Rainfall, groundwater deficits and runoff at Lichfield EWS weather station. Data retrieved from NIWA national Cliflo database.

Despite the short periods of surface outflow from cell 1, outflow from cell 5 occurred continuously from 10 June 2019 until 31 October 2019 (145 days), maintained by groundwater entering the wetland system downstream of cell 1.

[12] Data recorded at the nearby Lichfield weather station, Lichfield, Scriveners Road , -38.09137 , 175.82343

[13] Runoff is automatically calculated by the electronic weather station using Penman potential evapotranspiration.

Table 3 provides a hydrological balance for the wetland complex.

Table 3: Hydrological balance of the wetland (2019).

Source of water	Volume (m^3)	Comment
Cell 1 discharge	3 900	Direct measurement
Plus groundwater inflow	5 140	Estimated by difference
Plus direct rainfall	4 250	Estimated from remote site
Less estimated evapotranspiration	-2 790	Estimated from remote site
Outflow, Cell 5	2090	Direct measurement

Periods of outflow from cells 1 and 5 are shown in Figure 5.

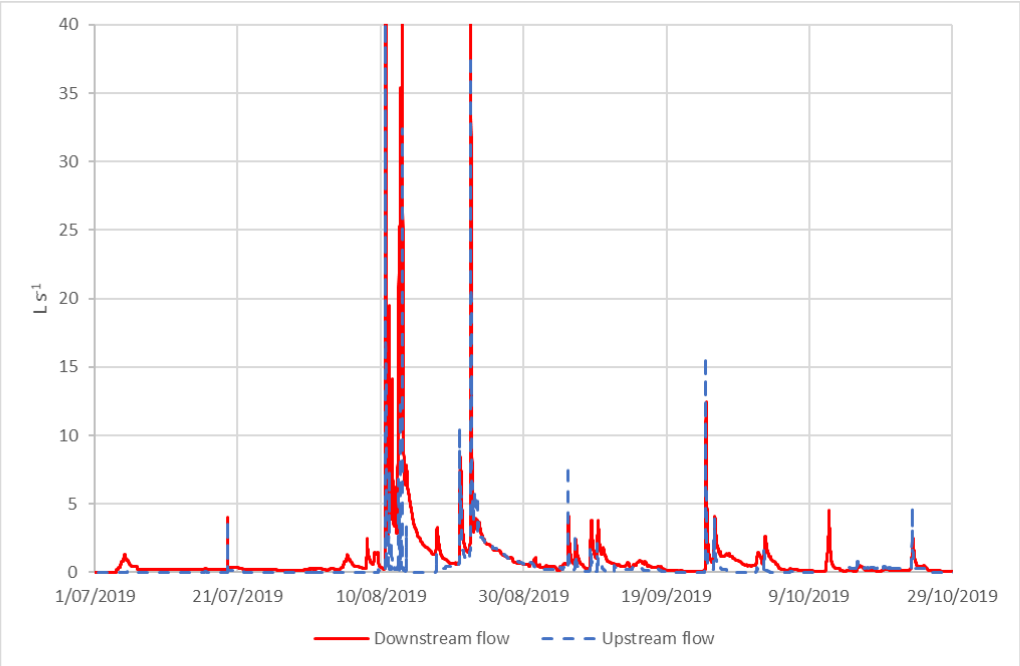


Figure 5: Outflow from cell 1 and cell 5 at the Lichfield constructed wetland. Cell 1 shown with a blue dashed line, cell 5 shown with a red line. Note the y-scale has been limited to 40 L s^{-1} to assist data visualisation, whereas peak flows were 106 L s^{-1}.

The seven rain events which caused outflow from cell 1 had 13 hydrological "peaks"[14]. The duration of rain event associated flows at cell 1 totalled 51.4 hours and at cell 5 totalled 173.1 hours. Average flows for these events were 8.16 L s^{-1} at the outflow of cell 1 and 8.04 L s^{-1} at the outflow of cell 5, with maxima of 97 and 106 L s^{-1} for cell 1 and cell 5, respectively.

Inflow to cell 1 from the farm laneways occurred in short pulses, with the longest period of continuous flow exceeding 17 hrs. The maximum inflow was 17.7 L s^{-1}, with a mean of 2.3 L s^{-1}.

[14] Note that peaks coincide with rain fronts, of which there may be more than one in a rain event.

5.2 Groundwater salt dilution experiments

The decrease in specific conductance in groundwater during the two salt dilution experiments is presented in Figure 10 in Appendix F. Appendix F also demonstrates how the relative contributions from the groundwater flows represented by the four wells were calculated. Based on these experiments, the relative flow contributions of the areas sampled by the four wells to total groundwater volumes were: well 1, 15%; well 2, 33%; well 3, 36%; and well 4, 16%.

We apportioned the groundwater volume represented by each water quality sample (calculated as the difference between cell 5 and cell 1 for this period) to each well using these proportions. These fractions of total groundwater flow volumes were multiplied by the concentration value for the relevant sample to estimate the groundwater load for each water quality variable (described in Section 4.3.3 and calculated in Section 5.3).

5.3 Mass load calculations

Surface water contaminant loads were estimated for the outflow of cell 1 and cell 5 using the RiverLoad software for the full 2019 data period. The estimates derived from the seven methods included in the software may be divided into two categories, differing by approximately an order of magnitude.

Our concentration dataset is biased towards event sampling, which caused Methods 1-3 of RiverLoad to overestimate the load for the monitoring period. For example, Method 1 is the product of the mean sample concentration and the mean discharge at the times samples were taken (3.12 L s^{-1}), and Method 4 uses the mean flow rate for the entire period (0.16 L s^{-1}) in the load estimate. Methods 4–6 and the Beale ratio method provided four reasonably similar load estimates. Method 6 underestimates unsampled events, leading to lower overall estimates than the other suitable methods.

RiverLoad requires both concentration and discharge data – we do not know the groundwater discharge. The RiverLoad methods were only applied to surface water flows. These methods cannot therefore account for the groundwater loads, and all methods (including methods 4–6 and the Beale ratio method) will underestimate the inflow mass of contaminants. Groundwater contributions to contaminant loads were calculated using the stratified load estimation method (detailed in Section 5.4 and Appendix M), and these were added to the cell 1 estimates derived from RiverLoad.

We used the median of four RiverLoad estimates (methods 4–6 plus the Beale ratio method), plus the estimate of groundwater contributions derived from the stratified method as the best estimate of wetland inflow loads, and as a defensible method for estimating load removal. The relative contributions of these sources and losses are summarised in Table 4 - Table 7 for TSS, TN, TP and *E. coli* respectively. These values were used to calculate attenuation efficacy [(Inflow mass – Outflow mass)/Inflow mass x 100 (%)]. Some groundwater samples were obviously contaminated with the bentonite used to seal the wells at the soil surface. Other than those samples, the groundwater had low turbidity and we are confident that groundwater transported negligible amounts of TSS, having passed through the well-consolidated, finely textured loam soils where the wetland was situated.

Load values for other forms of N, and other water quality variables are presented in Appendix C. They are not discussed here because changes in nitrate- or ammoniacal-N loads may represent transformations into other N forms rather than removal processes.

Table 4: RiverLoad estimates of TSS load. "Method" refers to the RiverLoad method identified in Appendix C.

Measurement location	Method	TSS load (kg)	Median load (kg)
Cell 1	Four	2 970	3 940
	Five	4 790	
	Six	3 090	
	Beale	4 980	
Groundwater	Sum of (vol. x conc.) values	0	0
Subtotal inflow			3 640
Cell 5	Four	1 490	1 360
	Five	1 370	
	Six	635	
	Beale	1 350	
Subtotal outflow			1 360
Inflow-outflow			**2 580**
Attenuation efficacy			65%

Table 5: RiverLoad estimates of TN load. "Method" refers to the RiverLoad method identified in Appendix C. The groundwater component is the sum of four components of the total groundwater load, each calculated as the product of the proportions of total groundwater and median groundwater TN concentrations using the stratified method.

Measurement location	Method	TN load (kg)	Median load (kg)
Cell 1	Four	52.7	62.6
	Five	72.5	
	Six	48.0	
	Beale	74.9	
Groundwater	Sum of (vol. x conc.) values	50.8	50.8
Subtotal inflow			113.4
Cell 5	Four	52.6	43.4
	Five	43.6	
	Six	31.7	
	Beale	43.1	
Subtotal outflow			43.4
Inflow-outflow			**70.0**
Attenuation efficacy			62%

Table 6: RiverLoad estimates of TP load. "Method" refers to the RiverLoad method identified in Appendix C. The groundwater component is the sum of four components of the total groundwater load, each calculated as the product of the proportions of total groundwater and median groundwater TP concentrations using the stratified method.

Measurement location	Method	TP load (kg)	Median load (kg)
Cell 1	Four	14.7	18.7
	Five	22.7	
	Six	13.8	
	Beale	23.7	
Groundwater	Sum of (vol. x conc.) values	1.6	1.6
Subtotal inflow			20.3
Cell 5	Four	9.39	7.01
	Five	7.09	
	Six	4.16	
	Beale	6.93	
Subtotal outflow			7.01
Inflow-outflow			**13.3**
Attenuation efficacy			65%

Table 7: RiverLoad estimates of *E. coli* load. "Method" refers to the RiverLoad method identified in Appendix C. The groundwater component is the sum of four components of the total groundwater load, each calculated as the product of the proportions of total groundwater and median groundwater *E. coli* concentrations using the stratified method.

Measurement location	Method	*E. coli* load (MPN)	Median load (MPN)
Cell 1	Four	1.73×10^{13}	3.78×10^{13}
	Five	4.92×10^{13}	
	Six	2.63×10^{13}	
	Beale	5.21×10^{13}	
Groundwater	Sum of (vol. x conc.) values		4.68×10^{10}
Subtotal inflow			3.78×10^{13}
Cell 5	Four	1.09×10^{13}	1.33×10^{13}
	Five	1.57×10^{13}	
	Six	5.78×10^{12}	
	Beale	1.63×10^{13}	
Subtotal outflow			1.33×10^{13}
Inflow-outflow			$\mathbf{2.45 \times 10^{13}}$
Attenuation efficacy			65%

5.4 Stratified load calculations

Seven rain events generated outflow from cell 1 during the 2019 drainage year. Water quality samples were collected during five of these events. We describe the calculation method for one event and one variable in detail and thereafter provide a summary for each event and variable.

In the following subsection, we present the data for the 21-23 August 2019 rain event as an example of how TSS mass loads were calculated. Mass loads for all other contaminants for each event and under baseflow were calculated in the same manner. These have been presented in detail in the appendices for all sampled rain events and periods of baseflow.

5.4.1 21–23 August 2019 rain event

During this event, runoff entered the wetland from the seepage input and laneway input. A timeseries of flows and sample collection time is shown in Figure 6. The full water quality data for this event is shown in Appendix I, with other events presented in detail in Appendix G to Appendix K.

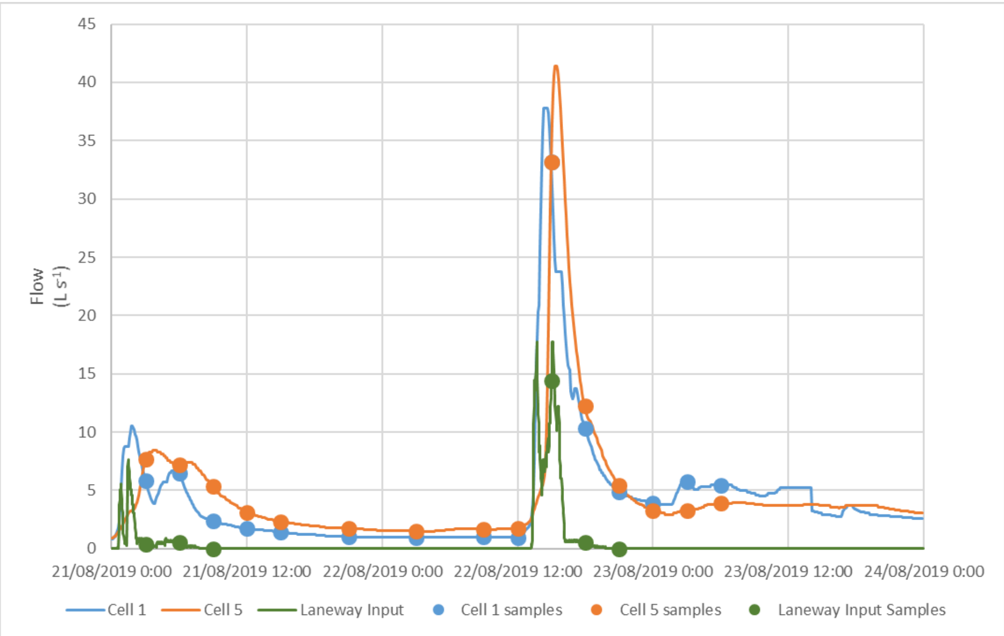


Figure 6: Flow and sample times for 21st – 23rd August 2019.

The following TSS loads were estimated - the laneway (Table 8), the outflow from cell 1 (Table 9), and the outflow from cell 5 (Table 10).

Table 8: **TSS load calculation for laneway input.** The TSS load is the product of volume and concentration, after adjusted for units.

Sample date and time	Volume (m^3)	TSS concentration ($g\ m^{-3}$)	TSS load (kg)
21/08/2019 03:00	21.12	188	3.97
21/08/2019 06:00	4.79	364	1.74
21/08/2019 09:00	1.63	585	0.95
22/08/2019 15:00	58.54	1 700	99.52
22/08/2019 18:00	44.72	775	34.66
22/08/2019 21:00	1.57	405	0.64
Totals	**132**	**–**	**141**

Table 9: **TSS outflow load calculations for cell 1.** The TSS load is the product of volume and concentration, adjusted for units.

Sample date and time	Volume (m^3)	TSS concentration ($g\ m^{-3}$)	TSS load (kg)
21/08/2019 3:00	72.72	380	27.63
21/08/2019 6:00	59.54	296	17.62
21/08/2019 9:00	40.00	80	3.20
21/08/2019 12:00	21.68	14.8	0.32
21/08/2019 15:00	17.04	12.8	0.22
21/08/2019 21:00	25.68	312	8.01
22/08/2019 3:00	21.81	118	2.57
22/08/2019 9:00	21.18	35.2	0.75
22/08/2019 12:00	10.80	16.6	0.18
22/08/2019 15:00	173.75	1120	194.60
22/08/2019 18:00	191.72	660	126.53
22/08/2019 21:00	73.24	368	26.95
23/08/2019 0:00	46.31	124	5.74
23/08/2019 3:00	47.57	422	20.07
23/08/2019 6:00	57.86	156	9.03
Total	**880.9**	**–**	**443**

Table 10: TSS outflow load calculations for cell 5. The TSS load is the product of volume and concentration, adjusted for units.

Sample date and time	Volume (m^3)	TSS concentration ($g\ m^{-3}$)	TSS load (kg)
21/08/2019 3:00	35.47	39.5	1.40
21/08/2019 6:00	85.24	141	12.02
21/08/2019 9:00	72.69	113	8.21
21/08/2019 12:00	43.72	69.7	3.05
21/08/2019 15:00	29.00	54.2	1.57
21/08/2019 21:00	42.62	23.5	1.00
22/08/2019 3:00	34.65	21.2	0.73
22/08/2019 9:00	34.84	22.8	0.79
22/08/2019 12:00	18.27	22.0	0.40
22/08/2019 15:00	69.51	99.0	6.88
22/08/2019 18:00	286.19	493	141.09
22/08/2019 21:00	88.80	240	21.31
23/08/2019 0:00	44.43	118	5.24
23/08/2019 3:00	33.60	70.0	2.35
23/08/2019 6:00	38.86	52.7	2.05
Total	**957.9**	–	**208**

The inflow volume from the laneways was 132 m^3 (Table 8), which occurred in two short pulses (Figure 6). This input contained faecal material and solids, and contributed a TSS load of 141 kg (Table 8), principally inorganic SS (79%) (Appendix I).

The seepage input TSS load (12.2 kg) was much smaller than the laneway load, even though it represented a much greater volume (the volume of the seepage input was the volume at cell 1 minus the laneway input = 749 m^3).

A total volume of 881 m^3 was measured at the outlet of cell 1, which represented a TSS load of 443 kg (Table 9).

At the outlet from cell 5, the TSS load was 208kg (Table 10), a reduction of 235kg (53%) (Table 10).

Table 11: TSS loads through the wetland system. The TSS load is the product of volume and concentration, adjusted for units.

Measurement point	Volume (m^3)	TSS mass (kg)
Laneway	132	141
Plus Seepage	749	12.2
Inflow subtotal	881	153.2
Cell 1 outflow	881	443
Less Cell 5 outflow	958	208
Mass retained in the wetland		**235**
Proportion of TSS mass retained in wetland		53%

The most notable feature of this event is the magnitude of the TSS load discharged from cell 1 (443 kg), which was much larger than the combined input load (approximately 153 kg). Although the reasons for this difference are uncertain, it is very likely that much of the material discharged from cell 1 was remobilised material that had been deposited in cell 1 during previous events[15].

The difference in volume between the cell 5 outflow and cell 1 outflow (77 m^3) was groundwater entering the wetland system. We can ignore the mass flow contribution from groundwater because groundwater generally has very low TSS concentrations. We account for the mass transported into the wetland by the groundwater inflow for other variables.

5.4.2 Combined events and baseflow summary

Loads in the remaining sampled events were estimated using the stratified load method in a similar manner to the event summarised in Section 5.4.1, and the results are summarised on an annual basis for key variables in Table 12-Table 14. Baseflow calculations are presented in Appendix L.

In Section 5.4 we noted that two events were not sampled in the 2019 drainage year. We developed a method to quantify the mass of material transported during non-monitored events based on a relationship between mass of contaminant transported during an event and the total volume of discharge measured during the event. While we rely on RiverLoad estimates between cell 1 and cell 5 for mass loads at these sampling locations, the stratified load estimation method provides values for groundwater inputs that RiverLoad is unable to provide. Details of the method used to estimate the groundwater inputs are provided in Appendix M.

During the 10–12 August event a proportion of flow from the laneway bypassed cell 1 and flowed directly into cell 2, resulting in under-reporting of discharge from cell 1. Failure to correct for this bypass would result in under-reporting of input contaminant loads in surface waters, and potentially result in overestimating the (smaller) groundwater contribution to the wetland load. We describe correction of surface flow volumes for this event in Appendix H.

When runoff from the laneways occurred, contamination with faecal material, detritus and laneway grit was considerable. Nitrogen in this input was largely organic-N along with ammoniacal-N. Nitrate-N was typically a minor component. This input also contributed a large proportion of TP. In contrast, the seepage wetland input much smaller loads of TSS, TN, TP and *E. coli*, despite generally contributing a much larger proportion of the total water volume measured at cell 1. We conclude that the natural seepage wetlands "pre-treat" flow prior to it entering the constructed wetland.

The small 4–5 July event was the first of the year to generate flows out of cell 1, and was atypical in that removals for TSS, TN, TP and *E. coli* were all negative (i.e., greater mass left the wetland than entered it). The proportion of organic fractions of N and P also increased. These characteristics suggest that materials were mobilised from the wetland after the long period of drought. Subsequent events generally resulted in consistent removal of all of these contaminants.

[15] Note: in 2018 it was identified that the capacity of these shallow cells to settle solids was becoming saturated.

We summarise contaminant removal performance of the Baldwin wetland over the entire drainage year for several water quality variables in Table 12 through Table 15.

Table 12: TSS load estimates. Removal efficacy = [(C1 mass-C5 mass)/C1 mass x 100 (%)]. Negative values indicate the wetland was a nett source of contaminant during an event.

Sample class	Event	Peak discharge (L s^{-1})	Total suspended solids (kg)			Removal efficacy (%)
			Cell 1	Cell 5	Cell 1 - Cell 5	
Sampled events	July 4–5 2019	0.8	3.1	7.4	-4.3	-139%
	August 10–12 2019	106	1 199	1007	191.6	16%
	August 21–23 2019	41.4	443.4	208.1	235.3	53%
	September 5–6 2019	4.1	27.0	5.1	22.0	81%
	September 8–9 2019	3.8	9.2	6.3	3.0	33%
Unsampled events	August 12–14 2019	74	908.1	597.3	310.8	34%
	September 9–10 2019	3.8	9.2	6.3	3.0	33%
Mass transported by event flow			**2 599**	**1 838**	**761**	**29%**
Mass transported by baseflow			**259**	**248**	**11**	**4%**
Combined drainage year mass			**2 858**	**2 086**	**772**	**27%**

Table 13: TN load estimates. Removal efficacy = [((C1 mass-C5 mass)/C1 mass x 100 (%)], after accounting for groundwater inputs. Negative values indicate the wetland was a nett source of contaminant during an event.

Sample class	Sampled events	Peak discharge (L s^{-1})	Total nitrogen (kg)					Removal efficacy (%)
			Cell 1	Ground water	Inflow total	Cell 5	Total inflow - Cell 5	
Sampled events	July 4–5 2019	0.8	0.07	0.23	0.30	0.44	-0.14	-47%
	August 10–12 2019	106	19.30	0.65	19.95	18.22	1.73	9%
	August 21–23 2019	41.4	7.91	0.46	8.37	5.74	2.63	31%
	September 5–6 2019	4.1	0.56	0.34	0.90	0.34	0.56	62%
	September 8–9 2019	3.8	0.20	0.66	0.86	0.36	0.50	58%
Un-sampled events	August 12–14 2019	74	14.8	0.66	15.46	11.5	3.96	26%
	September 9–10th 2019	3.8	0.20	0.66	0.86	0.36	0.50	58%
Sum of event flow			**43.0**	**3.7**	**46.7**	**37.0**	**9.7**	**21%**
Baseflow			**6.3**	**46.3**	**52.6**	**19.3**	**33.3**	**63%**
Combined drainage year mass			**49.3**	**50.0**	**99.3**	**56.3**	**43.0**	**43%**

Table 14: TP load estimates. Removal efficacy = [(C1 mass-C5 mass)/C1 mass x 100 (%)], after accounting for groundwater inputs. Negative values indicate the wetland was a nett source of contaminant during an event.

Sample class	Sampled events	Peak discharge (L s^{-1})	Total phosphorus (kg)					Removal efficacy (%)
			Cell 1	Ground water	Inflow total	Cell 5	Total inflow - Cell 5	
Sampled events	July 4–5 2019	0.8	0.022	0.004	0.026	0.069	-0.043	-85%
	August 10–12 2019	106	5.7	0.012	5.7	6.1	-0.4	-5%
	August 21–23 2019	41.4	2.3	0.009	2.3	1.3	1.0	43%
	September 5–6 2019	4.1	0.125	0.012	0.137	0.064	0.073	53%
	September 8t–9 2019	3.8	0.044	0.046	0.090	0.059	0.031	33%
Un-sampled events	August 12–14 2019	74	4.41	0.025	4.44	3.52	0.92	21%
	September 9–10 2019	3.8	0.044	0.046	0.090	0.059	0.031	33%
Sum of event flow			**12.6**	**0.15**	**12.8**	**11.2**	**1.6**	**12%**
Baseflow			**1.6**	**1.4**	**3.0**	**2.7**	**0.3**	**8%**
Combined drainage year mass			**14.2**	**1.6**	**15.8**	**13.9**	**1.9**	**12%**

Table 15: ***E. coli* load estimates.** Removal efficacy = [(C1 mass-C5 mass)/C1 mass x 100 (%)], after accounting for groundwater inputs. Negative values indicate the wetland was a nett source of contaminant during an event.

Sample class	Sampled events	*Escherichia coli* load. (MPN)					Removal efficacy (%)
		Cell 1	Groundwater	Combined inflow	Cell 5	Inflow - Cell 5	
Sampled events	July 4–5 2019	1.94E+10	2.50E+07	1.94E+10	1.02E+11	-8.23E+10	+424%
	August 10–12 2019	7.73E+12	7.06E+07	7.73E+12	6.16E+12	1.57E+12	20%
	August 21–23 2019	6.87E+12	5.07E+07	6.87E+12	5.73E+12	3.83E+12	40%
	September 5–6 2019	2.08E+11	1.13E+08	2.08E+11	8.53E+10	1.23E+11	59%
	September 8–9 2019	3.10E+10	2.02E+08	3.12E+10	1.47E+10	1.65E+10	53%
Unsampled events	August 12 – 14 2019	4.36E+11	3.16E+08	4.36E+11	7.22E+10	3.64E+11	83%
	September 9–10 2019	4.86E+10	1.25E+07	4.86E+10	3.84E+10	1.02E+10	21%
Sum of event flow		**1.53E+13**	**7.89E+08**	**1.53E+13**	**9.83E+12**	**5.51E+12**	**36%**
Baseflow		**2.10E+12**	**4.60E+10**	**2.15E+12**	**3.52E+11**	**1.80E+12**	**84%**
Combined drainage year mass		**1.74E+13**	**4.68E+10**	**1.75E+13**	**1.02E+13**	**7.31E+12**	**42%**

5.5 Comparison of loads estimated with RiverLoad and stratified load estimation methods

Table 16 provides a comparison of load estimates from RiverLoad (Methods 4–6 plus the Beale Ratio) with the stratified load estimation method undertaken on an event by event basis[16].

Table 16: Comparison of annual loads estimated using RiverLoad with values derived from the stratified load estimation method. Median and average values are derived from the four RiverLoad estimates.

