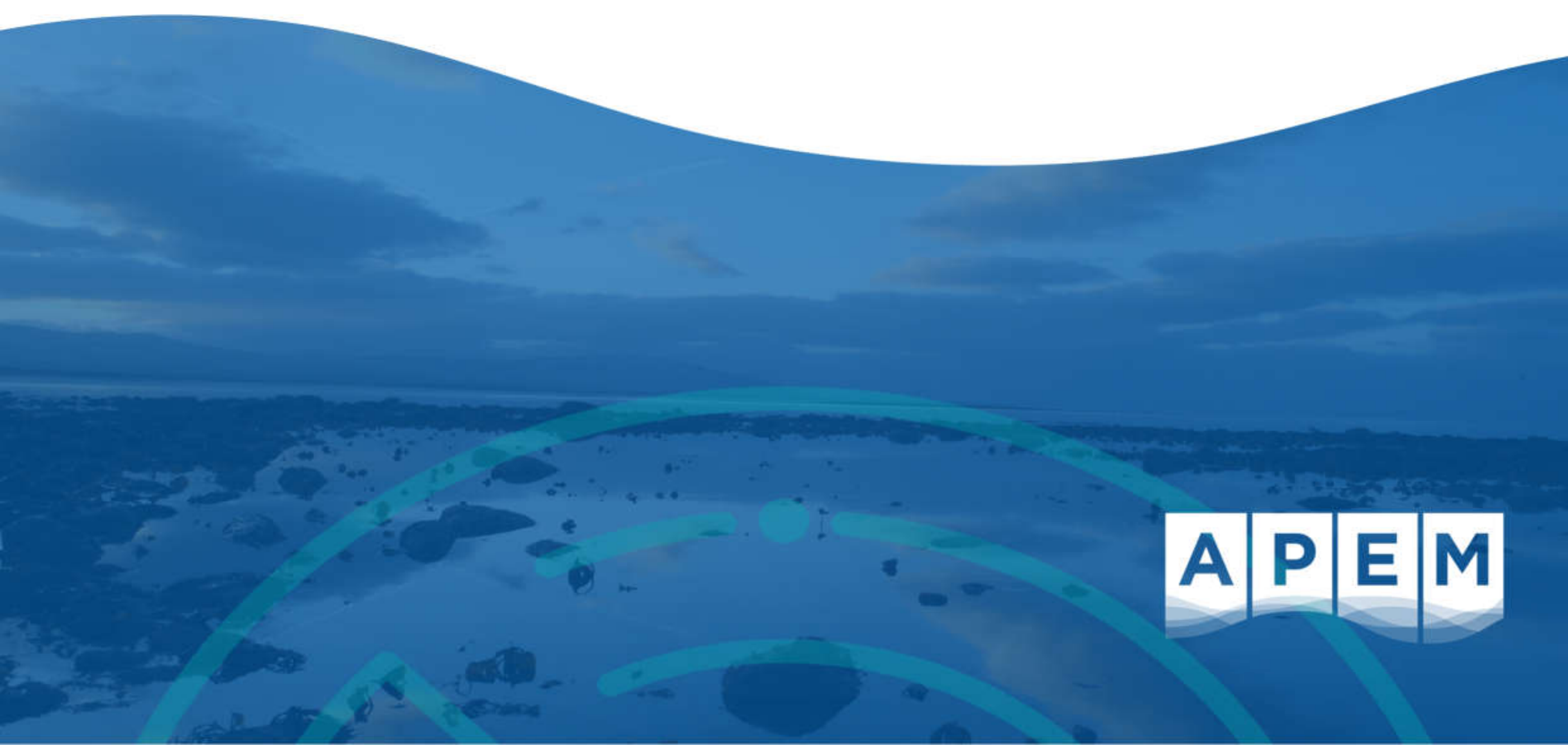
Galway County Council

Rahasane Turlough nutrient investigation

Final report

P00014600

May 2025



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[2] Martyn Kelly is the author of the discussion section of the macroalgal assessment, Appendix D.

