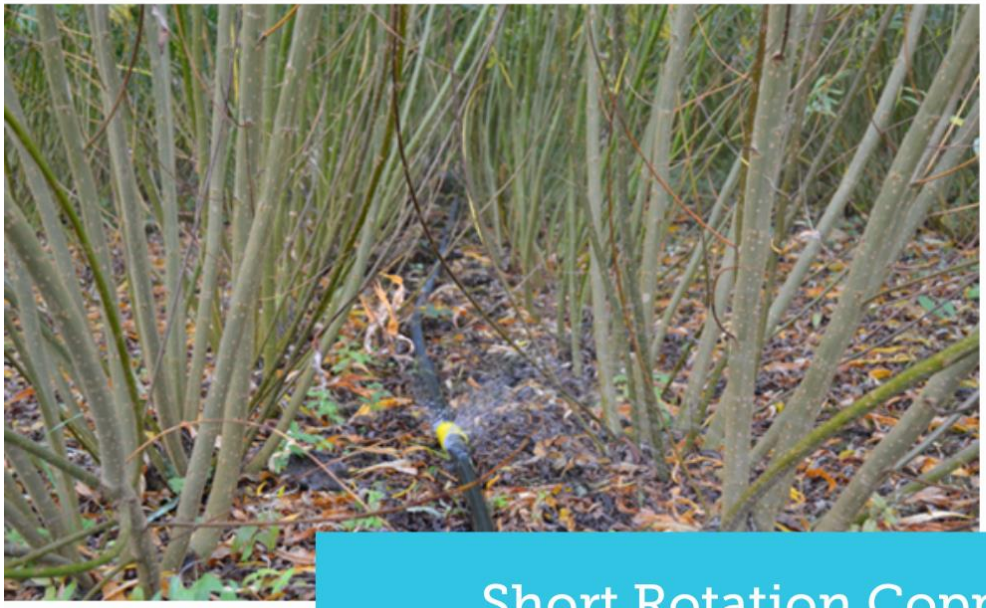
CatchmentCARE
Community Actions for Resilient Ecosystems



Short Rotation Coppice Willow for Point Source Pollution Mitigation

D.T1.5.1 WWTW influences on existing downstream WFD monitoring sites and ecological status

D.T3.1.2 Assessment report of augmented treatment to reduce point source pollution burdens from small WWTWs

Dr Gabriel Gaffney and Prof Phil Jordan
School of Geography and Environmental Sciences
Ulster University
Coleraine

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Catchment CARE
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Short Rotation Coppice Willow for Point Source Pollution Mitigation

Ulster University

Comhairle Contae Dhún na nGall
Donegal County Council

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Contents

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Executive Summary

This report, for the SEUPB funded CatchmentCARE project covers two deliverables. First, in T1 *"Scoping and Action Targeting"* and part of Activity A.T1.5 *"Hydrological connectivity and point source pollution: scoping studies for willow biomass as point and diffuse pollution mitigation actions"*, the specific Deliverable D.T1.5.1 *"WWTW influences on existing downstream WFD monitoring sites and ecological status"* is reported. Second, in T3 "*Catchment Land Use Actions*" and part of Activity A.T3.1 "*Assessment of augmented treatment to reduce point source pollution burdens from small WWTWs*", the specific Deliverable D.T3.1.2 "*Assessment report of augmented treatment to reduce point source pollution burdens from small WWTWs*" is reported.

This work used short rotation coppice (SRC) willow as a point source mitigation measure for small WWTWs effluent normally discharged to surface head-water streams. These discharges can cause a water quality pressure (phosphorus) and impact (benthic algae) during vulnerable low flow periods.

At two established SRC locations, monitoring upstream and downstream of SRC irrigation showed i) no apparent water quality pressure or impact on a stream adjacent to one site (Bridge End, Co. Donegal) and hence the site was effectively attenuating WWTW effluent, and ii) an observed pressure and impact at a second site (Drumkee, Co. Tyrone) as the irrigation system had been stopped during willow harvest, coincident with the water quality monitoring period.

A protocol of 24hour water sampling was developed as a phosphorus pressure metric to capture the sub-daily variation of stream water polluted by waste-water discharge. This was a better monitoring solution than benthic algae as an impact metric due to inconsistencies in algal data captured at small stream reach scale. At two new sites, scoping datasets indicated both WWTWs were contributing to pressures on the water quality of adjacent streams and with phosphorus concentrations above WFD thresholds for poor water quality.

One of the new sites (Cavanagrow, Co. Armagh) indicated extreme phosphorus pollution during summer low flow periods from a discharged load of approximately 12kg P/yr. Diversion of this load to a new SRC irrigation system effectively reduced stream P concentrations by 95-100% by matching background concentrations—**hence showing an improvement in water quality**. The second site (Liscooley, Co. Donegal) only became operational in early 2023 and so no post-assessment data are available for this report. Monitoring at both sites will, however, be continued in summer 2023 and made available to CatchmentCARE stakeholders. **The two sites continue to treat effluent and so are a legacy from the project.**

A soil archive was collected prior to waste-water irrigation at both new sites and will be tested for soil P saturation properties in the years following the establishment of the SRC irrigation systems.

Results from three of the four sites monitored for water quality (Drumkee, Liscooley, Cavanagrow) showed the immediate impact of waste-water discharges especially during periods of low flow (ecological vulnerability) where mitigation was interrupted or absent. However, background P concentrations upstream and further downstream of the discharges also indicated other pollution pressures. This is an example of the pervasiveness of phosphorus pollution from point sources in headwater streams of low assimilation capacity and where **transferrable SRC mitigation measures are likely to be effective.**

1. Introduction

Phosphorus (P) is a considerable stressor to the aquatic environment and is often considered the limiting agent resulting in eutrophication. Along with diffuse pollution, point source pollution especially from waste-water treatment works (WWTWs) is a significant source of P to lotic systems. To improve water quality, it is therefore desirable to switch off the supply of P before it enters the water environment.

However, while some larger WWTWs are effective in diluting/removing P before it enters aquatic systems, this is less cost productive for smaller WWTW systems (e.g., population equivalent < 500), and alternative methods need to be identified. One method is the use of Short Rotation Coppice (SRC) willow plantations where WWTW discharges are irrigated to the growing trees. Other methods are reviewed in the CatchmentCARE report "*Alternatives to willow coppice plantations for the treatment of small-scale waste-water treatment works (WWTWs) effluent" (D.T1.5.2)*.

In terms of pathways for P loss from land to water (Figure 1), the potential impact of small, point sources in the form of rural WWTWs is within the range of other domestic/urban point sources, and where effluent quality is variable and less assured than much larger treatment systems. The distribution of these potential point sources also requires considered (Figure 2).

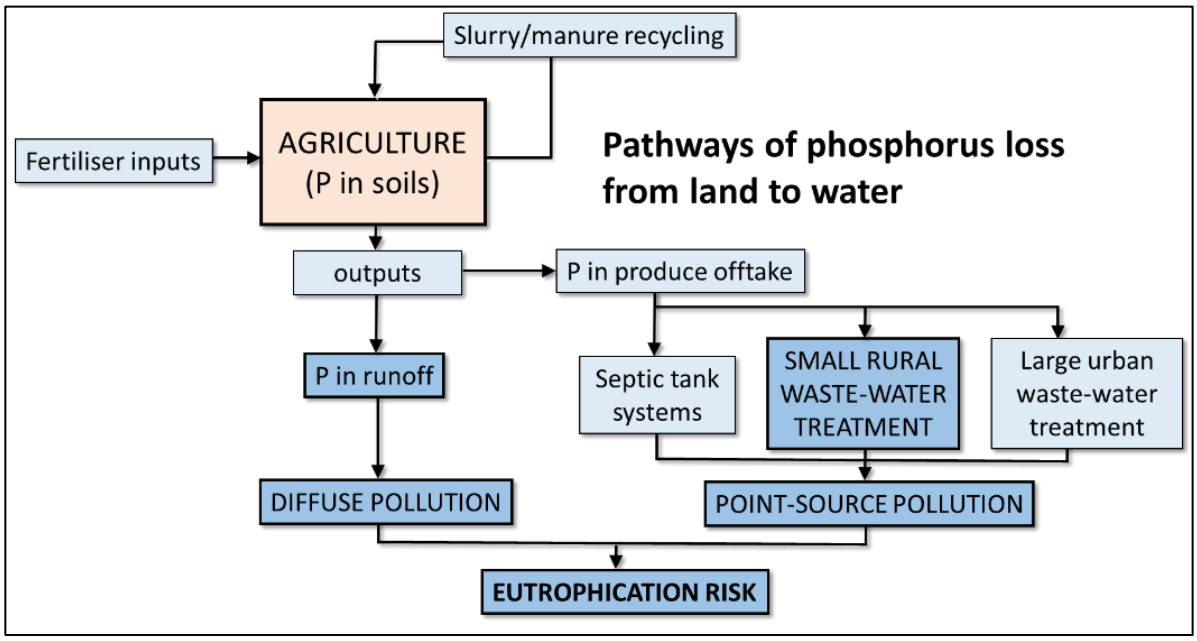

Figure 1 – Schematic of point and diffuse pathways for P loss from land to water, identifying small rural WWTWs as potential point sources.

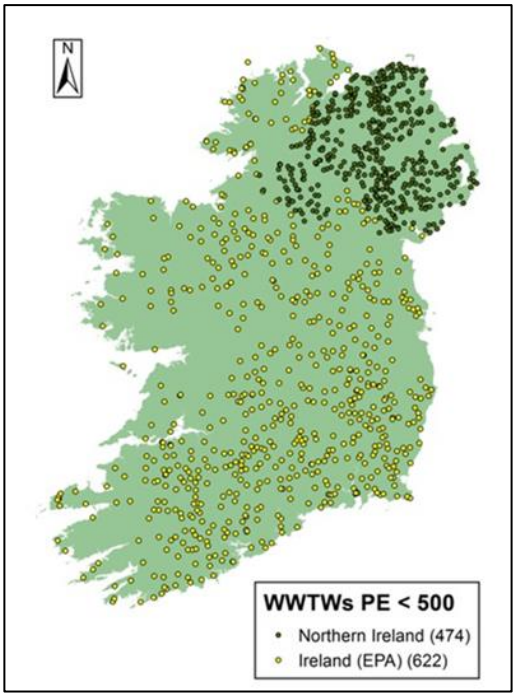

Figure 2 – Distribution of small rural WWTW on the island of Ireland.

The initial stage of this project aimed to identify three potential sites from the Arney, Blackwater or Finn catchments to be used as trial sites to assess the potential of SRC to attenuate P (and other pollutants) from WWTW discharges. A database of sites were prioritised with consultation between Ulster University, AFBI, Donegal County Council, and Northern Ireland Water and based on the following considerations:

1) What catchment does the WWTW discharge into (Blackwater, Arney or Finn)?
2) Who owns the WWTW (public or private) and is the water utility or WWTW owner willing to work on an improvement using willows?
3) What size are the WWTWs (what Population Equivalent [PE] are they serving)?
4) Are they suitably rural with the potential for access to land area for planting?
5) Is there a clear and obvious discharge point (i.e. not underground or in a culvert)?
6) Is the discharge receiving body accessible for sampling and ecological assessment?
7) Is there are clear water quality impact downstream of the discharge point?
8) Is the land owner willing and interested to enter into some kind of arrangement?

The process of prioritising and negotiating sites for SRC irrigation of waste-water (AFBI deliverables) was protracted and ultimately two were selected for new works at Liscooley (Finn catchment) in Co. Donegall and Cavanagrow (Blackwater catchment) in Co. Armagh. Liscooley was selected first, and this enabled troubleshooting with various methods to enable scoping (deliverable D.T1.5.1) and action (deliverable D.T3.1.2) monitoring to be fine-tuned. As an augmentation to these deliverables, this period of negotiating also enabled water quality monitoring at two previously established SRC sites treating waste-water at Bridge End in Co. Donegal and Drumkee in Co. Tyrone. These latter two sites had no prior reported water quality data both upstream or downstream of where waste-water had been diverted to irrigation and so the objective here was to determine if the sites were attenuating pollution and not leaking to surface waters.

This part of CatchmentCARE, to provide the 'before' (T1) and 'after' (T3) water quality assessments on the impacts of new SRCs on waste-water treatment, was constrained. This was due to planning and landowner barriers to installing SRC at WWTW sites and COVID-19 restrictions all of which combined to reduce the amount of time for 'after' surveys. Nevertheless, the monitoring protocol developed provided a benchmark for assessing immediate impacts on water quality, which is reported here, and a basis for further surveillance for both water and soil quality as the new SRC sites become established. In this regard, the three focal points of CatchmentCARE on transferability, demonstrating a water quality improvement, and a legacy for development are all firmly represented in this part of the project.

2. Methods

2.1. Study areas

The locations of the two new CatchmentCARE SRC sites and two previously established sites are shown in Figure 3. The established Bridge End and Drumkee sites were part of the previous SEUPB INTERREG IVA funded ANSWER project.

Figure 3 – Study location of new (red circles) and established (teal circles) SRC sites for treating waste-water. Population equivalents (PE) also indicated.

2.2. Bridge End and Drumkee

Monitoring was undertaken at two WWTW sites where effluent irrigation was established under the previous INTERREG funded ANSWER project. This was done to place mature sites into water quality context with potential sites being scoped for CatchmentCARE SRC schemes. The original ANSWER project assessment was based on volume of effluent irrigated and, by definition, not discharged to the adjacent water-courses – compared to previous conditions (similar to CatchmentCARE sites). Water quality monitoring included periodic P analysis in shallow groundwater piezometers and surface water. The additional monitoring included and reported here places the two sites into a more frequently sampled SRP pressure and diatom impact context. The assumption is that the sites should not show any significant pressures and/or impact change between upstream and downstream monitoring locations. That is to say that WWTW effluent irrigated to mature SRC sites has no subsequent water quality pressure or impact.

The Bridge End WWTW, has an agglomeration population equivalent (PE) of 391 and a design PE of 260 (according to EPA-Eden), although it is classified as being in the agglomeration PE sub-category of 500 to 1,000. It is a secondary treatment WWTW that discharges into the Skeoge River (EPA code 39S01). The Skeoge River is 2nd order and part of the Burnfoot sub-catchment, which in turn is part of the Lough Swilly catchment. The designed point of final treatment effluent discharge is adjacent to the WWTW (Figure 4). There are four EPA monitoring points on the Skeoge, although only RS39S010050 and RS39S0100300 have been monitored since 1991. The most recent EPA Q-value at these monitoring points was in 2016 giving a Q-value of 3 and the Skeoge is considered to be in poor condition. WWTW effluent is irrigated (variably) to a SRC site established under the previous INTERREG funded ANSWER project. The estimated area of the willow SRC at Bridge End is 7 hectares (Figure 4).