	Method	Total suspends solids (kg)	Total-N (kg)	Total-P (kg)	*E. coli* (MPN)
Cell 1	Method 4	2970	52.7	14.7	1.73×10^{13}
	Method 5	4790	72.5	22.7	4.92×10^{13}
	Method 6	3090	48.0	13.8	2.63×10^{13}
	Beale ratio	4980	74.9	23.7	5.21×10^{13}
	Median value	3940	62.6	18.7	3.78×10^{13}
	Average value	3958	62.0	18.7	3.62×10^{13}
	Stratified estimation	2272	56.1	12.7	1.74×10^{13}
Cell 5	Method 4	1490	52.6	9.4	1.09×10^{13}
	Method 5	1370	43.6	7.1	1.57×10^{13}
	Method 6	635	31.7	4.2	5.78×10^{12}
	Beale ratio	1350	43.1	6.9	1.63×10^{13}
	Median value	1360	43.4	7.0	1.33×10^{13}
	Average value	1211	42.8	6.9	1.22×10^{13}
	Stratified estimation	1569	41.2	10.7	1.02×10^{13}

At cell 1, the stratified load estimation gave values that were lower than the RiverLoad estimates for TSS and TP, but within the range of RiverLoad estimates for TN. At cell 5, the stratified load estimate was higher than the RiverLoad range for TSS and TP, but within the range for TN. Although the stratified load estimation method gave a lower wetland removal efficacy (relative to RiverLoad), the difference is relatively small. Figure 7 to Figure 9 present the total mass values in Table 16 graphically. While agreement between these different techniques is not perfect, we note that the variability provided by the RiverLoad estimates is similar or less than the difference between the RiverLoad and the stratified load estimation techniques; this gives confidence that the stratified load estimation technique used primarily for groundwater loads is defensible.

[16] Note that values at cell 1 do not include groundwater contributions to the total load.

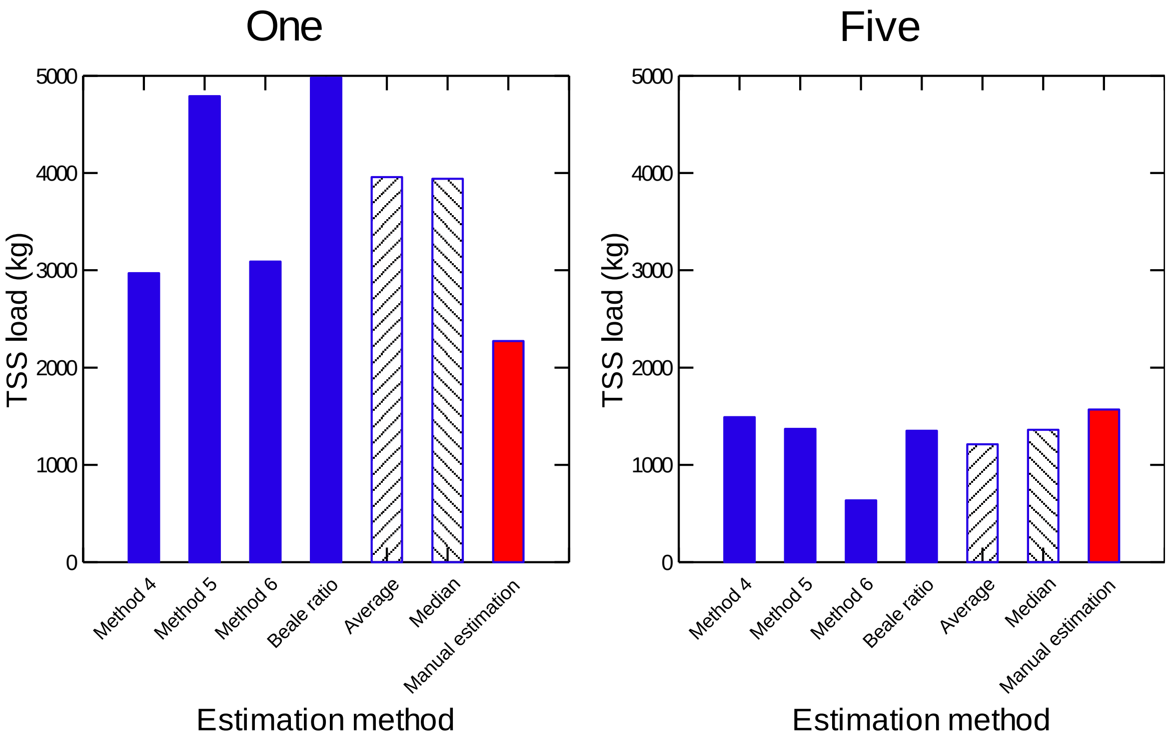


Figure 7: Comparison between the different RiverLoad estimates of TSS load and the stratified estimation method. "One" and "Five" refer to the respective wetland cell outflows.

.

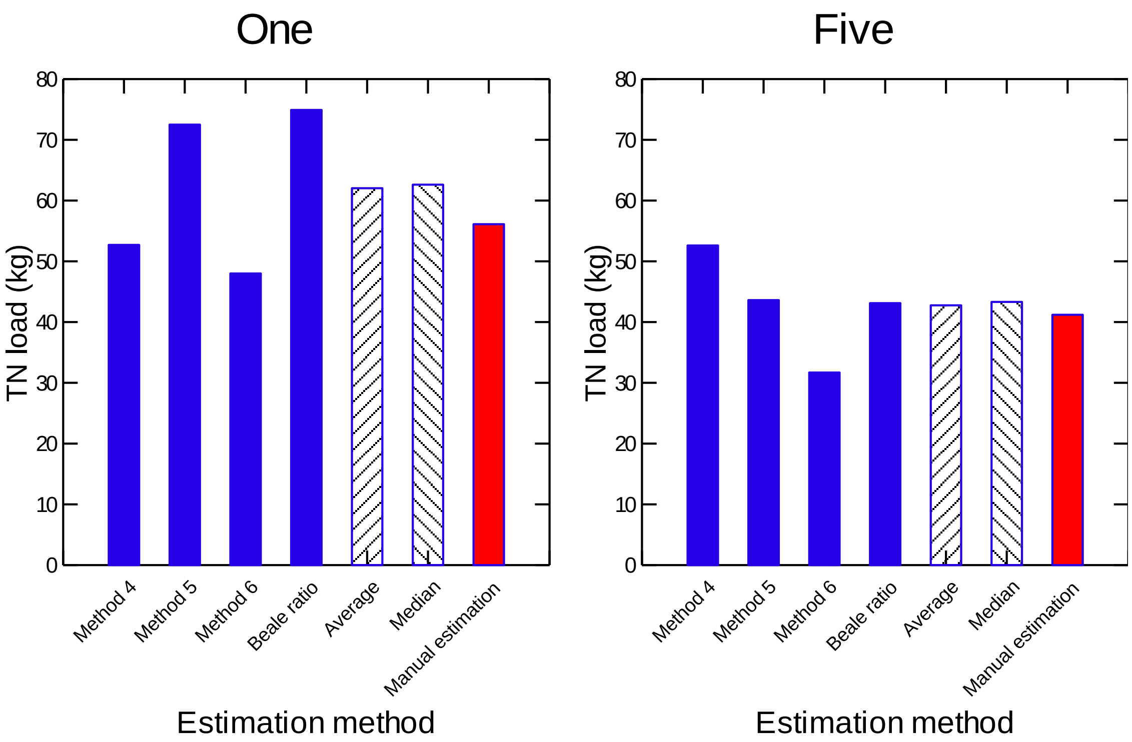


Figure 8: Comparison between the different RiverLoad estimates of TN load and the stratified estimation method. "One" and "Five" refer to the respective wetland cell outflows.

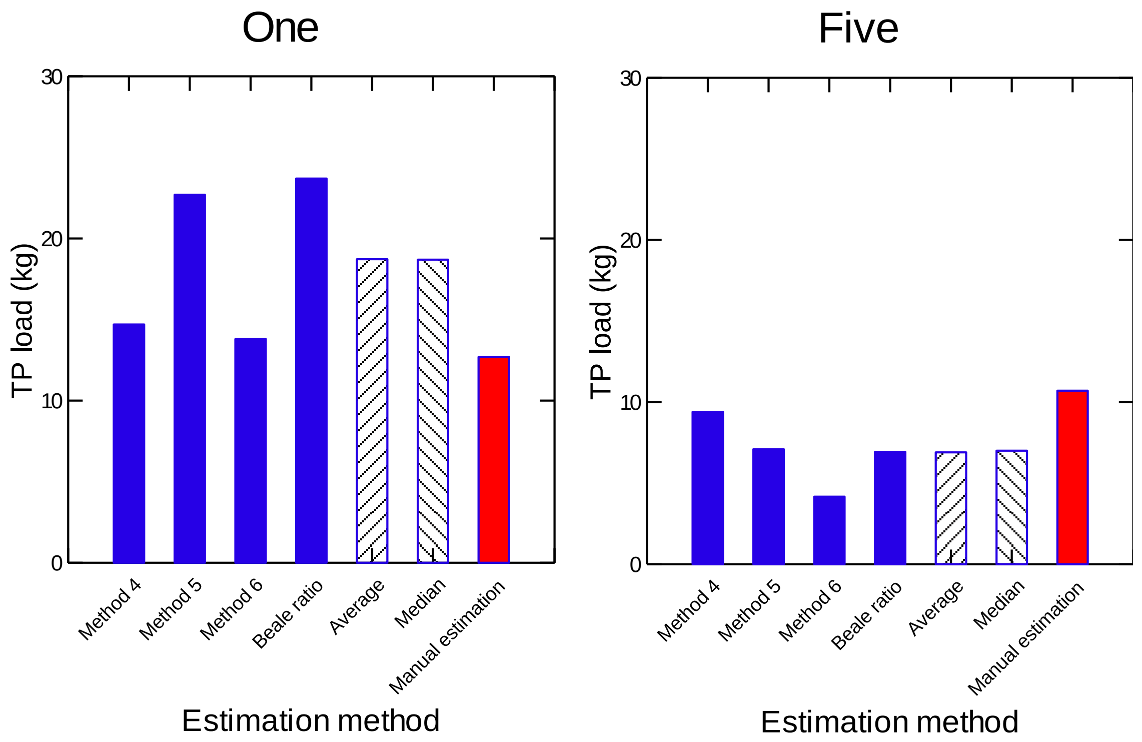


Figure 9: Comparison between the different RiverLoad estimates of TP load and the stratified estimation method. "One" and "Five" refer to the respective wetland cell outflows.

5.6 Comparison of 2017 and 2019 drainage years

We noted previously that hydrological conditions were very different in the two assessment years. Several key characteristics are summarised in Table 17. Estimated annual loads and removal efficacies for 2017 and 2019 are summarised in Table 18.

Table 17: Summary of composition and total nett cell 5 outflow volumes.

No events	2017 water volumes (m^{-3})				No events	2019 water volumes (m^{-3})			
	Surface		Groundwater (+rain – E.T.)	Total		Surface		Groundwater (+rain – E.T.)	Total
	Baseflow	Event				Baseflow	Event		
25	33 520	33 430	29 550	96 500	7	1 380	2 540	6 580	10 500

Table 18: Comparison of estimated annual loads and removal efficacies, 2017 and 2019 drainage years. Negative values indicate the wetland was a nett source of contaminant during a year.

Variable	2017				2019			
	Annual load			Removal efficacy (%)	Annual load (kg)			Removal efficacy (%)
	In	Out	Removal		In	Out	Removal	
Nitrate-N (kg)	86.1	158.6	-72.5	-84%	48.9	15.1	33.8	69%
Ammonia-N (kg)	36.8	8.4	28.4	77%	5.11	2.78	2.33	46%
Organic-N (kg)	446.1	117.9	328.2	74%	51.3	25.4	25.9	50%
TN (kg)	569.0	284.9	284.1	50%	113.4	43.4	70.0	62%
DRP (kg)	8.0	8.4	-0.4	-6%	2.58	1.59	0.99	38%
TP (kg)	122	18	104	85%	20.3	7.0	13.3	66%
TSS (kg)	30 980	6 280	24 700	80%	3 940	1 360	2 580	65%
E. coli (MPN)	1.60×10^{12}	2.44×10^{11}	1.36×10^{12}	85%	3.78×10^{13}	1.33×10^{13}	2.45×10^{13}	65%

6 Discussion

6.1.1 TSS removal

Using annual median estimates (Table 4), the difference between the inflow TSS load (3 940 kg) and outflow load (1 360 kg) was 2 580 kg, or 65% of the inflow load in 2019. Much of the incoming TSS load originated from the laneways, which are recognised as an important source of agricultural contaminants (Monaghan and Smith 2012). The TSS load comprised faecal matter, detritus and laneway grit. The seepage input was relatively uncontaminated, as might be expected in surface waters derived from surface flows and groundwater that had been filtered through the upstream seepage wetlands.

Removal of TSS in the wetland complex was likely to have occurred principally via settling and filtration in the wetland cells. It is likely that deposition in the first three wetland cells was the main removal mechanism. TSS had accumulated in these cells during previous events/years, causing them to become shallower (Sukias et al. 2018). The rainfall events of the 2019 drainage year appear to have resuspended TSS from these cells in some instances. As a result, TSS removal efficacy appears to have decreased from 2017 to 2019. Restoring and maintaining consistent TSS removal will require periodic removal of material deposited in these cells.

6.1.2 TP removal

The median annual TP load at the outlet of cell 1 calculated using RiverLoad was 18.7 kg (Table 6), with an additional groundwater load of 1.6 kg[17], resulting in an annual input load of 20.3 kg. The small input of TP from groundwater relative to surface water inputs contrasts with TN, where groundwater inputs (containing a substantial proportion of nitrate-N) were much more important. Phosphate (a soluble ion with positive charge) readily binds with soil particles, reducing the concentration of dissolved P (which would be present in groundwater). Particulate material that entered the wetland off the raceway during rain events was the major source of P entering the wetland.

The annual median TP load discharged from cell 5 was 7.0 kg, indicating that 13.3 kg (65%) of the inflow load was removed by the wetland. Attenuation of phosphorus occurs by two primary mechanisms: plant uptake of dissolved phosphorus, and adsorption and sedimentation of particulate phosphorus. Gaseous removal under biologically mediated natural systems is unlikely[18]. As was the case with nitrogen, plant uptake by plant biomass is limited, once the maximum biomass has been achieved, further removal is not possible. Plant uptake represented approximately 8% of total annual TP removal in the wetland complex. Sedimentation of particulate phosphorus is likely to occur principally in the first three wetland cells. Increasing sedimentation decreases the volume of water in each wetland cell, which in turn reduces retention time within these cells, unless wetland water volumes are maintained by sediment removal, sedimentation is likely to become a less effective removal mechanism over time, which appears likely from the comparison of removal performance for 2017 and 2019.

[17] As estimated using the event-by-event method.
[18] Gaseous forms of phosphorus such as phosphine and diphosphane, are unlikely to be present in these freshwater environments.

In addition, under certain biogeochemical conditions there is the potential for the wetland to become a source of phosphorus, where the reversibly bound phosphate is released from deposited material. Removal of these solids (and associated P) would enhance long-term phosphorus (and TSS) removal.

6.1.3 TN removal

Using estimated annual median loads, approximately 70 kg of TN was removed by the wetland in 2019, this represented 62% of the incoming load. TN removal occurs via several mechanisms including microbial denitrification, physical filtration, deposition of N-containing detritus, and plant and microbial assimilation of dissolved N (Kadlec and Wallace 2009). Denitrification is likely to be the dominant removal mechanism, because a significant proportion of the incoming nitrogen was in nitrate form. In addition, the wetland has a significant amount of plant leafy debris, which acts as an energy source for denitrifying microbes (Kadlec 2020), large areas of the wetland are inundated for extended periods of the drainage year, and low oxygen conditions are present in the leafy debris – these conditions favour denitrification.

Uptake by plants will be limited by maximum plant biomass. Assessment of plant biomass over time (Appendix N) demonstrated a modest increase in wetland plant biomass (560 kg of dry biomass) since 2017, equivalent to a retention of 8 kg of TN. If this all was attributable to the 2019 drainage year, plant uptake represents 11% of the total annual TN removal.

Accumulation of plant debris (and other forms of organic N) can occur within the wetland, but this should be regarded as temporary storage, rather than complete removal. Some deposited N may subsequently be released to overlying waters under particular biogeochemical conditions.

The monitoring data indicate that input of TN to the wetland via groundwater was principally in nitrate-N form. Approximately equal annual TN loads came from surface and groundwater. However, groundwater inputs were generally more consistent (surface water inflows ceased during summer, and inputs from the laneway were transient during rain events). In addition, relatively small TN loads came from the seepage inflow, this suggests significant denitrification was occurring in the upstream seepage wetland. The form of TN, and the relatively large and more consistent input of nitrate-N in groundwater suggests that maximising removal of nitrate-N in groundwater should be an important design objective for constructed wetlands generally.

6.1.4 Faecal Indicator bacteria removal

During the 2019 monitoring year, the median RiverLoad estimate for inputs to the wetland complex for *E. coli*, was 3.78 x 10^{13} MPN. The laneway input was the largest source of *E. coli* to the wetland complex (Figure 10)[19]. Using the stratified (event-by-event) method of estimating loads, it was clear that events were the major contributor of *E. coli* inputs (86%) compared with baseflow.

The annual *E. coli* load at cell 5 was 1.33 x 10^{13} which indicates an annual removal rate of 65% (Table 18). Using the stratified load estimation method, removal during rain events averaged 36%, compared with 84% under baseflow conditions. Bacteria are particles, and tend to adsorb to and be associated with other particulate material.

[19] As it also was in the 2017 drainage year.

Deposition is an important removal mechanism. The lower removal performance observed during events results from the shortened hydraulic residence time. In addition, there is reduced time during rain events for solar inactivation, waters are more turbid during rain events (limiting light penetration) and solar UV radiation is reduced by cloud cover during rainfall events.

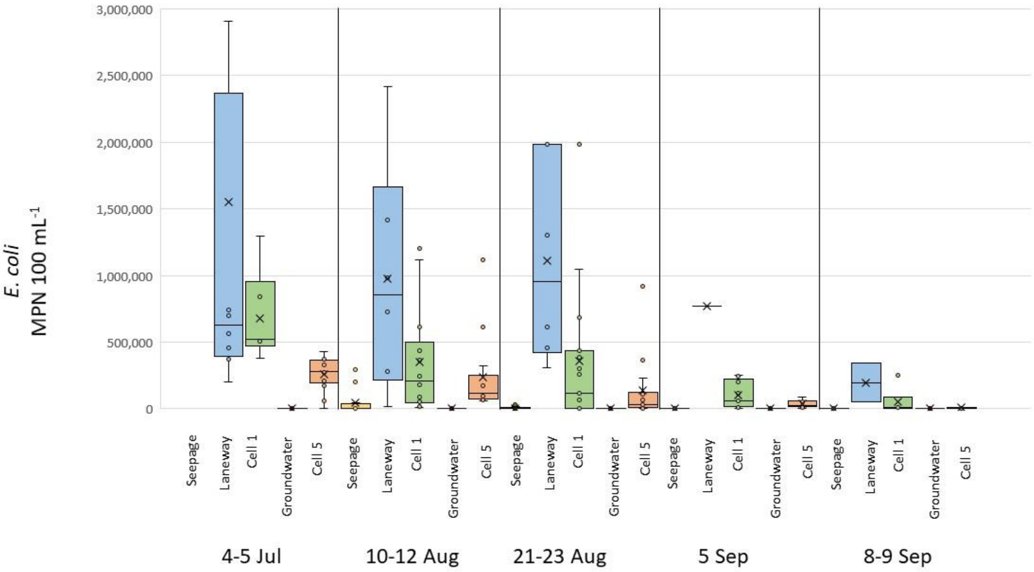


Figure 10: Box plots of *E. coli* concentrations during rainfall events. Average number of samples for seepage input, cell 1 and cell 5 was 10.5. The average number of samples for the laneway input was 5. The average number of samples of groundwater was 4 (one per well). X = average, horizontal line within the box is the median and circles are individual data.

6.2 Comparison of 2017 and 2019 results

In Section 5.6 we compared several characteristics related to flows entering and leaving the wetland. The total volume of drainage in 2017 was approximately 9 times larger than in 2019, and there were almost four times more rainfall events (causing discharge to exceed 3 L s^{-1}) in 2017 than in 2019. In addition, the groundwater input in 2017 was approximately equal to surface inflow, whereas in 2019, groundwater inflow was approximately half (55%) of surface flow, and during several event, the inflow did not even reach the 3.0 L s^{-1} value used to define the threshold between baseflow and event flow in 2017. These differences have a bearing on wetland performance in the two periods.

6.2.1 TSS loads in 2017 and 2019

The hydrology in 2017 was event-dominated, which explains much of the difference in TSS load estimated for the two periods.

Although approximately eight times more sediment entered the wetland complex in 2017 than in 2019, the mass of TSS leaving the wetland was approximately 4.5 times greater in 2017 than in 2019, and the total mass retained within the wetland was approximately 10 times greater in 2017 than in 2019.

The performance of the wetland was better in 2017 (80% removal) than in 2019 (65%). These results indicate that the wetland complex is able to retain TSS over a wide range of hydrological conditions, and that performance may be maintained by managing (reducing) the mass of material trapped within the first cells of the wetland. Performance in 2019 was degraded by one large event which mobilised materials retained from previous events (possibly even the 2017 drainage year), if a proportion of accumulated material was removed from the first wetland cells periodically to maintain a target minimum storage volume, TSS removal could possibly be kept more constant.

6.2.2 Total phosphorus loads in 2017 and 2019

The load of TP is primarily associated with particulate materials, so the factors that determined TSS performance are likely to determine TP removal efficacy as well. The wetland retained a greater proportion of TP in 2017 (85%) than in 2019 (66%), analogous to TSS removal.

6.2.3 Nitrogen loads in 2017 and 2019

Earlier we indicated that the dominant form of nitrogen in the TN load was nitrate-N, which is soluble and unlikely to be influenced appreciably by sedimentation processes. Nitrate-N is primarily transported by groundwater. Although the total volume of water passing through the wetland complex was approximately 9 times greater in 2017 than in 2019, the surface water component was 17 times greater in 2017 than in 2019 (66 950 m^3 and 3 900 m^3 respectively). The volume of groundwater entering the wetland in 2017 was approximately 4.5 times greater than in 2019 (29 550 m^3 and 6 580 m^3 respectively), which substantially increased the nitrate-N load during 2017 relative to 2019. The efficacy of denitrification is dependent on several factors: the mass of nitrate-N in the inflow, the availability of organic carbon, and residence time (time is required for microbially-mediated process to occur). The large volume of water passing through the wetland in 2017 required a generally higher flow, and was likely to have reduced retention times and contributed to the relatively poor performance observed (the wetland appeared to be a nett source of nitrate-N in 2017). Another factor was the uncertain estimate of mass of nitrate-N transported into the wetland complex as groundwater.

In 2019, however, the mass of nitrate-N introduced into the wetland complex as groundwater was better-estimated, the smaller hydrological load allowed longer residence times in the wetland, and the mass of nitrate-N was more likely to be balanced by that of organic carbon; these factors probably contributed to the higher removal efficacy observed in 2019.

6.3 Wetland performance during high flow events

There have been questions from the agricultural sector, regulators and policy-makers regarding the performance (efficacy of contaminant removal) of wetlands that receive a large proportion of incoming loads during brief rain events. These stakeholders have raised the following questions:

- Will attenuation and removal mechanisms be overwhelmed by high water and contaminant inflows?
- What effect will preceding loads have on future performance?
- What can be done to maintain acceptable wetland performance?

Results obtained over two very different drainage years indicate that removal performance of a wetland receiving high TSS loads can remain high, provided the wetland has been designed to facilitate retention of sediments (e.g., by incorporating ponds or basins specifically for the capture of TSS). Wetland designs that assist with maximising TSS removal are likely to improve TN and TP removal efficacies as well. There was evidence of reduced efficacy of attenuation of particulate material during the 2019 drainage season, as well as resuspension of solids previously accumulated during one event. Removal of deposited sediment from sedimentation ponds or basins will help reduce mobilisation of previously deposited particulate material, as well as the discharge of soluble forms of P and N that may be generated from the sediments under favourable biogeochemical conditions.

Removal of nitrate N via denitrification however is reduced during storm events, probably associated with shorter hydraulic retention times, alteration of the balance between dissolved organic carbon and nitrate-N, and cooler temperatures.

The total mass of nutrients stored in above ground plant biomass is small compared with the total nutrient store in the wetland, and thus manual removal of plant biomass (i.e. harvest and removal) is unlikely to substantially improve constructed wetland nutrient removal. In addition, the carbon component of wetland plant material depositied in the wetland represent a vital energy source for denitrification. In addition, a good cover of mature wetland plants reduces the opportunity for invasion of weed species. Thus we do not recommend harvest and removal of wetland plant materials as a nutrient removal strategy.

7 Acknowledgements

We thank the Baldwin family for allowing site access and their ongoing co-operation with this research.

In preparing this report, various NIWA staff have assisted with data analysis. Lucy McKergow estimated contaminant loads using RiverLoad, and Simon Woodward assisted with calculation of the relative contributions of groundwater intercepted by the groundwater monitoring piezometers/wells.

8 References

Bengtson, H.H. (2000) Spreadsheet use for partially full pipe flow calculations.

Hudson, N., Heubeck, S., Baddock, E. (2019) Woodchip denitrification filter - Performance evaluation. Third year of operation, *Client report: 144.*

Kadlec, R.H. (2020) *Treatment marshes for runoff and polishing*. CRC Press, Taylor and Francis Group, Boca Raton.

Kadlec, R.H., Wallace, S.D. (2009) *Treatment wetlands*. CRC Press, Boca Raton.

Lamontagne, S., Dighton, J., Ullman, W. (2002) Estimation of groundwater velocity in riparian zones using point dilution tests, *CSIRO Land and Water Technical report:* 16.

MacGibbon, R. (2015) A3 Gray Baldwin 20150728 Areas.pdf.