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1. Introduction

1.1. Background

APEM Group Woodrow (APEM) is undertaking field surveys and assessments at a completed Flood Relief Scheme (FRS) at Rahasane Turlough, on behalf of Galway County Council. This monitoring is continuing annually for five years, starting in July 2021. While the aim of this work is to determine any impacts of the FRS on water levels and ecological responses in the turlough system, several potential issues in relation to water quality have been identified. In analysing the first two years' data, the following were noted:

- Water pH at all sites was slightly acid, even though this is a karst (i.e. alkaline) catchment. This could be as a result of the natural breakdown of vegetative matter at the bottom of the more permanent ponds in the turlough, acidifying the water during low water levels in summer, or possibly as a result of a hydrological connection to a concentrated source of nutrients such as silage or livestock feed.
- An assessment of ecological condition using aquatic invertebrates and plants, using Pond PSYM metrics, suggested the impacts of excessive nutrient concentrations at the site, consistent with other macroinvertebrate metrics indicating general poor water quality.
- A visual observation of slimy green algae in rafts on the water surface, also indicating excessive localised nutrient enrichment.
- The presence of large numbers of livestock and horses grazing on the turlough during summer low water periods.

Rahasane Turlough is unusual in that, although groundwater determines water levels, it also has a river running through it: the Dunkellin River (EPA river water body name: Kilcolgan 030). The turlough was originally a natural sink for the river, which continued downstream as an elongated area of marshland rather than a clearly defined river channel (as shown on the Ordnance Survey of Ireland first edition 6 inch map series, completed in 1846), but an artificial channel created later in the 19^{th} Century now takes some of the water further downstream (NPWS, 2013). The turlough itself is not monitored, but EPA monitoring in the river provides further evidence of poor water quality, with Q values from sites upstream and downstream of the turlough classed as Q3.

In view of these observations, there is a desire to investigate potential nutrient enrichment of the site further. Rahasane Turlough has several conservation designations, including Special Protection Area (SPA), Special Area of Conservation (SAC) and proposed Natural Heritage Area (pNHA). It is considered to be moderately sensitive to nutrient enrichment and the SAC conservation objectives include a water quality target of $\leq$20 µg/l total phosphorus. It has a range of vegetation communities and zonations that are of conservation importance, and which may be sensitive to nutrient enrichment, and a further objective is to maintain soil nutrient status appropriate to the soil types and vegetation on the site (NPWS 2020).

It is noted that Local Authority Water Programme (LAWPRO) is planning a focused investigation of the Dunkellin River and is especially concerned about potential nutrient inputs from septic tanks. Therefore, an understanding of the nutrient status of the wider catchment is a useful addition to a study of the turlough itself.

1.2. Scope of the project

The aim of this work was to identify potential sources of nutrients into Rahasane Turlough, and to identify any key gaps in our understanding. The symptoms of high nutrient levels (the excessive algal growths; the assessment of ecological condition using macroinvertebrates and aquatic plants; and the pH of the water) will have been caused by nutrient input or cycling via one or more of four pathways.

- Pathway 1. Localised inputs at a few locations, leading to localised high concentrations in specific pools or ditches, but no impact across the site generally. Localised inputs in this case would include features such as road runoff, farm runoff or poorly maintained septic tanks.
- Pathway 2. As above but in multiple locations, leading to a general negative impact across the site.
- Pathway 3. Inputs from outside the turlough area, leading to a general negative impact across the site. Such inputs could come in via (a) the river, (b) the groundwater or (c) direct runoff from the higher ground to the north and south of the turlough.
- Pathway 4. Activities of livestock, which could be either localised or widespread. Livestock grazing on the land during drier periods may simply recycle the nutrients already present, but by feeding will release nutrients from a stable, fixed state (incorporated into plant tissues) into a highly mobile, unstable state (faeces and urine.)

In order to investigate each of these options, a multi-stage approach was developed, as described below.

a) A walkover survey to identify any obvious direct pollution sources. This would determine the role of Pathways 1, 2 and 3c.
b) Water quality determination from surface waters within and around the turlough, under different flow conditions. Surveys in 2023 examined rivers in the catchment upstream, to determine the role of Pathway 3a. A further survey In 2024 examined sites within the turlough, to look for evidence for Pathway 3b or 3c.
c) Examination of existing data on water quality and land use. This would examine the role of Pathways 3b and 4.

Additionally, a survey was carried out of algal mats at four sites within the turlough, identifying the microalgae and cyanobacteria taxa present to further understand the nutrient status of the turlough. The full details of the provided in Appendix D. The elements of this report relevant to nutrient assessment are discussed in Section 4.

A longer-term objective is to create a nutrient budget for the turlough, with a source apportionment, in which the relative importance of each nutrient input type is quantified. This in turn enables targeted interventions to manage and control excessive nutrient inputs. A full nutrient budget requires a comprehensive dataset that is currently not available, and we are unaware of any previous attempts at source apportionment for a turlough. However, using the data currently available and some realistic estimates, a first attempt was made to create an indicative nutrient budget for Rahasane Turlough.