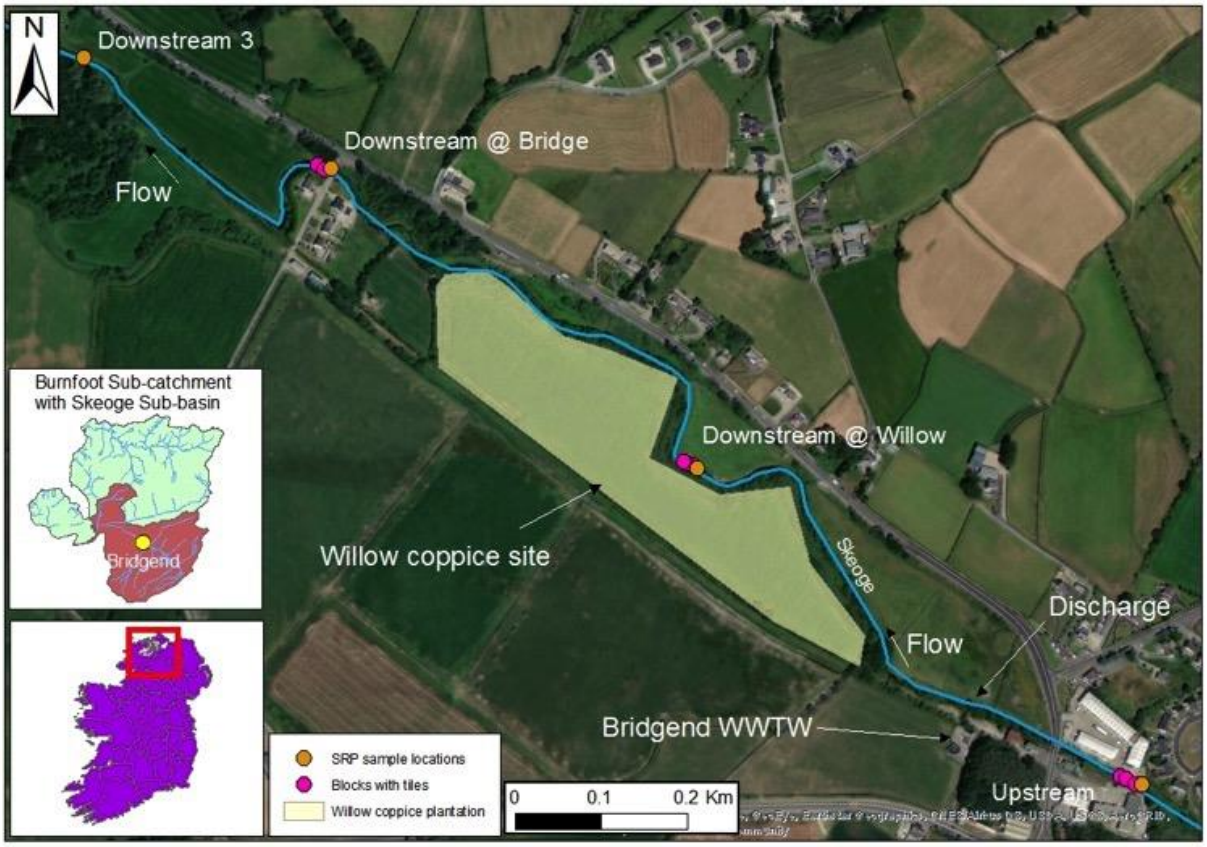

Figure 4 - Map of Bridge End showing the location of monitoring points upstream and downstream of the SRC willow site.

The Drumkee WWTW, has an agglomeration population equivalent (PE) of 17 and a design PE of 12. The WWTWs discharges into an adjacent stream (unknown name) that is within the Blackwater catchment. The estimated area of the Willow Coppice Plantation at Drumkee is 1 hectare (Figure 5).

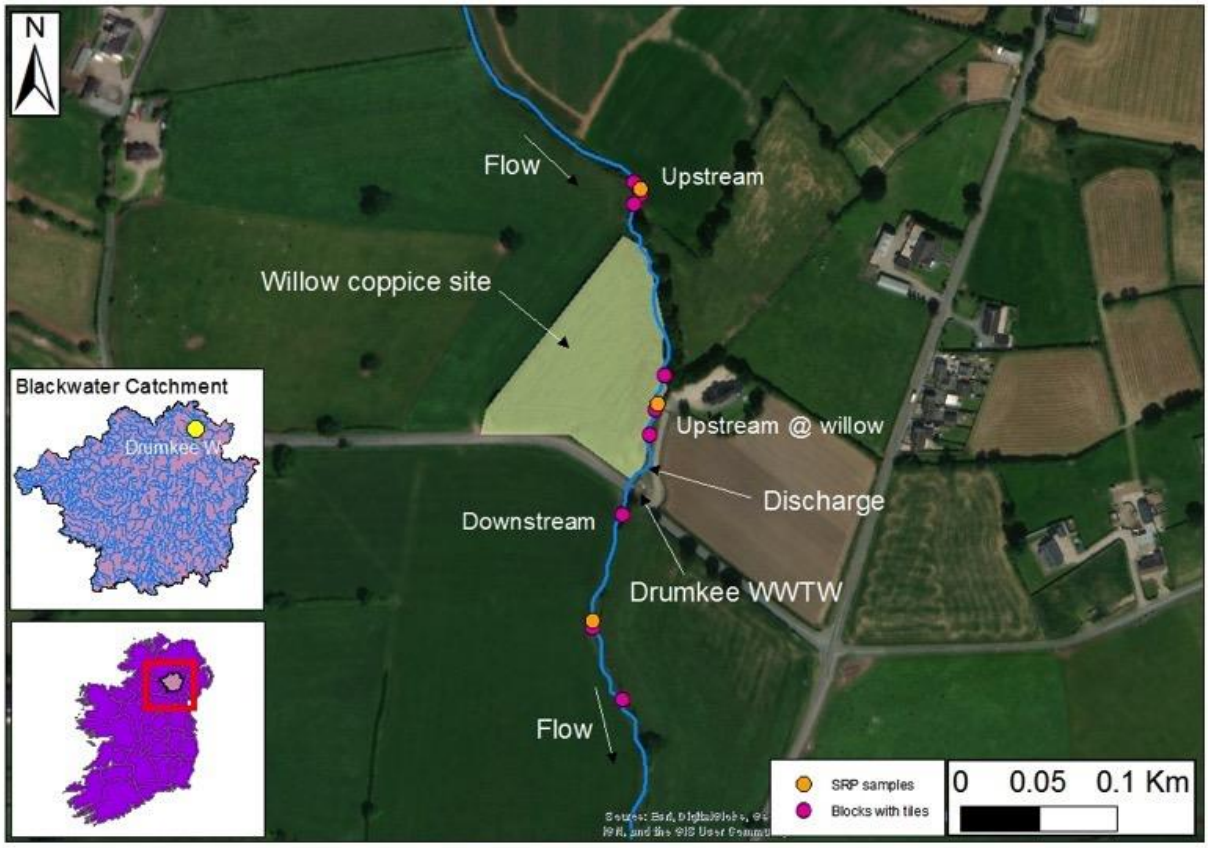

Figure 5 - Map of Drumkee showing the location of monitoring points upstream and downstream of the SRC willow site.

Water quality monitoring at Drumkee and Bridge End focused on a low flow summer and autumn period (July to November 2019) where dilution would be minimal and could indicate chemical and/or biological pollution from a point source. As a pressure indicator samples for soluble reactive phosphorus (SRP) were collected weekly through this period at upstream-adjacent-downtream sites. Streamwater samples were filtered using a 20 mL syringe and a Polyethersulfone (PES) membrane filter, of pore size 0.45 µm, returned to the laboratory in cool-boxes and P determined by solution spectrometry (UVmini 1240, Shimadzu, Japan) using the molybdate blue method (Murphy and Riley, 1962). As an impact indicator, artificial substrate tiles (100mm x 100mm) were fixed to concrete blocks (triplicates) and left in-stream for benthic algae to develop. Algae were measured after 4, 8 and 12 week exposures using a field fluorometer for determining pigment (Benthotorch, bbe, Germany) and recording diatoms (µg/cm^2) on each tile.

Results from upstream/downstream chemical measurements were collated as median concentrations and assessed for significant differences using the non-parametric Wilcoxon signed-ranks test and referenced to WFD categories for P. Diatom results were similarly collated and analysed.

2.3. Liscooley

The WWTW at Liscooley Housing Scheme (LHS) serves a current population equivalent (PE) of 60 and has a design PE of 70. Effluent from this WWTWs discharges into the adjacent Blairstown stream (EPA code 01B22) (Figure 6). This stream, which has an approximate width of 3 to 4 m, is a

2nd order stream that is a tributary of the Finn River. It is approximately 3.4 km in length and achieves its 2nd order status following the input of the 1st order stream Leaght (EPA code 01L18). The only EPA monitoring point on the Blairstown stream (RS01F011000) is at "Finn (Donegal) - Liscooly Bridge". However, this site has not been monitored since 1990 when it was classified as "good" status (i.e. EPA Q-value of 4).

A number of early monitoring trials were undertaken at Liscooley using a similar design to the monitoring undertaken at Bridge End and Drumkee (weekly SRP sampling, and diatom monitoring on artificial substrate on 4, 8 and 12 week exposures) (Figure 6). Following these results and a one-off longitudinal survey (sites and data in the Results section), and with dye tracing of the discharge point into the stream (Figure 7), a new monitoring protocol was used to capture the periodic nature of discharges that may have been not fully monitored using the weekly chemical grab sampling method. The new method involved deployment of an automatic water sampler (6712, ISCO, USA) upstream and downstream of the discharge point taking a water sample once every hour over a 24hour period (Figures 8 and 9). The samplers were only deployed following a three-day rain free period each month of the low flow period (with some samples also taken each side of this period). Water samples were returned to the laboratory immediately following the last sample being taken and analysed for SRP. Benthic algae were also measured on a combination of natural cobbles and tiles to increase coverage, and all outputs were recorded (total algae, diatoms, blue-green algae). The new protocols did not start until August 2020 due to the COVID-19 lockdowns.

Figure 6 – Sites for weekly SRP and monthly benthic algae monitoring at Liscooley.

Figure 7 - Dye-tracing at Liscooley showing the WWTW discharge point on the left bank.

Figure 8 - Location of the WWTWs and discharge at Liscooley, the upstream and downstream 24hour monitoring points, and the proposed willow coppice plantation.

Figure 9 - ISCO 24 hour auto-samplers positioned at the Blairstown Stream, Liscooley.

2.4. Cavanagrow

Cavanagrow (Blackwater Catchment) is a townland in Kilclooney Civil Parish, in Barony, County Armagh. The WWTW at Cavanagrow is located at the back of the housing development south-west from the T-section (roads) (Figure 10). The WWTWs discharges into a stream at the back of the WWTWs. The stream is approx. 2.5 m wide, and has a substrate primarily made up of pebbles, cobbles, boulders and sand. The WWTWs has a current PE of 38, with an unknown design PE.

In response to COVID – 19 regulations and lockdown, field work did not commence at Cavanagrow until the 12th June 2020 when artificial substrate tiles set on concrete blocks were positioned at the stream adjacent to the WWTWs. The first round of usable chemical/SRP monitoring did not commence until the 16/17th September 2020 and this was based on the 24hour sampling protocol. For benthic algae, this was based on a combination of natural cobbles and artificial tiles, as with Liscooley (Figure 11 and 12).

2.5. Comparative tests

To test the difference between upstream and downstream chemical/SRP concentrations collected at Liscooley and Cavanagrow using the new sampling protocol, the non-parametric Wilcoxon signed-ranks test (paired test) was employed (e.g., September 2020 SRP upstream *vs* September 2020 SRP downstream). A non-parametric paired test was used as the data did not have a normal distribution and the upstream and downstream sample locations were on the same river. The SRP data were also compiled into box whisker plot charts giving a monthly breakdown of SRP results and an hourly breakdown of SRP results. The SRP results were additionally referenced to EPA and Northern Ireland Environment Agency (NIEA) WFD categories for P in each jurisdiction. Results from the Cavanagrow benthic algae upstream and downstream measurements were collated as average concentrations and assessed for significant differences again using the non-parametric Wilcoxon signed-ranks test (paired test).

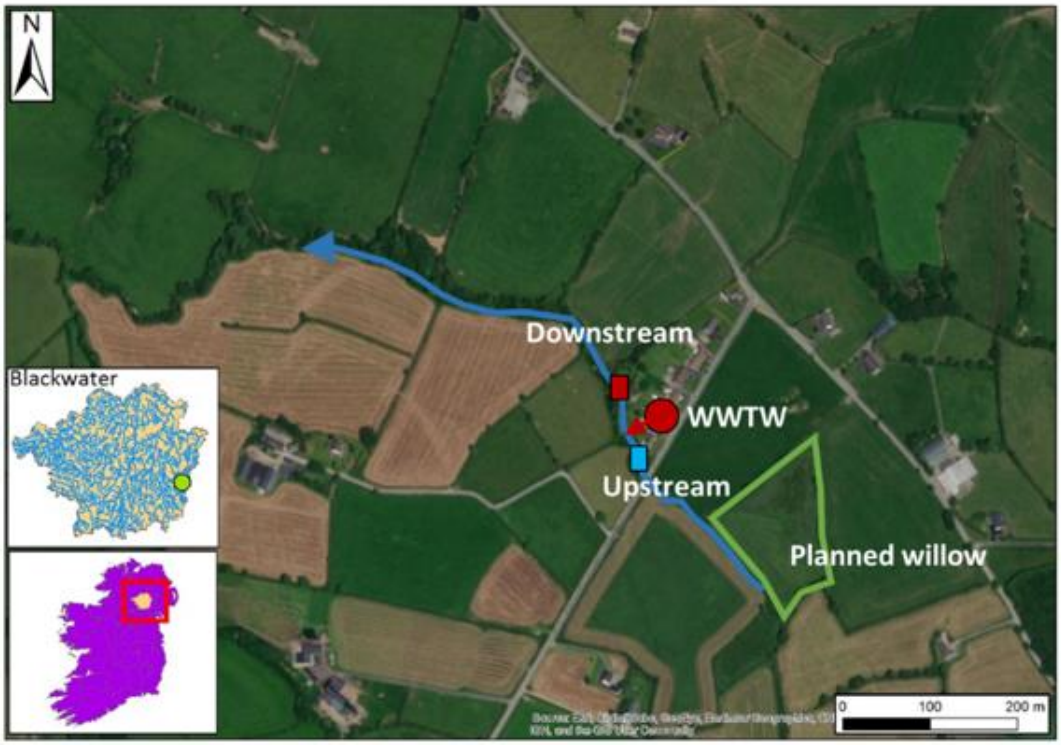

Figure 10 - Location of the WWTWs, the upstream and downstream monitoring points, and the willow coppice plantation at Cavanagrow.