Monaghan, R.M., Smith, L.C. (2012) Contaminant losses in overland flow from dairy farm laneways in southern New Zealand. *Agriculture, Ecosystems & Environment*, 159: 170-175. https://doi.org/10.1016/j.agee.2012.07.022

Piccinini, L., Fabbri, P., Pola, M. (2016) Point dilution tests to calculate groundwater velocity: an example in a porous aquifer in northeast Italy. *Hydrological Sciences Journal*, 61(8): 1512-1523. http://dx.doi.org/10.1080/02626667.2015.1036756

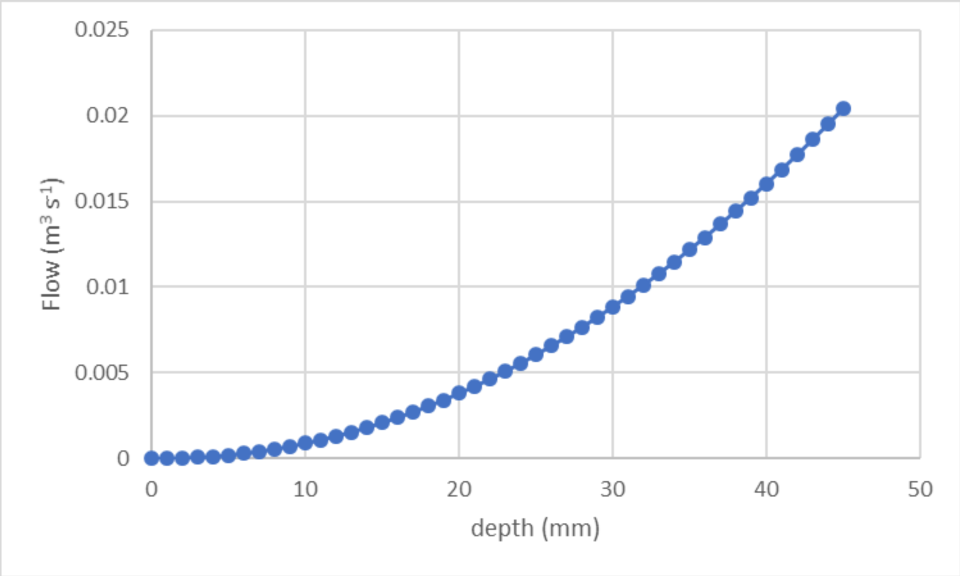
Quilbé, R., Rousseau, A.N., Duchemin, M., Poulin, A., Gangbazo, G., Villeneuve, J.P. (2006) Selecting a calculation method to estimate sediment and nutrient loads in streams: Application to the Beaurivage River (Québec, Canada). *Journal of Hydrology*, 326(1): 295-310. https://doi.org/10.1016/j.jhydrol.2005.11.008

Shafer, J.M., Brantley, D.T., Waddell, M.G. (2010) Variable-density flow and transport simulation of wellbore brine displacement. *Ground Water*, 48 (1): 122–130. doi:10.1111/gwat.2010.48.issue-1

Snelder, T.H., McDowell, R.W., Fraser, C.E. (2017) Estimation of Catchment Nutrient Loads in New Zealand Using Monthly Water Quality Monitoring Data. *JAWRA Journal of the American Water Resources Association*, 53(1): 158-178. 10.1111/1752-1688.12492

Sukias, J., Tanner, C., Montemezzani, V. (2018) Performance of a constructed wetland intercepting run-off from a Lichfield dairy farm, Client report for Dairy NZ: 68.

Appendix A Inflow rate v. water depth for laneway inflow



Appendix B Water quality variables

Table 19: Laboratory and field analyses. Shaded rows indicate on-site measurements using a hand-held water quality meter (TPS Pty Ltd, Brendale, QLD, Australia). The detection limit of microbiological samples is dependent on dilution of sample.

Variables	Method	Detection limit
Temperature	Meter - TPS PTY Ltd, Brendale, QLD, Australia	0.1 °C
pH	Meter - TPS PTY Ltd, Brendale, QLD, Australia	0.01 pH units
Dissolved oxygen	Meter - TPS PTY Ltd, Brendale, QLD, Australia	0.1%
Conductivity	Meter - TPS PTY Ltd, Brendale, QLD, Australia	0.1 µS cm^{-1}
Total coliforms	IDEXX Laboratories Inc Colilert Test Kit, APHA 9223B	1 colony forming unit (cfu) per 100 mL
Escherichia coli (*E. coli*)	IDEXX Laboratories Inc Colilert Test Kit, APHA 9223B	1 colony forming unit (cfu) per 100 mL
Nitrate + nitrite	Filtered sample. Total oxidised nitrogen. Lachat flow injection analyser. APHA 4500-NO3-I 22nd ed. 2012 (modified).	1 mg m^{-3}
Ammonium	Filtered sample. Total oxidised nitrogen. Lachat flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 22nd ed. 2012.	1 mg m^{-3}
Total nitrogen (TN)	Persulphate digest, auto cadmium reduction, Lachat flow injection analyser.	10 mg m^{-3}
Dissolved reactive phosphorus (DRP)	Filtered sample. Total oxidised nitrogen. Lachat flow injection analyser. APHA 4500-P G (modified). 22nd ed. 2012.	1 mg m^{-3}
Total phosphorus (TP)	Persulphate digest, molybdenum blue Lachat flow injection analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012.	1 mg m^{-3}
Total suspended solids (TSS)	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5 µm), gravimetric determination after drying at 104°C. APHA 2540 D 22nd ed. 2012.	0.5 g m^{-3}
Inorganic suspended solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5 µm), gravimetric determination after drying at 104°C followed by furnacing at 400°C. APHA 2540 D 22nd ed. 2012.	1 g m^{-3}
Volatile suspended solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5 µm), gravimetric determination after drying at 104°C followed by furnacing at 400°C. APHA 2540 D 22nd ed. 2012.	1 g m^{-3}
Turbidity	Turbidimeter rated against Formazin standards, APHA2130B	0.1 NTU

Appendix C RiverLoad estimation methods and results

Table 20: Summary of different load estimation methods in the RiverLoad *R* package.

Method	Name	Description	Algorithm	Comments
1	Time-weighted Q and C.	Mean C x mean Q at time of sampling.	$L = K\left(\sum_{i=1}^{n} \frac{C_i}{n}\right)\left(\sum_{i=1}^{n} \frac{Q_i}{n}\right)$	Reported to be precise, but can be biased and underestimate load.
2	Discharge-weighted C.	Mean of instantaneous loads (C_i x Q_i), all concentrations and flows equally weighted.	$L = K\left(\sum_{i=1}^{n} \frac{C_i Q_i}{n}\right)$	Large bias for discrete samples.
3	Mean discharge-weighted C.	Each C_i x mean Q for interval between sample and previous sample.	$L = K' \sum_{i=1}^{n} C_i \overline{Q_{i,i-1}}$	
4	Time-weighted C.	Mean C x mean Q over the period.	$L = K\bar{Q}\left(\sum_{i=1}^{n} \frac{C_i}{n}\right)$	Reported to be precise, but can be biased.
5	Time and discharge weighted.	Weights mean daily load by the mean of all measured flows.	$L = K\frac{\sum_{i=1}^{n} C_i Q_i}{\sum_{i=1}^{n} Q_i}\bar{Q}$	Can result in large variability in load estimates.
6	Linear interpolation of C.	Simple linear interpolation between samples.	$L = K'' \sum_{j=1}^{n} C_j^{int} Q_j$	This method will underestimate unsampled events.
Beale ratio	Beale ratio (with bias correction).	Mean daily load (C x Q on days when samples taken) multiplied by flow ratio (average Q/average Q on sample days). A bias correction factor is included.	$L = Q\frac{\bar{l}}{\bar{q}}\left[\frac{1+\frac{1}{n}\left[\frac{Cov(l,q)}{\bar{l}\,\bar{q}}\right]}{1+\frac{1}{n}\left[\frac{Var(\bar{q})}{\bar{q}^2}\right]}\right]$	Produces robust and statistically unbiased results.

In the algorithms, C_i is the instantaneous sample concentration, Q_i is the instantaneous discharge at time of sampling, n is the number of samples collected, K is a conversion factor to account for measurement units, $\bar{q}$ is the mean flow for times when measured and $\bar{l}$ is the mean load for times when samples were collected.

Table 21: RiverLoad estimations of load at cell 1 and cell 5. All values as kg except *E. coli* which are MPN.

Measure-ment location	Method	TSS	VSS	ISS	DRP	Ammonia-N	Nitrate-N	Organic-N	Total-N	Total-P	*E. coli*
Cell 1	Method 1	57000	11900	45100	39.70	78.20	125.00	807.0	1010.0	281.0	3.32×10^{14}
	Method 2	91800	17400	74400	52.50	107.00	126.00	1160.0	1390.0	436.0	9.43×10^{14}
	Method 3	42800	8440	34300	30.90	54.90	95.80	589.0	740.0	212.0	4.75×10^{14}
	Method 4	2970	620	2350	2.07	4.08	6.49	42.1	52.7	14.7	1.73×10^{13}
	Method 5	4790	905	3880	2.74	5.58	6.56	60.4	72.5	22.7	4.92×10^{13}
	Method 6	3090	649	2440	1.99	4.00	5.33	38.6	48.0	13.8	2.63×10^{13}
	Beale ratio	4980	943	4030	2.83	5.79	6.53	62.6	74.9	23.7	5.21×10^{13}
Cell 5	Method 1	21600	5140	16500	25.4	34.3	228	500	762	136	1.58×10^{14}
	Method 2	19900	4210	15700	23.3	46	219	367	632	103	2.27×10^{14}
	Method 3	19600	4530	15000	23.5	36.7	177	381	594	108	2.03×10^{14}
	Method 4	1490	355	1130	1.75	2.37	15.7	34.5	52.6	9.39	1.09×10^{13}
	Method 5	1370	291	1080	1.60	3.18	15.1	25.3	43.6	7.09	1.57×10^{13}
	Method 6	635	157	479	1.16	1.77	12.9	17.0	31.7	4.16	5.78×10^{12}
	Beale ratio	1350	285	1060	1.58	3.26	15.1	24.8	43.1	6.93	1.63×10^{13}

Appendix D Stratified load estimation method

Estimating the mass of contaminants transported by surface flows

Inflows to the wetland comprise surface inflows (seepage input and laneway input), as well as groundwater inflows. Periods of inflow were arbitrarily separated into baseflow and event flows, depending on whether they were associated with a distinct rain event or not. During the 2019 drainage year, we recognised seven rainfall events which caused elevated inflow and outflow from the wetland complex, during five of which multiple water quality samples were collected using autosamplers. Flows were considered to have returned to baseflow when flows were less than 3 L s^{-1} (or at the termination of autosampler collection when flows during the event did not exceed 3 L s^{-1}). Water samples were not collected during the other two rainfall events. Baseflow samples were collected whenever possible during the drainage year.

During baseflow conditions:

- The accumulated or total volume of surface water was estimated for the inflow (cell 1) and for the outflow (cell 5) for each period defined by baseflow samples (i.e., excluding periods of event flow).
- The volume of groundwater was estimated as the difference in flow volume between the inflow and outflow.
- The volume of water estimated for each period was multiplied by the concentration of the sample at the end of the estimation period to calculate the total mass of contaminant that entered or left the wetland in each flow interval.
- These values were summed to provide the total mass transported into the wetland by the surface flow and groundwater inputs, and the total mass that left the wetland under baseflow conditions.

During monitored rain event conditions:

- Each rain event comprised a measured total volume of water at the inflow and outflow points, as well as direct rainfall.
- Groundwater inputs were calculated as the difference between the outflow volume and the inflow volume combined with direct rainfall.
- The concentration of contaminants that occurred during each event was represented by a series of grab samples collected using autosamplers.
- Each water quality sample represented the volume of water that entered the wetland since the previous water quality sample was collected; the total event therefore comprised multiple discrete volumes of water, each associated with a sample concentration for each variable of concern.
- Multiplying each discrete volume of water by the concentration of the variable of concern in the representative sample provided a series of discrete loads for each contaminant.
- Summing the discrete loads provided the total load of each contaminant during each event, for both the inflow and the outflow.

During non-monitored event conditions:

- Use was made of the strong positive relationship between maximum discharge rate recorded in each monitored event and the total mass transported in each event.
- This relationship was used to estimate the total mass represented by each un-monitored event.

The total mass transported by surface flows was obtained by summing:

- the mass estimated for baseflows
- the mass estimated for monitored events
- the mass estimated for unmonitored events
- This process provided an estimate of the mass transported in surface flow during the entire monitoring period.

Estimating the mass of contaminants transported by groundwater inflows

- In Section 4.1.3 we identified that the total volume of groundwater entering the wetland was the difference between the total measured inflow (including direct rainfall during rain events less evapotranspiration) and the total measured outflow.
- We also indicated how the estimated groundwater flow volume was apportioned between the four inflow “zones” represented by the four monitoring wells.
- Multiplying the total volume for each well or zone by the concentration for each well provided a total mass for each groundwater zone.
- Summing these four groundwater contaminant mass estimates provided an estimate of the total mass of each contaminant for the each event, and for the period of baseflow.

Appendix E Long-term weather record – Lichfield EWS[20]

Table 22: Rainfall, soil moisture deficits and calculated runoff from the Lichfield electronic weather station.

Drainage year	Rainfall (mm)	Soil moisture deficit on 1st April (mm)	Runoff (mm)
2000	1462	122	614
2001	1329	34	562
2002	1418	44	668
2003	1599	82	774
2004	1387	77	687
2005	1523	82	572
2006	1375	8	573
2007	1077	29	520
2008	1629	119	853
2009	1290	90	505
2010	1669	112	819
2011	1568	26	691
2012	1111	58	483
2013	1280	120	601
2014	1220	127	523
2015	1469	102	693
2016	1702	15	827
2017	1756	6	989
2018	1329	43	695
2019	1242	114	467
Arithmetic mean	**1422**	**70**	**656**

[20] EWS – Electronic weather station.

Appendix F Relative groundwater contributions

Specific conductance measured in all wells in both experiments are shown in Figure 11[21]. An exponential decay curve was fitted in Excel. The exponential of the fitted curve is approximately proportional to the Darcy Velocity v_d according to the formula,

$$C_t \approx C_0^{exp\left(-2\alpha v_d \, t/_{\Pi r}\right)}$$

Where C_t is concentration at time t, C_0 is initial concentration, $\boldsymbol{\alpha}$ is a flow field distortion factor[22], v_d is the Darcy velocity, and r is the radius of the piezometer.

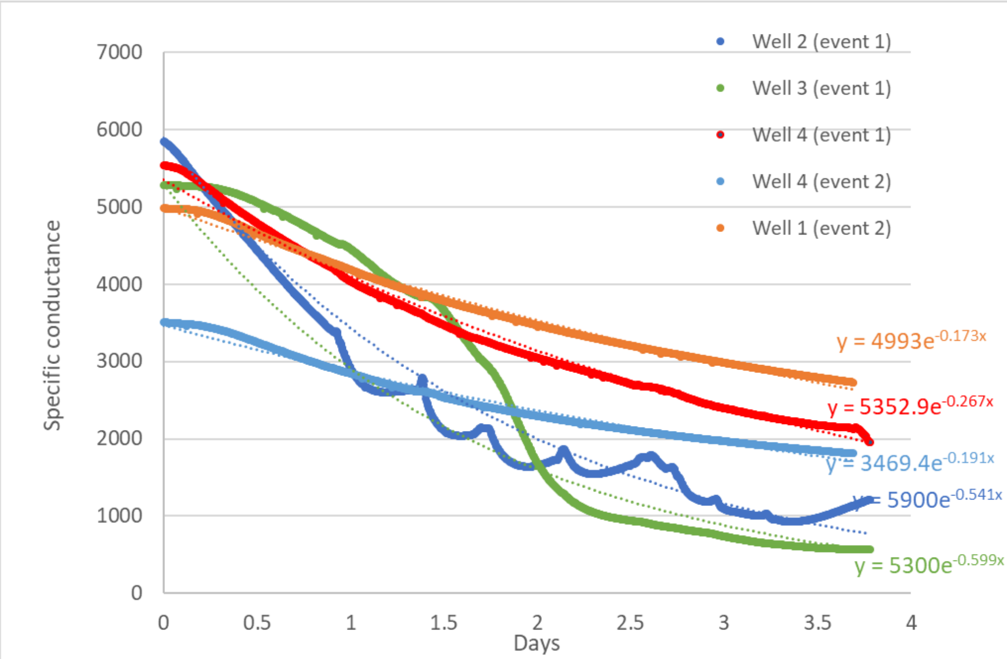


Figure 11: Tracer solution concentrations in both tracer experiments.

The exponents of each curve have been used to determine the relative contribution of each flow path sampled by the groundwater wells/piezometers in the table below. A scaling factor of 1.40 has been applied between experiment 1 and experiment 2 based on the curve exponent for Well 4 (present in both experiments) to allow a scaled exponent for Well 1. The relative contribution from each well has been derived from these values (highlighted). We note that these "relative contribution values" assume that the wells have been placed in representative areas and that the relative inflow rates adequately represent all groundwater inflows to the wetland complex. By using four wells that largely surround the wetland complex, we are satisfied that this approach provides a fair representation of groundwater input locations.

[21] Note that background specific conductance values were low compared with the tracer solution.
[22] For open pipe piezometers, a value of 2 is widely accepted (Piccinini et al. 2016).

Table 23: Curve exponents and derived groundwater contributions. Highlighted values are those from which the relative contribution of each well are taken.

Well	Experiment	Exponent	Scaling for Experiment 2	Relative contribution
2	1	-0.541		33%
3	1	-0.599		36%
4	1	-0.267		16%
4	2	-0.191		
1	2	-0.173	-0.24	15%

Appendix G 4–5 July 2019 event water quality results

This was the first rain event of the 2019 drainage year to cause outflow from cell 1. This rain event lasted 35 hours with a total of 4.3 m^3 inflow to the wetland at cell 1 (Figure 12). Inflow from the farm laneways had a total volume of 3.1 m^3 with an additional 1.2 m^3 of surface flow entered from the seepage input. This small volumetric contribution from the seepage wetlands proved to be atypical of events during this drainage year, and likely reflects the long period of high soil moisture deficits prior to this event. Automatic sampling of this inflow was not possible on this occasion[23], although based on the outflow from cell 1, the seepage outflow must have been very low. Outflow from cell 1 did not exceed 0.1 L s^{-1}, and flow from cell 5 increased from just under 0.2 L s^{-1} to a peak of 0.8 L s^{-1}. Total flow through the wetland during the event was 42 m^3, of which the bulk was derived from groundwater inputs (90%).

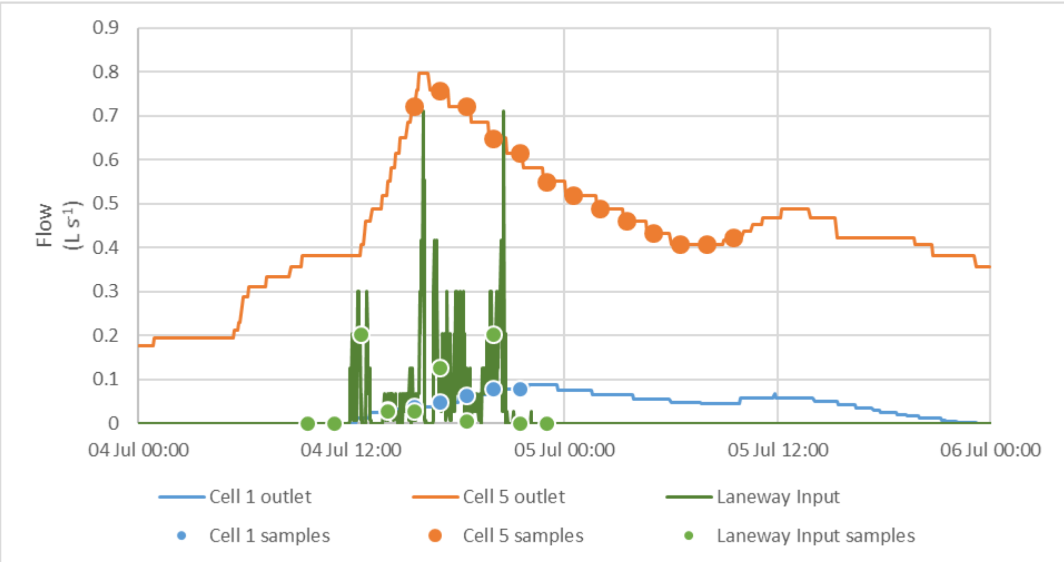


Figure 12: Flows during 4th – 5th July rain event.

Runoff from the farm laneways was highly contaminated, with mass loads of TSS, TN and TP of 7.3 kg, 0.10 kg and 0.03 kg respectively. Groundwater had high concentrations of nitrate in some wells (maximum of 11.8 g m^{-3}) and contributed a further 0.23 kg of TN (mostly as nitrate) to total loads. The contribution to TP was much lower, at 0.004 kg. Some elevated turbidity values were found in the wells[24], but based on sample colour, it was concluded that there was some contamination from the bentonite used to seal the wells, which had only been installed 2 months previously. Bentonite associated turbidity remained an issue throughout the drainage year, thus TSS and turbidity were not analysed for groundwater, which would be expected to contribute little of these contaminants. The groundwater *E. coli* inputs to the wetland were minor, with concentrations ranging from 20 to 175 MPN 100 mL^{-1}.

TSS load reduced to 3.1 kg in cell 1, however by cell 5 it had increased to 7.4 kg, mostly from inorganic solids, suggesting mobilisation of plant debris in the wetland. Total nitrogen increased from 0.33 kg to 0.44 kg (+33%), and total phosphorus increased from 0.035 kg to 0.069 kg (+97%) between the outlet of cell 1 and outlet of cell 5. *E. coli* however showed a 46% reduction in median concentrations.

[23] The sampler hose was positioned too high in the dry "stream bed" prior to flow being present, and the low level of flow never reached the sampler intake.
[24] Repeated emptying of the wells only marginally reduced this contamination.

Laneway Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	**Turbidity**	**Total suspended solids**	**Volatile suspended solids**	**Inorganic suspended solids**	**Total coliforms**	***Escherichia coli***	**Dissolved reactive phosphorus**	**Ammoniacal nitrogen**	**Nitrate nitrogen**	**Organic nitrogen**	**Total nitrogen**	**Total phosphorus**
	$L\ s^{-1}$	NTU	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	MPN 100 mL^{-1}	MPN 100 mL^{-1}	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$
Median	0.030	1360	967	249	718	1,043,000	459,000	1.29	2.08	0.43	23.51	25.70	8.90
Mean	0.089	2039	1889	569	1321	3,348,336	1,208,455	1.57	2.39	0.81	32.13	35.23	11.07
SD	0.088	2137	2132	668	1473	6,981,701	1,909,947	0.49	1.09	0.81	30.14	30.70	9.78
n		8	8	8	8	8	8	8	8	8	8	8	8
Date													
4/07/2019 9:30	0.00												
4/07/2019 11:00	0.00												
4/07/2019 12:30	0.20	7680	7340	2210	5130	3,873,000	2,909,000	2.37	4.78	<0.001	99.22	104.00	32.90
4/07/2019 14:00	0.03	3440	3960	1430	2530	24,191,700	6,488,000	2.19	3.00	0.05	50.95	54.00	16.10
4/07/2019 15:30	0.03	1360	1540	473	1070	1,956,000	738,000	1.84	2.41	0.40	25.99	28.80	10.20
4/07/2019 17:00	0.13	2500	2410	603	1810	1,043,000	563,000	1.28	1.69	0.45	23.56	25.70	9.49
4/07/2019 18:30	0.01	2040	2220	573	1650	960,000	369,000	1.15	1.95	0.29	23.46	25.70	8.30
4/07/2019 20:00	0.20	916	967	249	718	1,076,000	459,000	1.29	1.63	0.73	12.34	14.70	4.07
4/07/2019 21:30	0.00	575	456	145	311	1,515,000	697,000	1.21	1.44	2.35	8.61	12.40	3.57
4/07/2019 23:00	0.00	675	530	197	333	554,000	201,000	1.23	2.20	1.42	12.88	16.50	3.91
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
4/07/2019 9:30	0.000												
4/07/2019 11:00	0.000												
4/07/2019 12:30	0.235		1.73	0.52	1.21	4.61E+09	1.74E+09	0.0006	0.0011	0.0000	0.0234	0.0245	0.0077
4/07/2019 14:00	0.340		1.35	0.49	0.86	3.54E+09	1.91E+09	0.0007	0.0010	0.0000	0.0173	0.0183	0.0055
4/07/2019 15:30	0.232		0.36	0.11	0.25	2.22E+09	8.54E+08	0.0004	0.0006	0.0001	0.0060	0.0067	0.0024
4/07/2019 17:00	0.768		1.85	0.46	1.39	8.26E+09	3.52E+09	0.0010	0.0013	0.0003	0.0181	0.0197	0.0073
4/07/2019 18:30	0.582		1.29	0.33	0.96	8.82E+09	4.06E+09	0.0007	0.0011	0.0002	0.0137	0.0150	0.0048
4/07/2019 20:00	0.457		0.44	0.11	0.33	2.53E+09	9.18E+08	0.0006	0.0007	0.0003	0.0056	0.0067	0.0019
4/07/2019 21:30	0.519		0.24	0.08	0.16	2.44E+09	1.55E+09	0.0006	0.0007	0.0012	0.0045	0.0064	0.0019
4/07/2019 23:00	0.003		0.002	0.001	0.001	1.99E+07	9.81E+06	0.000004	0.000007	0.000005	0.000044	0.000056	0.000013
Total event load			**7.3**	**2.1**	**5.2**	**3.24E+10**	**1.46E+10**	**0.005**	**0.007**	**0.002**	**0.089**	**0.097**	**0.031**