2. Methods

The methods used to deliver this work are outlined in this section.

2.1. Rahasane Turlough topography

As a first stage in understanding the hydrology of Rahasane Turlough, a detailed topographic model is required. This determines the contours of the site, from which lake surface area and water volumes can be determined for any depth of water. Computer modelling software was used to create a detailed drainage network of the survey area from the Light Detection and Ranging (LiDAR) data provided to APEM. This was done using hydrological channel network analysis of the survey area on the 2m LiDAR Digital Elevation Model (DEM) data provided.

As a secondary output, the topographic model identifies any surface drainage channels present. The artificial Dunkellin River channel runs directly through the centre of the turlough, although the original channel is still present to the north of the basin. Drainage routes were identified from small changes in topography and classed under the Strahler stream order system, in which channels with no tributaries are first-order, two first-order channels join to create second-order, etc. These were then plotted on a map.

2.2. Walkover survey

The topographic outputs were used to identify any surface runoff channels into the turlough. As this is a karstic system none were present, so the walkover survey covered the periphery of the turlough and accessible locations within it. This walkover survey was conducted by two trained field scientists on 22 February 2023, who undertook a standardised and systematic walkover survey around the perimeter of the Rahasane Turlough under dry winter conditions. Water levels appeared moderately low with strandlines (high water marks) circa. 2 m higher than the water level on the day. Cattle, sheep and horses were present on site, and it was noted that the periphery of the turlough is apparently grazed all year around with open access to the livestock.

All potential sources of aquatic pollution entering the watercourses were classified, using the method detailed in Appendix A, and mapped. The origins of each source were identified where possible.

A second site visit, on 20th June 2023, coincided with a period of extremely heavy rain showers, which would create temporary runoff channels in most environments. While the survey on this day was not comprehensive, spot visits to peripheral locations in the northwest and southeast parts of the turlough confirmed no evidence of surface runoff.

2.3. Water quality sampling

Water samples were taken from locations shown in Table 2-1 and Figure 2-1. These locations were chosen to assess potential issues within the turlough itself but also to understand better the potential catchment sources of any high nutrient concentrations entering via the Dunkellin River. Samples were taken on two occasions from accessible sites: during relatively low flow on 13 September 2023[3] and during high flow following heavy rain on 20 September 2023; the latter date was to identify any changes in water quality due to catchment runoff. During the high flow period several of the sites

[3] During the summer of 2023 there were no truly low flow events, so these data are indicative of average flow conditions.

within the turlough were inaccessible due to high water levels and so a second sample could not be taken (see Table 2-1).

Additional water samples were collected on 24 July 2024 from Sites 16WQ and 15WQ, upstream and downstream of the turlough respectively, and from four locations within the turlough that retain pools during low water levels and are subject to annual biological survey as part of the five year monitoring programme (Table 2-1, Figure 2-2); site coding from annual monitoring (1A-4A) was therefore retained for these sites. River flow and water levels at this time were lower than during the 2023 surveys, and more typical of those expected in summer.

Water samples were collected by hand in accordance with best practice sampling methodology and subsequently delivered within 24 hours to an INAB accredited analytical laboratory. Analysis was completed as detailed in Table 2- to the limits of detection (LOD) outlined.

Three of the measured parameters – nitrate, orthophosphate and ammonia – were compared against appropriate standards. The Water Framework Directive (WFD) has standards for ammonia and orthophosphate (DEHLG, 2019). The orthophosphate (as P) thresholds are a concentration less than 0.025 mg/l for High status and less than 0.035 mg/l for Good status. Equivalent ammonia thresholds are 0.04 mg/l for High and 0.065 for Good. There is no WFD standard for nitrate, but the EPA recognises 0.9 mg/l (as N) as the boundary for High quality status and 1.8 mg/l for Good status (EPA, 2024). Note that these standards are based on statistics derived from multiple measurements, so comparing a small number of values with these is purely indicative. Results are compared to these standards for indicative purposes only. This does not constitute an assessment of the overall official status of a water body.