Figure 11 - ISCO auto-sampler positioned upstream at Cavanagrow (block and tiles in foreground).

Figure 12 - Concrete block and tiles (in triplicate) positioned in stream at Cavanagrow

2.6. Reference conditions

To provide assurance with chemical and biological monitoring at Liscooley and Cavanagrow stream sites, the same surveys were repeated in an identified "High" status river. Lowerymore is a fourth order river that rises in the Blue Stack Mountains in Donegal and flows through the Barnsmore Gap into Lough Eske. It is the closest water-body to the study streams that is at "High" status and, at the "Lowerymore – Keadew or New Bridge" monitoring point (EPA code - RS37L010300), the EPA Q-value scoring has been 4 – 5 over three preceding monitoring periods (2011, 2015 and 2018).

Weekly SRP samples were collected at Lowerymore to compliment weekly sampling campaigns at Bridge End, Drumkee and Liscooley. This was not continued with the new 24hour sampling protocol. For algal monitoring artificial tiles were deployed at Lowerymore during the period of biological monitoring at Bridge End and Drunkee, and also the first monitoring trials at Liscooley. Following the new sampling protocol at Liscooley and Cavanagrow, Lowerymore was samped for all benthic algae using the Benthotorch on both tiles and natural cobbles.

2.7. Soil samples

The irrigation of SRC with waste-water uses a principle of biological and chemical attenuation to retain P and hence reduce/eliminate discharges to water. A caveat may be i) the inability for willow to retain P biologically during the winter period, and ii) the chemical saturation of soil by P and loss of P sorbing sites. The two are linked with the former biological attenuation in the summer period anticipated to reduce the potential for soil P saturation. Although testing soils before and after waste-water irrigation was outside the scope of CatchmentCARE, soil surveys using two sampling strategies were conducted at Liscooley and Cavanagrow prior to irrigation starting. Samples were taken in 20 core composited subsamples from 9 georeferenced locations, and also in a standard single W pattern where each georeferenced subsample was also composited (Figures 13, 14, 15 and 16). Soils were air-dried, sieved to 2mm and archived at Ulster University (Coleraine). These sites

and soils can be repeated several times over the next years after irrigation to assess for changes in soil P attenuation properties (no further results reported here).

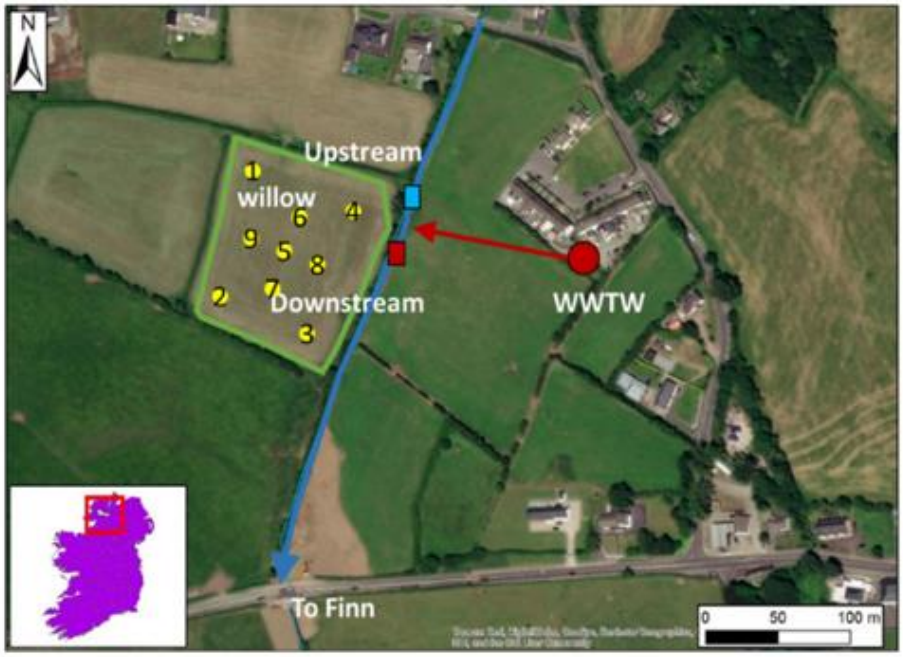

Figure 13 – Location of 9 georeferenced soil sample clusters at the proposed SRC site at Liscooley. Each cluster with 20 composited subsamples.

Figure 14 – Location of 17 soil subsamples (georeferenced) at the proposed SRC site at Liscooley taken in a standard W pattern. Subsamples were composited.

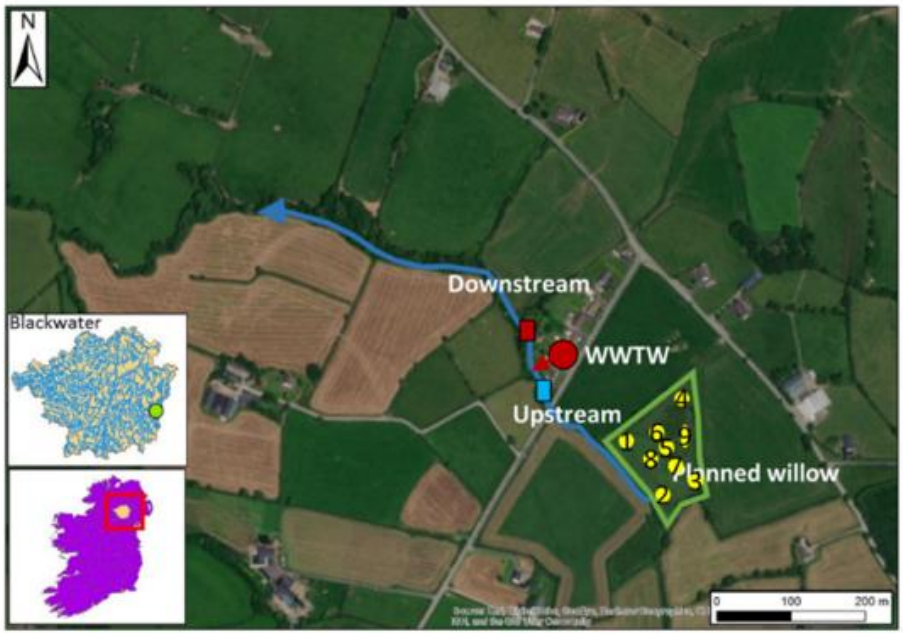

Figure 15 – Location of 9 georeferenced soil sample clusters at the proposed SRC site at Cavanagrow. Each cluster with 20 composited subsamples

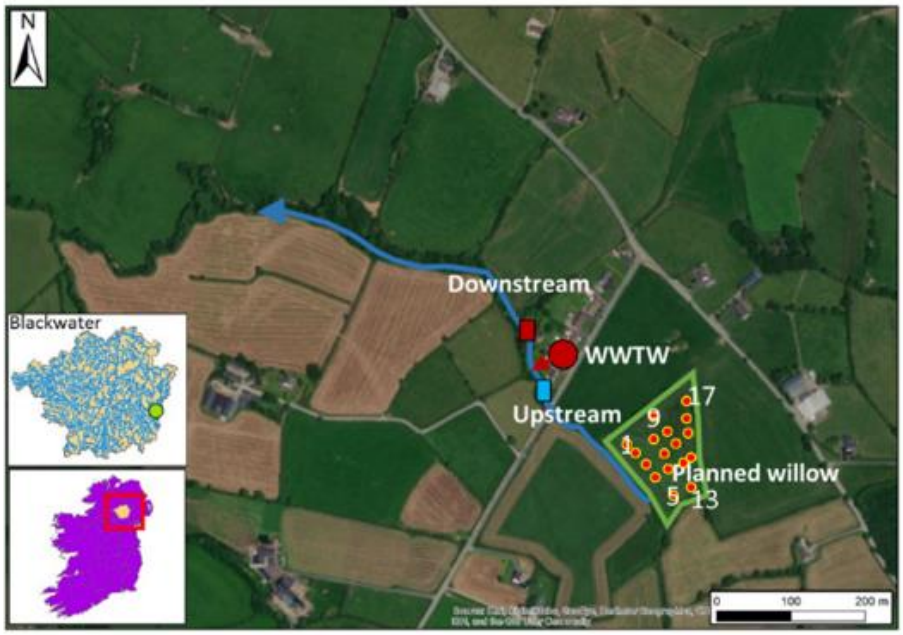

Figure 16 – Location of 17 soil subsamples (georeferenced) at the proposed SRC site at Cavanagrow taken in a standard W pattern. Subsamples were composited.

3. Bridge End and Drumkee results

3.1. Bridge End diatom concentrations

The average diatom concentrations occurring on tiles 1, 2 and 3 at the 'Upstream', 'Downstream@willow' and 'Downstream@Bridge' locations are presented in Table 1. For all tiles the diatom concentrations occurring were less than 2 µg/cm^2. Only 'Upstream' Block 2 on the 10th of October and 'Downstream@bridge' Block 2 on the 15th of August had diatom concentrations above 1.2 µg/cm^2. These blocks were also the only blocks to have diatom concentrations higher than those of the Lowerymore reference site.

Table 1 - Average of diatom concentrations at the Upstream, Downstream@willow and Downstream@bridge locations at Bridgend, and at the Lowerymore reference site. (STDEV in parenthesis).

Diatoms (µg/cm^2)					
Location	Section	15th August	12th September	10th October	Block
Bridgend	Up stream	0.48 (0.09)	0.31 (0.05)	0.3 (0.14)	1
Bridgend	Up stream	0.34 (0.14)	0.3 (0.08)	1.34 (0.23)	2
Bridgend	Up stream	0.37 (0.09)	0.35 (0.03)	0.5 (0.1)	3
Bridgend	D/S - @ Willow	0.13 (0.08)	0.24 (0.09)	0.37 (0.18)	1
Bridgend	D/S - @ Willow	0.58 (0.18)	0.12 (0.09)	0.39 (0.15)	2
Bridgend	D/S - @ Willow	0.23 (0.12)	0.22 (0.1)	0.71 (0.1)	3
Bridgend	D/S 1 @Bridge		0.52 (0.21)	0.45 (0.11)	1
Bridgend	D/S 1 @Bridge	1.63 (0.25)	0.14 (0.08)	0.63 (0.21)	2
Bridgend	D/S 1 @Bridge	0.59 (0.18)	0.54 (0.13)	0.82 (0.18)	3
Lowerymore	Lowerymore Block 1	0.82 (0.21)	0.7 (0.23)		1
Lowerymore	Lowerymore Block 2	0.73 (0.21)	1.06 (0.41)		2
Lowerymore	Lowerymore Block 3				3

Using Wilcoxon signed rank tests to compare the diatom concentration data, significant differences were found between concentrations of diatoms occurring on 'Downstream@bridge' tiles compared to those at 'Upstream and 'Downstream@willow' (both $p < 0.001$) for samples recorded on the 15th August, with 'Downstream@bridge' tiles having higher concentrations of diatoms occurring. Significant differences were also found between diatom concentrations at 'Downstream@willow' and those at 'Upstream' and 'Downstream@bridge' ($p < 0.01$) for samples recorded on the 12th September, and between 'Downstream@willow' and 'Downstream@bridge' for samples recorded on the 10th of October. Diatom concentrations were lower on the 'Downstrean@willow' tiles. Of note was that almost all mean diatom concentrations measured at the Bridgend tiles were lower than the mean diatom concentrations measured at the Lowerymore high status site

3.2. Bridge End SRP concentrations

The weekly SRP analysis results at Bridgend were all below 0.030 mg/L at all sample locations, with P concentrations being slightly higher in July and early August compared to the subsequent sampling periods (see Table 2). Using a Wilcoxon signed rank test no significant difference was found between 'Upstream' and all Downstream SRP concentrations. Significant differences in SRP concentrations were, however, found between SRP concentrations recorded at 'Downstream@willow' and those recorded at 'Downstream@bridge' ($p = 0.011$) and 'Downstream 3' ($p = 0.04$), with SRP values being less at Downstream@willow. Soluble reactive phosphorus

concentrations at the Lowerymore reference site were significantly less than those at locations at the Bridgend site ($p < 0.001$). Based on the the EPA Parameters of Water Quality (2001) report, and at least for soluble P, all sites at Bridgend may be considered unpolluted (i.e. sites that have MRP concentrations of 0.03 mg/l or less are considered to be unpolluted). For this sampling period, these results are in contradiction with EPA data for the Skeoge river.

Table 2 - SRP concentration analysis at Bridgend.

SRP Concentration (mg/L)				
Date	Upstream	D/s @ Willow	D/S @ Bridge	Downstream 3
05/07/2019	0.019	0.014		0.014
11/07/2019	0.027	0.021	0.021	0.021
18/07/2019	0.027	0.030	0.029	0.027
08/08/2019	0.019	0.022	0.023	0.024
16/08/2019	0.019	0.018	0.019	0.019
22/08/2019	0.019	0.018	0.019	0.019
29/08/2019	0.021	0.021	0.021	0.028
05/09/2019	0.017	0.013	0.013	0.015
12/09/2019	0.014	0.014	0.014	0.015
03/10/2019	0.011	0.012	0.013	0.012
10/10/2019	0.011	0.011	0.012	0.012
17/10/2019	0.011	0.009	0.011	0.011
24/10/2019	0.012	0.011	0.012	0.012
07/11/2019	0.008	0.006	0.008	0.009
MEDIAN	0.018	0.014	0.014	0.015

3.3. Drumkee diatom concentrations

The average diatom concentrations occurring on tiles 1, 2 and 3 at the 'Upstream', 'Upstream@willow' and 'Downstream' locations at Drumkee are presented in Table 3. Diatom concentrations varied considerably both between and within sample locations with the highest recording occurring on the 12th of September at 'Downstream' Block 1 (average of 7.86 µg/cm^2). Using Wilcoxon signed rank tests to compare the diatom concentration data, a significant difference between concentrations of diatoms was only found between 'Upstream@willow' and 'Downstream' ($p < 0.001$), with 'Downstream' having significantly higher diatom concentrations and most notably influenced by 'Downstream' Block 1 on 12th September.