Cell 1 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s^{-1}	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	0.056	203	1070	338	751	1,711,500	520,000	1.34	1.50	0.43	22.39	26.75	8.24
Mean	0.056	185	1294	373	922	1,674,667	676,333	1.33	1.77	1.76	21.70	25.23	7.88
SD	0.020	47	639	164	479	714,654	339,833	0.16	0.81	0.74	6.99	6.89	2.40
n		6	6	6	6	6	6	6	6	6	6	6	6
Date													
4/07/2019 14:00	0.031	225	2090	553	1540	2,224,000	1,296,000	1.44	0.73	0.97	26.80	28.50	9.09
4/07/2019 15:30	0.038	200	2050	573	1480	2,613,000	839,000	1.44	2.91	0.96	29.93	33.80	11.00
4/07/2019 17:00	0.048	133	1160	343	817	1,467,000	504,000	1.52	2.54	2.66	23.30	28.50	9.01
4/07/2019 18:30	0.064	227	980	333	647	1,017,000	520,000	1.22	1.50	2.03	21.47	25.00	7.47
4/07/2019 20:00	0.078	205	980	295	685	1,956,000	520,000	1.23	1.49	1.50	18.81	21.80	6.62
4/07/2019 21:30	0.078	118	505	142	363	771,000	379,000	1.13	1.43	2.47	9.90	13.80	4.07
			(kg)	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
4/07/2019 14:00	0.12		0.25	0.07	0.18	2.64E+09	1.54E+09	0.0002	0.0001	0.0001	0.0032	0.0034	0.0011
4/07/2019 15:30	0.18		0.37	0.10	0.27	4.76E+09	1.53E+09	0.0003	0.0005	0.0002	0.0055	0.0062	0.0020
4/07/2019 17:00	0.22		0.26	0.08	0.18	3.23E+09	1.11E+09	0.0003	0.0006	0.0006	0.0051	0.0063	0.0020
4/07/2019 18:30	0.29		0.28	0.10	0.19	2.93E+09	1.50E+09	0.0004	0.0004	0.0006	0.0062	0.0072	0.0022
4/07/2019 20:00	0.35		0.34	0.10	0.24	6.84E+09	1.82E+09	0.0004	0.0005	0.0005	0.0066	0.0076	0.0023
4/07/2019 21:30	3.14		1.59	0.45	1.14	2.42E+10	1.19E+10	0.0035	0.0045	0.0078	0.0311	0.0433	0.0128
Total event load			**3.09**	**0.89**	**2.20**	**4.46E+10**	**1.94E+10**	**0.005**	**0.007**	**0.010**	**0.058**	**0.074**	**0.022**

Groundwater (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

		Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Well 1		>24,192	74	0.019	0.045	7.560	1.165	8.770	0.190
Well 2		1,722	20	0.063	0.022	11.800	0.878	12.700	0.152
Well 3		4,352	175	0.019	0.029	5.420	0.621	6.070	0.099
Well 4		>24,192	52	0.037	0.039	1.200	1.651	2.890	0.265
	(m^3)	**(total no.)**	**(total no.)**	**(kg)**	**kg)**	**kg)**	**kg)**	**kg)**	**kg)**
Well 1	4.2	1.06E+09	3.12E+06	0.00008	0.00019	0.0319	0.0049	0.037	0.0008
Well 2	9.3	1.60E+08	1.86E+06	0.00058	0.00020	0.1096	0.0082	0.118	0.0014
Well 3	10.1	4.41E+08	1.77E+07	0.00019	0.00029	0.0549	0.0063	0.061	0.0010
Well 4	4.5	1.13E+09	2.34E+06	0.00017	0.00018	0.0054	0.0074	0.013	0.0012
Total event load		**2.80E+09**	**2.50E+07**	**0.0010**	**0.0009**	**0.20**	**0.03**	**0.23**	**0.004**

Cell 5 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	**Turbidity**	**Total suspended solids**	**Volatile suspended solids**	**Inorganic suspended solids**	**Total coliforms**	***Escherichia coli***	**Dissolved reactive phosphorus**	**Ammoniacal nitrogen**	**Nitrate nitrogen**	**Organic nitrogen**	**Total nitrogen**	**Total phosphorus**
	$L\ s^{-1}$	NTU	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	MPN 100 mL^{-1}	MPN 100 mL^{-1}	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$
Median	0.52	173	148	63	85	669,000	281,000	0.34	0.42	3.47	7.03	11.00	1.64
Mean	0.55	191	178	72	106	597,052	262,162	0.33	0.45	3.34	7.08	10.88	1.72
SD	0.13	78	99	38	63	219,595	125,271	0.10	0.20	0.71	2.52	3.24	0.66
n		13	13	13	13	13	13	13	13	13	13	13	13
Date													
4/07/2019 15:30	0.72	28.2	29.8	19.7	10.1	68,670	3,110	0.09	0.02	1.17	1.92	3.11	0.38
4/07/2019 17:00	0.76	130	93.0	30.8	62.2	262,000	63,000	0.35	0.27	3.55	3.46	7.28	0.94
4/07/2019 18:30	0.72	172	370	147	223	789,000	350,000	0.41	0.61	3.79	9.30	13.70	2.47
4/07/2019 20:00	0.65	158	285	117	168	669,000	292,000	0.41	0.62	3.82	9.77	14.20	2.51
4/07/2019 21:30	0.62	173	285	96.5	189	683,000	428,000	0.40	0.64	3.39	11.07	15.10	2.62
4/07/2019 23:00	0.55	153	288	117	171	809,000	374,000	0.49	0.83	4.15	9.02	14.00	2.36
5/07/2019 0:30	0.52	119	190	71.0	119	657,000	275,000	0.37	0.51	3.49	8.20	12.20	1.94
5/07/2019 2:00	0.49	307	163	72.3	90.7	708,000	281,000	0.34	0.47	3.50	7.03	11.00	1.66
5/07/2019 3:30	0.46	288	148	63.2	84.8	620,000	393,000	0.30	0.40	3.41	7.39	11.20	1.64
5/07/2019 5:00	0.43	271	112	62.6	49.4	820,000	328,000	0.29	0.40	3.25	6.75	10.40	1.57
5/07/2019 6:30	0.41	235	100	34.1	65.9	676,000	235,000	0.27	0.37	3.47	6.02	9.86	1.41
5/07/2019 8:00	0.41	234	127	56.8	70.2	471,000	175,000	0.29	0.42	3.14	6.20	9.76	1.44
5/07/2019 9:30	0.42	219	121	42.9	78.1	529,000	211,000	0.28	0.36	3.28	5.95	9.59	1.36
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
4/07/2019 15:30	6.01		0.18	0.12	0.06	4.13E+09	1.87E+08	0.0006	0.0001	0.0070	0.0115	0.0187	0.0023
4/07/2019 17:00	4.17		0.39	0.13	0.26	1.09E+10	2.63E+09	0.0015	0.0011	0.0148	0.0144	0.0303	0.0039
4/07/2019 18:30	3.95		1.46	0.58	0.88	3.12E+10	1.38E+10	0.0016	0.0024	0.0150	0.0368	0.0542	0.0098
4/07/2019 20:00	3.68		1.05	0.43	0.62	2.46E+10	1.07E+10	0.0015	0.0023	0.0141	0.0359	0.0522	0.0092
4/07/2019 21:30	3.41		0.97	0.33	0.64	2.33E+10	1.46E+10	0.0014	0.0022	0.0116	0.0377	0.0515	0.0089
4/07/2019 23:00	3.13		0.90	0.37	0.54	2.53E+10	1.17E+10	0.0015	0.0026	0.0130	0.0282	0.0438	0.0074
5/07/2019 0:30	2.92		0.55	0.21	0.35	1.92E+10	8.02E+09	0.0011	0.0015	0.0102	0.0239	0.0356	0.0057
5/07/2019 2:00	2.78		0.45	0.20	0.25	1.97E+10	7.80E+09	0.0010	0.0013	0.0097	0.0195	0.0305	0.0046
5/07/2019 3:30	2.62		0.39	0.17	0.22	1.62E+10	1.03E+10	0.0008	0.0010	0.0089	0.0193	0.0293	0.0043
5/07/2019 5:00	2.45		0.27	0.15	0.12	2.01E+10	8.03E+09	0.0007	0.0010	0.0080	0.0165	0.0255	0.0038
5/07/2019 6:30	2.29		0.23	0.08	0.15	1.55E+10	5.37E+09	0.0006	0.0008	0.0079	0.0138	0.0225	0.0032
5/07/2019 8:00	2.20		0.28	0.13	0.15	1.04E+10	3.86E+09	0.0006	0.0009	0.0069	0.0137	0.0215	0.0032
5/07/2019 9:30	2.22		0.27	0.10	0.17	1.18E+10	4.69E+09	0.0006	0.0008	0.0073	0.0132	0.0213	0.0030
Total event load			**7.40**	**2.98**	**4.42**	**2.32E+11**	**1.02E+11**	**0.013**	**0.018**	**0.13**	**0.28**	**0.44**	**0.069**
Change (all inflows minus outflow)(kg)			**0.14**	**0.88**	**-0.74**	**1.85E+11**	**8.23E+10**	**0.007**	**-0.015**	**-3.221**	**-0.717**	**0.047**	**0.032**
Change (% of inflow mass)			**2%**	**42%**	**-14%**	**390%**	**424%**	**126%**	**-45%**	**-96%**	**-72%**	**12%**	**85%**

Appendix H 10–12 August 2019 event water quality results

Flow for this event is shown in Figure 13. As noted in the results section there was evidence of runoff entering cell 1 and 2 from the lower east-west laneway (Figure 14). Without correction, this would result in an excessive volume being calculated as groundwater inputs[25]. The relative amounts of flow typically seen at cell 1 compared with cell 5 from this and subsequent events is presented in Table 24 to assist estimation likely flows at cell 1.0. In each instance (excluding this event) groundwater contributed less than 200 m^3 to flow at the outlet of cell 5, whereas the groundwater inputs calculated for the August 10–12 2019 event would be 626 m^3 (without correction). Of particular note is the subsequent event (August 21–23 2019) to this one, which occurred less than 10 days later and which had a similar overall volume. In that instance, the total volume exiting cell 1 was 92% of the total volume measured at the outlet of cell 5. Using this ratio of flow would mean that groundwater inputs during the August 10–12 2019 event should have been closer to 106 m^3 if flows had not been bypassing cell 1. Consequently, we have estimated that the total volume exiting cell 1 was 1 211 m^3, which has been allocated on a pro rata basis of measured flows exiting cell 1.

Table 24: Event volumes used to allow estimation of amount which bypassed cell 1.

Event	Cell 1 volume (m^3)	Cell 5 volume (m^3)	Groundwater + rainfall volume (m^3)	Cell 1 as % of Cell 5
4/07/2019	4.3	41.8	34.4	10%
10/08/2019	691	1317	626	52%
10/08/2019 Modified	1211	1317	106	92%
21/08/2019	881	958	77	92%
5/09/2019	113	188	75	60%
8/09/2019	36	166	130	22%

As observed in the July event, the laneway input was highly turbid (median of 1,445 NTU), with high TSS concentrations (median of 1 845 g m^{-3}), mostly as inorganic particulates (78%). The median TN concentration was 26 g m^{-3}, while the median TP concentration was 8.86 g m^{-3}. The median *E. coli* concentration was 853,700 MPN 100 ml^{-1}, indicating significant mobilisation of faecal material from the farm laneways.

In comparison, the seepage input had a low TSS median concentration 12 g m^{-3}, of which 9 g m^{-3} was inorganic (c. 75%). The median TN concentration of the seepage input was 3.4 g m^{-3}, mostly as nitrate-N (2.0 g m^{-3} or 59%), while the median TP concentration was 0.121 g m^{-3}. The median *E. coli* concentration of this input was 4,352 MPN 100 mL^{-1}.

Median contaminant values in flow exiting Cell 1 were intermediate between the seepage and laneways inputs with a TSS load of 1 199 kg, a TN load of 19.3 kg and a TP load of 5.74 kg. The median *E. coli* concentration was 210,209 MPN 100 mL^{-1}.

The groundwater TN load was 0.65 kg of which 0.57 kg (or 88% of TN) was nitrate-N, while the TP load was 0.012 kg, of which 0.003 kg was DRP (24%). Thus, in combination with the load at Cell 1, total inflow loads during this event were 1 199 kg of TSS, 20.0 kg of TN and 5.76 kg of TP.

[25] Groundwater volumes are relatively conservative during events compared with surface water inputs. Thus, by using a conservative estimate of the groundwater component of flow volume at cell 5, the flow at cell 1 can be calculated.

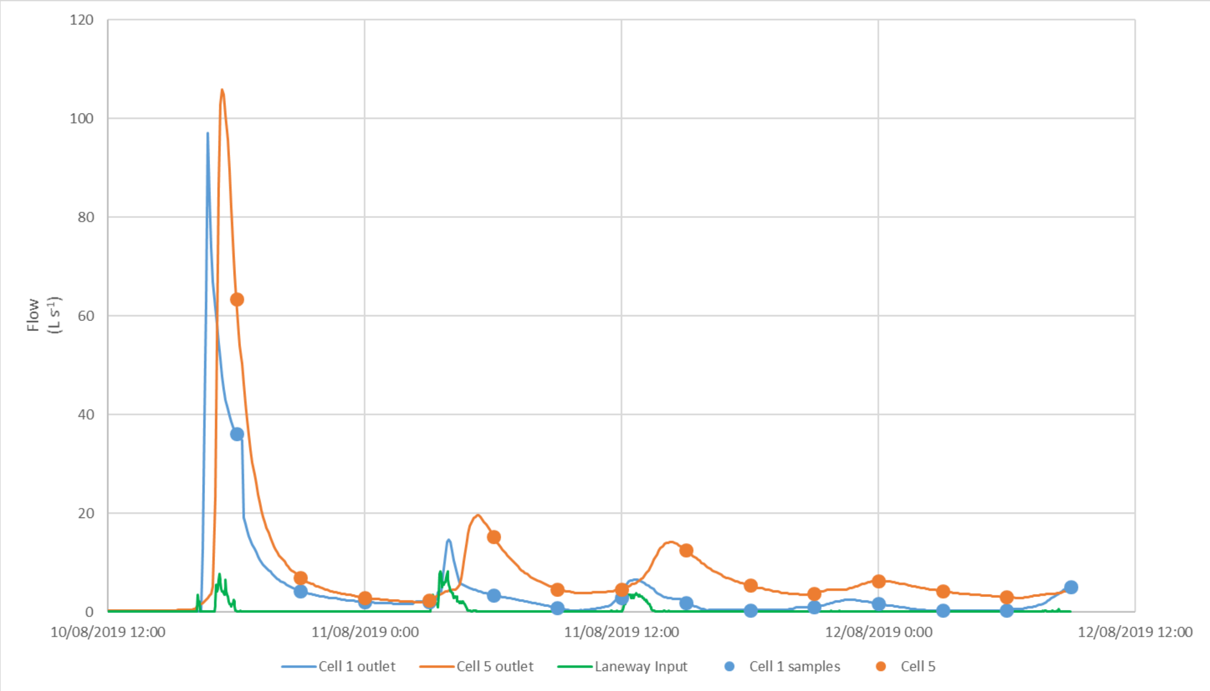


Figure 13: Flows and sample times during August 10th – 12th 2019 event.

Load reductions in the wetland were 192 kg (16% reduction) for TSS, 0.56 kg (9% reduction) for TN, whereas there was a 0.07 kg increase (5% increase) calculated for TP. *E. coli* showed a reduction of 53% based on concentrations.

Figure 14: Contaminated flow running off east-west farm laneway and directly into cells 1 and 2. Photograph taken 13/8/19, the day after the main rain event.

Seepage Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m3) or total numbers (bacteria))

	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	10	12	3	9	17,329	4,352	0.047	0.0197	2.020	0.868	3.410	0.121
Mean	262	332	42	290	598,811	46,549	0.083	0.231	2.038	3.072	5.342	1.170
SD	698	912	110	803	1,084,271	90,819	0.084	0.167	0.413	6.857	6.716	3.411
n	13	13	13	13	13	13	13	13	13	13	13	13
Date												
10/08/2019 18:00	70.5	83.5	18.3	65.2	>2,419,200	290,900	0.105	0.512	1.550	1.518	3.580	0.389
10/08/2019 21:00	9.0	11.7	2.4	9.3	17,329	4,106	0.052	0.299	1.750	0.861	2.910	0.126
11/08/2019 0:00	10.1	14.4	3.1	11.3	12,033	3,873	0.047	0.210	1.900	0.810	2.920	0.121
11/08/2019 3:00	2540	3330	403	2930	>2,419,200	198,628	0.339	0.637	1.160	25.803	27.600	12.500
11/08/2019 6:00	93.4	184	25.7	158	>2,419,200	15,530	0.081	0.242	1.950	1.528	3.720	0.324
11/08/2019 9:00	6.3	9.6	3.1	6.5	12,997	4,352	0.041	0.203	2.020	0.807	3.030	0.101
11/08/2019 12:00	138	125	23.7	101	72,700	28,510	0.085	0.197	1.830	1.533	3.560	0.352
11/08/2019 15:00	11.2	9.6	1.9	7.7	15,531	6,867	0.044	0.163	2.120	0.917	3.200	0.117
11/08/2019 18:00	5.5	5.3	1.2	4.1	9,208	2,489	0.036	0.110	2.420	0.810	3.340	0.086
11/08/2019 21:00	500	520	57.1	463	111,985	43,520	0.148	0.161	2.260	2.939	5.360	0.824
12/08/2019 0:00	10.4	8.6	1.3	7.3	17,329	3,654	0.036	0.092	2.480	0.868	3.440	0.098
12/08/2019 3:00	5.2	5.4	3.1	2.3	7,270	1,313	0.037	0.096	2.530	0.784	3.410	0.089
12/08/2019 6:00	4.1	3.6	1.9	1.7	8,164	1,396	0.031	0.085	2.530	0.755	3.370	0.078
		(kg)	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
10/08/2019 18:00		44.29	9.71	34.58	1.33E+13	1.54E+12	0.056	0.272	0.822	0.805	1.899	0.206
10/08/2019 21:00		2.47	0.51	1.96	3.65E+10	8.66E+09	0.011	0.063	0.369	0.182	0.614	0.027
11/08/2019 0:00		0.78	0.17	0.61	6.53E+09	2.10E+09	0.003	0.011	0.103	0.044	0.158	0.007
11/08/2019 3:00		115.14	13.93	101.31	8.64E+11	6.87E+10	0.012	0.022	0.040	0.892	0.954	0.432
11/08/2019 6:00		16.35	2.28	14.04	2.22E+12	1.38E+10	0.007	0.022	0.173	0.136	0.331	0.029
11/08/2019 9:00		0.38	0.12	0.26	5.15E+09	1.72E+09	0.002	0.008	0.080	0.032	0.120	0.004
11/08/2019 12:00		2.12	0.40	1.71	1.23E+10	4.82E+09	0.001	0.003	0.031	0.026	0.060	0.006
11/08/2019 15:00		0.66	0.13	0.53	1.06E+10	4.70E+09	0.003	0.011	0.145	0.063	0.219	0.008
11/08/2019 18:00		0.06	0.01	0.05	1.04E+09	2.82E+08	0.000	0.001	0.027	0.009	0.038	0.001
11/08/2019 21:00		5.81	0.64	5.18	1.25E+10	4.86E+09	0.002	0.002	0.025	0.033	0.060	0.009
12/08/2019 0:00		0.31	0.05	0.27	6.33E+09	1.34E+09	0.001	0.003	0.091	0.032	0.126	0.004
12/08/2019 3:00		0.08	0.04	0.03	1.04E+09	1.88E+08	0.001	0.001	0.036	0.011	0.049	0.001
12/08/2019 6:00		0.16	0.08	0.08	3.61E+09	6.18E+08	0.001	0.004	0.112	0.033	0.149	0.003
Load		**189**	**28**	**161**	**1.64E+13**	**1.65E+12**	**0.10**	**0.42**	**2.06**	**2.30**	**4.78**	**0.74**

Laneway Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	1,445	1,845	375	1,435	1,699,940	853,700	1.2	2.5	0.5	23.1	26.0	8.9
Mean	1,790	2,093	418	1,676	1,554,075	973,489	1.3	3.3	0.5	27.6	31.4	10.9
SD	1,024	1,286	277	1,015	950,460	864,127	0.5	2.1	0.5	18.5	20.3	6.5
n	6	6	6	6	6	6	6	6	6	6	6	6
Date												
10/08/2019 18:00	1,660	2,450	462	1,990	1,986,280	980,400	0.871	2.31	0.571	26.319	29.2	9.82
11/08/2019 6:00	1,070	1,150	157	993	>24,192	19,863	0.888	1.72	1.35	14.13	17.2	5.74
11/08/2019 12:00	1,990	2,320	533	1,790	2,419,170	1,413,600	1.4	3.2	0.034	21.566	24.8	7.9
11/08/2019 15:00	1,050	890	178	712	980,400	280,900	1.22	2.78	0.605	15.115	18.5	5.63
12/08/2019 0:00	1,230	1,370	287	1,080	1,413,600	727,000	1.25	2.29	0.361	24.549	27.2	13.8
12/08/2019 12:00	3,740	4,380	893	3,490	>2,419,200	2,419,170	2.23	7.53	0.036	64.134	71.7	22.7
		(kg)	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
10/08/2019 18:00		32.77	6.18	26.62	2.66E+11	1.31E+11	0.012	0.031	0.008	0.352	0.391	0.131
11/08/2019 6:00		25.92	3.54	22.38	5.64E+09	4.48E+09	0.020	0.039	0.030	0.318	0.388	0.129
11/08/2019 12:00		0.55	0.13	0.43	5.75E+09	3.36E+09	0.0003	0.001	0.00001	0.005	0.006	0.002
11/08/2019 15:00		11.56	2.31	9.25	1.27E+11	3.65E+10	0.016	0.036	0.008	0.196	0.240	0.073
12/08/2019 0:00		0.39	0.08	0.31	4.04E+09	2.08E+09	0.0004	0.001	0.00010	0.007	0.008	0.004
12/08/2019 12:00		2.33	0.48	1.86	1.33E+10	1.29E+10	0.001	0.004	0.00002	0.034	0.038	0.012
Load		**74**	**13**	**61**	**4.22E+11**	**1.90E+11**	**0.05**	**0.11**	**0.05**	**0.91**	**1.07**	**0.35**

Cell 1 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	**Turbidity**	**Total suspended solids**	**Volatile suspended solids**	**Inorganic suspended solids**	**Total coliforms**	***Escherichia coli***	**Dissolved reactive phosphorus**	**Ammoniacal nitrogen**	**Nitrate nitrogen**	**Organic nitrogen**	**Total nitrogen**	**Total phosphorus**
	L s^{-1}	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		454	429	87	342	686,700	210,209	0.37	1.07	1.93	5.85	9.17	2.23
Mean		833	890	143	747	614,539	350,647	0.42	0.98	1.75	10.18	12.91	3.67
SD		963	1,138	161	984	499,736	392,583	0.26	0.63	0.60	10.78	10.82	3.99
n		14	14	14	14	14	14	14	14	14	14	14	14
Date													
10/08/2019 18:00	36.1	1,200	1,450	247	1,200	1,553,070	1,119,850	0.781	2.09	1.61	18.7	22.4	7.07
10/08/2019 21:00	4.3	430	425	88	337	435,200	178,500	0.445	1.18	2.51	5.74	9.43	2.09
11/08/2019 0:00	2.0	64	56	13	43	155,307	54,750	0.195	0.434	2.31	2.326	5.07	0.757
11/08/2019 3:00	2.1	48	61	13	49	>24,192	19,863	0.099	0.245	1.92	1.605	3.77	0.431
11/08/2019 6:00	3.4	478	432	85	347	>241,920	241,917	0.739	1.01	1.94	5.95	8.9	2.36
11/08/2019 9:00	0.8	192	153	31	122	>241,920	98,040	0.268	0.466	2.17	3.624	6.26	1.04
11/08/2019 12:00	2.8	1,840	1,810	317	1,490	686,700	461,100	0.713	1.29	0.914	18.696	20.9	6.62
11/08/2019 15:00	1.9	1,200	1,030	207	823	980,400	365,400	0.805	1.8	0.901	15.099	17.8	5.91
11/08/2019 18:00	0.4	194	132	25	107	>241,920	86,640	0.319	0.595	2.12	3.755	6.47	1.05
11/08/2019 21:00	0.9	3,480	4,200	573	3,630	>241,9200	1,203,310	0.252	1.77	0.878	40.952	43.6	14.8
12/08/2019 0:00	1.6	1,360	1,540	133	1,410	816,400	435,200	0.412	1.24	1.41	12.05	14.7	4.4
12/08/2019 3:00	0.3	132	112	31	81	14,670	8,570	0.212	0.338	2.2	3.082	5.62	0.843
12/08/2019 6:00	0.4	30	30	6	23	72,700	22,820	0.064	0.137	2.47	1.023	3.63	0.182
12/08/2019 9:00	5.0	1,010	1,030	227	803	816,400	613,100	0.598	1.12	1.19	9.89	12.2	3.83
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
10/08/2019 18:00	543.8		788.49	134.32	652.54	8.45E+12	6.09E+12	0.42	1.14	0.88	10.17	12.18	3.84
10/08/2019 21:00	211.0		89.66	18.63	71.10	9.18E+11	3.77E+11	0.09	0.25	0.53	1.21	1.99	0.44
11/08/2019 0:00	54.3		3.02	0.71	2.31	8.43E+10	2.97E+10	0.01	0.02	0.13	0.13	0.28	0.04
11/08/2019 3:00	34.6		2.12	0.44	1.68	8.71E+09	6.87E+09	0.00	0.01	0.07	0.06	0.13	0.01
11/08/2019 6:00	111.3		48.10	9.50	38.63	2.80E+11	2.69E+11	0.08	0.11	0.22	0.66	0.99	0.26
11/08/2019 9:00	39.6		6.06	1.24	4.83	9.98E+10	3.88E+10	0.01	0.02	0.09	0.14	0.25	0.04
11/08/2019 12:00	17.2		31.06	5.44	25.57	1.18E+11	7.91E+10	0.01	0.02	0.02	0.32	0.36	0.11
11/08/2019 15:00	81.4		83.83	16.85	66.99	7.98E+11	2.97E+11	0.07	0.15	0.07	1.23	1.45	0.48
11/08/2019 18:00	11.3		1.49	0.29	1.21	2.85E+10	9.80E+09	0.00	0.01	0.02	0.04	0.07	0.01
11/08/2019 21:00	11.2		46.99	6.41	40.62	2.82E+11	1.35E+11	0.00	0.02	0.01	0.46	0.49	0.17
12/08/2019 0:00	36.8		56.69	4.90	51.90	3.01E+11	1.60E+11	0.02	0.05	0.05	0.44	0.54	0.16
12/08/2019 3:00	14.3		1.60	0.45	1.15	2.10E+09	1.22E+09	0.00	0.00	0.03	0.04	0.08	0.01
12/08/2019 6:00	5.7		0.17	0.04	0.13	4.16E+09	1.31E+09	0.00	0.00	0.01	0.01	0.02	0.00
12/08/2019 9:00	38.6		39.71	8.75	30.96	3.15E+11	2.36E+11	0.02	0.04	0.05	0.38	0.47	0.15
Load			**1,199**	**208**	**990**	**1.17E+13**	**7.73E+12**	**0.75**	**1.84**	**2.16**	**15.29**	**19.30**	**5.74**