Table 2-1: Description of water quality sampling points

Site number	Water body	Location	Sampled? Low flow - 13 Sep 2023	High flow - 20 Sep 2023	Low flow – 24 July 2024
1WQ	Dunkellin R	Upstream of Raford River confluence	Yes	Yes	No
2WQ	Raford River	Tributary of Dunkellin River	Yes	Yes	No
3WQ	Dunkellin R	Downstream of Raford River confluence	Yes	Yes	No
4WQ	Dunkellin R	Upstream of Craughwell Village	Yes	Yes	No
5WQ	Dunkellin R	Downstream of Craughwell Village	Yes	Yes	No
6WQ	Aggard Stream	Upstream of Killora Stream confluence	Yes	Yes	No
7WQ	Killora Stream	Tributary of Aggard Stream	Yes	Yes	No
8WQ	Aggard Stream	Downstream of Killora Stream confluence	Yes	Yes	No
9WQ	Dunkellin R	Upstream of Aggard Stream confluence	Yes	Yes	No
10WQ	Dunkellin R	Immediately upstream of turlough	Yes	No	No
11WQ	Rahasane Turlough	Within turlough / Walkover Site 1	Yes	No	No
12WQ	Dunkellin R	Within turlough	Yes	No	No
13WQ*	Rahasane Turlough	Within turlough / Walkover Site 7 / Site 3A (annual monitoring site)	Yes	No	Yes
14WQ	Dunkellin R	Immediately downstream of turlough	Yes	No	No
15WQ	Dunkellin R	1 km downstream of turlough	Yes	Yes	Yes
16WQ	Dunkellin R	Immediately upstream of turlough	No	No	Yes
1A	Rahasane Turlough	Within turlough (annual monitoring site)	No	No	Yes
2A	Rahasane Turlough	Within turlough (annual monitoring site)	No	No	Yes
3A*	Rahasane Turlough	Within turlough / Site 13WQ / Walkover Site 7 (annual monitoring site)	Yes	No	Yes
4A	Rahasane Turlough	Within turlough (annual monitoring site)	No	No	Yes

*Site 13WQ and Site 3A are identical.