Table 3 - Average of diatom concentrations measured at the Upstream, Upstream @ willow and Downstream locations at Drumkee, and at the Lowerymore reference site. (STDEV in parenthesis).

Diatoms (µg/cm^2)				
Location	Section	15th August	12th September	Block
Drumkee	Upstream	0.52 (0.24)	0.5 (0.19)	1
Drumkee	Upstream	0.68 (0.36)	1.1 (0.16)	2
Drumkee	Upstream	0 (0)	2.03 (0.76)	3
Drumkee	Upstream @ willow	1 (0.77)	3.93 (1.81)	1
Drumkee	Upstream @ willow	0.01 (0.01)	0.46 (0.1)	2
Drumkee	Upstream @ willow	0.98 (0.62)	0.44 (0.24)	3

Drumkee	Downstream	2.01 (0.55)	7.86 (1.96)	1
Drumkee	Downstream	0.19 (0.11)	0.59 (0.18)	2
Drumkee	Downstream	0.75 (0.26)	1.67 (0.23)	3

3.4. Drumkee SRP concentrations

The weekly SRP analysis results at Drumkee are presented in Table 4. The SRP values ranged from a low of 0.014 mg/L P at the 'Upstream@willow' location to a high of 0.115 at the Downstream sample location. With the exception of three dates (05th of July, 18th of August and 29th of August) SRP concentrations at the Downstream location were higher than those recorded at the 'Upstream' or the 'Upstream@willow' locations. Using a Wilcoxon signed rank test a significant difference was found between SRP concentrations recorded at 'Downstream' and those recorded at 'Upstream' ($p = 0.028$) and 'Upstream@willow' ($p < 0.01$), with SRP concentrations being higher at the 'Downstream' location. Soluble reactive phosphorus concentrations at the Lowerymore reference site were significantly less than those of all Drumkee site locations ($p < 0.001$). Based on the the EPA Parameters of Water Quality (2001) report, samples collected between the July and August period indicate that the Drumkee stream is seriously/moderately polluted (i.e. MRP values between 0.05 and 0.07 mg/l P indicate moderate pollution, while 0.07 mg/l P or above indicate a seriously polluted site), although SRP concentrations reduced later in the sampling periods due to dilution (increased baseflows).

Table 4 - SRP concentration analysis at Drumkee.

SRP concentration (mg/l)			
Date	Upstream	Upstream @ Willow	Downstream
05/07/2019	0.019	0.014	0.014
11/07/2019	0.023	0.032	0.036
18/07/2019	0.101	0.039	0.115
08/08/2019	0.029	0.035	0.039
16/08/2019	0.049	0.060	0.063
22/08/2019	0.049	0.060	0.063
29/08/2019	0.075	0.042	0.042
05/09/2019	0.041	0.045	0.045
12/09/2019	0.025	0.050	0.060
03/10/2019	0.034	0.038	0.041
10/10/2019	0.036	0.040	0.043
17/10/2019	0.027	0.028	0.030
24/10/2019	0.019	0.019	0.021
07/11/2019	0.019	0.020	0.027
MEDIAN	0.032	0.039	0.042

3.5. Bridge End and Drumkee implications

i. Two mature short rotation coppice (SRC) sites were monitored to place these established WWTW effluent irrigated schemes into context with proposed sites using a nutrient-pressure and benthic ecology-impact framework. Sites were compared with a high status reference site.

ii. At the Bridgend WWTW SRC site, SRP and diatom concentration data indicated that water quality was satisfactory in the river upstream of the site and this was maintained at downstream locations. This strongly suggested that the potential pressure (SRP) from irrigating SRC with WWTW effluent was not transferred to the adjacent river and, subsequently, benthic ecology was not impacted.

iii. At the Drumkee site, two key results were highlighted. Firstly, water quality entering the stream reach before the SRC irrigated site indicated high a SRP pressure and high ecological impact. Secondly, there appeared to be higher SRP pressure and subsequent higher ecological impact downstream of the SRC irrigated site. It was noted that irrigation of the SRC had ceased during harvesting coincident with the monitoring period. This may have resulted in direct effluent discharge, which potentially influenced the data. Nevertheless, the data indicated a higher pressure and impact upstream of the SRC site compared with the difference caused by this potential direct WWTW discharge.

4. Liscooley initial water quality results

The initial water quality data from Liscooley included weekly upstream-downstream SRP concentration data, 4, 8, and 12 week diatom data, and a longitudinal SRP concentration survey along a longer section of the river reach.

4.1. Liscooley diatom concentrations

The average diatom concentrations occurring on tiles 1, 2 and 3 at the Upstream, Downstream 1 and Downstream 2 locations are presented in Table 5. The data show that for all sample dates, with the exception of Upstream tile 3 on the 12th of September, Downstream 2 tiles had higher concentrations of diatom growth than that of Upstream or Downstream 1. Figure 9 also displays limited differences between diatom communities occurring at Upstream and those occurring at Downstream 1.

Table 5 - Average diatom concentrations measured at the Upstream and Downstream 1 and 2 locations at Liscooley, and at the Lowerymore reference site (STDEV in parenthesis).

Location	Section	15th August	12th September	10th October	Block
Liscooley	Upstream Block 1	0.57 (0.07)	0.52 (0.08)	0.62 (0.04)	1
Liscooley	Upstream Block 2	0.72 (0.24)	0.45 (0.1)	0.86 (0.04)	2
Liscooley	Upstream Block 3	0.52 (0.08)	1.41 (1.02)	0.73 (0.15)	3
Liscooley	Downstream 1 Block 1		0.71 (0.18)	0.55 (0.08)	1
Liscooley	Downstream 1 Block 2		0.65 (0.11)	1.21 (0.12)	2
Liscooley	Downstream 1 Block 3		1.2 (0.14)	0.59 (0.12)	3
Liscooley	Downstream 2 Block 1	2.61 (0.37)	3.35 (1.68)	3.69 (0.5)	1
Liscooley	Downstream 2 Block 2	2.49 (0.83)	1.29 (0.21)	3.05 (1.46)	2
Liscooley	Downstream 2 Block 3	6.36 (2.53)	6.74 (1.72)	3.1 (0.53)	3
Lowerymore	Lowerymore Block 1	0.82 (0.21)	0.7 (0.23)		1
Lowerymore	Lowerymore Block 2	0.73 (0.21)	1.06 (0.41)		2
Lowerymore	Lowerymore Block 3				3

Using Wilcoxon signed rank tests to compare the diatom concentration data, significant differences were found between concentrations of diatoms occurring on Downstream 2 tiles, compared to those of Upstream and Downstream 1 ($p < 0.01$) across all sample dates, with Downstream 2 having significantly higher concentrations of diatoms present. A significant difference between diatoms occurring on Upstream and Downstream 1 tiles was observed for the 15th of September sampling date ($P < 0.05$), with Downstream 1 having higher concentrations of diatoms. However, no difference between Upstream and Downstream 1 was observed for the diatom measurements taken on the 10th of October.

4.2. Liscooley SRP concentrations

The weekly SRP analysis results indicate that, with the exception of the 10th and 17th of October 2019, Downstream 1 and Downstream 2 locations had higher P concentrations than the Upstream location. This difference (for Downstream 2) was more substantive in the July and early August sampling period. Indeed, for all sampling locations concentrations of P were much higher in July and early August compared to the subsequent sampling periods (Table 6). Using a Wilcoxon signed rank test a significant difference in P concentrations was found between Upstream and Downstream 2 ($p = 0.014$), with Downstream 2 having a higher P concentration. No significant

difference between Upstream and Downstream 1 or, Downstream 1 and Downstream 2 was found between the dates 16th August to 31st October.

Phosphorus concentrations at the Lowerymore reference site were significantly less than those of Upstream, Downstream 1 and Downstream 2 at the LHS site ($p < 0.001$).

The EPA Parameters of Water Quality (2001) report assigns a Q-value rating of 5 (high status) to rivers with a P (MRP) value of 0.015 mg/L P or less, a Q-value of 4.5 (high status) to MRP values of between 0.02 mg/L P and 0.015 mg/L P, and a Q-value of 4 (Good status) to MRP values of between 0.03 mg/L P and 0.02 mg/L P. Sites that have MRP concentrations of 0.03 mg/L or less are considered to be unpolluted. In contrast, MRP values between 0.05 and 0.07 mg/L P indicate moderate pollution, while 0.07 mg/L P or above indicate a seriously polluted site. Although the SRP fraction (filtered) may be operationally lower than the MRP fraction (unfiltered), some comparison is possible and, based on these categories, Downstream 2 should be considered seriously polluted during the early July period, although it improved to unpolluted by the October sampling period. Indeed, on four of the sampling dates, P concentrations at Downstream 2 were at concentrations of 0.03 mg/L or less (similar to Downstream 1 over the same period), which following the EPA Parameters of Water Quality (2001) is indicative of good (Q-value 4) water quality. However, for five of the sampling periods P concentrations in the Upstream section were above 0.05 mg/L and indicative of moderate pollution.

Table 6 - Weekly SRP concentrations at Liscooley. Note: Lowerymore is a reference site location.

	Concentration P (mg/L)			
Date	Upstream	Downstream 1	Downstream 2	Lowerymore
05/07/2019	0.068		0.086	0.002
11/07/2019	0.068		0.101	0.002
18/07/2019	0.074		0.16	0.002
08/08/2019	0.055		0.067	0.002
16/08/2019	0.033	0.038	0.044	0.002
22/08/2019	0.033	0.038	0.044	0.002
29/08/2019	0.033	0.036	0.037	0.002
05/09/2019	0.02	0.024	0.025	0
12/09/2019	0.026	0.029	0.03	0
03/10/2019	0.021	0.028	0.027	0.002
10/10/2019	0.062	0.039	0.041	0
17/10/2019	0.019	0.024	0.019	0
24/10/2019	0.02	0.026	0.024	0.002
31/10/2019	0.016	0.023	0.02	0.002
MEDIAN	0.033	0.029	0.039	0.002

4.3. Liscooley longitudinal SRP survey

The P concentrations recorded during the one-off reach scale longitudinal assessment conducted on the 12th August 2019 are presented in Figure 17. Figure 17 indicates that for the majority of the assessed portion of the Blairstown stream the P concentrations were between 0.046 and 0.049 mg/L P. The lowest P concentration (0.03 mg/L) was recorded at the Blairstown stream prior to it joining with the Leact stream, while the highest P concentrations (0.067 mg/L P and 0.056 mg/L P) were recorded in the upper-reaches and at the furthest downstream sampling point respectively.

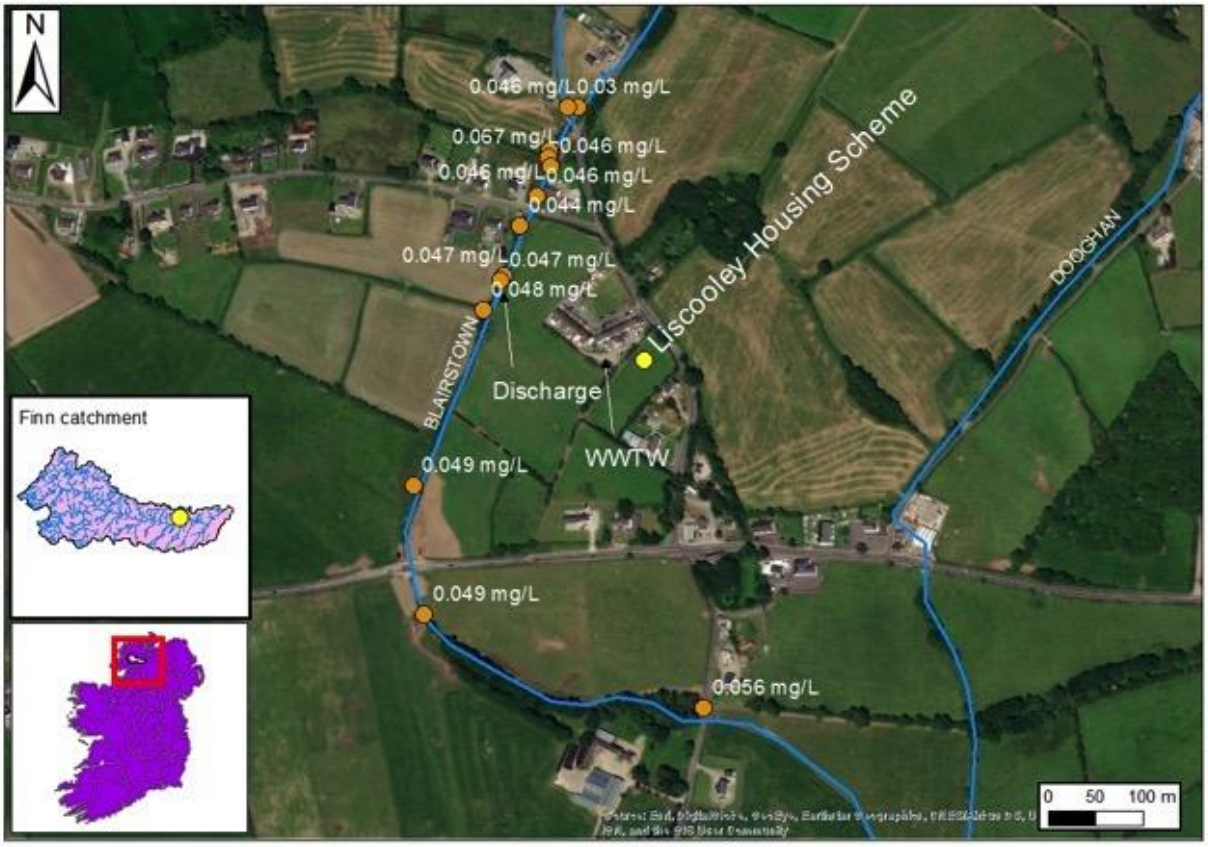

Figure 17 - SRP concentrations recorded during the one-off reach scale longitudinal assessment conducted on the 12th August 2019.

4.4. Decision on new sampling protocols

The results from the weekly SRP data, diatom data, and the longitudinal survey indicated several pollution sources in the Blairstown stream reach. The most prominent of these were at sites further upstream and further downstream of the WWTW discharge point the latter of which only indicated a subtle water quality impact with the techniques used. Following dye tracing (section 2.3), it was noted that discharge from the WWTW was not consistent and that a more appropriate 24hour sampling method should be used (sections 2.3 and 2.4) to further establish SRP pressures and to further constrain benthic algae sampling to shorter reach lengths in the vicinity of the WWTW outfall. Results from this new protocol are presented in section 5 for Liscooley and Cavanagrow.