Groundwater (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

		Temperature	pH	Conductivity	Dissolved oxygen	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		°C		µS cm^{-1}	%	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Well 1		10.8	5.98	240	96.4	>24,192	74	0.019	0.045	7.56	1.165	8.77	0.19
Well 2		11.2	5.94	246	72.4	1,722	20	0.063	0.022	11.8	0.878	12.7	0.152
Well 3		11.8	7.92	144	99.3	4,352	175	0.019	0.029	5.42	0.621	6.07	0.099
Well 4		11.1	5.83	163	78.3	>24,192	52	0.037	0.039	1.2	1.651	2.89	0.265
						(total no.)	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
Well 1	15.87					2.98E+09	8.81E+06	0.0003	0.0007	0.1200	0.0185	0.1392	0.0030
Well 2	34.91					4.51E+08	5.24E+06	0.0022	0.0008	0.4120	0.0307	0.4434	0.0053
Well 3	38.09					1.24E+09	5.00E+07	0.0007	0.0011	0.2064	0.0237	0.2312	0.0038
Well 4	16.93					3.17E+09	6.60E+06	0.0006	0.0007	0.0203	0.0279	0.0489	0.0045
Load (kg)						**7.84E+09**	**7.06E+07**	**0.004**	**0.003**	**0.76**	**0.10**	**0.86**	**0.017**

Cell 5 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s^{-1}	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		343	237	69	155	290,900	113,700	0.42	0.80	1.28	6.22	8.46	1.80
Mean		497	413	100	312	540,702	239,350	0.45	0.85	1.24	7.44	9.54	2.61
SD		481	526	109	416	646,851	305,067	0.19	0.43	0.31	5.79	6.00	2.83
n		13	13	13	13	13	13	13	13	13	13	13	13
Date													
10/08/2019 18:00	63.4	1,960	2,060	437	1,620	2,419,170	1,119,850	0.963	1.84	0.448	25.112	27.4	11.5
10/08/2019 21:00	6.9	681	530	137	393	1,299,650	613,100	0.645	1.51	1.74	10.95	14.2	3.98
11/08/2019 0:00	2.9	343	237	82	155	191,800	98,400	0.455	1.02	1.65	6.22	8.89	1.89
11/08/2019 3:00	2.4	783	680	158	522	290,900	113,700	0.541	1.03	1.1	9.37	11.5	3.51
11/08/2019 6:00	15.3	234	147	42	105	160,700	67,000	0.354	0.703	1.34	4.597	6.64	1.38
11/08/2019 9:00	4.6	410	320	85	235	149,700	72,300	0.422	0.843	1.28	7.327	9.45	2.01
11/08/2019 12:00	4.6	222	140	37	103	156,500	90,700	0.323	0.478	1.18	4.022	5.68	1.15
11/08/2019 15:00	12.5	562	432	103	329	410,600	172,500	0.518	0.8	1.3	7.26	9.36	2.3
11/08/2019 18:00	5.3	406	283	69	214	579,400	172,300	0.489	0.931	1.18	6.349	8.46	1.8
11/08/2019 21:00	3.8	240	135	39	96	547,500	123,300	0.347	0.603	1.05	4.357	6.01	1.23
12/08/2019 0:00	6.2	125	72	19	53	224,700	60,900	0.281	0.363	1.23	3.257	4.85	0.881
12/08/2019 3:00	4.2	294	202	55	147	461,100	325,500	0.279	0.523	1.32	4.297	6.14	1.31
12/08/2019 6:00	3.0	196	126	39	87	137,400	82,000	0.248	0.444	1.35	3.616	5.41	0.988
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
10/08/2019 18:00	341.48		703.45	149.23	553.20	8.26E+12	3.82E+12	0.33	0.63	0.15	8.58	9.36	3.93
10/08/2019 21:00	229.40		121.58	31.43	90.15	2.98E+12	1.41E+12	0.15	0.35	0.40	2.51	3.26	0.91
11/08/2019 0:00	46.62		11.05	3.83	7.23	8.94E+10	4.59E+10	0.02	0.05	0.08	0.29	0.41	0.09
11/08/2019 3:00	24.79		16.86	3.92	12.94	7.21E+10	2.82E+10	0.01	0.03	0.03	0.23	0.29	0.09
11/08/2019 6:00	112.64		16.56	4.75	11.83	1.81E+11	7.55E+10	0.04	0.08	0.15	0.52	0.75	0.16
11/08/2019 9:00	91.79		29.37	7.83	21.57	1.37E+11	6.64E+10	0.04	0.08	0.12	0.67	0.87	0.18
11/08/2019 12:00	44.40		6.22	1.66	4.57	6.95E+10	4.03E+10	0.01	0.02	0.05	0.18	0.25	0.05
11/08/2019 15:00	108.09		46.69	11.13	35.56	4.44E+11	1.86E+11	0.06	0.09	0.14	0.78	1.01	0.25
11/08/2019 18:00	88.09		24.93	6.10	18.85	5.10E+11	1.52E+11	0.04	0.08	0.10	0.56	0.75	0.16
11/08/2019 21:00	44.11		5.95	1.73	4.23	2.41E+11	5.44E+10	0.02	0.03	0.05	0.19	0.27	0.05
12/08/2019 0:00	53.74		3.87	1.04	2.83	1.21E+11	3.27E+10	0.02	0.02	0.07	0.18	0.26	0.05
12/08/2019 3:00	56.92		11.50	3.15	8.37	2.62E+11	1.85E+11	0.02	0.03	0.08	0.24	0.35	0.07
12/08/2019 6:00	37.60		9.42	2.94	6.48	1.03E+11	6.13E+10	0.02	0.03	0.10	0.27	0.40	0.07
Total event load			**1007**	**229**	**778**	**1.35E+13**	**6.16E+12**	**0.77**	**1.5**	**1.5**	**15.2**	**18.2**	**6.06**
Change (all inflows minus outflow)(kg)			**-192**	**21**	**-212**	**1.78E+12**	**-1.57E+12**	**0.0**	**-0.3**	**-1.4**	**-0.2**	**-1.9**	**0.3**
Change (% of inflow mass)			**-16%**	**10%**	**-21%**	**15%**	**-20%**	**2%**	**-18%**	**-63%**	**-1%**	**-10%**	**5%**

Appendix I 21–23 August 2019 event water quality results

This event has been used in the results section as an example of load estimation methods, thus further details will not be presented here.

Seepage Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

		Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		6.3	8.5	1.7	5.1	4,220	520	0.024	0.051	1.53	0.53	2.14	0.072
Mean		12.0	15.7	3.7	11.9	11,663	5,604	0.025	0.064	1.51	0.58	2.16	0.075
SD		12.9	15.2	3.4	12.5	14,870	8,382	0.009	0.039	0.13	0.12	0.20	0.034
		15	15	15	15	15	15	15	15	15	15	15	15
Date													
21/08/2019 3:00		3.0	5.9	1.7	4.3	2,850	310	0.019	0.114	1.42	0.386	1.92	0.044
21/08/2019 6:00		6.8	10.5	<1.0	9.5	4,880	1,100	0.03	0.086	1.53	0.524	2.14	0.072
21/08/2019 9:00		2.7	4.7	<1.0	4.1	4,220	410	0.024	0.061	1.59	0.509	2.16	0.055
21/08/2019 12:00		36.3	41.9	6.7	35.2	3,050	200	0.035	0.038	1.74	0.712	2.49	0.164
21/08/2019 15:00		4.0	5.2	<1.0	4.2	1,890	520	0.025	0.03	1.65	0.52	2.2	0.057
21/08/2019 21:00		2.9	8.5	1.5	7.1	1,460	310	0.047	0.103	1.58	0.527	2.21	0.084
22/08/2019 3:00		1.9	3.7	<1.0	2.7	1,730	<100	0.02	0.051	1.47	0.469	1.99	0.044
22/08/2019 9:00		1.7	2.1	1.1	1.1	1,210	200	0.016	0.022	1.39	0.478	1.89	0.039
22/08/2019 12:00		1.8	1.9	1.1	0.9	1,210	100	0.016	0.021	1.34	0.469	1.83	0.039
22/08/2019 15:00		37.4	47.1	8.1	39.0	36,540	17,850	0.037	0.113	1.25	0.757	2.12	0.111
22/08/2019 18:00		15.8	23.5	9.3	14.2	13,960	5,810	0.024	0.051	1.45	0.609	2.11	0.072
22/08/2019 21:00		6.3	7.6	3.2	4.4	13,130	7,120	0.019	0.026	1.5	0.584	2.11	0.062
23/08/2019 0:00		12.7	9.9	4.8	5.1	18,500	9,340	0.019	0.022	1.62	0.638	2.28	0.078
23/08/2019 3:00		31.7	30.9	6.3	24.6	51,720	28,510	0.028	0.13	1.58	0.79	2.5	0.115
23/08/2019 6:00		15.6	31.9	9.3	22.6	18,600	12,230	0.02	0.092	1.57	0.738	2.4	0.093
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
21/08/2019 3:00	51.60		0.3	0.1	0.2	1.47E+09	1.60E+08	0.001	0.006	0.073	0.020	0.099	0.002
21/08/2019 6:00	54.75		0.5	0.0	0.5	2.67E+09	6.02E+08	0.002	0.004	0.079	0.027	0.110	0.004
21/08/2019 9:00	38.37		0.2	0.0	0.2	1.62E+09	1.57E+08	0.001	0.003	0.082	0.026	0.111	0.003
21/08/2019 12:00	21.68		2.2	0.3	1.8	6.61E+08	4.34E+07	0.002	0.002	0.090	0.037	0.128	0.008
21/08/2019 15:00	17.04		0.3	0.0	0.2	3.22E+08	8.86E+07	0.001	0.002	0.085	0.027	0.114	0.003
21/08/2019 21:00	25.68		0.4	0.1	0.4	3.75E+08	7.96E+07	0.002	0.005	0.082	0.027	0.114	0.004
22/08/2019 3:00	21.81		0.2	0.0	0.1	3.77E+08	1.09E+07	0.001	0.003	0.076	0.024	0.103	0.002
22/08/2019 9:00	21.18		0.1	0.1	0.1	2.56E+08	4.24E+07	0.001	0.001	0.072	0.025	0.098	0.002
22/08/2019 12:00	10.80		0.1	0.1	0.0	1.31E+08	1.08E+07	0.001	0.001	0.069	0.024	0.094	0.002
22/08/2019 15:00	115.21		2.4	0.4	2.0	4.21E+10	2.06E+10	0.002	0.006	0.064	0.039	0.109	0.006
22/08/2019 18:00	147.00		1.2	0.5	0.7	2.05E+10	8.54E+09	0.001	0.003	0.075	0.031	0.109	0.004
22/08/2019 21:00	71.67		0.4	0.2	0.2	9.41E+09	5.10E+09	0.001	0.001	0.077	0.030	0.109	0.003
23/08/2019 0:00	46.31		0.5	0.2	0.3	8.57E+09	4.33E+09	0.001	0.001	0.084	0.033	0.118	0.004
23/08/2019 3:00	47.57		1.6	0.3	1.3	2.46E+10	1.36E+10	0.001	0.007	0.082	0.041	0.129	0.006
23/08/2019 6:00	57.86		1.6	0.5	1.2	1.08E+10	7.08E+09	0.001	0.005	0.081	0.038	0.124	0.005
Load			**12.2**	**0.5**	**4.2**	**1.24E+11**	**6.04E+10**	**0.020**	**0.050**	**1.17**	**0.45**	**1.67**	**0.058**

Laneway Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Turbidity	Suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	$L\ s^{-1}$	NTU	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	MPN 100 mL^{-1}	MPN 100 mL^{-1}	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$
Median		707	495	131	389	1,184,735	956,375	1.10	1.45	0.71	12.59	14.95	4.14
Mean		801	670	149	520	1,320,592	1,109,002	1.10	1.46	0.84	13.32	15.62	5.20
SD		384	543	132	415	822,716	759,410	0.05	0.13	0.45	4.82	4.50	2.88
n		6	6	6	6	6	6	6	6	6	6	6	6
Date													
21/08/2019 3:00	0.42	705	188	24.7	163	579,400	461,100	1.09	1.56	1.38	9.96	12.9	3.56
21/08/2019 6:00	0.55	426	364	57.3	307	816,400	613,100	1.06	1.44	0.908	9.152	11.5	3.3
21/08/2019 9:00	0.00	708	585	114	471	488,400	307,600	1.05	1.4	1.37	8.93	11.7	3.13
22/08/2019 15:00	14.43	1,520	1,700	397	1300	>2,419,200	1,986,280	1.1	1.63	0.441	21.029	23.1	10.7
22/08/2019 18:00	0.55	884	775	153	622	1,553,070	1,299,650	1.2	1.46	0.407	15.633	17.5	5.79
22/08/2019 21:00	0.00	564	405	147	258	1,986,280	1,986,280	1.11	1.27	0.515	15.215	17	4.71
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
21/08/2019 3:00	21.12		3.97	0.52	3.44	1.22E+11	9.74E+10	0.02	0.03	0.03	0.21	0.27	0.08
21/08/2019 6:00	4.79		1.74	0.27	1.47	3.91E+10	2.93E+10	0.01	0.01	0.00	0.04	0.06	0.02
21/08/2019 9:00	1.63		0.95	0.19	0.77	7.96E+09	5.01E+09	0.00	0.00	0.00	0.01	0.02	0.01
22/08/2019 15:00	58.54		99.52	23.24	76.10	1.46E+12	1.16E+12	0.06	0.10	0.03	1.23	1.35	0.63
22/08/2019 18:00	44.72		34.66	6.84	27.82	6.95E+11	5.81E+11	0.05	0.07	0.02	0.70	0.78	0.26
22/08/2019 21:00	1.57		0.64	0.23	0.41	3.12E+10	3.12E+10	0.00	0.00	0.00	0.02	0.03	0.01
Load			**141**	**31**	**110**	**2.36E+12**	**1.91E+12**	**0.15**	**0.20**	**0.08**	**2.22**	**2.51**	**0.99**

Cell 1 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	$L\ s^{-1}$	NTU	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	MPN 100 mL^{-1}	MPN 100 mL^{-1}	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$
Median		145.0	156.0	46.7	109.0	137,400	120,100	0.17	0.15	1.20	2.54	4.04	1.01
Mean		253.1	274.4	56.0	218.4	494,296	355,488	0.22	0.38	1.18	4.30	5.86	1.46
SD		299.0	300.7	64.0	237.5	716,452	543,300	0.21	0.40	0.28	3.98	3.98	1.52
n		15	15	15	15	15	15	15	15	15	15	15	15
Date													
21/08/2019 3:00	5.85	379	380	77.3	303	920,800	686,700	0.606	0.756	1.34	7.584	9.68	2.67
21/08/2019 6:00	6.52	327	296	69.3	227	686,700	387,300	0.2	0.147	1.47	8.383	10	2.32
21/08/2019 9:00	2.39	71.1	80	17.3	62.7	137,400	120,100	0.0482	0.04	1.46	2.33	3.83	0.601
21/08/2019 12:00	1.76	13.3	14.8	2.9	11.9	13,400	3,000	0.0309	0.019	1.41	0.811	2.24	0.137
21/08/2019 15:00	1.41	10.3	12.8	1.3	11.5	6,300	2,000	0.0735	0.149	1.35	0.551	2.05	0.097
21/08/2019 21:00	1.05	193	312	54.7	257	24,300	13,400	0.072	0.152	1.35	2.538	4.04	1.07
22/08/2019 3:00	0.96	95.9	118	26.3	91.7	24,900	14,800	0.305	1.45	0.983	0.827	3.26	0.65
22/08/2019 9:00	1.01	19.8	35.2	5.7	29.5	27,500	4,100	0.0359	0.0877	1.19	0.8023	2.08	0.178
22/08/2019 12:00	0.96	9.1	16.6	1.5	15.1	5,100	4,100	0.0359	0.0877	1.19	0.5623	1.84	0.111
22/08/2019 15:00	33.16	1,050	1,120	246	874	2,419,170	1,986,280	0.605	0.804	0.59	12.206	13.6	5.35
22/08/2019 18:00	10.36	750	660	129	531	1,732,870	1,046,240	0.573	0.764	0.629	11.507	12.9	3.77
22/08/2019 21:00	4.86	317	368	73.3	295	579,400	298,700	0.212	0.265	1.2	5.625	7.09	1.65
23/08/2019 0:00	3.89	72.9	124	23.3	101	72,700	69,100	0.0634	0.086	1.48	1.924	3.49	0.502
23/08/2019 3:00	5.72	343	422	65.3	357	275,500	261,300	0.17	0.425	1.07	5.035	6.53	1.74
23/08/2019 6:00	5.47	145	156	46.7	109	488,400	435,200	0.263	0.428	1.06	3.792	5.28	1.01
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
21/08/2019 3:00	72.72		27.63	5.62	22.03	6.70E+11	4.99E+11	0.044	0.055	0.10	0.55	0.70	0.19
21/08/2019 6:00	59.54		17.62	4.13	13.52	4.09E+11	2.31E+11	0.012	0.009	0.09	0.50	0.60	0.14
21/08/2019 9:00	40.00		3.20	0.69	2.51	5.50E+10	4.80E+10	0.002	0.002	0.06	0.09	0.15	0.02
21/08/2019 12:00	21.68		0.32	0.06	0.26	2.90E+09	6.50E+08	0.001	0.000	0.03	0.02	0.05	0.00
21/08/2019 15:00	17.04		0.22	0.02	0.20	1.07E+09	3.41E+08	0.001	0.003	0.02	0.01	0.03	0.00
21/08/2019 21:00	25.68		8.01	1.40	6.60	6.24E+09	3.44E+09	0.002	0.004	0.03	0.07	0.10	0.03
22/08/2019 3:00	21.81		2.57	0.57	2.00	5.43E+09	3.23E+09	0.007	0.032	0.02	0.02	0.07	0.01
22/08/2019 9:00	21.18		0.75	0.12	0.62	5.83E+09	8.69E+08	0.001	0.002	0.03	0.02	0.04	0.00
22/08/2019 12:00	10.80		0.18	0.02	0.16	5.51E+08	4.43E+08	0.000	0.001	0.01	0.01	0.02	0.00
22/08/2019 15:00	173.75		194.60	42.74	151.86	4.20E+12	3.45E+12	0.105	0.140	0.10	2.12	2.36	0.93
22/08/2019 18:00	191.72		126.53	24.73	101.80	3.32E+12	2.01E+12	0.110	0.146	0.12	2.21	2.47	0.72
22/08/2019 21:00	73.24		26.95	5.37	21.61	4.24E+11	2.19E+11	0.016	0.019	0.09	0.41	0.52	0.12
23/08/2019 0:00	46.31		5.74	1.08	4.68	3.37E+10	3.20E+10	0.003	0.004	0.07	0.09	0.16	0.02
23/08/2019 3:00	47.57		20.07	3.11	16.98	1.31E+11	1.24E+11	0.008	0.020	0.05	0.24	0.31	0.08
23/08/2019 6:00	57.86		9.03	2.70	6.31	2.83E+11	2.52E+11	0.015	0.025	0.06	0.22	0.31	0.06
Load			**443.4**	**92.4**	**351.1**	**9.55E+12**	**6.87E+12**	**0.326**	**0.46**	**0.88**	**6.6**	**7.9**	**2.3**

Groundwater (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

		Temperature	pH	Conductivity	Dissolved oxygen	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		°C		µS cm^{-1}	%	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Well 1		10.8	5.98	240	96.4	>24,192	74	0.019	0.045	7.56	1.165	8.77	0.19
Well 2		11.2	5.94	246	72.4	1,722	20	0.063	0.022	11.8	0.878	12.7	0.152
Well 3		11.8	7.92	144	99.3	4,352	175	0.019	0.029	5.42	0.621	6.07	0.099
Well 4		11.1	5.83	163	78.3	>24,192	52	0.037	0.039	1.2	1.651	2.89	0.265
	(m^3)					**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
Well 1	8.5					2.15E+09	6.32E+06	0.0002	0.0004	0.0645	0.0099	0.0749	0.0016
Well 2	18.8					3.23E+08	3.76E+06	0.0012	0.0004	0.2216	0.0165	0.2385	0.0029
Well 3	20.5					8.91E+08	3.58E+07	0.0004	0.0006	0.1110	0.0127	0.1243	0.0020
Well 4	9.1					2.29E+09	4.73E+06	0.0003	0.0004	0.0109	0.0150	0.0263	0.0024
Load						**5.66E+09**	**5.07E+07**	**0.002**	**0.002**	**0.408**	**0.054**	**0.464**	**0.009**

Cell 5 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Volume	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	Escherichia coli	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	$L\ s^{-1}$	m^3	NTU	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	MPN 100 mL^{-1}	MPN 100 mL^{-1}	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$	$g\ m^{-3}$
Median			88.0	69.7	17.3	48.4	117,800	34,100	0.16	0.23	1.02	2.25	3.48	0.58
Mean			126.6	105.3	28.1	77.2	245,054	136,627	0.23	0.28	0.96	2.78	4.02	0.77
SD			146.8	122.4	34.7	88.1	399,991	239,168	0.16	0.24	0.22	2.11	2.39	0.68
n			15	15	15	15	15	15	15	15	15	15	15	15
Date														
21/08/2019 3:00	7.67	35.47	40.6	39.5	12.1	27.4	36,540	4,100	0.093	0.019	0.592	1.349	1.96	0.266
21/08/2019 6:00	7.23	85.24	160	141	37.3	104	209,800	125,900	0.219	0.454	1.2	3.086	4.74	0.789
21/08/2019 9:00	5.34	72.69	119	113	27.3	85.7	172,300	107,100	0.201	0.41	1.32	2.76	4.49	0.719
21/08/2019 12:00	3.13	43.72	88.0	69.7	21.3	48.4	143,000	24,200	0.164	0.271	1.21	2.429	3.91	0.584
21/08/2019 15:00	2.31	29.00	54.9	54.2	11.8	42.4	65,700	34,100	0.133	0.109	1.14	1.941	3.19	0.479
21/08/2019 21:00	1.76	42.62	32.6	23.5	7.2	16.3	16,000	10,900	0.113	0.088	1.01	1.402	2.5	0.316
22/08/2019 3:00	1.52	34.65	29.1	21.2	4.9	16.3	7,400	4,100	0.109	0.078	0.753	1.249	2.08	0.286
22/08/2019 9:00	1.70	34.84	24.9	22.8	5.7	17.1	11,000	4,100	0.102	0.08	0.708	1.172	1.96	0.269
22/08/2019 12:00	1.76	18.27	24.0	22.0	5.3	16.7	13,100	9,700	0.091	0.039	0.641	1.15	1.83	0.269
22/08/2019 15:00	33.16	69.51	94.3	99.0	16.3	82.7	55,600	30,500	0.155	0.155	1.02	1.515	2.69	0.508
22/08/2019 18:00	12.27	286.19	582	493	139	354	1,553,070	920,800	0.623	0.848	0.871	8.881	10.6	2.73
22/08/2019 21:00	5.47	88.80	305	240	68.3	172	547,500	365,400	0.452	0.566	1.06	5.824	7.45	1.83
23/08/2019 0:00	3.31	44.43	178	118	26.7	91.3	517,200	228,200	0.306	0.367	1.02	4.073	5.46	1.13
23/08/2019 3:00	3.31	33.60	103	70.0	17.3	52.7	209,800	110,600	0.232	0.231	1.03	2.659	3.92	0.757
23/08/2019 6:00	3.89	38.86	63.2	52.7	21.6	31.1	117,800	69,700	0.473	0.479	0.751	2.25	3.48	0.575
	(m^3)			(kg)	(kg)	(kg)	(total no.)	(total no.)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
21/08/2019 3:00	35.47			1.40	0.43	0.97	1.30E+10	1.45E+09	0.0033	0.0007	0.0210	0.05	0.070	0.009
21/08/2019 6:00	85.24			12.02	3.18	8.87	1.79E+11	1.07E+11	0.0187	0.0387	0.1023	0.26	0.404	0.067
21/08/2019 9:00	72.69			8.21	1.98	6.23	1.25E+11	7.79E+10	0.0146	0.0298	0.0960	0.20	0.326	0.052
21/08/2019 12:00	43.72			3.05	0.93	2.12	6.25E+10	1.06E+10	0.0072	0.0118	0.0529	0.11	0.171	0.026
21/08/2019 15:00	29.00			1.57	0.34	1.23	1.91E+10	9.89E+09	0.0039	0.0032	0.0331	0.06	0.093	0.014
21/08/2019 21:00	42.62			1.00	0.31	0.69	6.82E+09	4.65E+09	0.0048	0.0038	0.0430	0.06	0.107	0.013
22/08/2019 3:00	34.65			0.73	0.17	0.56	2.56E+09	1.42E+09	0.0038	0.0027	0.0261	0.04	0.072	0.010
22/08/2019 9:00	34.84			0.79	0.20	0.60	3.83E+09	1.43E+09	0.0036	0.0028	0.0247	0.04	0.068	0.009
22/08/2019 12:00	18.27			0.40	0.10	0.31	2.39E+09	1.77E+09	0.0017	0.0007	0.0117	0.02	0.033	0.005
22/08/2019 15:00	69.51			6.88	1.13	5.75	3.86E+10	2.12E+10	0.0108	0.0108	0.0709	0.11	0.187	0.035
22/08/2019 18:00	286.19			141.09	39.78	101.31	4.44E+12	2.64E+12	0.1783	0.2427	0.2493	2.54	3.034	0.781
22/08/2019 21:00	88.80			21.31	6.07	15.27	4.86E+11	3.24E+11	0.0401	0.0503	0.0941	0.52	0.662	0.163
23/08/2019 0:00	44.43			5.24	1.19	4.06	2.30E+11	1.01E+11	0.0136	0.0163	0.0453	0.18	0.243	0.050
23/08/2019 3:00	33.60			2.35	0.58	1.77	7.05E+10	3.72E+10	0.0078	0.0078	0.0346	0.09	0.132	0.025
23/08/2019 6:00	38.86			2.05	0.84	1.21	4.58E+10	2.71E+10	0.0184	0.0186	0.0292	0.09	0.135	0.022
Total event load				**208.1**	**57.2**	**150.9**	**5.73E+12**	**3.36E+12**	**0.330**	**0.44**	**0.93**	**4.4**	**5.7**	**1.3**
Change (all inflows minus outflow)(kg)				**-235.3**	**-35.1**	**-200.2**	**-3.83E+12**	**-3.51E+12**	**0.0**	**0.0**	**-0.5**	**-2.3**	**-2.8**	**-1.1**
Change (% of inflow mass)				**-53%**	**-38%**	**-57%**	**-40%**	**-51%**	**0%**	**-5%**	**-53%**	**-35%**	**-35%**	**-46%**

Appendix J 5–6 September 2019 event water quality results

This event was a relatively brief, but did cause runoff from the laneways (Figure 15). The peak flow at cell 1 arriving earlier than seen in cell 5 as would be expected. In this instance it is also higher than in cell 5. Total flow during the event measured at the outlet of cell 5 was 188 m^3, of which 76 m^3 was from groundwater inputs, with the remaining 112 m^3 from surface inputs. Inputs from the laneway were much more contaminated than the seepage input, but as had been the case in the previous event, these did not sum to the amount recorded as exiting cell 1, potentially due to some flows directly entering cell 1 from the laneway but not passing through the culvert where sampling of the laneway was undertaken.

Loads measured at the outlet of cell 1 amounted to 27 kg of TSS, 0.90 kg of TN load and 0.14 kg of TP. The median *E. coli* concentration was 57,940 MPN 100 mL^{-1}. Loads at the outlet of cell 5 were 5.0 kg of TSS (81% reduction), 0.34 kg of TN (62% reduction) and 0.06 kg of TP (53% reduction). The median *E. coli* concentration was 27,550 MPN 100 mL^{-1}, equivalent to a 52% reduction.

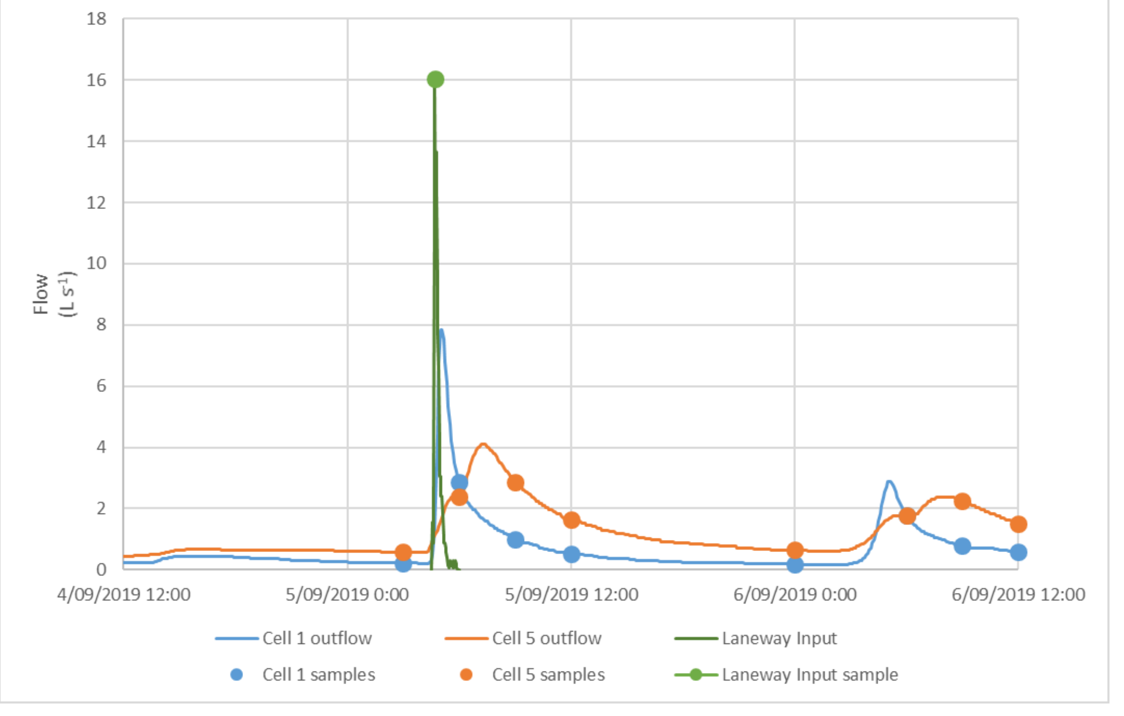


Figure 15: Flows during 5th – 6th September 2019 event.

Seepage Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

		Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		3.8	4.2	1.0	2.9	2,030	410	0.023	0.028	0.318	0.535	0.850	0.066
Mean		3.8	4.4	1.3	3.5	4,052	1,846	0.023	0.027	0.313	0.542	0.882	0.066
SD		0.6	1.7	0.3	1.5	4,637	1,739	0.004	0.005	0.051	0.068	0.066	0.011
n		9	9	9	9	9	9	9	9	9	9	9	9
Date													
5/09/2019 3:00		3.7	7.1	<1.0	6.1	2,030	310	0.0228	0.026	0.357	0.433	0.816	0.058
5/09/2019 6:00		3.9	3.9	<1.0	2.9	12,110	4,650	0.024	0.029	0.395	0.508	0.932	0.063
5/09/2019 9:00		3.0	1.9	<1.0	<1.0	2,780	410	0.0152	0.02	0.322	0.486	0.828	0.049
5/09/2019 12:00		4.4	4.5	1.5	3.0	1,100	410	0.0263	0.03	0.318	0.502	0.85	0.066
5/09/2019 18:00		4.6	6.7	1.2	5.5	310	<100	0.0234	0.034	0.253	0.561	0.848	0.072
6/09/2019 0:00		3.5	4.2	1.8	2.4	1,180	<100	0.0188	0.027	0.261	0.535	0.823	0.059
6/09/2019 6:00		4.6	5.1	1.1	4.0	11,690	3,640	0.0266	0.03	0.362	0.618	1.01	0.081
6/09/2019 9:00		3.2	3.0	<1.0	2.2	4,640	2,280	0.0228	0.0204	0.286	0.5886	0.895	0.066
6/09/2019 12:00		3.8	3.1	1.0	2.1	630	1,220	0.0259	0.028	0.261	0.645	0.934	0.081
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/09/2019 3:00	2.47		0.02	0.00	0.02	5.02E+07	7.67E+06	0.0001	0.0001	0.0009	0.0011	0.0020	0.0001
5/09/2019 6:00	16.54		0.06	0.01	0.05	2.00E+09	7.69E+08	0.0004	0.0005	0.0065	0.0084	0.0154	0.0010
5/09/2019 9:00	10.88		0.02	0.01	0.01	3.02E+08	4.46E+07	0.0002	0.0002	0.0035	0.0053	0.0090	0.0005
5/09/2019 12:00	5.61		0.03	0.01	0.02	6.17E+07	2.30E+07	0.0001	0.0002	0.0018	0.0028	0.0048	0.0004
5/09/2019 18:00	5.79		0.04	0.01	0.03	1.79E+07	2.89E+06	0.0001	0.0002	0.0015	0.0020	0.0049	0.0004
6/09/2019 0:00	3.82		0.02	0.01	0.01	4.51E+07	1.91E+06	0.0001	0.0001	0.0010	0.0051	0.0031	0.0002
6/09/2019 6:00	38.10		0.19	0.04	0.15	4.45E+09	1.39E+09	0.0010	0.0011	0.0138	0.0235	0.0385	0.0031
6/09/2019 9:00	8.61		0.03	0.00	0.02	3.99E+08	1.96E+08	0.0002	0.0002	0.0025	0.0051	0.0077	0.0006
6/09/2019 12:00	6.30		0.02	0.01	0.01	3.97E+07	7.68E+07	0.0002	0.0002	0.0016	0.0041	0.0059	0.0005
Load			**0.42**	**0.09**	**0.31**	**7.37E+09**	**2.51E+09**	**0.002**	**0.003**	**0.033**	**0.056**	**0.091**	**0.007**

Laneway Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Volume	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	m^3	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
5/09/2019 6:00		271	628	80.3	548	920,800	770,100	0.182	0.597	2.07	6.753	9.42	2.34
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/09/2019 6:00 **Load**	14.4		**9.05**	**1.16**	**7.90**	**1.33E+11**	**1.11E+11**	**0.003**	**0.01**	**0.03**	**0.10**	**0.14**	**0.034**

Cell 1 (values in rows shaded green are mass loads (kg), total volumes (discharge, m³) or total numbers (bacteria))

	Instantaneous flow estimate	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s^{-1}	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		47.5	85.5	20.5	65.0	141,360	57,940	0.055	0.300	0.217	1.631	2.150	0.379
Mean		97.9	142.8	27.3	115.5	80,315	85,572	0.082	0.343	0.399	2.400	3.142	0.675
SD		96.9	137.9	20.0	118.5	73,591	91,711	0.061	0.209	0.410	1.698	2.283	0.583
n		9	9	9	9	9	9	9	9	9	9	9	9
Date													
5/09/2019 3:00	0.229	44.9	84.4	24.5	59.9	12,960	1,930	0.0667	0.3	0.112	1.138	1.55	0.352
5/09/2019 6:00	2.866	80.5	468	70.2	398	>241920	>241920	0.212	0.677	1.31	6.203	8.19	2.01
5/09/2019 9:00	1.007	47.5	94.4	18.8	75.6	>241920	198,628	0.0537	0.162	0.357	1.631	2.15	0.379
5/09/2019 12:00	0.519	30.6	57.6	15.5	42.1	141,360	57,940	0.0485	0.225	0.217	1.488	1.93	0.343
5/09/2020 18:00	0.268	28.5	33.0	9.2	23.8	22,470	11,530	0.0344	0.084	0.126	1.12	1.33	0.231
6/09/2019 0:00	0.177	172	172	36.2	136	51,720	34,480	0.065	0.337	0.137	2.376	2.85	0.756
6/09/2019 6:00	1.764	325	238	44.2	194	>241920	241,917	0.161	0.661	0.848	4.071	5.58	1.19
6/09/2019 9:00	0.797	108	85.5	20.5	65.0	198,628	120,331	0.0552	0.425	0.274	2.231	2.93	0.518
6/09/2019 12:00	0.583	43.9	52.3	6.9	45.4	54,750	17,820	0.0454	0.218	0.21	1.342	1.77	0.297
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/09/2019 3:00	2.47		0.21	0.06	0.15	3.21E+08	4.77E+07	0.00016	0.0007	0.0003	0.0028	0.0038	0.0009
5/09/2019 6:00	30.95		14.49	2.17	12.32	7.74E+10	7.74E+10	0.00656	0.0210	0.0405	0.1920	0.2535	0.0622
5/09/2019 9:00	10.88		1.03	0.20	0.82	2.72E+10	2.16E+10	0.00058	0.0018	0.0039	0.0177	0.0234	0.0041
5/09/2019 12:00	5.61		0.32	0.09	0.24	7.92E+09	3.25E+09	0.00027	0.0013	0.0012	0.0083	0.0108	0.0019
5/09/2020 18:00	5.79		0.19	0.05	0.14	1.30E+09	6.67E+08	0.00020	0.0005	0.0007	0.0065	0.0077	0.0013
6/09/2019 0:00	3.82		0.66	0.14	0.52	1.98E+09	1.32E+09	0.00025	0.0013	0.0005	0.0091	0.0109	0.0029
6/09/2019 6:00	38.10		9.07	1.68	7.39	9.53E+10	9.22E+10	0.00613	0.0252	0.0323	0.1551	0.2126	0.0453
6/09/2019 9:00	8.61		0.74	0.18	0.56	1.71E+10	1.04E+10	0.00048	0.0037	0.0024	0.0192	0.0252	0.0045
6/09/2019 12:00	6.30		0.33	0.04	0.29	3.45E+09	1.12E+09	0.00029	0.0014	0.0013	0.0084	0.0111	0.0019
Load			**27.03**	**4.62**	**22.42**	**2.32E+11**	**2.08E+11**	**0.01**	**0.06**	**0.08**	**0.42**	**0.56**	**0.125**

Groundwater (values in rows shaded green are mass loads (kg), total volumes (discharge, m³) or total numbers (bacteria))

	Groundwater inflow volume	**Total coliforms**	***Escherichia coli***	**Dissolved reactive phosphorus**	**Ammoniacal nitrogen**	**Nitrate nitrogen**	**Organic nitrogen**	**Total nitrogen**	**Total phosphorus**
		MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Well 1		959	<100	0.008	0.033	10.10	0.67	10.80	0.11
Well 2		1,722	37	0.019	0.022	0.62	1.10	1.74	0.20
Well 3		1,565	31	0.004	0.029	8.14	1.15	9.32	0.24
Well 4		>24,192	1,046	0.007	0.037	1.45	1.40	2.89	0.27
	(m³)	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
Well 1	8.5	8.17E+07	4.26E+06	0.000068	0.000281	0.0861	0.0057	0.0921	0.0009
Well 2	18.8	3.23E+08	6.92E+06	0.000356	0.000413	0.0117	0.0205	0.0326	0.0037
Well 3	20.5	3.20E+08	6.34E+06	0.000082	0.000593	0.1665	0.0235	0.1907	0.0050
Well 4	9.1	2.27E+09	9.51E+07	0.000064	0.000336	0.0132	0.0128	0.0263	0.0024
Load		**3.00E+09**	**1.13E+08**	**0.00057**	**0.00162**	**0.278**	**0.0625**	**0.341**	**0.0120**

Cell 5 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	**Turbidity**	**Total suspended solids**	**Volatile suspended solids**	**Inorganic suspended solids**	**Total coliforms**	***Escherichia coli***	**Dissolved reactive phosphorus**	**Ammoniacal nitrogen**	**Nitrate nitrogen**	**Organic nitrogen**	**Total nitrogen**	**Total phosphorus**
	L s^{-1}	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		34.0	20.7	7.4	15.0	86,640	27,550	0.088	0.029	0.308	1.483	1.800	0.322
Mean		36.9	27.2	7.7	19.5	113,757	38,320	0.084	0.028	0.306	1.497	1.831	0.334
SD		16.1	16.1	3.7	12.6	81,415	28,735	0.014	0.011	0.052	0.144	0.185	0.048
n		9	9	9	9	9	9	9	9	9	9	9	9
Date													
5/09/2019 3:00	0.583	20.7	19.6	6.1	13.5	11,530	3,410	0.0789	0.038	0.242	1.31	1.59	0.284
5/09/2019 6:00	2.386	23.5	20.4	7.4	13.0	173,287	34,480	0.101	0.029	0.26	1.391	1.68	0.322
5/09/2019 9:00	2.866	45.2	37.9	8.4	29.5	155,307	51,720	0.0991	0.046	0.322	1.562	1.93	0.383
5/09/2019 12:00	1.641	74.6	66.2	16.8	49.4	198,628	92,080	0.0824	0.031	0.374	1.825	2.23	0.438
5/09/2020 18:00	0.685	39.3	20.7	5.7	15.0	48,840	27,550	0.0632	0.014	0.303	1.483	1.8	0.3
6/09/2019 0:00	0.65	34.0	24.9	7.4	17.5	26,020	12,810	0.0632	0.022	0.308	1.52	1.85	0.312
6/09/2019 6:00	1.764	27.0	18.2	5.4	12.8	241,917	72,700	0.09	0.0376	0.236	1.4264	1.7	0.311
6/09/2019 9:00	2.239	30.5	13.2	4.1	9.1	86,640	26,130	0.0895	0.023	0.331	1.446	1.8	0.325
6/09/2019 12:00	1.522	37.7	23.7	7.6	16.1	81,640	24,000	0.0875	0.013	0.375	1.512	1.9	0.328
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/09/2019 3:00	6.30		0.12	0.04	0.09	7.26E+08	2.15E+08	0.0005	0.0002	0.002	0.008	0.010	0.002
5/09/2019 6:00	25.77		0.53	0.19	0.33	4.47E+10	8.89E+09	0.0026	0.0007	0.007	0.036	0.043	0.008
5/09/2019 9:00	30.95		1.17	0.26	0.91	4.81E+10	1.60E+10	0.0031	0.0014	0.010	0.048	0.060	0.012
5/09/2019 12:00	17.72		1.17	0.30	0.88	3.52E+10	1.63E+10	0.0015	0.0005	0.007	0.032	0.040	0.008
5/09/2020 18:00	14.80		0.31	0.08	0.22	7.23E+09	4.08E+09	0.0009	0.0002	0.004	0.022	0.027	0.004
6/09/2019 0:00	14.04		0.35	0.10	0.25	3.65E+09	1.80E+09	0.0009	0.0003	0.004	0.021	0.026	0.004
6/09/2019 6:00	38.10		0.69	0.21	0.49	9.22E+10	2.77E+10	0.0034	0.0014	0.009	0.054	0.065	0.012
6/09/2019 9:00	24.18		0.32	0.10	0.22	2.10E+10	6.32E+09	0.0022	0.0006	0.008	0.035	0.044	0.008
6/09/2019 12:00	16.44		0.39	0.12	0.26	1.34E+10	3.95E+09	0.0014	0.0002	0.006	0.025	0.031	0.005
Total event load			**5.05**	**1.40**	**3.65**	**2.66E+11**	**8.53E+10**	**0.016**	**0.01**	**0.06**	**0.28**	**0.34**	**0.064**
Change (all inflows minus outflow)(kg)			**-21.97**	**-3.22**	**-18.77**	**3.12E+10**	**-1.23E+11**	**0.001**	**-0.05**	**-0.040**	**-0.22**	**-0.67**	**-0.077**
Change (% of inflow mass)			**-81%**	**-70%**	**-84%**	**13%**	**-59%**	**5%**	**-90%**	**-87%**	**-44%**	**-66%**	**-55%**

Appendix K 8-9 September 2019 event water quality results

As seen in previous events, the laneways input was highly contaminated with median turbidity, TSS and *E. coli* values of 1,013 NTU, 895 g m^{-3} and 198,400 MPN 100 ml^{-1} respectively. However loads from this and the seepage input do not sum to those at the outlet from cell 1, so it appears that some flows from the laneway were continuing to bypass this sampling location.

The seepage runoff was relatively "clean", with medians for turbidity and TSS of 3.5 NTU and 3.7 g m^{-3}, respectively. Medians concentrations of TN and TP were 0.81 g m^{-3} and 0.066 g m^{-3} respectively.

Peak flows at the outlet of Cell 1 were around 1.5 L^{-1}, and a little over 3.5 L s^{-1} at the outlet from cell 5, totalling 36 and 166 m^3 respectively (Figure 16).

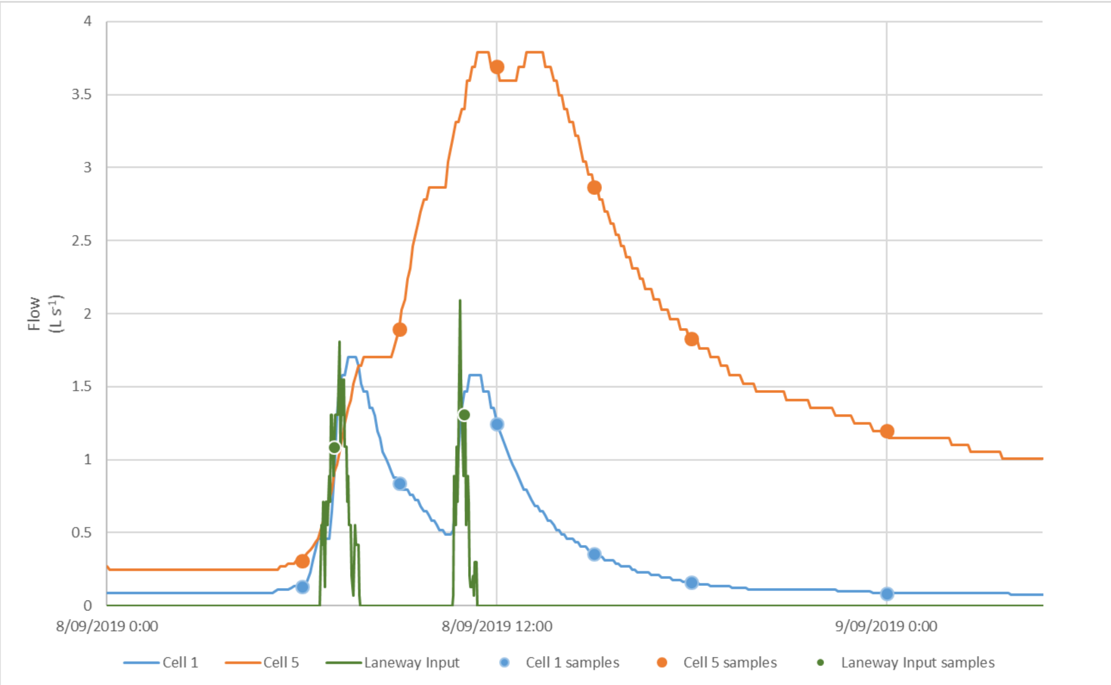


Figure 16: Flows during 8th – 9th September event.

The total load of TSS at the outlet of cell 1 was 9.2 kg, with a TN load of 0.2 kg and a TP load of 0.044 kg. Groundwater inputs contributed a load of 0.66 kg of TN, mostly of nitrate-N (79%), with a TP load of 0.034 kg. *E. coli* ranged from <10 MPN 100 ml^{-1} to 1,046 MPN 100 ml^{-1}. In combination, the TSS load was 9.2 kg, the TN load was 0.86 kg and the TP load was 0.08 kg.

Load reductions in the wetland were 6.3 kg (32% reduction) for TSS, 0.36 kg (58% reduction) for TN, and 0.06 kg (24% reduction) for TP. *E. coli* showed a reduction of 31% based on concentrations.