5. 24hour SRP concentration and benthic algae results

These results cover the period August 2020 to October 2021 using the new sampling protocol for water quality before and following establishment of the SRC site and diversion of waste-water to irrigation.

5.1. Liscooley 24hour SRP results

The results of SRP concentrations from water samples collected monthly (n=13) using 24 hr auto-samplers positioned upstream and downstream of the Liscooley WWTWs discharge locations are presented in Tables 7 (upstream) and 8 (downstream), and in Figures 18 (monthly breakdown of SRP results) and 19 (hourly breakdown of SRP results). The results indicate that for all months SRP concentrations from downstream were higher than that of upstream. This was confirmed using Wilcoxon signed rank tests (paired test) where for each sample period, significant differences in P concentrations were found between upstream and downstream, with downstream having significantly higher P concentrations than upstream ($p < 0.01$ for all). In general, the highest SRP concentrations for both upstream and downstream were recorded in June, August and September, while lower values were recorded in February and March. This trend is more than likely related to the water levels being lower in summer/drier months compared to wetter months, than increased P levels entering the stream from the WWTWs discharge. That is, while the P concentrations coming from the WWTWs are likely to remain relatively constant, reduced water levels due to less rainfall etc. in summer months result in less of a dilution effect occurring and therefore higher P oncentrations being observed in the stream water.

Hourly trends in downstream SRP concentrations at Liscooley indicate peaks/rises at certain times of the day, such as the morning-lunchtime period (8am – 1 pm) and in the evening from 6pm – 8pm, while contrastingly upstream SRP trends remained relatively constant through-out the day. These downstream SRP trends are likely related to increased use of household amenities (e.g., toilets etc.) feeding into the WWTWs at certain times of the day.

Although the SRP fraction (filtered) may be operationally lower than the MRP fraction (unfiltered), some comparison is possible with the EPA WFD classification described earlier (section 4.2). Based on these categories, twelve of the thirteen sampling periods/months (all except October 2020) had SRP peak concentrations in excess of the 0.07 mg/L seriously polluted cut-off point, with October 2020 falling in the moderately polluted range. This indicates that the WWTW discharge at Liscooley is taking Blairstown stream into seriously polluted category.

Table 7 - Hourly breakdown (i.e. midnight to 1 am, 1 am to 2 am… etc.) of soluble reactive phosphorus (SRP) concentrations from water samples collected monthly (n=13) using 24 hr auto-samplers positioned UPSTREAM of the Liscooley WWTWs discharge location.

Time	2020			2021									
	Aug	Sep	Oct	Feb	Mar	Mar	Apr	May	Jun	Aug_**a**	Aug_**b**	Sep	Oct
00:00 - 01:00	0.042	0.047	0.025	0.025	0.026	0.022	0.025	0.021	0.052	0.113	0.057		0.044
01:00 - 02:00	0.042	0.048	0.025	0.025	0.019	0.020	0.023	0.019	0.045	0.116	0.055		0.043
02:00 - 03:00	0.041	0.047	0.025	0.029	0.018	0.019	0.023	0.017	0.052	0.114	0.054		0.040
03:00 - 04:00	0.040	0.045	0.023	0.026	0.017	0.019	0.020	0.016	0.045	0.109	0.059		0.041
04:00 - 05:00	0.038	0.045	0.023	0.021	0.016	0.018	0.019	0.017	0.045	0.106	0.054		0.039
05:00 - 06:00	0.039	0.047	0.023	0.020	0.017	0.019	0.018	0.016	0.043	0.103	0.054		0.037
06:00 - 07:00	0.038	0.046	0.023	0.019	0.017	0.018	0.018	0.016	0.044	0.100	0.054		0.035
07:00 - 08:00	0.038	0.046	0.023	0.021	0.015	0.017	0.018	0.015	0.042	0.098	0.054		0.034
08:00 - 09:00	0.043	0.050	0.023	0.020	0.017	0.019	0.018	0.016	0.042	0.098	0.054		0.046
09:00 - 10:00	0.047	0.043	0.025	0.022	0.019	0.021	0.025	0.016	0.045	0.102	0.054		0.043
10:00 - 11:00	0.041	0.047	0.023	0.019	0.019	0.026	0.022	0.018	0.044	0.110	0.058		0.048
11:00 - 12:00	0.041	0.045	0.023	0.023	0.019	0.024	0.022	0.021	0.052	0.116	0.066		0.049
12:00 - 13:00	0.050	0.043	0.025	0.024	0.019	0.038	0.025	0.020	0.044	0.107	0.055		0.042
13:00 - 14:00	0.034	0.059	0.023	0.017	0.015	0.015	0.018	0.014	0.041	0.085	0.060		0.027
14:00 - 15:00	0.036	0.062	0.023	0.019	0.015	0.021	0.052	0.019	0.049	0.102	0.044	0.058	0.043
15:00 - 16:00	0.038	0.059	0.021	0.020	0.017	0.021	0.022	0.019	0.047	0.097	0.061	0.059	0.042
16:00 - 17:00	0.040	0.058	0.023	0.024	0.017	0.019	0.021	0.025	0.050	0.096	0.054	0.060	0.043
17:00 - 18:00	0.040	0.056	0.023	0.024	0.017	0.022	0.022	0.016	0.070	0.130	0.057	0.063	0.041
18:00 - 19:00	0.041	0.060	0.023	0.027	0.019	0.021	0.023	0.015	0.054	0.125	0.051	0.060	0.039
19:00 - 20:00	0.042	0.056	0.025	0.026	0.019	0.021	0.020	0.016	0.052	0.095	0.051	0.060	0.041
20:00 - 21:00	0.040	0.050	0.027	0.026	0.017	0.023	0.022	0.017	0.048	0.085	0.053		0.042
21:00 - 22:00	0.039	0.053	0.027	0.024	0.023	0.021	0.023	0.019	0.045	0.138	0.059		0.042
22:00 - 23:00	0.040	0.053	0.025	0.022	0.017	0.022	0.025	0.019	0.043	0.119	0.057		0.034
23:00 - 00:00	0.039	0.049	0.025	0.024	0.029	0.019	0.023	0.017	0.046	0.108	0.059		0.046

Table 8 - Hourly breakdown (i.e. midnight to 1 am, 1 am to 2 am… etc.) of soluble reactive phosphorus (SRP) concentrations from water samples collected monthly (n=13) using 24 hr auto-samplers positioned DOWNSTREAM of the Liscooley WWTWs discharge location.

Time	2020			2021									
	Aug	Sep	Oct	Feb	Mar	Mar	Apr	May	Jun	Aug_a	Aug_b	Sep	Oct
00:00 - 01:00	0.057	0.056	0.028	0.035	0.037	0.045	0.203	0.046	0.090	0.183	0.098		0.078
01:00 - 02:00	0.052	0.056	0.028	0.031	0.028	0.038	0.127	0.061	0.110	0.177	0.089		0.066
02:00 - 03:00	0.048	0.052	0.025	0.028	0.024	0.040	0.099	0.036	0.104	0.161	0.081		0.069
03:00 - 04:00	0.043	0.051	0.021	0.026	0.023	0.031	0.092	0.044	0.096	0.137	0.079		0.050
04:00 - 05:00	0.043	0.050	0.023	0.024	0.021	0.029	0.069	0.033	0.072	0.124	0.086		0.043
05:00 - 06:00	0.040	0.052	0.021	0.023	0.020	0.032	0.060	0.031	0.063	0.123	0.083		0.042
06:00 - 07:00	0.039	0.048	0.021	0.023	0.019	0.029	0.063	0.022	0.062	0.118	0.080		0.085
07:00 - 08:00	0.040	0.049	0.021	0.023	0.019	0.036	0.057	0.032	0.070	0.115	0.076		0.039
08:00 - 09:00	0.041	0.049	0.025	0.024	0.026	0.044	0.084	0.034	0.071	0.148	0.102		0.069
09:00 - 10:00	0.069	0.061	0.039	0.032	0.024	0.062	0.150	0.036	0.225	0.192	0.147		0.082
10:00 - 11:00	0.073	0.069	0.035	0.034	0.046	0.122	0.260	0.051	0.241	0.291	0.189		0.082
11:00 - 12:00	0.117	0.082	0.043	0.040	0.038	0.109	0.298	0.125	0.427	0.353	0.289		0.095
12:00 - 13:00	0.092	0.074	0.069	0.058	0.038	0.074	0.366	0.188	0.284	0.261	0.233		0.106
13:00 - 14:00	0.059	0.067	0.025	0.048	0.128	0.057	0.081	0.073	0.097	0.169	0.162		0.067
14:00 - 15:00	0.052	0.065	0.027	0.042	0.034	0.038	0.223	0.062	0.153	0.333	0.104	0.080	0.075
15:00 - 16:00	0.051	0.069	0.025	0.045	0.038	0.045	0.125	0.050	0.163	0.237	0.155	0.126	0.075
16:00 - 17:00	0.060	0.062	0.025	0.041	0.032	0.068	0.116	0.063	0.119	0.226	0.238	0.355	0.090
17:00 - 18:00	0.048	0.084	0.021	0.047	0.042	0.065	0.416	0.064	0.134	0.098	0.090	0.237	0.070
18:00 - 19:00	0.055	0.092	0.041	0.082	0.047	0.067	0.253	0.070	0.181	0.275	0.127	0.236	0.067
19:00 - 20:00	0.090	0.054	0.027	0.046	0.030	0.057	0.182	0.108	0.196	0.196	0.177	0.101	0.074
20:00 - 21:00	0.053	0.059	0.032	0.042	0.032	0.044	0.175	0.089	0.129	0.072	0.174		0.082
21:00 - 22:00	0.081	0.060	0.037	0.043	0.041	0.040	0.175	0.052	0.088	0.307	0.082		0.234
22:00 - 23:00	0.060	0.058	0.053	0.041	0.024	0.051	0.119	0.056	0.079	0.260	0.093		0.067
23:00 - 00:00	0.070	0.061	0.030	0.046	0.039	0.040	0.272	0.057	0.113	0.245	0.114		0.075

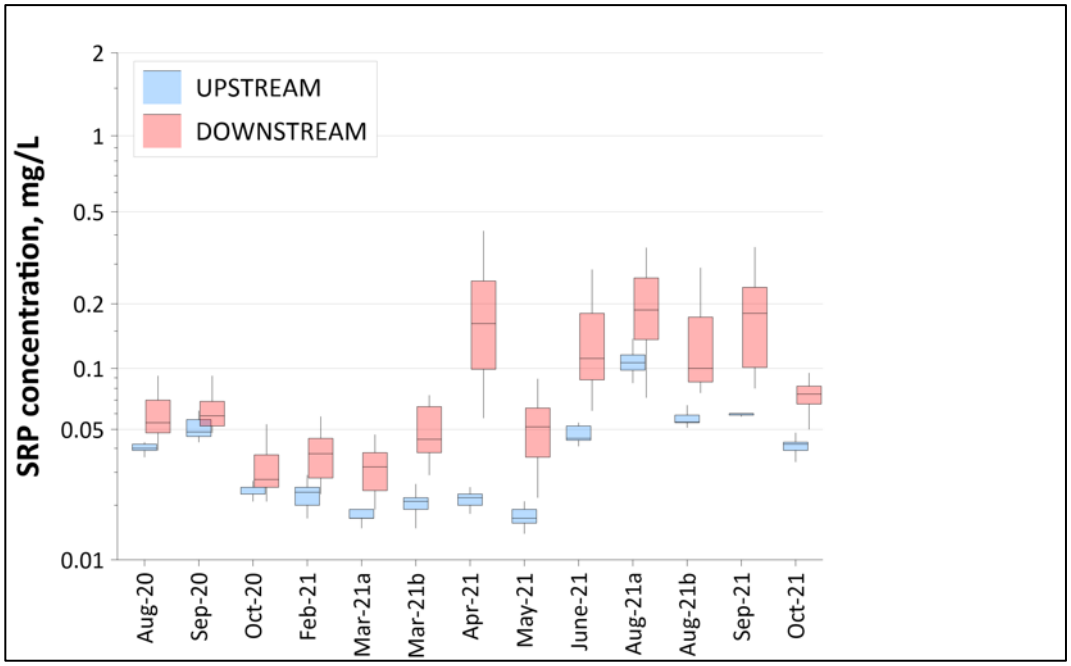

Figure 18 - Boxplots showing the soluble reactive phosphorus (SRP) concentrations from water samples collected monthly between August 2020 and October 2021 (n=13) using 24 hr auto-samplers positioned upstream and downstream of the Liscooley WWTWs discharge location.

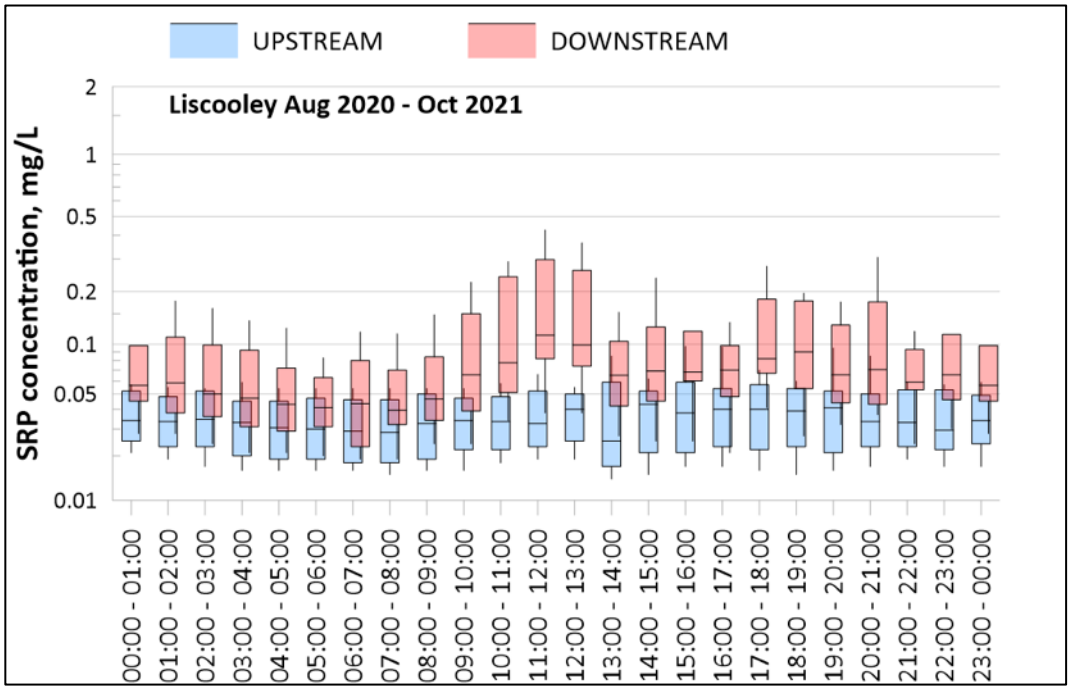

Figure 19 - Boxplots showing the hourly breakdown (i.e. midnight to 1 am, 1 am to 2 am… etc.) of soluble reactive phosphorus (SRP) concentrations from water samples collected monthly (n=13) using 24 hr auto-samplers positioned upstream and downstream of the Liscooley WWTWs discharge location.

5.2. Liscooley benthic algae results in the vicinity of the WWTW discharge point

The average cyanobacteria, blue-green algae, diatoms, and total algae concentrations occurring on tiles at the Upstream and Downstream locations are presented in Table 9, while results for data collected from cobbles are presented in Table 10. In general, the algae concentrations observed at Liscooley were relatively low and comparable to those observed at the high-status reference site at Lowerymore. This may be related to shading at the Blairstown stream in the immediate location of the WWTW discharge point, with the lack of light potentially restricting the growth of algae on the tile substrates. Using Wilcoxon signed rank tests (paired test), significant differences in the concentrations of cyanobacteria, diatoms and total algae growing on tiles upstream and those growing on downstream tiles were observed in the sampling periods June, July (except total concentration) and August in 2020 and in February, March A, March B, June (cyanobacteria only), September and October in 2021. These differences were all at $p < 0.01$, except for March A (cyanobacteria – $p = 0.016$; diatoms – $p = 0.027$; and total concentration – $p = 0.02$) and June (cyanobacteria – $p = 0.027$). Where significant differences between upstream and downstream were observed, concentrations of cyanobacteria, diatoms and total algae were higher upstream than downstream, except for June 2020 where downstream concentrations were higher than upstream, although this result was based only on one concrete block (three tiles) from upstream and downstream. For blue-green algae significant differences in concentrations growing on upstream tiles and those growing on downstream tiles were observed in July 2020 and in June 2021, with Downstream tiles having higher blue-green algae concentrations. For the cobbles however, for all sample periods/months, no difference between upstream and downstream of cyanobacteria, blue-green algae, diatoms or total algae concentrations was observed.

Table 9 - The average (and STDEV) cyanobacteria, blue-green algae, diatoms and total algae concentrations occurring on tiles at the Upstream and Downstream locations in Liscooley and from the Lowerymore reference site.

Position	Month	Cyano	Blue-green Algae	Diatoms	Total Conc.
Upstream	June_2020	0.37 (0.27)	0.01 (0.01)	0.28 (0.2)	0.66 (0.46)
Downstream	June_2020	2.08 (0.82)	0 (0)	2.63 (1.04)	4.71 (1.82)
Lowerymore	June_2020	0.04 (0.04)	0.49 (0.34)	0.18 (0.15)	0.71 (0.51)
Upstream	July_2020	0.37 (0.25)	0.02 (0.05)	0.4 (0.15)	0.8 (0.37)
Downstream	July_2020	0.13 (0.11)	0.18 (0.27)	0.23 (0.11)	0.54 (0.25)
Lowerymore	July_2020	0.13 (0.14)	0.29 (0.32)	0.26 (0.23)	0.68 (0.62)
Upstream	August_2020	0.52 (0.27)	0 (0)	0.54 (0.31)	1.06 (0.58)
Downstream	August_2020	0.29 (0.12)	0.02 (0.1)	0.34 (0.15)	0.65 (0.33)
Lowerymore	August_2020	0.66 (0.46)	3.24 (1.85)	0.97 (0.67)	4.87 (2.68)
Upstream	September_2020	0.68 (0.32)	0 (0)	0.68 (0.35)	1.37 (0.66)
Downstream	September_2020	0.54 (0.51)	0 (0)	0.63 (0.66)	1.17 (1.17)
Lowerymore	September_2020	0.5 (0.23)	2.42 (0.69)	1.14 (0.63)	4.06 (0.97)
Upstream	February_2021	0.95 (0.44)	0 (0)	0.83 (0.43)	1.77 (0.85)
Downstream	February_2021	0.65 (0.22)	0 (0)	0.55 (0.24)	1.2 (0.44)
Lowerymore	February_2021	0.17 (0.2)	0.29 (0.37)	0.21 (0.2)	0.67 (0.55)
Upstream	March_A_2021	0.42 (0.37)	0 (0)	0.37 (0.36)	0.79 (0.72)
Downstream	March_A_2021	0.28 (0.25)	0 (0)	0.26 (0.32)	0.54 (0.55)
Lowerymore	March_A_2021	0.07 (0.08)	0.15 (0.16)	0.23 (0.14)	0.44 (0.33)

Upstream	March_B_2021	0.41 (0.34)	0 (0)	0.34 (0.28)	0.74 (0.61)
Downstream	March_B_2021	0.21 (0.19)	0.02 (0.1)	0.21 (0.3)	0.44 (0.57)
Lowerymore	March_B_2021	0.1 (0.1)	0.3 (0.29)	0.24 (0.13)	0.64 (0.47)
Upstream	April_2021	0.44 (0.45)	0 (0)	0.4 (0.56)	0.84 (1)
Downstream	April_2021	0.29 (0.14)	0 (0.02)	0.21 (0.14)	0.51 (0.3)
Lowerymore	April_2021	0.16 (0.15)	0.84 (0.64)	0.49 (0.41)	1.49 (0.81)
Upstream	May_2021	0.8 (0.98)	0 (0)	0.9 (1.5)	1.71 (2.46)
Downstream	May_2021	0.46 (0.32)	0.15 (0.55)	0.59 (0.95)	1.2 (1.59)
Lowerymore	May_2021	0.27 (0.2)	1.61 (1.05)	0.57 (0.34)	2.45 (1.46)
Upstream	June_2021	0.62 (0.46)	0 (0)	0.59 (0.53)	1.21 (0.98)
Downstream	June_2021	0.44 (0.36)	0.31 (0.73)	0.62 (0.84)	1.37 (1.82)
Lowerymore	June_2021	0.24 (0.16)	0.56 (0.58)	0.31 (0.15)	1.11 (0.74)
Upstream	August_A_2021	0.93 (1.28)	0 (0)	0.97 (1.41)	1.9 (2.69)
Downstream	August_A_2021	0.73 (0.32)	0.04 (0.21)	0.77 (0.36)	1.54 (0.68)
Lowerymore	August_A_2021	0.52 (0.28)	0.98 (1.08)	0.81 (0.32)	2.31 (1.55)
Upstream	August_B_2021	1.16 (1.37)	0 (0)	1.42 (1.81)	2.58 (3.17)
Downstream	August_B_2021	0.68 (0.34)	0.04 (0.19)	0.69 (0.37)	1.41 (0.74)
Lowerymore	August_B_2021	0.36 (0.08)	0.53 (0.46)	0.6 (0.31)	1.49 (0.73)
Upstream	September_2021	2.29 (1.32)	0 (0)	2.69 (2.11)	4.98 (3.41)
Downstream	September_2021	1.46 (1.09)	0 (0)	1.36 (0.89)	2.82 (1.93)
Lowerymore	September_2021	0.73 (0.18)	0.18 (0.32)	2.01 (0.62)	2.92 (0.71)
Upstream	October_2021	2.71 (0.85)	0 (0)	2.52 (0.76)	5.23 (1.59)
Downstream	October_2021	1.4 (0.51)	0 (0)	1.17 (0.36)	2.57 (0.86)
Lowerymore	October_2021	0.8 (0.27)	0.01 (0.02)	1.01 (0.41)	1.82 (0.5)

Table 10 - The average (and STDEV) cyanobacteria, blue-green algae, diatoms and total algae concentrations occurring on cobbles at the Upstream and Downstream locations in Liscooley and from the Lowerymore reference site.

Position	Month	Cyano	Blue-green Algae	Diatoms	Total Conc.
Upstream	July_2020	3.49 (1.66)	0 (0)	3.4 (2.32)	6.89 (3.97)
Downstream	July_2020	1.43 (1.28)	0 (0)	1.23 (1.24)	2.66 (2.44)
Upstream	August_2020	3.31 (2.18)	0 (0)	3.09 (2.16)	6.4 (4.33)
Downstream	August_2020	2.93 (2.11)	0 (0)	2.78 (2.28)	5.71 (4.36)
Upstream	September_2020	0.47 (2.05)	0 (0)	0.6 (2.92)	1.07 (4.97)
Downstream	September_2020	1.38 (0.25)	0 (0)	1.81 (0.27)	3.19 (0.49)
Upstream	February_2021	1.87 (1.22)	0 (0)	2.59 (3.27)	4.47 (4.17)
Downstream	February_2021	2.55 (1.1)	0 (0.22)	2.49 (1.16)	5.05 (2.12)
Lowerymore	February_2021	0.83 (0.33)	0.67 (0.53)	0.81 (0.45)	2.31 (0.71)
Upstream	March_A_2021	1.47 (1.58)	0 (0)	1.17 (1.16)	2.64 (2.74)
Downstream	March_A_2021	0.78 (0.71)	0 (0.01)	0.76 (0.52)	1.55 (1.23)
Upstream	March_B_2021	1.27 (1.39)	0 (0)	1.16 (0.94)	2.43 (2.28)
Downstream	March_B_2021	0.73 (0.51)	0.04 (0.08)	0.68 (0.45)	1.45 (0.89)
Lowerymore	March_B_2021	0.72 (0.38)	2.15 (1.22)	1.6 (1.29)	4.47 (2.57)

Upstream	April_2021	1.84 (1.18)	0 (0)	1.4 (1.19)	3.23 (2.35)
Downstream	April_2021	2.55 (2.09)	0.71 (1.28)	2.94 (1.7)	6.19 (3.68)
Lowerymore	April_2021	0.14 (0.08)	0.89 (0.61)	0.33 (0.12)	1.36 (0.74)
Upstream	May_2021	1.59 (0.93)	0 (0)	0.87 (0.44)	2.45 (1.37)
Downstream	May_2021	1.43 (0.88)	0 (0)	0.92 (0.47)	2.35 (1.35)
Lowerymore	May_2021	0.43 (0.17)	1.3 (0.92)	1.14 (0.85)	2.87 (1.13)
Upstream	June_2021	2.06 (2.07)	0 (0)	1.69 (2.16)	3.75 (4.22)
Downstream	June_2021	1.17 (1.11)	0.44 (0.76)	1.12 (0.69)	2.73 (1.83)
Lowerymore	June_2021	0.45 (0.2)	0.43 (0.5)	0.36 (0.22)	1.24 (0.63)
Upstream	August_A_2021	3 (2.1)	0.05 (0.1)	3.96 (3.12)	7.01 (5.06)
Downstream	August_A_2021	4.2 (2.47)	0.02 (0.05)	5.25 (3.41)	9.46 (5.68)
Lowerymore	August_A_2021	0.38 (0.11)	0.59 (0.35)	1.24 (0.5)	2.21 (0.69)
Upstream	August_B_2021	3.47 (1.61)	0 (0)	3.61 (1.66)	7.08 (3.18)
Downstream	August_B_2021	3.86 (2.54)	0 (0)	4.43 (4.12)	8.28 (6.59)
Lowerymore	August_B_2021	0.43 (0.21)	0.56 (0.63)	0.45 (0.22)	1.44 (0.51)
Upstream	September_2021	2.63 (1.2)	0 (0)	3.02 (1.08)	5.65 (2.23)
Downstream	September_2021	3.39 (1.75)	0.01 (0.02)	3.82 (1.79)	7.22 (3.28)
Lowerymore	September_2021	0.53 (0.37)	0.39 (0.18)	0.35 (0.47)	1.27 (0.7)
Upstream	October_2021	3.41 (2.06)	0 (0)	4.36 (2.78)	7.77 (4.79)
Downstream	October_2021	2.46 (1.24)	0 (0)	2.02 (0.75)	4.48 (1.89)
Lowerymore	October_2021	0.91 (0.65)	0.79 (0.67)	0.56 (0.44)	2.26 (1.05)

5.3. Cavanagrow 24hour SRP results

The results of SRP concentrations from water samples collected monthly (n=11) using 24 hr auto-samplers positioned upstream and downstream of the Cavanagrow WWTWs discharge locations are presented in Table 11 (Upstream) and Table 12 (Downstream) and in Figures 20 (monthly breakdown of SRP results) and 21 (hourly breakdown of SRP results). As at Liscooley, the results at Cavanagrow indicate that for all months SRP concentrations from downstream were higher than that of upstream. This was again confirmed using Wilcoxon signed rank tests (paired test) where for each sample period, Downstream SRP concentrations were found to be significantly higher than Upstream ($p < 0.01$ for all). The highest SRP concentrations for both upstream and Downstream were recorded in July, while the lowest value was recorded in March B. As at Liscooley, the trend of higher SRP concentrations in some months compared to others is again likely related to the water levels being lower in summer/drier months compared to wetter months, than increased P levels entering the stream from the WWTWs discharge. That is (and as described earlier), while the P levels coming from the WWTWs are likely to remain relatively constant, reduced water levels due to less rainfall etc. in summer months result in less of a dilution effect occurring and therefore higher P levels being observed in the stream water. Hourly trends in downstream SRP concentrations at Cavanagrow again indicate peaks/rises at certain times of the day, such as the morning (8am-10am), lunchtime (1pm – 3pm) and in the evening from 5pm – 8pm, while contrastingly upstream SRP trends remain relatively constant through-out the day. Again, these downstream SRP trends are likely related to increased use of amenities (e.g., toilets etc.) feeding into the WWTWs at these times of the day.

The Northern Ireland Environment Agency (NIEA) uses site specific altitude and alkalinity levels to generate/classify reactive P (mg/L) boundary ranges for rivers/streams. The nearest NIEA monitoring point to Cavanagrow is at F10318 Killeen Water at St. Luke's Hospital. Data obtained from the NIEA for this site (which currently has a P WFD status of moderate), classify the reference reactive P (m/L) boundaries there for High/Good status as 0.042 reactive P (mg/L), the Good/Moderate boundary as 0.078 reactive P (mg/L), the Moderate/Poor boundary as 0.19 reactive P (mg/L), and the Poor/Bad Boundary as 1.042 reactive P (mg/L). Based on these categories, three SRP sampling periods/months (April, June and July 2021) had SRP peak concentrations in excess of the Poor/Bad Boundary of 1.042 mg/L P, while of the other eight monitoring periods seven were above the Moderate/Poor boundary. Only October 2020 was below the Moderate/Poor boundary range. This indicates that the WWTWs discharge at Cavanagrow is having a negative impact on the water quality status there.