Seepage Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

		Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
						MPN 100 mL^{-1}	MPN 100 mL^{-1}						
		NTU	g m^{-3}	g m^{-3}	g m^{-3}			g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		3.5	3.7	2.0	1.1	1090	200	0.019	0.039	0.184	0.578	0.808	0.066
Mean		3.9	4.2	2.3	1.9	961	279	0.020	0.036	0.208	0.581	0.824	0.066
SD		0.7	2.3	1.0	2.2	498	238	0.004	0.013	0.043	0.032	0.048	0.008
n		7	7	7	7	7	7	7	7	7	7	7	7
Date													
8/09/2019 6:00		4.5	8.4	2.0	6.4	1210	310	0.0158	0.041	0.184	0.533	0.758	0.057
8/09/2019 9:00		3.4	1.3	1.0	<1.0	520	<100	0.0273	0.057	0.172	0.638	0.867	0.077
8/09/2019 12:00		3.5	2.3	1.8	<1.0	1350	200	0.0205	0.0394	0.181	0.5766	0.797	0.066
8/09/2019 15:00		3.4	3.4	2.0	1.4	<100	<100	0.0246	0.045	0.171	0.592	0.808	0.074
8/09/2019 18:00		3.9	5.1	2.0	3.1	1430	730	0.0169	0.025	0.213	0.559	0.797	0.057
9/09/2019 0:00		5.3	5.2	4.1	1.1	1090	410	0.0189	0.02	0.25	0.578	0.848	0.066
9/09/2019 6:00		3.3	3.7	3.1	<1.0	1080	200	0.0182	0.025	0.282	0.589	0.896	0.064
	(m^3)		**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
8/09/2019 6:00	0.995		0.008	0.002	0.006	1.20E+07	3.08E+06	0.00002	0.00004	0.0002	0.0005	0.0008	0.0001
8/09/2019 9:00	7.468		0.010	0.007	0.004	3.88E+07	3.73E+06	0.0002	0.0004	0.0013	0.0048	0.0065	0.0006
8/09/2019 12:00	8.552		0.020	0.015	0.004	1.15E+08	1.71E+07	0.0002	0.0003	0.0015	0.0049	0.0068	0.0006
8/09/2019 15:00	7.129		0.024	0.014	0.010	3.56E+06	3.56E+06	0.0002	0.0003	0.0012	0.0042	0.0058	0.0005
8/09/2019 18:00	2.562		0.013	0.005	0.008	3.66E+07	1.87E+07	0.00004	0.0001	0.0005	0.0014	0.0020	0.0001
9/09/2019 0:00	2.43		0.013	0.010	0.003	2.64E+07	9.95E+06	0.00005	0.00005	0.0006	0.0014	0.0021	0.0002
9/09/2019 6:00	1.78		0.007	0.006	0.001	1.92E+07	3.56E+06	0.00003	0.00004	0.0005	0.0010	0.0016	0.0001
Event load			**0.09**	**0.06**	**0.04**	**2.52E+08**	**5.97E+07**	**0.001**	**0.001**	**0.006**	**0.018**	**0.025**	**0.002**

Laneway Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

		Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		1013	895	135	760	429,150	198,400	0.427	2.482	1.262	10.201	13.945	2.990
Mean		1013	895	135	760	429,150	198,400	0.427	2.482	1.262	10.201	13.945	2.990
SD		944	842	120	722	421,224	207,041	0.193	2.529	1.044	7.361	8.846	2.277
n		2	2	2	2	2	2	2	2	2	2	2	2
Date													
8/09/2019 9:00		345	299	49.8	249	131,300	52,000	0.29	0.694	2.00	4.996	7.69	1.38
8/09/2019 0:00		1680	1490	220	1270	727,000	344,800	0.563	4.27	0.524	15.406	20.2	4.6
			(kg)	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
8/09/2019 9:00	3.6		1.07	0.18	0.89	4.71E+09	1.87E+09	0.0010	0.0025	0.0072	0.0179	0.0276	0.0050
8/09/2019 0:00	2.0		2.92	0.43	2.49	1.43E+10	6.76E+09	0.0011	0.0084	0.0010	0.0302	0.0396	0.0090
Event load			**4.0**	**0.61**	**3.38**	**1.90E+10**	**8.63E+09**	**0.002**	**0.011**	**0.008**	**0.048**	**0.067**	**0.014**

Cell 1 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s^{-1}	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		85.8	95.4	25.7	69.7	43,585	13,565	0.064	0.256	0.215	1.674	2.180	0.463
Mean		215.5	176.0	40.7	135.3	84,433	53,422	0.107	0.572	0.298	3.252	4.122	0.870
SD		310.2	226.3	44.2	182.3	93,912	96,962	0.127	0.818	0.176	3.355	4.264	1.017
n		6	6	6	6	6	6	6	6	6	6	6	6
Date													
8/09/2019 6:00	0.134	87.4	107	30.7	76.3	46110	10630	0.0242	0.026	0.201	1.743	1.97	0.516
8/09/2019 9:00	0.836	84.2	83.7	20.7	63.0	41060	16500	0.082	0.246	0.54	1.604	2.39	0.41
8/09/2019 12:00	1.248	840	633	129	504	>241920	>241920	0.362	2.21	0.501	9.889	12.6	2.91
8/09/2019 15:00	0.357	186	132	35.6	96.4	141360	34480	0.0804	0.513	0.228	3.549	4.29	0.796
8/09/2019 18:00	0.163	60.4	63.7	17.2	46.5	23590	7440	0.0455	0.17	0.177	1.483	1.83	0.337
9/09/2019 0:00	0.086	34.7	36.5	10.9	25.6	4480	1480	0.0472	0.266	0.138	1.246	1.65	0.248
			(kg)	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
8/09/2019 6:00	7.17		0.77	0.22	0.55	3.31E+09	7.62E+08	0.0002	0.0002	0.0014	0.0125	0.0141	0.0037
8/09/2019 9:00	9.06		0.76	0.19	0.57	3.72E+09	1.50E+09	0.0007	0.0022	0.0049	0.0145	0.0217	0.0037
8/09/2019 12:00	10.93		6.92	1.41	5.51	2.73E+10	2.73E+10	0.0040	0.0241	0.0055	0.1081	0.1377	0.0318
8/09/2019 15:00	3.44		0.45	0.12	0.33	4.86E+09	1.19E+09	0.0003	0.0018	0.0008	0.0122	0.0148	0.0027
8/09/2019 18:00	2.56		0.16	0.04	0.12	6.04E+08	1.91E+08	0.0001	0.0004	0.0005	0.0038	0.0047	0.0009
9/09/2019 0:00	4.21		0.15	0.05	0.11	1.88E+08	6.22E+07	0.0002	0.0011	0.0006	0.0052	0.0069	0.0010
Event load			**9.2**	**2.0**	**7.2**	**4.00E+10**	**3.10E+10**	**0.005**	**0.030**	**0.014**	**0.156**	**0.200**	**0.044**

Groundwater (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Groundwater inflow volume	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Well 1		959	<10	0.0026	0.005	10.1	0.795	10.9	0.135
Well 2		1296	40	0.0095	0.014	0.623	1.103	1.74	0.448
Well 3		1565	74	0.001	0.02	9.43	1.75	11.2	0.343
Well 4		19863	1046	0.0135	0.06	1.57	1.85	3.48	0.376
		(total no.)	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
Well 1	14.6	1.40E+08	7.29E+05	0.00004	0.00007	0.15	0.01	0.16	0.002
Well 2	32.1	4.16E+08	1.28E+07	0.00030	0.00045	0.02	0.04	0.06	0.014
Well 3	35.0	5.48E+08	2.59E+07	0.00004	0.00070	0.33	0.06	0.39	0.012
Well 4	15.6	3.09E+09	1.63E+08	0.00021	0.00093	0.02	0.03	0.05	0.006
Event load		**4.19E+09**	**2.02E+08**	**0.001**	**0.002**	**0.522**	**0.137**	**0.66**	**0.034**

Cell 5 (values in rows shaded green are mass loads (kg), total volumes (discharge, m³) or total numbers (bacteria))

	Instantaneous flow estimate	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s⁻¹	NTU	g m⁻³	g m⁻³	g m⁻³	MPN 100 mL⁻¹	MPN 100 mL⁻¹	g m⁻³	g m⁻³	g m⁻³	g m⁻³	g m⁻³	g m⁻³
Median		39.9	30.5	10.5	22.8	34,480	9,330	0.071	0.054	0.489	1.462	2.010	0.329
Mean		43.5	35.1	10.8	24.3	29,986	7,614	0.071	0.066	0.473	1.522	2.061	0.330
SD		20.5	13.7	2.8	12.2	15,380	4,534	0.013	0.029	0.149	0.202	0.371	0.053
n		7	7	7	7	7	7	7	7	7	7	7	7
Date													
8/09/2019 6:00	0.311	21.1	22.5	9.7	12.8	43520	630	0.0544	0.0312	0.259	1.3598	1.65	0.268
8/09/2019 9:00	1.893	21.6	20.1	7.4	12.7	27550	4500	0.0848	0.054	0.347	1.329	1.73	0.292
8/09/2019 12:00	3.689	34.0	29.1	14.4	14.7	46110	10760	0.0901	0.069	0.418	1.373	1.86	0.329
8/09/2019 15:00	2.866	47.6	39.4	10.5	28.9	34480	9330	0.0754	0.047	0.489	1.534	2.07	0.329
8/09/2019 18:00	1.829	69.6	45.7	12.9	32.8	38730	13130	0.071	0.101	0.617	1.752	2.47	0.372
9/09/2019 0:00	1.197	70.6	58.5	13.3	45.2	4510	10760	0.0614	0.109	0.688	1.843	2.64	0.423
9/09/2019 6:00	1.053	39.9	30.5	7.7	22.8	15000	4190	0.0611	0.052	0.496	1.462	2.01	0.300
			(kg)	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
8/09/2019 6:00	8.1		0.18	0.08	0.10	3.51E+09	5.08E+07	0.0004	0.0003	0.0021	0.011	0.013	0.002
8/09/2019 9:00	26.5		0.53	0.20	0.34	7.29E+09	1.19E+09	0.0022	0.0014	0.0092	0.035	0.046	0.008
8/09/2019 12:00	39.8		1.16	0.57	0.58	1.83E+10	4.28E+09	0.0036	0.0027	0.0166	0.055	0.074	0.013
8/09/2019 15:00	28.8		1.13	0.30	0.83	9.92E+09	2.68E+09	0.0022	0.0014	0.0141	0.044	0.060	0.009
8/09/2019 18:00	18.8		0.86	0.24	0.62	7.28E+09	2.47E+09	0.0013	0.0019	0.0116	0.033	0.046	0.007
9/09/2019 0:00	27.6		1.61	0.37	1.25	1.25E+09	2.97E+09	0.0017	0.0030	0.0190	0.051	0.073	0.012
9/09/2019 6:00	25.4		0.77	0.20	0.58	3.81E+09	1.06E+09	0.0016	0.0013	0.0126	0.037	0.051	0.008
Total event load			**6.3**	**2.0**	**4.3**	**5.14E+10**	**1.47E+10**	**0.013**	**0.012**	**0.085**	**0.266**	**0.363**	**0.059**
Change (all inflows minus outflow)(kg)			**-3.0**	**-0.1**	**-2.9**	**7.20E+09**	**-1.65E+10**	**0.007**	**-0.021**	**-0.620**	**-0.070**	**-0.71**	**-0.03**
Change (% of inflow mass)			**-32%**	**-4%**	**-40%**	**16%**	**-53%**	**107%**	**-64%**	**-88%**	**-21%**	**-66%**	**-33%**

Appendix L Baseflow water quality results

Seepage Input (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Days of baseflow since last sample	Temperature	pH	Conductivity	Dissolved oxygen	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s^{-1}		°C		µS cm^{-1}	%	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	0.0		12.7	7.45	82.8	86.0	3.0	5.9	2.0	4.3	1,210	310	0.016	0.041	0.227	0.386	0.758	0.044
Mean	0.2		12.6	7.36	88.1	87.4	3.2	5.8	2.3	3.6	1,527	240	0.016	0.057	0.610	0.434	1.101	0.046
SD	0.4		0.4	0.45	11.7	3.5	1.3	2.6	0.8	3.3	1,197	121	0.003	0.051	0.702	0.086	0.712	0.010
n			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Date																		
27/05/2019	0.0	0																
7/06/2019	0.0	0																
19/06/2019	0.0	0																
5/07/2019	0.0	0																
23/07/2019	0.0	0																
26/07/2019	0.0	0																
9/08/2019	0.0	0																
13/08/2019	0.0	0																
21/08/2019	1.6	15.8					3.0	5.9	1.7	4.3	2,850	310	0.019	0.114	1.420	0.386	1.920	0.044
3/09/2019	0.2	11.8	12.9	7.76	101.5	91.4	2.0	3.2	3.2	0.0	520	100	0.014	0.016	0.227	0.383	0.626	0.037
6/09/2019	0.6	3.0	12.7	6.87	82.8	84.8												
11/09/2019	0.4	5.0	12.1	7.45	79.9	86.0	4.5	8.4	2.0	6.4	1,210	310	0.016	0.041	0.184	0.533	0.758	0.057
9/10/2019	0.0	18.7																
25/10/2019	0.0	10.8																
	(m^3)							**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
21/08/2019	0.2	15.8						1.73	0.49	1.24	8.32E+09	9.05E+08	0.00001	0.00003	0.00041	0.00011	0.00056	0.00001
3/09/2019	1.1	11.8						3.45	3.45	0.00	5.61E+09	1.08E+09	0.00002	0.00002	0.00024	0.00041	0.00068	0.00004
11/09/2019	0.3	8.0						1.86	0.44	1.42	2.68E+09	6.86E+08	0.000003	0.00001	0.00004	0.00012	0.00017	0.00001
Load								**7.0**	**4.4**	**2.7**	**1.66E+10**	**2.67E+09**	**0.00002**	**0.00006**	**0.001**	**0.001**	**0.001**	**0.0001**

Well 1 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Groundwater inflow volume	**Temperature**	**pH**	**Conductivity**	**Dissolved oxygen**	**Total coliforms**	***Escherichia coli***	**Dissolved reactive phosphorus**	**Ammoniacal nitrogen**	**Nitrate nitrogen**	**Organic nitrogen**	**Total nitrogen**	**Total phosphorus**
		°C		µS cm^{-1}	%	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		12.7	5.98	215.5	66.3	959	<100	0.008	0.033	10.10	0.656	10.80	0.111
Mean		12.2	6.22	216.7	64.1	5,957	206	0.009	0.028	9.36	0.748	10.13	0.119
SD		1.0	0.61	31.0	22.4	10,704	147	0.006	0.018	2.17	0.257	2.026	0.048
n		9	9	9	9	5	5	5	5	5	5	5	5
Date													
27/05/2019													
7/06/2019		13	6.83	212.0	69.7								
19/06/2019													
5/07/2019		10.8	5.98	240.0	96.4	>24,192	74	0.019	0.045	7.56	1.165	8.77	0.190
23/07/2019													
26/07/2019		12.8	7.05	190.2	91.5	3,076	364	0.009	0.033	6.83	0.637	7.50	0.097
9/08/2019													
13/08/2019		10.5	6.01	171.0	71.5								
21/08/2019													
3/09/2019		12.7	5.89	231.5	66.3	200	<100	0.008	0.013	12.20	0.487	12.70	0.111
6/09/2019		12	5.85	275.8	62.8								
11/09/2019		12.2	5.72	215.5	46.5	959	<10	0.003	0.005	10.10	0.795	10.90	0.135
9/10/2019		12.7	7.11	222.0	47.7	548	179	0.005	0.044	10.10	0.656	10.80	0.061
25/10/2019		13.3	5.52	192.0	24.8								
	(m^3)					**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/07/2019	446					1.11E+11	3.30E+08	0.0085	0.0201	3.3710	0.5195	3.9106	0.0847
26/07/2019	194					5.96E+09	7.05E+08	0.0017	0.0064	1.3224	0.1233	1.4522	0.0188
3/09/2019	179					3.58E+08	8.95E+07	0.0014	0.0023	2.1838	0.0872	2.2733	0.0199
11/09/2019	55					5.32E+08	2.77E+06	0.0001	0.0003	0.5605	0.0441	0.6049	0.0075
9/10/2019	132					7.22E+08	2.35E+08	0.0007	0.0058	1.3322	0.0865	1.4246	0.0080
Rest of the drainage year	15					9.46E+07	3.08E+07	0.0001	0.0007	0.1549	0.0101	0.1657	0.0009
Load						**1.19E+11**	**1.39E+09**	**0.013**	**0.036**	**8.92**	**0.871**	**9.831**	**0.140**

Well 2 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Groundwater inflow volume	Temperature	MPN/100 mL	Conductivity	Dissolved oxygen	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		°C		µS cm^{-1}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	
Median		12.3	5.87	189.6	32.2	1,722	37	0.019	0.022	0.623	0.878	1.740	0.195
Mean		12.1	5.87	199.1	35.2	1,795	41	0.027	0.031	2.79	0.86	3.68	0.228
SD		0.8	0.34	29.8	26.4	1,110	35	0.021	0.024	5.06	0.27	5.06	0.136
n		10	10	8	10	5	5	5	5	5	5	5	5
Date													
27/05/2019													
7/06/2019		13.2	5.89	192.3	38.9								
19/06/2019		13	6.08		83								
5/07/2019		11.2	5.94	246.0	72.4	1,722	20	0.063	0.022	11.80	0.88	12.70	0.152
23/07/2019													
26/07/2019		12.8	6.24	173.1	47.5	3,076	10	0.025	0.022	1.31	0.55	1.88	0.093
9/08/2019													
13/08/2019		10.9	5.47		25.4								
21/08/2019													
3/09/2019		12.7	5.85	241.2	39.4	2,620	100	0.019	0.026	0.13	0.63	0.78	0.195
6/09/2019		11.1	5.65	205.9	15.7								
11/09/2019		11.6	5.58	186.9	10.6	1,296	40	0.010	0.014	0.62	1.10	1.74	0.448
9/10/2019		12.2	6.5	174.0	6.4	261	37	0.016	0.073	0.07	1.16	1.30	0.251
25/10/2019		12.4	5.48	173.0	13.0								
	(m^3)					**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/07/2019	981					1.69E+10	1.96E+08	0.0618	0.0216	11.58	0.86	12.46	0.15
26/07/2019	426					1.31E+10	4.26E+07	0.0106	0.0094	0.5580	0.2334	0.8008	0.0396
3/09/2019	738					1.93E+10	7.38E+08	0.0140	0.0192	0.0930	0.4657	0.5779	0.1439
11/09/2019	122					1.58E+09	4.88E+07	0.0012	0.0017	0.0761	0.1347	0.2124	0.0547
9/10/2019	440					1.15E+09	1.62E+08	0.0070	0.0321	0.0304	0.5099	0.5724	0.1105
Rest of year	7					3.85E+08	5.43E+07	0.0001	0.0005	0.0005	0.0082	0.0092	0.0018
Load						**5.25E+10**	**1.24E+09**	**0.095**	**0.085**	**12.3**	**2.21**	**14.6**	**0.50**

Well 3 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Groundwater inflow volume	Temperature	pH	Conductivity	Dissolved oxygen	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		°C		µS cm^{-1}	%	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		12.2	6.29	188.9	63.0	1,565	31	0.004	0.029	8.14	1.07	9.32	0.242
Mean		12.0	6.48	204.5	65.8	1,771	60	0.007	0.028	7.66	1.03	8.73	0.228
SD		0.8	0.64	84.1	24.6	1,710	70	0.008	0.012	2.04	0.47	2.23	0.088
n		9	9	8	9	5	5	5	5	5	5	5	5
Date													
27/05/2019													
7/06/2019		13.5	6.77	403	63.0								
19/06/2019													
5/07/2019		11.8	7.92	144.0	99.3	4,352	175	0.019	0.029	5.42	0.62	6.07	0.099
23/07/2019													
26/07/2019		12.2	6.29	129.9	95.5	247	31	0.004	0.036	5.63	1.07	6.74	0.248
9/08/2019													
13/08/2019		10.9	5.78		77.4								
21/08/2019													
3/09/2019		12.6	6.48	188.4	82.1	2,419	1	0.009	0.012	9.70	0.59	10.30	0.242
6/09/2019		11	6.16	197.5	58.5								
11/09/2019		11.5	6.19	189.4	42.6	1,565	74	0.001	0.02	9.43	1.75	11.20	0.343
9/10/2019		12.4	6.80	188.0	46.0	272	17	0.001	0.041	8.14	1.14	9.32	0.210
25/10/2019		12.4	5.97	196.0	28.0								
	(m^3)					**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/07/2019	1070					4.66E+10	1.87E+09	0.0203	0.0310	5.800	0.665	6.496	0.106
26/07/2019	465					1.15E+09	1.44E+08	0.0019	0.0167	2.616	0.499	3.132	0.115
3/09/2019	431					1.04E+10	4.31E+06	0.00388	0.00517	4.181	0.253	4.439	0.104
11/09/2019	133					2.08E+09	9.86E+07	0.0001	0.0027	1.256	0.233	1.492	0.046
9/10/2019	317					8.62E+08	5.35E+07	0.0003	0.0130	2.577	0.361	2.950	0.066
Rest of year	37					1.13E+08	7.00E+06	0.00004	0.00151	0.300	0.042	0.343	0.0077
Load						**6.12E+10**	**2.18E+09**	**0.027**	**0.070**	**16.7**	**2.05**	**18.9**	**0.45**

Well 4 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Groundwater inflow volume	Temperature	pH	Conductivity	Dissolved oxygen	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
		°C		µS cm^{-1}	%	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median		12.1	5.72	145.0	52.5	>24,192	1,046	0.007	0.037	1.450	1.313	2.890	0.265
Mean		12.0	5.77	149.5	46.0	23,115	4,576	0.013	0.036	1.400	1.406	2.842	0.277
SD		1.0	0.30	12.5	27.3	13,045	8,316	0.014	0.016	0.587	0.363	0.704	0.064
n		10	10	9	10	5	5	5	5	5	5	5	5
Date													
27/05/2019													
7/06/2019		12.6	5.75	142.1	66.5								
19/06/2019		14	5.52	161.0	62.5								
5/07/2019		11.1	5.83	163.0	78.3	>24,192	52	0.037	0.039	1.200	1.651	2.890	0.265
23/07/2019													
26/07/2019		12.9	6.34	137.7	69.9	>24,192	31	0.007	0.017	1.450	0.903	2.370	0.212
9/08/2019													
13/08/2019		10.8	5.69		25								
21/08/2019													
3/09/2019		12.2	5.66	168.8	42.5	41,060	19,350	0.005	0.037	2.200	1.313	3.550	0.296
6/09/2019		11.1	5.58	133.5	74.3								
11/09/2019		11.3	5.75	141.1	14.1	19,863	1,046	0.014	0.060	1.570	1.850	3.480	0.376
9/10/2019		11.9	6.20	153.0	16.0	4,650	2,400	0.004	0.027	0.582	1.311	1.920	0.237
25/10/2019		12.2	5.37	145.0	11.1								
	(m^3)					**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/07/2019	476					1.19E+11	2.47E+08	0.0176	0.0185	0.571	0.785	1.375	0.126
26/07/2019	207					5.16E+10	6.40E+07	0.0014	0.0035	0.299	0.186	0.489	0.044
3/09/2019	191					7.84E+10	3.70E+10	0.0010	0.0071	0.420	0.251	0.678	0.057
11/09/2019	59					1.18E+10	6.19E+08	0.0008	0.0036	0.093	0.110	0.206	0.022
9/10/2019	141					6.54E+09	3.38E+09	0.0006	0.0038	0.082	0.184	0.270	0.033
Rest of the year	16					8.57E+08	4.42E+08	0.0001	0.0004	0.0095	0.0215	0.0314	0.0039
Load						**2.68E+11**	**4.17E+10**	**0.021**	**0.037**	**1.5**	**1.54**	**3.0**	**0.29**

Cell 1 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Days of baseflow since last sample	Temper-ature	pH	Conductivity	Dissolved oxygen	Encoder	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s^{-1}		°C		µS cm^{-1}	%	mm	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	0.0		16.2	7.19	98.9	96.6	1,014	156	244	54.0	190	483,455	348,665	0.349	0.488	0.592	4.66	5.83	1.59
Mean	0.8		15.7	7.18	166.4	83.4	1,000	181	656	168	488	798,110	498,435	0.541	0.439	0.681	9.30	10.42	3.14
SD	2.1		2.1	0.11	139.1	37.3	86	155	967	258	711	1,040,554	621,165	0.653	0.362	0.567	12.03	12.62	4.11
n			4	4	4	4	6	4	4	4	4	4	4	4	4	4	4	4	4
Date																			
27/05/2019	0.0	0																	
7/06/2019	0.0	0	12.7	7.28	375	29.1	868												
19/06/2019	0.0	0																	
5/07/2019	0.0	0						225	2,090	553	1,540	2,224,000	1,296,000	1.44	0.730	0.968	26.80	28.50	9.09
23/07/2019	0.0	0					944												
26/07/2019	0.0	0																	
9/08/2019	0.0	0																	
13/08/2019	7.5	0					1,120												
21/08/2019	1.6	15.8						379	380	77.3	303	920,800	686,700	0.606	0.756	1.340	7.58	9.68	2.67
3/09/2019	0.2	11.8	17.6	7.26	99.7	111.2	1,018	30.7	46.3	12.7	33.6	1,530	410	0.092	0.245	0.216	1.08	1.54	0.30
6/09/2019	0.6	3	15.8	7.05	92.8	89.7	1,039												
11/09/2019	0.36	5	16.6	7.11	98.1	103.5	1,010												
9/10/2019	0.0	18.7						87.4	107	30.7	76.3	46,110	10,630	0.024	0.026	0.201	1.74	1.97	0.52
25/10/2019	0.0	10.8																	
									(kg)	**(kg)**	**(kg)**	**(total)**	**(total)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/07/19	0.838								0.108	0.029	0.080	1.15E+09	6.72E+08	0.00007	0.00004	0.00005	0.00139	0.00148	0.00047
21/08/2019	105								110.9	22.6	88.4	2.69E+12	2.00E+12	0.177	0.221	0.391	2.213	2.825	0.779
3/09/2019	975								49.9	13.7	36.2	1.65E+10	4.42E+09	0.099	0.264	0.233	1.164	1.661	0.322
9/10/2019	455								60.9	17.5	43.4	2.62E+11	6.05E+10	0.014	0.015	0.114	0.992	1.121	0.294
25/10/2019	331								35.40	10.16	25.25	1.52E+11	3.51E+10	0.01	0.01	0.07	0.58	0.65	0.17
Rest of year	12								1.32	0.38	0.94	5.69E+09	1.31E+09	0.0003	0.000	0.002	0.022	0.024	0.006
Load									**258.6**	**64.3**	**194.4**	**3.13E+12**	**2.11E+12**	**0.30**	**0.51**	**0.81**	**4.97**	**6.28**	**1.40**

Cell 2

Date	Temperature	pH	Conductivity	Dissolved oxygen	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	*Escherichia coli*	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	°C		µS cm^{-1}	%	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	15.3	7.06	132.9	102.0	94.1	105	30.7	74	>24,192	10,860	0.26	2.04	0.050	3.62	6.73	1.22
Mean	16.2	7.06	165.8	83.6	114	95.9	29.4	67	22,873	8,995	0.46	1.80	0.057	3.35	5.37	1.13
SD	4.9	0.19	72.3	42.6	61.7	37.5	15.3	22	6,028	6,284	0.41	1.43	0.056	1.00	2.38	0.33
n	6	6	6	6	3	3	3	3	3	3	3	3	3	3	3	3
Date																
27/05/2019																
7/06/2019	11.8	7.09	257	24.2												
19/06/2019																
5/07/2019																
23/07/2019																
26/07/2019	13.2	6.86	257.3	35.5	183	128	44.0	84.0	>24,192	14,136	0.196	2.040	<0.001	4.19	6.73	1.40
9/08/2019																
13/08/2019																
21/08/2019																
3/09/2019	15.7	7.08	146.7	107.5	94.1	105	30.7	74.3	27,550	1,990	0.94	0.257	0.112	2.25	2.62	0.77
6/09/2019	14.8	6.89	113.7	96.4												
11/09/2019	16.0	7.03	101.0	122												
9/10/2019	25.6	7.40	119.0	115.9	64.5	54.6	13.4	41.2	16,070	10,860	0.255	3.090	0.058	3.62	6.77	1.22
25/10/2019																