Table 11 - Table showing the hourly breakdown (i.e., midnight to 1 am, 1 am to 2 am… etc.) of soluble reactive phosphorus (SRP) concentrations from water samples collected monthly (n=11) using 24 hr auto-samplers positioned upstream of the Cavanagrow WWTWs discharge location.

Time	2020		2021								
	Sep	Oct	Mar_a	Mar_b	Apr	May	Jun	Jul	Aug	Sep	Oct
00:00 - 01:00	0.096	0.063	0.070	0.061	0.087	0.102	0.140	0.285	0.116	0.206	0.130
01:00 - 02:00	0.094	0.065	0.071	0.059	0.085	0.106	0.120	0.295	0.113	0.229	0.127
02:00 - 03:00	0.098	0.065	0.069	0.059	0.084	0.110	0.125	0.302	0.112	0.233	0.128
03:00 - 04:00	0.094	0.063	0.070	0.058	0.083	0.112	0.126	0.315	0.114	0.226	0.130
04:00 - 05:00	0.098	0.061	0.068	0.058	0.085	0.118	0.125	0.327	0.111	0.252	0.126
05:00 - 06:00	0.095	0.063	0.068	0.056	0.086	0.117	0.123	0.348	0.111	0.253	0.124
06:00 - 07:00	0.094	0.060	0.067	0.057	0.084	0.119	0.122	0.353	0.111	0.230	0.124
07:00 - 08:00	0.093	0.063	0.064	0.058	0.082	0.121	0.115	0.374	0.112	0.215	0.126
08:00 - 09:00	0.095	0.066	0.081	0.057	0.082	0.119	0.100	0.395	0.115	0.206	0.126
09:00 - 10:00	0.095	0.086	0.065	0.055	0.080	0.107	0.112	0.488	0.120	0.203	0.124
10:00 - 11:00	0.094	0.080	0.065	0.054	0.080	0.110	0.116	0.573	0.120	0.198	0.135
11:00 - 12:00	0.093	0.078	0.066	0.057	0.080	0.116	0.111	0.525	0.120	0.154	0.128
12:00 - 13:00	0.109	0.075	0.066	0.057	0.081	0.122	0.111	0.437	0.119	0.164	0.124
13:00 - 14:00	0.106	0.063	0.066	0.051	0.076	0.080	0.092	0.224	0.096	0.153	0.126
14:00 - 15:00	0.108	0.061	0.058	0.055	0.081	0.083	0.100	0.242	0.111	0.153	0.124
15:00 - 16:00	0.094	0.068	0.064	0.056	0.082	0.086	0.100	0.259	0.111	0.160	0.101
16:00 - 17:00	0.093	0.066	0.068	0.057	0.082	0.089	0.102	0.269	0.114	0.172	0.116
17:00 - 18:00	0.095	0.066	0.066	0.056	0.089	0.086	0.106	0.276	0.113	0.186	0.118
18:00 - 19:00	0.096	0.064	0.066	0.057	0.087	0.089	0.106	0.281	0.115	0.190	0.120
19:00 - 20:00	0.096	0.065	0.067	0.057	0.086	0.098	0.105	0.277	0.119	0.203	0.119
20:00 - 21:00	0.094	0.065	0.075	0.060	0.087	0.094	0.114	0.276	0.146	0.207	0.118
21:00 - 22:00	0.089	0.065	0.068	0.060	0.085	0.098	0.105	0.276	0.142	0.193	0.119
22:00 - 23:00	0.092	0.065	0.068	0.060	0.089	0.101	0.121	0.276	0.128	0.198	0.123
23:00 - 00:00	0.094	0.066	0.068	0.061	0.087	0.097	0.108	0.280	0.121	0.135	0.124

***Table** 12 - Table showing the hourly breakdown (i.e., midnight to 1 am, 1 am to 2 am… etc.) of soluble reactive phosphorus (SRP) concentrations from water samples collected monthly (n=11) using 24 hr auto-samplers positioned downstream of the **Cavanagrow** WWTWs discharge location.*

Time	2020		2021								
	Sep	Oct	Mar_a	Mar_b	Apr	May	Jun	Jul	Aug	Sep	Oct
00:00 - 01:00	0.157	0.082	0.075	0.072	0.186	0.205	0.153	1.619	0.275	0.291	0.210
01:00 - 02:00	0.140	0.081	0.077	0.094	0.167	0.203	0.163	1.607	0.268	0.271	0.167
02:00 - 03:00	0.141	0.092	0.077	0.293	0.142	0.151	0.149	1.578	0.266	0.286	0.167
03:00 - 04:00	0.142	0.129	0.076	0.081	0.147	0.196	0.153	1.479	0.266	0.258	0.267
04:00 - 05:00	0.140	0.076	0.076	0.060	0.417	0.225	0.265	1.547	0.261	0.290	0.177
05:00 - 06:00	0.143	0.077	0.077	0.059	0.182	0.231	0.157	1.507	0.255	0.296	0.238
06:00 - 07:00	0.172	0.083	0.075	0.059	0.209	0.215	0.155	1.477	0.256	0.281	0.160
07:00 - 08:00	0.160	0.089	0.076	0.156	0.422	0.215	0.164	1.398	0.218	0.387	0.196
08:00 - 09:00	0.217	0.077	0.075	0.071	0.215	0.255	0.151	1.886	0.223	0.466	0.306
09:00 - 10:00	0.182	0.101	0.306	0.066	0.226	0.318	0.262	1.175	0.244	0.384	0.302
10:00 - 11:00	0.203	0.106	0.108	0.061	0.160	0.185	0.207	1.072	0.253	0.432	0.357
11:00 - 12:00	0.195	0.103	0.108	0.125	0.179	0.272	0.176	1.070	0.262	0.335	0.160
12:00 - 13:00	0.173	0.098	0.083	0.074	0.171	0.178	0.151	1.178	0.271	0.427	0.196
13:00 - 14:00	0.232	0.061	0.076	0.041	0.178	0.247	1.034	0.742	0.140	0.427	0.261
14:00 - 15:00	0.200	0.091	0.089	0.074	0.139	0.106	1.148	0.890	0.251	0.419	0.460
15:00 - 16:00	0.179	0.080	0.073	0.063	0.341	0.101	0.559	1.148	0.255	0.188	0.163
16:00 - 17:00	0.179	0.072	0.087	0.086	0.742	0.307	0.199	0.872	0.255	0.400	0.266
17:00 - 18:00	0.231	0.089	0.074	0.068	1.425	0.295	0.167	0.942	0.264	0.681	0.306
18:00 - 19:00	0.180	0.044	0.077	0.069	1.602	0.226	0.501	1.107	0.276	0.648	0.337
19:00 - 20:00	0.226	0.090	0.141	0.070	0.429	0.133	0.548	1.154	0.275	0.885	0.328
20:00 - 21:00	0.251	0.082	0.086	0.066	0.186	0.232	0.182	1.475	0.332	0.746	0.280
21:00 - 22:00	0.179	0.131	0.078	0.266	0.561	0.233	0.421	1.328	0.311	0.662	0.280
22:00 - 23:00	0.147	0.097	0.090	0.295	0.344	0.213	0.193	1.454	0.296	0.580	0.189
23:00 - 00:00	0.182	0.080	0.079	0.090	0.167	0.204	0.278	1.638	0.289	0.348	0.177

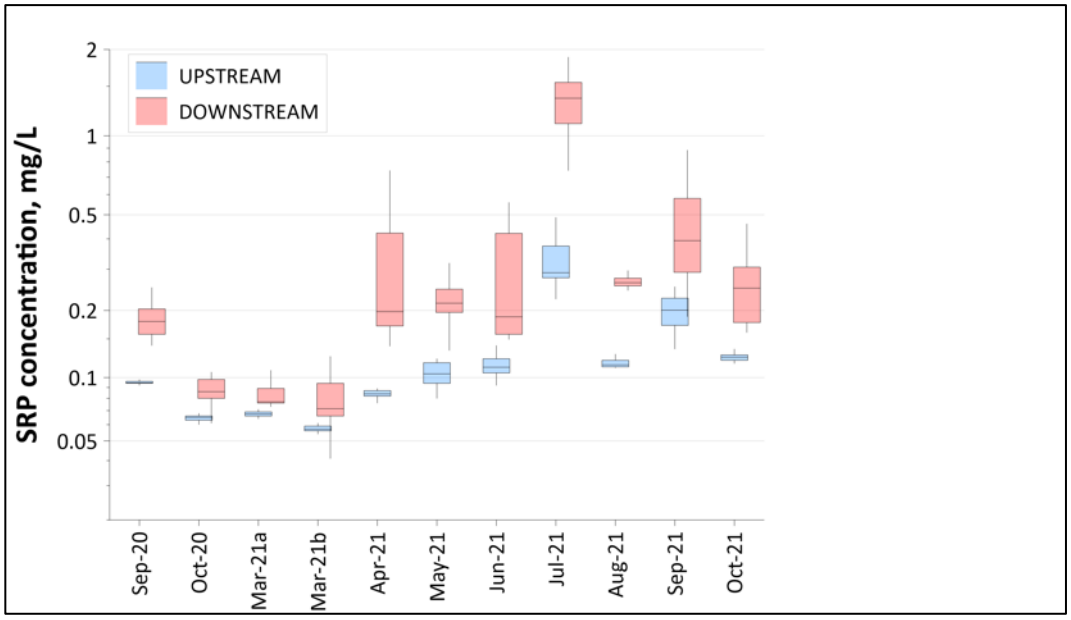

Figure 20 - Boxplots showing the soluble reactive phosphorus (SRP) concentrations from water samples collected monthly between September 2020 and October 2021 (n=11) using 24 hr auto-samplers positioned upstream and downstream of the Cavanagrow WWTWs discharge location.

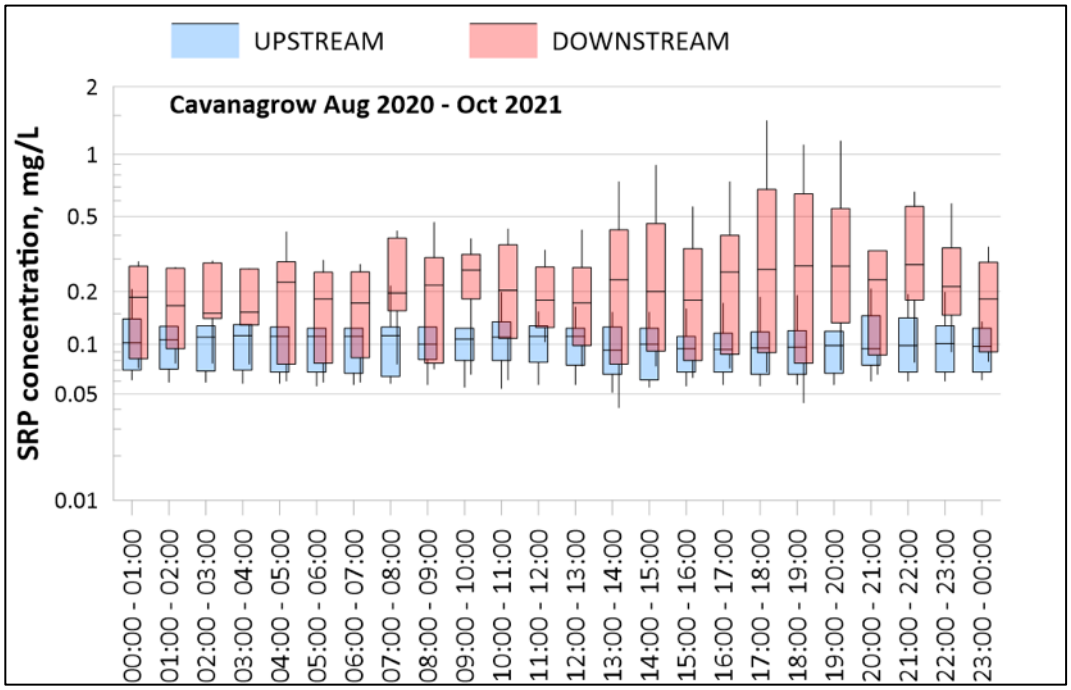

Figure 21 - Boxplots showing the hourly breakdown (i.e. midnight to 1 am, 1 am to 2 am… etc.) of soluble reactive phosphorus (SRP) concentrations from water samples collected monthly (n=11) using 24 hr auto-samplers positioned upstream and downstream of the Cavanagrow WWTWs discharge location.

5.4. Cavanagrow benthic algae results in the vicinity of the WWTW discharge point

The average cyanobacteria, blue-green algae, diatoms and total algae concentrations occurring on tiles at the Upstream and Downstream locations at Cavanagrow are presented in Table 13, while results for data collected from cobbles are presented in Table 14. As at Liscooley, the limited growth of algae on the tiles positioned at Cavanagrow was likely related to the extensive shading that occurs there, with the lack of light potentially restricting the growth of algae on the tile substrates. Using Wilcoxon signed rank tests (paired test), significant differences in the concentrations of cyanobacteria occurring upstream and downstream was observed in May ($p < 0.01$), June ($p < 0.01$), July ($p < 0.01$) and October ($p = 0.031$) 2021, with downstream having higher concentrations than upstream for these months except in May where upstream concentrations were higher. Diatom concentrations were significantly higher Upstream compared to Downstream in October 2020 ($p = 0.012$), but higher Downstream compared to upstream in June 2021 ($p = 021$) and July 2021 ($p = 0.047$). Total algae concentrations were significantly higher Upstream compared to Downstream in August 2020 ($p = 0.037$) and May 2021 ($p < 0.01$), but higher Downstream compared to upstream in June 2021 ($p < 0.01$) and July ($p = 0.01$). There were very limited blue-green algae recorded growing on the tile substrates. For the cobbles, the only significant difference between upstream and downstream concentrations of cyanobacteria, blue-green algae, diatoms or total algae concentrations was observed in April 2021 ($p = 0.031$ for all), with downstream cobbles recording higher values than upstream.

Table 13 - The average (and STDEV) cyanobacteria, blue-green algae, diatoms and total algae concentrations occurring on tiles at the Upstream and Downstream locations at Cavanagrow, and at the Lowerymore reference site.

Position	Month	Cyano	Blue-green Algae	Diatoms	Total Conc.
Upstream	July_2020	0.14 (0.27)	0.05 (0.06)	1.29 (1.92)	1.49 (2.11)
Downstream	July_2020	0.01 (0.01)	0.08 (0.06)	0.16 (0.11)	0.25 (0.11)
Lowerymore	July_2020	0.13 (0.14)	0.29 (0.32)	0.26 (0.23)	0.68 (0.62)
Upstream	August_2020	0.25 (0.43)	0.08 (0.16)	0.44 (0.5)	0.76 (0.91)
Downstream	August_2020	0.09 (0.1)	0.06 (0.07)	0.27 (0.25)	0.42 (0.32)
Lowerymore	August_2020	0.66 (0.46)	3.24 (1.85)	0.97 (0.67)	4.87 (2.68)
Upstream	October_2020	0.22 (0.11)	0.02 (0.05)	0.71 (0.36)	0.95 (0.45)
Downstream	October_2020	0.18 (0.27)	0.06 (0.11)	0.27 (0.24)	0.51 (0.49)
Upstream	May_2021	1.37 (1.11)	0.19 (0.36)	2.37 (1.13)	3.94 (2)
Downstream	May_2021	0.52 (0.23)	0.23 (0.52)	2.11 (1.19)	2.85 (1.14)
Lowerymore	May_2021	0.27 (0.2)	1.61 (1.05)	0.57 (0.34)	2.45 (1.46)
Upstream	June_2021	1.04 (0.52)	0 (0)	1.68 (0.88)	2.72 (1.39)
Downstream	June_2021	1.84 (1.12)	0 (0)	2.57 (1.56)	4.41 (2.61)
Lowerymore	June_2021	0.24 (0.16)	0.56 (0.58)	0.31 (0.15)	1.11 (0.74)
Upstream	July_2021	0.52 (0.12)	0 (0)	0.69 (0.18)	1.2 (0.28)
Downstream	July_2021	1.51 (1.39)	0 (0)	2.55 (2.84)	4.06 (4.21)
Lowerymore	August_A_2021 (July)	0.52 (0.08)	0.98 (0.46)	0.81 (0.31)	2.31 (0.73)
Upstream	August_B_2021	0.62 (0.16)	0 (0)	0.7 (0.17)	1.32 (0.31)
Downstream	August_B_2021	0.65 (0.82)	0 (0)	0.6 (0.96)	1.25 (1.77)
Lowerymore	August_B_2021	0.36 (0.18)	0.53 (0.32)	0.6 (0.62)	1.49 (0.71)
Upstream	September_2021	0.66 (0.19)	0 (0)	0.64 (0.23)	1.29 (0.4)
Downstream	September_2021	1.06 (1.14)	0 (0)	1 (0.99)	2.06 (2.13)
Lowerymore	September_2021	0.73 (0.27)	0.18 (0.02)	2.01 (0.41)	2.92 (0.5)
Upstream	October_2021	0.76 (0.13)	0 (0)	0.78 (0.19)	1.54 (0.3)

Downstream	October_2021	1.45 (0.34)	0 (0)	1.13 (0.4)	2.59 (0.72)
Lowerymore	October_2021	0.8 (0.28)	0.01 (1.08)	1.01 (0.32)	1.82 (1.55)

Table 14 - The average (and STDEV) cyanobacteria, blue-green algae, diatoms and total algae concentrations occurring on cobbles at the Upstream and Downstream locations at Cavanagrow, and at the Lowerymore reference site.

Position	Month	Cyano	Blue-green Algae	Diatoms	Total Conc.
Upstream	June_2020	2.04 (0.46)	0 (0)	1.96 (0.49)	4 (0.59)
Downstream	June_2020	0.69 (0.52)	0.91 (1.8)	1.02 (0.75)	2.62 (2.51)
Upstream	July_2020	3.4 (1.97)	0.25 (0.56)	2.95 (1.66)	6.6 (2.74)
Downstream	July_2020	1.65 (2.05)	0.15 (0.25)	1.63 (1.84)	3.43 (3.77)
Upstream	August_2020	1.56 (1.19)	0.5 (0.61)	1.71 (0.79)	3.77 (1.43)
Downstream	August_2020	1.23 (0.96)	0.51 (0.51)	1.41 (0.79)	3.15 (1.43)
Upstream	September_2020	0.73 (1)	0.08 (0.12)	1.01 (1.04)	1.82 (2.02)
Downstream	September_2020	1.28 (0.87)	0.25 (0.61)	1.79 (1.43)	3.32 (2)
Upstream	April_2021	1.51 (0.98)	0.08 (0.18)	3.17 (2.5)	4.76 (3.32)
Downstream	April_2021	3.29 (1.04)	0 (0)	8.22 (2.48)	11.51 (3.17)
Lowerymore	April_2021	0.14 (0.08)	0.89 (0.61)	0.33 (0.12)	1.36 (0.74)
Upstream	May_2021	1.68 (1.91)	0.54 (0.75)	2.38 (3.47)	4.61 (5.04)
Downstream	May_2021	0.86 (0.79)	0.53 (0.72)	2.28 (2.47)	3.68 (3.01)
Lowerymore	May_2021	0.43 (0.17)	1.3 (0.92)	1.14 (0.85)	2.87 (1.13)
Upstream	June_2021	3.79 (1.87)	0 (0)	5.03 (2.25)	8.82 (3.89)
Downstream	June_2021	3.53 (2.06)	0 (0)	4.84 (2.92)	8.37 (4.85)
Lowerymore	June_2021	0.45 (0.2)	0.43 (0.5)	0.36 (0.22)	1.24 (0.63)
Upstream	July_2021	2.04 (1.39)	0 (0)	2.04 (0.86)	4.08 (2.15)
Downstream	July_2021	1.28 (1.1)	0.23 (0.45)	1.44 (1.12)	2.94 (2.06)
Lowerymore	August_2021_A (July)	0.38 (0.11)	0.59 (0.35)	1.24 (0.5)	2.21 (0.69)
Upstream	August_2021	2.04 (0.83)	0 (0)	2.21 (0.74)	4.25 (1.39)
Downstream	August_2021	1.61 (1.51)	0.01 (0.01)	3.19 (3.89)	4.8 (4.86)
Lowerymore	August_2021	0.43 (0.21)	0.56 (0.63)	0.45 (0.22)	1.44 (0.51)
Upstream	September_2021	1.27 (1.5)	0.01 (0.02)	1.69 (2.08)	2.97 (3.56)
Downstream	September_2021	1.29 (1.5)	0.55 (0.71)	2 (1.41)	3.83 (2.71)
Lowerymore	September_2021	0.53 (0.37)	0.39 (0.18)	0.35 (0.47)	1.27 (0.7)
Upstream	October_2021	2.73 (1.24)	0 (0)	2.67 (1.27)	5.4 (2.46)
Downstream	October_2021	1.25 (0.96)	0.44 (0.73)	1.41 (1.07)	3.1 (1.75)
Lowerymore	October_2021	0.91 (0.65)	0.79 (0.67)	0.56 (0.44)	2.26 (1.05)

5.5 Summary of water quality using new sampling protocol

At both Liscooley and Cavanagrow, SRP concentrations were found to be higher downstream of the WWTWs discharge than those occurring upstream. At Liscooley, SRP peak concentrations in excess of the EPA seriously polluted cut-off point (0.07 mg/L P) occurred in twelve of the thirteen sampling periods/months (all except October 2020 which fell in the moderately polluted range), thereby indicating that the WWTWs discharge at Liscooley is taking the Blairstown stream into seriously polluted status (based on SRP concentrations). Similarly, SRP peak concentrations at Cavanagrow were in excess of the Poor/Bad Boundary of a near-by NIEA river monitoring site for three SRP sampling periods/months, and above the Moderate/Poor boundary for another seven sampling

periods/months. This again indicates that the WWTWs discharge at Cavanagrow is having a negative impact on the water quality status there. At both sites, SRP concentrations were higher at certain times of the year (i.e., summer months). However, this is more likely related to the water levels being lower in summer/drier months compared to wetter months, than to increased P levels entering the stream from the WWTWs discharge, with less of a dilution effect occurring at lower flows and therefore higher P levels being observed in the stream water.

In contrast to the SRP results, algae concentrations occurring at Liscooley and Cavanagrow did not indicate water quality impairment. However, algae growth at both sites was relatively low (and comparable to that observed at the reference site Lowerymore), and it is likely that the limited growth of algae is related to the shading occurring at both sites, with the lack of light potentially restricting the growth of algae on the tile substrates.

This considered, as the benthic algae impact indicator was inconsistent at both sites over short stream reaches and where shading was an issue, the 24hour SRP pressure sampling protocol is likely to be of most beneficial. This is a recommendation for continued monitoring post SRC irrigation at these sites (see section 6) and other sites in the future and which can be augmented with other pollution pressure indicator parameters.

6. Water quality following diversion of waste-water to SRC

Installation of the SRC at Liscooley and Cavanagrow was delayed and this constrained the amount of data that could be gathered for comparison with 24hour datasets as shown in Figures 18 and 20. At Liscooley, the SRC and irrigation system was not operational until early 2023 and so no assessment data are available for this report. At Cavanagrow, the SRC and irrigation system became operational in late April 2022 and this provided an opportunity for further 24hour SRP concentration data collection using the ISCO autosamplers. However, personnel support for this period of monitoring only provided data to September 2022 but does cover most of the low flow period in that year.

These data for Cavanagrow are shown in Figure 22 and augment Figure 20 with the 2022 data.

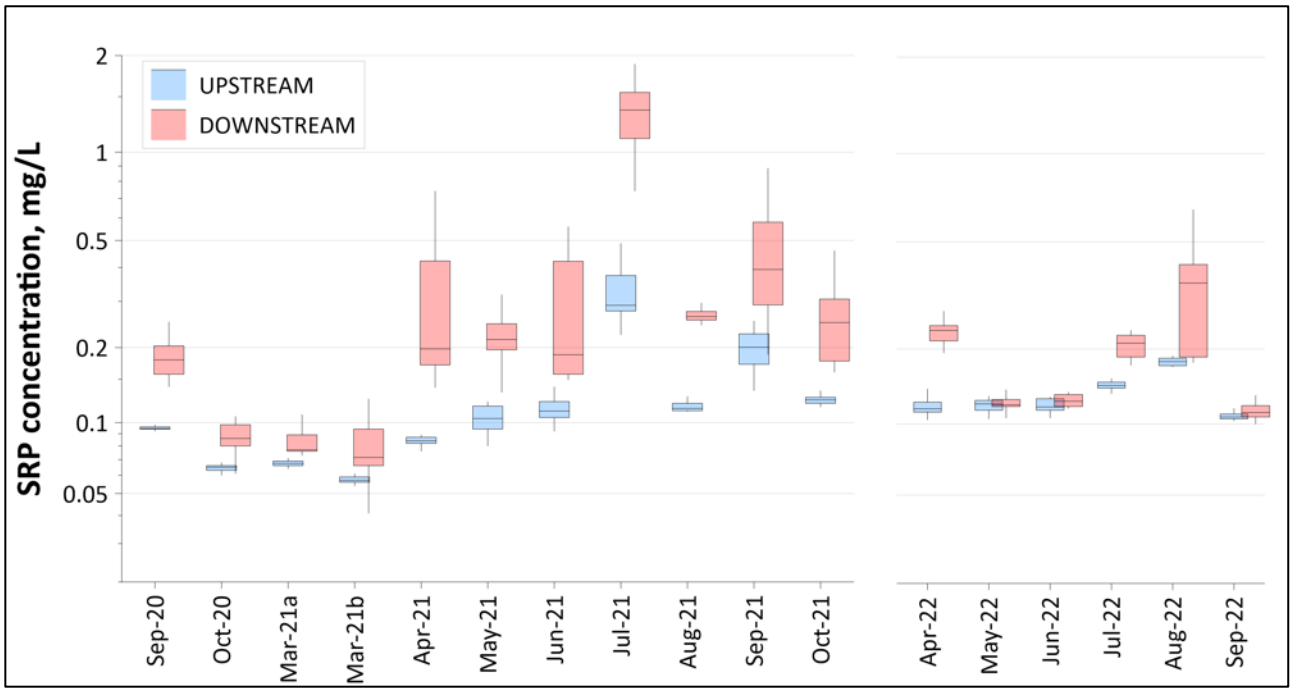

Figure 22 - Boxplots showing the soluble reactive phosphorus (SRP) concentrations from water samples collected monthly between September 2020 and October 2021 (n=11) using 24 hr auto-samplers positioned upstream and downstream of the Cavanagrow WWTWs discharge location. Also shown are data after April 2022 (n=6). The SRC and irrigation system became operational in late April 2022.

Of note in Figure 22 is the decrease in downstream SRP concentration to upstream levels in May 2022 and June 2022 following the diversion of the waste-water. In July and August 2022, the irrigation plant required adjustment and the waste-water was again discharged to the downstream location. This was rectified in late August 2022 and the irrigation was restarted, reducing the downstream SRP concentrations in September 2022 to those noted at the upstream site.

Even with these few data, the complete reduction of the SRP concentration effectively mitigates this rural point source at Cavanagrow. Effluent quality data from the WWTW at Cavanagrow was poor (approximately 6 mg/L AFBI personal communication) and, factoring in a hydraulic loading for 38 PE, the P load to the stream system was estimated to be approximately 12kg P/yr. Assuming a constant loading, this explains the very high P concentrations monitored in the receiving stream in

the summer periods during low flows and which became higher as flows decreased and assimilative capacity reduced. While diverting the 12kg P/yr to the SRC irrigation system mitigates the point source, the background (upstream) P concentrations monitored are still excessive and reflective of further upstream (point and/or diffuse) P sources that require mitigation. Nevertheless, the diversion of P load indicated 95-100% improvement in average stream SRP concentration.

6.1. Future monitoring requirements

Further low flow monitoring data are required for both sites, and this is planned for 2023. An emphasis will be on the 24hour SRP sampling protocol as this captures the sub-daily variation in SRP concentration as a good pressure metric to compare pre- and post-diversion of waste-water to the SRC sites. The Wilcoxon signed-ranks non-parametric test was used to compare all upstream and downstream data pairs and this can be continued.

Of less certainty is the measurement of benthic algae as an impact indicator in such short stream reaches and under areas of shading. While the data were useful in earlier monitoring trials, it was clear from the Liscooley results that other point sources were being monitored (in further stream sections) upstream and downstream of the waste-water discharge point.

These findings, along with background P pressures at Cavanagrow, show the pervasiveness of water quality pollution in rural areas of the Irish border region with indications of P pressures found in addition to the waste-water discharges intended for mitigation.