Cell 3

Date	Temperature	pH	Conductivity	Dissolved oxygen	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	Escherichia coli	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	°C		µS cm^{-1}	%	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	14.8	6.95	151.3	92.4	86.1	77.2	25.2	52.1	26,275	1,018	0.122	0.705	0.099	2.082	2.88	0.710
Mean	15.6	7.02	175.2	96.3	86.1	77.2	25.2	52.1	26,275	1,018	0.122	0.705	0.099	2.082	2.88	0.710
SD	4.5	0.25	82.0	59.5	74.8	66.2	14.6	51.5	1,803	704	0.007	0.955	0.129	0.592	1.67	0.323
n	6	6	6	6	2	2	2	2	2	2	2	2	2	2	2	2
Date																
27/05/2019																
7/06/2019	11.2	6.80	330	56.3												
19/06/2019																
5/07/2019																
23/07/2019																
26/07/2019	13.2	6.89	194.6	25.0	139	124	35.5	88.5	>24,192	1,515	0.127	1.38	0.190	2.500	4.070	0.938
9/08/2019																
13/08/2019																
21/08/2019																
3/09/2019	15.0	7.02	142.5	89.4	33.2	30.4	14.8	15.6	27,550	520	0.117	0.029	0.008	1.663	1.700	0.481
6/09/2019	14.6	6.88	114.0	95.3												
11/09/2019	15.4	7.00	110.2	111.5												
9/10/2019	24.3	7.50	160.0	200												
25/10/2019																

Cell 4

	Temperature	pH	Conductivity	Dissolved oxygen	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	Escherichia coli	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
Date	°C		µS cm^{-1}	%	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	12.1	7.01	118.0	74.8	55.1	70.7	17.2	53.5	14,395	900	0.097	0.205	0.037	1.629	2.120	0.554
Mean	12.7	7.06	128.7	73.0	55.1	70.7	17.2	53.5	14,395	900	0.097	0.205	0.037	1.629	2.120	0.554
SD	1.8	0.21	27.6	17.1	22.1	29.9	5.9	24.0	14,998	778	0.026	0.146	0.052	0.330	0.778	0.185
n	5	5	5	5	2	2	2	2	2	2	2	2	2	2	2	2
Date																
27/05/2019																
7/06/2019	10.9	6.83	176.4	58.0												
19/06/2019																
5/07/2019																
23/07/2019																
26/07/2019	14.9	7.01	127.8	54.2	70.7	91.8	21.3	70.5	>24,192	350	0.115	0.308	<0.001	1.862	2.67	0.684
9/08/2019																
13/08/2019																
21/08/2019																
3/09/2019	14.4	7.21	118.0	95.1	39.4	49.5	13.0	36.5	3,790	1,450	0.078	0.101	0.074	1.395	1.57	0.423
6/09/2019	12.1	6.92	112.4	74.8												
11/09/2019	11.2	7.33	109.1	82.7												
9/10/2019																
25/10/2019																

Cell 5 (values in rows shaded green are mass loads (kg), total volumes (discharge, m^3) or total numbers (bacteria))

	Instantaneous flow estimate	Days of baseflow since last sample	Temper-ature	pH	Conductivity	Dissolved oxygen	Encoder	Turbidity	Total suspended solids	Volatile suspended solids	Inorganic suspended solids	Total coliforms	Escherichia coli	Dissolved reactive phosphorus	Ammoniacal nitrogen	Nitrate nitrogen	Organic nitrogen	Total nitrogen	Total phosphorus
	L s^{-1}		°C		µS cm^{-1}	%	mm	NTU	g m^{-3}	g m^{-3}	g m^{-3}	MPN 100 mL^{-1}	MPN 100 mL^{-1}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}	g m^{-3}
Median	0.3		13.1	7.00	123.0	114.9	1,031	24.8	26.3	10.1	13.0	30,770	2,800	0.054	0.025	0.532	1.324	1.765	0.267
Mean	1.2		13.8	7.00	129.4	121.1	1,037	26.4	27.2	11.1	16.1	33,783	3,424	0.063	0.040	0.555	1.367	1.962	0.286
SD	2.0		3.4	0.58	22.0	55.9	14	9.0	7.5	4.8	6.6	21,701	3,461	0.024	0.036	0.338	0.302	0.584	0.061
n			7	7	7	7	8	6	6	6	6	6	6	6	6	6	6	6	6
Date																			
27/05/2019	0	0																	
7/06/2019	0.25	0	12.1	6.05	171.8	44.5													
19/06/2019	0	0																	
5/07/2019	0.8	27.6					1,050	28.2	29.8	19.7	10.1	68,670	3,110	0.093	0.019	1.170	1.921	3.110	0.377
23/07/2019	0.15						1,029												
26/07/2019	0.19	21.0	11.6	7.07	141.8	160.0	1,028	31.6	22.9	10.4	12.5	>24,192	364	0.053	0.056	0.244	1.270	1.570	0.261
9/08/2019	1.4																		
13/08/2019	7.1		10.9	6.77	123.0	65.0	1,024												
21/08/2019	3.0	21.3						40.6	39.5	12.1	27.4	36,540	4,100	0.093	0.019	0.592	1.349	1.960	0.266
3/09/2019	0.4	11.6	14.2	7.43	132.6	164.6	1,033	15.6	18.6	5.4	13.2	4,160	2,490	0.044	0.010	0.588	1.002	1.600	0.206
6/09/2019	1.5		13.1	6.75	113.3	100.9	1,060												
11/09/2019	0.12	7.6	13.4	7.00	109.0	114.9	1,047	21.1	22.5	9.7	12.8	43,520	630	0.054	0.031	0.259	1.360	1.650	0.268
9/10/2019	0.01	27.5	21.1	7.90	114.0	198	1,021	21.3	29.6	9.1	20.5	24,810	9,850	0.041	0.107	0.475	1.298	1.880	0.338
25/10/2019																			
	(m³)								**(kg)**	**(kg)**	**(kg)**	**(total no.)**	**(total no.)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
5/07/2019	2974								88.6	58.6	30.0	2.04E+12	9.25E+10	0.28	0.06	3.48	5.71	9.25	1.12
26/07/2019	1291								29.6	13.4	16.1	3.23E+11	4.70E+09	0.068	0.072	0.315	1.639	2.03	0.34
21/08/2019	1300								51.4	15.7	35.6	4.75E+11	5.33E+10	0.121	0.025	0.770	1.754	2.55	0.35
3/09/2019	937								17.4	5.1	12.4	3.90E+10	2.33E+10	0.041	0.009	0.551	0.939	1.50	0.19
11/09/2019	370								8.3	3.6	4.7	1.61E+11	2.33E+09	0.020	0.012	0.096	0.503	0.61	0.10
9/10/2019	1334								39.5	12.1	27.4	3.31E+11	1.31E+11	0.055	0.143	0.634	1.732	2.51	0.45
Rest of the year	446								13.2	4.1	9.1	1.11E+11	4.39E+10	0.02	0.05	0.21	0.58	0.84	0.15
Total load									**248.0**	**112.6**	**135.4**	**3.48E+12**	**3.52E+11**	**0.60**	**0.36**	**6.06**	**12.86**	**19.28**	**2.70**
Change (all inflows minus outflow)(kg)									-10.6	48.3	-59.0	1.45E+11	1.80E+12	0.1	-0.4	-34.2	1.2	-33.4	-0.2
Change (% of inflow mass)									-4%	75%	-30%	-4%	-84%	32%	-50%	-85%	11%	-63%	-8%

Appendix M Sampled and unsampled events and loads

Sampled events have been circled in Figure 17. There are two unsampled events identified with arrows.

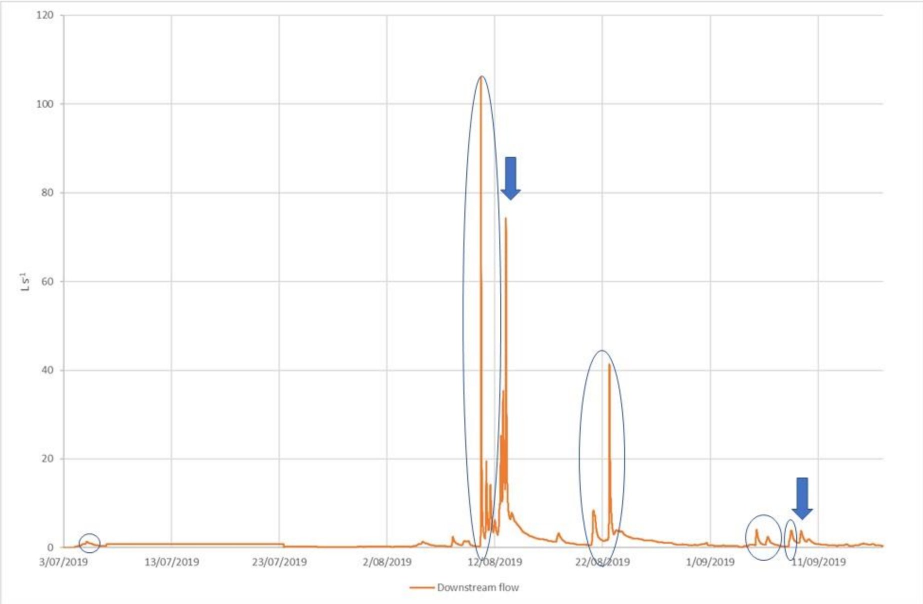


Figure 17: Sampled and unsampled events.

Estimation of loads and load reduction for the unsampled events was explored using linear and exponential regression techniques against total flow as well as peak flow rates. It was found that peak flow rate gave the best fit to these measures using a linear regression. The relationships between event peak height and the loads of TSS, TN and TP measured at the outlet of cell 1 are shown in Figure 18. R^2 values were all >0.99 indicating a strong positive relationship which could be used to calculate loads for the unsampled events with confidence.

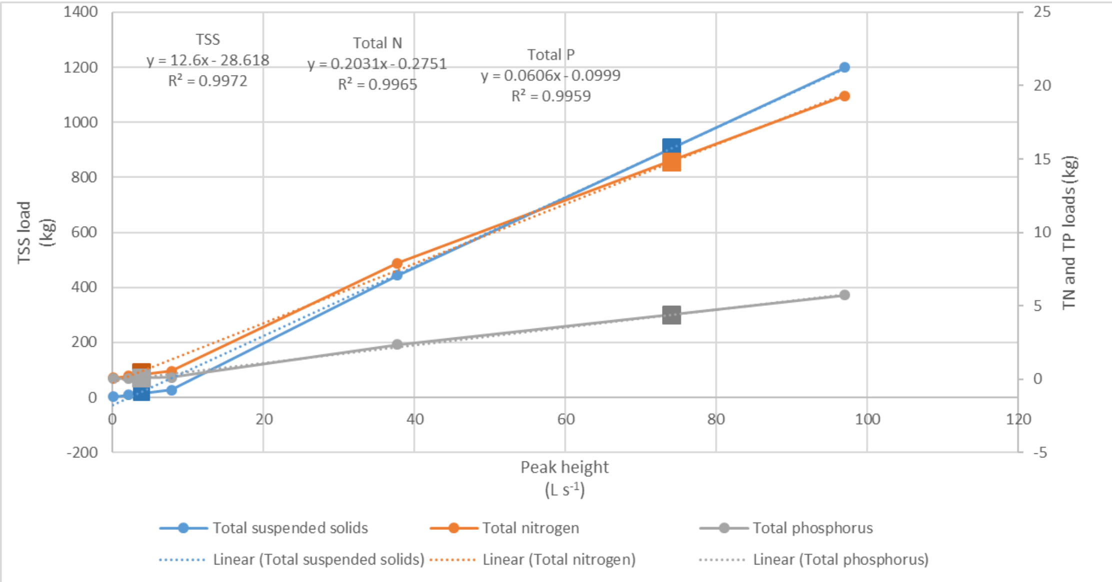


Figure 18: Linear regression models between total event volumes and loads of key pollutants measured at the outlet of Cell 1. Calculated load values for the two unsampled events are added to each data series as large square markers.

Examination of the relationship between peak height and the percentage removal of key contaminants was linear except for the very small event at the beginning of the drainage period where mobilisation of organic debris from the previously dry wetland cells was considered a cause for this anomalous result. Removal rates measured in events which were of similar peak height to the unsampled events were used to estimate likely removals (or increases) for the unsampled events.

Larger events mobilised greater amounts of settleable particulate material from the laneways associated with the relationship between total load and total event volume seen in Figure 18. There was however a reduction of percentage removal as event sizes increased.

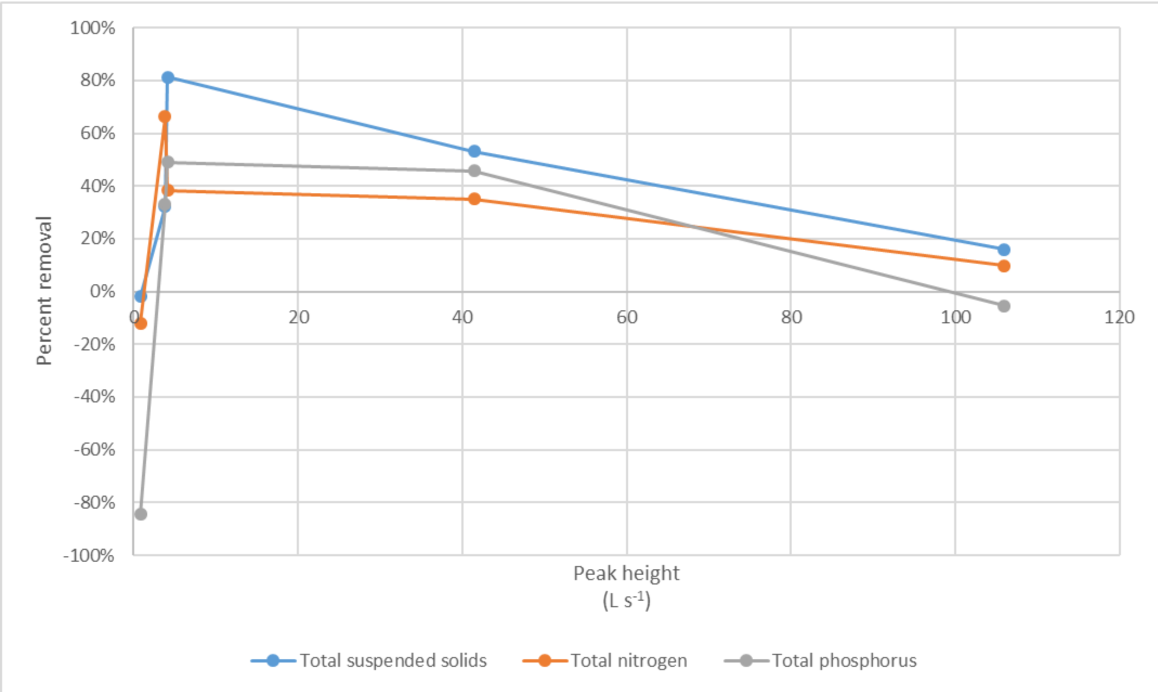


Figure 19: **Relationship between total event size and proportion of key contaminant removal.**

The stratified event method calculated a TN load at cell 1 of 49.3 kg, and at cell 5 of 56.3 kg, whereas RiverLoad calculated a range of 48.0 kg to 74.9 kg at cell 1 and a range of 31.7 kg to 52.6 kg at cell 5. We consider the agreement between EBE and RiverLoad to be good. This provides some confidence that the stratified event method estimate for groundwater TN loads can be relied upon.

For TP, the stratified event method calculated a load at cell 1 of 14.2 kg, and at cell 5 of 13.9 kg. Riverload calculated a range of 13.8 kg to 23.7 kg at cell 1, and 4.16 kg to 9.39 kg at cell 5. Thus the agreement between stratified event method and RiverLoad was reasonably good for phosphorus at cell 1, but weaker at cell 5. However the stratified event method calculated load of groundwater phosphorus was only 1.6 kg, so even if this is an overestimate, it is only a small contribution to the calculated total load of 20.3 kg.

There was a reasonably good fit between total *E. coli* loads at cell 1 and cell 5 and total event volume (R^2 of 0.979 and 0.969 respectively) allowing calculation of loads of unsampled events.

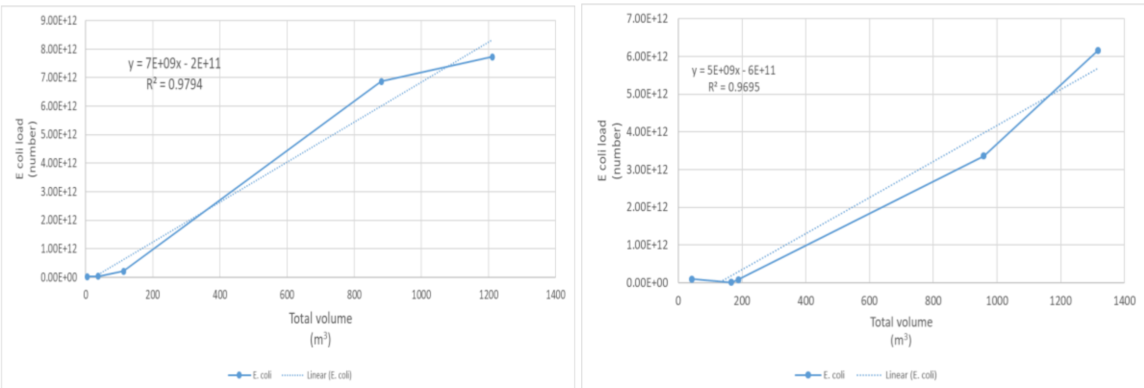


Figure 20: **Relationships between total event flow and total event *E. coli* loads.** Cell 1, left. Cell 5 right.

Appendix N Vegetation assessment

Changes in plant cover, biomass and total nutrient pool were assessed using a variety of methods. Mapping of wetland vegetation was undertaken using imagery derived from photographs taken from a drone. Ground truthing/calibration of the drone imagery involved assessing the abundance of major wetland species within a series of 0.25 x 0.25 m quadrats.

In addition, plant biomass was sampled across the same 10 transects previously monitored during the 2017 drainage year (Sukias et al. 2018). Above ground biomass of representative areas of each key species were harvested using standard size quadrats (0.5 x 0.5 m). Estimates of the relative abundance of each species were made. Harvested vegetation samples were stored in paper bags. Bags and their contents were then dried at 80°C (~7-10 days). Total dry biomass within each wetland cell was calculated from these measurements and typical nutrient values for each species applied to calculate the total nutrient pool within the plants.

Aerial drone imagery is shown in Figure 21. Vegetation cover was 77% in 2019. The native wetland species, *Carex virgata* remained the most common plant species, with *Juncus saraphora* and *Cyperus ustellatus* as the next most common. *Macherina articulata*, *Juncus pallidus* and *Schoenoplectus tabernaemontani* were present at low spatial cover. Non-native species which had entered the wetland as adventives[26] (e.g. Yorkshire fog and lotus) were present at low densities. Calculated total plant biomass during the May 2020 sampling was 4.6 T of wet biomass which equated to 2.03 T dry biomass. Wet biomass during the winter monitoring of the 2017 year was also calculated to be 4.6 T of wet biomass, or 1.47 T of dry biomass[27]. It is unclear whether the dry biomass increase recorded between 2017 and 2019 is real or simply variability associated with a sampling technique which requires estimation of plant cover which had increased to 77% during the May 2020 sampling compared with 66% during the 2017.

Nutrients stored in the plant biomass (above ground only) equated to ~26 kg of nitrogen and ~3 kg of phosphorus. Compared with the nutrient estimations in the 2017 drainage year, these equated to increases of 8 kg of nitrogen and 1 kg of phosphorus. This equates to 11 % of the nitrogen and 8% of the phosphorus removed during this period. These are higher than recorded in 2017 where plant nutrients only equated to 6% of total nitrogen and 2% of total phosphorus removed by the wetland that year.

[26] Adventive plants have not been planted and have self-entered the ecosystem.
[27] Differences between the wet:dry ratios associated with different sampling events can be due to moisture on the outside of harvested biomass.

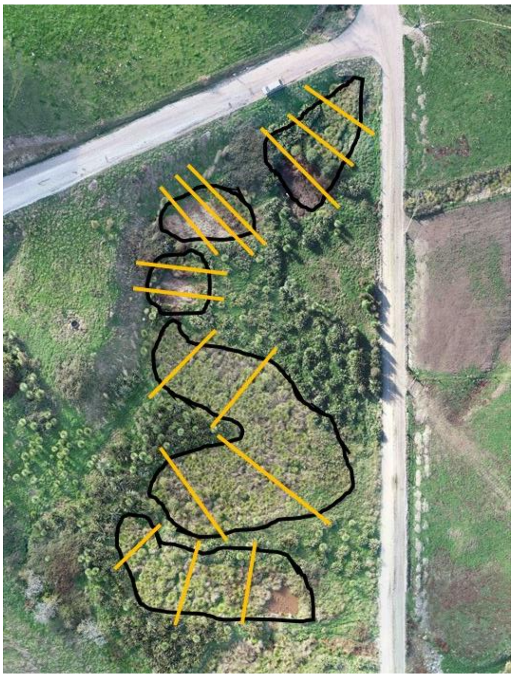


Figure 21: Aerial drone imagery of Baldwin's wetland. The wetland cells are outlined in black and transects are marked in bright yellow.

Table 25: Wetland plant species and biomass. Samples collected across transects in each wetland cell as noted in Figure 17.

Wetland	Transect	Species	Sample Notes notes	Wet (g)	Dry (g)	Dry wt (g) per m²	% dry weight	Area	% cover	Biomass by species (kg)	Transect biomass kg	% cover Transect	N (kg)	P (kg)	Wet mass (kg)
	Above 1	*Carex virgata*	quarter	2003.3	733.8	513.7	36.6%	127	70%	65.2			0.85	0.078	178.1
		Holcus lanatus		368.5	79.0	31.6	21.4%	127	10%	4.0			0.04	0.005	18.7
2	1	*Juncus saraphora*		1263.7	618.0	247.2	48.9%	98	10%	24.2			0.27	0.033	49.5
		Juncus pallidus		682.3	306.3	245.0	44.9%	98	20%	24.0			0.26	0.034	53.5
		Carex virgata		1606.0	698.3	488.8	43.5%	98	70%	47.9			0.62	0.057	110.2
3	1	*Juncus saraphora*		1263.7	629.7	503.8	49.8%	26	20%	13.1			0.14	0.018	26.3
		Carex virgata		1475.9	795.7	557.0	53.9%	26	70%	14.5			0.19	0.017	26.9
4	1	*Juncus pallidus*		682.3	306.3	245.0	44.9%	223	20%	54.6			0.71	0.066	121.7
		Carex virgata		1984.2	859.7	429.9	43.3%	223	50%	95.9			1.24	0.115	221.2
		Cyperus		1323.2	419.6	83.9	31.7%	223	5%	18.7			0.21	0.026	59.0
		Juncus saraphora		1263.7	629.7	503.8	49.8%	223	20%	112.3			1.12	0.135	225.4
		Macherina		361.7	161.3	32.3	47.2%	223	5%	7.2			0.08	0.010	16.1
		pasture		409.4	84.1	33.6	20.5%	223	10%	7.5	296.2	100%	0.08	0.009	36.5
	2	*Juncus saraphora*	1 of 2	1053.9	499	199.6	47.3%	359	10%	71.7			0.79	0.100	151.3
		Carex virgata		1984.2	869.4	652.1	43.8%	359	75%	234.1			3.04	0.281	534.2
		Juncus pallidus		682.3	306.3	183.8	44.9%	359	15%	66.0			0.73	0.092	147.0
	3	*Juncus saraphora*		1263.7	629.7	251.9	49.8%	348	10%	87.7			0.96	0.123	175.9
		Carex virgata		2604.8	1172.5	785.6	45.0%	348	67%	273.4			3.55	0.328	607.3
		Macherina		361.7	170.6	136.5	47.2%	348	20%	47.5			0.52	0.066	100.7
		Ranunculus		409.4	84.1	10.1	20.5%	348	3%	3.5	412.0	100%	0.04	0.004	17.1
	4	*Juncus pallidus*		682.3	306.3	208.3	44.9%	326	17%	67.9			0.75	0.095	151.3
		Juncus saraphora		1263.7	629.7	503.8	49.8%	326	20%	164.2			1.81	0.230	329.6
		Cyperus		1323.2	422.8	118.4	32.0%	326	7%	38.6			0.39	0.046	120.8
		Carex virgata	1/4	1944.4	842.4	337.0	43.3%	326	40%	109.8			1.43	0.132	253.5
		Buttercup		77.9	12.4	4.0	15.9%	326	8%	1.3			0.01	0.0016	8.1
		pasture		409.4	84.1	26.9	20.5%	326	8%	8.8	390.6	100%			
5	1	*Carex virgata*	1/4	2604.8	1141.4	570.7	43.8%	162	50%	92.5			1.20	0.111	211.0
		Holcus lanatus		368.5	75.7	30.3	20.5%	162	10%	4.9			0.04	0.006	23.9
		Juncus saraphora		1116.4	614.1	245.6	55.0%	162	10%	39.8			0.44	0.056	72.3
		Juncus pallidus		682.3	306.3	122.5	44.9%	162	10%	19.8			0.22	0.028	44.2
		Ranunculus		77.9	16.0	3.2	20.5%	162	5%	0.5			0.01	0.001	2.5
		Cyperus		1323.2	422.8	253.7	32.0%	162	15%	41.1	198.6	100%			
	2	*Juncus pallidus*		682.3	306.3	183.8	44.9%	170	15%	31.2			0.34	0.044	69.6
		Carex virgata	1/4	3341.7	1362.4	327.0	40.8%	170	24%	55.6			0.72	0.067	136.3
		Holcus lanatus		368.5	75.7	84.8	20.5%	170	28%	14.4			0.14	0.017	70.2
		pasture		409.4	73.2	87.8	20.5%	170	30%	14.9			0.15	0.018	83.5
		Schoenoplectus tabernaemontani		148.1	37.4	4.5	25.3%	170	3%	0.8	116.9	100%			
Grand total											**2026.0**	**91%**	**26.2**	**2.9**	**4572**