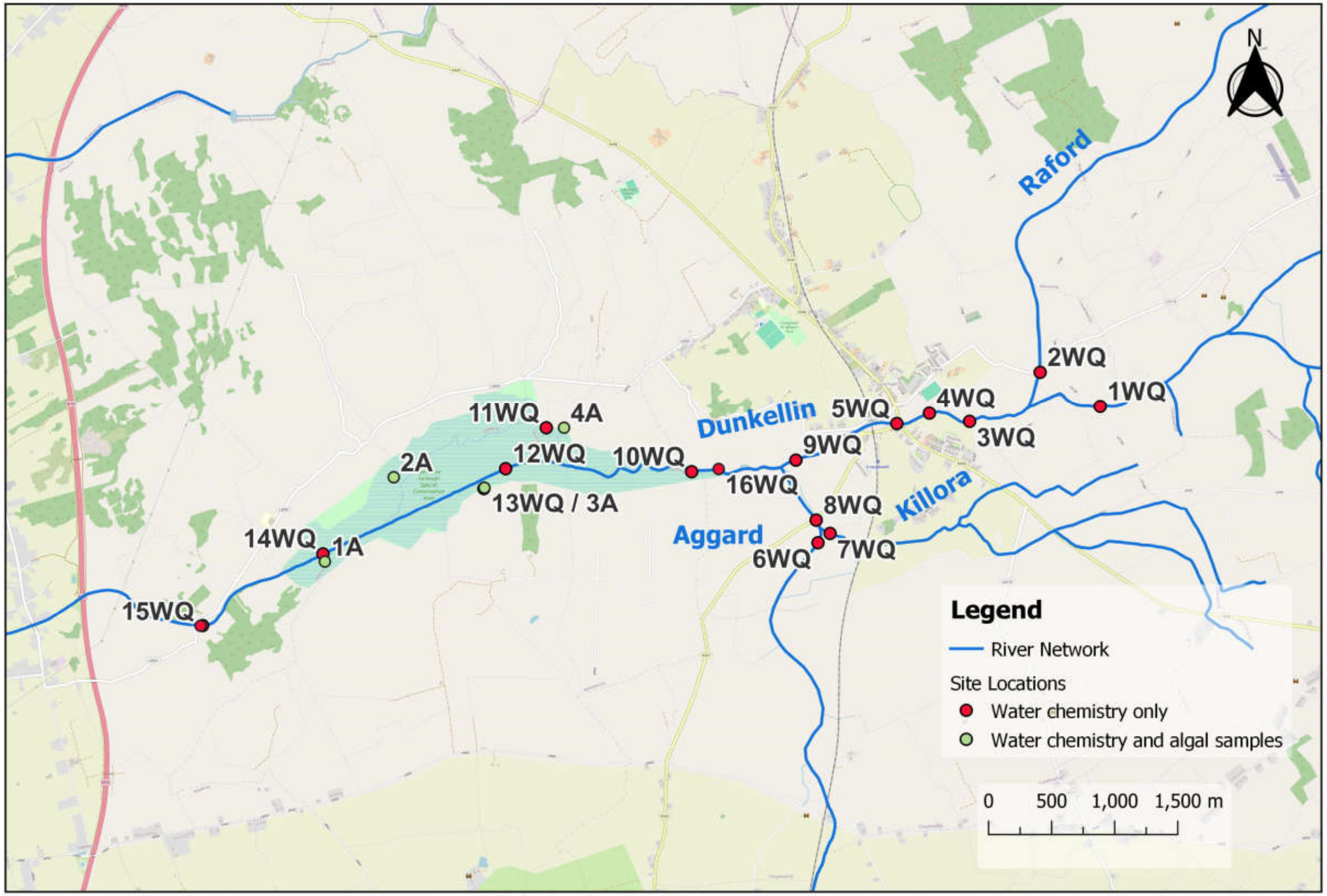

Figure Reference: P00014600 Rahasane Turlough Nutrient Investigation Map

Figure 2-1: Location of water quality and algal sampling sites.
Sample sites are numbered and details can be found in Table 2-1.

Table 2-2: Water quality parameters determined

Determinant	Units	Limit of detection	Accreditation
BOD	mg/l	1	INAB
Total Nitrogen as N	mg/l	0.33	INAB
Nitrate as N (by calculation)	mg/l	0.100	INAB
Ammonia as N	mg/l	0.005	INAB
Total Phosphorus as P	mg/l	0.050	
Orthophosphate (filtered) as P	mg/l	0.003	INAB

2.4. Draft nutrient budget for Rahasane Turlough

Using the data available, a first attempt was made to create a draft nutrient budget for Rahasane Turlough. A nutrient budget first requires estimates of load from each source, defined as a measure of nutrient inputs by weight over a defined period of time. In view of the number of unknown variables in any nutrient budget, and availability of different data types at different levels of resolution and often from time periods that do not overlap precisely, an attempt was made to estimate annual loads (i.e. inputs from each source over a period of one calendar year). Inputs were estimated from the following sources:

- Inflow river load;
- Groundwater load;
- Direct rainfall load;
- Bird load;
- Grazing livestock load; and
- Direct runoff load.

At this stage, no attempt was made to estimate losses from the system. Further detail on data sources and methods is provided in Appendix 4.

It must be emphasised that any estimates made at this stage are purely indicative of the type of method that can be deployed and should not be taken as any statement of actual source apportionment.

3. Results

3.1. Rahasane Turlough topography

A number of detailed maps of the Rahasane Turlough's topography and drainage network were produced as part of the project and are shown in this section.

3.1.1. Lake area and volume estimates

The elevation at which the turlough is largely dry, apart from the river channel and a few deep pools, is 13.58 m ASL[4]. Increasing the water level height gradually increases the surface area and volume, as shown in Table 3-1; the typical maximum water level elevation is around 19.5 m.

The approximate extent of surface water area at different water levels is shown in Figure 3-1.

Table 3-1: Surface area and volume of Rahasane Turlough at different water depths

Elevation (m ASL)	Area (ha)	Area (km^2)	Volume (mL)[5]
13.58	0.00	0.00	0.00
14.08	45.39	0.00	0.14
14.58	6285.88	0.63	128.01
15.08	13860.02	1.39	637.59
15.58	19592.48	1.96	1466.67
16.08	24357.61	2.44	2571.05
16.58	28229.11	2.82	3897.85
17.08	30801.12	3.08	5374.49
17.58	33253.24	3.33	6975.37
18.08	35950.00	3.60	8704.12
18.58	39034.24	3.90	10578.71
19.08	41857.32	4.19	12600.93
19.58	44787.08	4.48	14766.55

3.1.2. Map of Drainage Network

Potential flow pathways into the Rahasane Turlough, produced from hydrological channel network analysis on the provided 2m LiDAR DEM data of the survey area are shown in Figure 3-2 and Figure 3-3. The Strahler order and approximate length was estimated for each channel.

The two maps were generated to illustrate the drainage network. All channels were coloured by Strahler order number, which is used to define stream size based on the hierarchy of tributaries (1 being stream sources and increasing as tributaries join one another). 5 m contours were generated from the DEM.

[4] Above sea level
[5] Megalitres. 1 mL = 1000 m^3

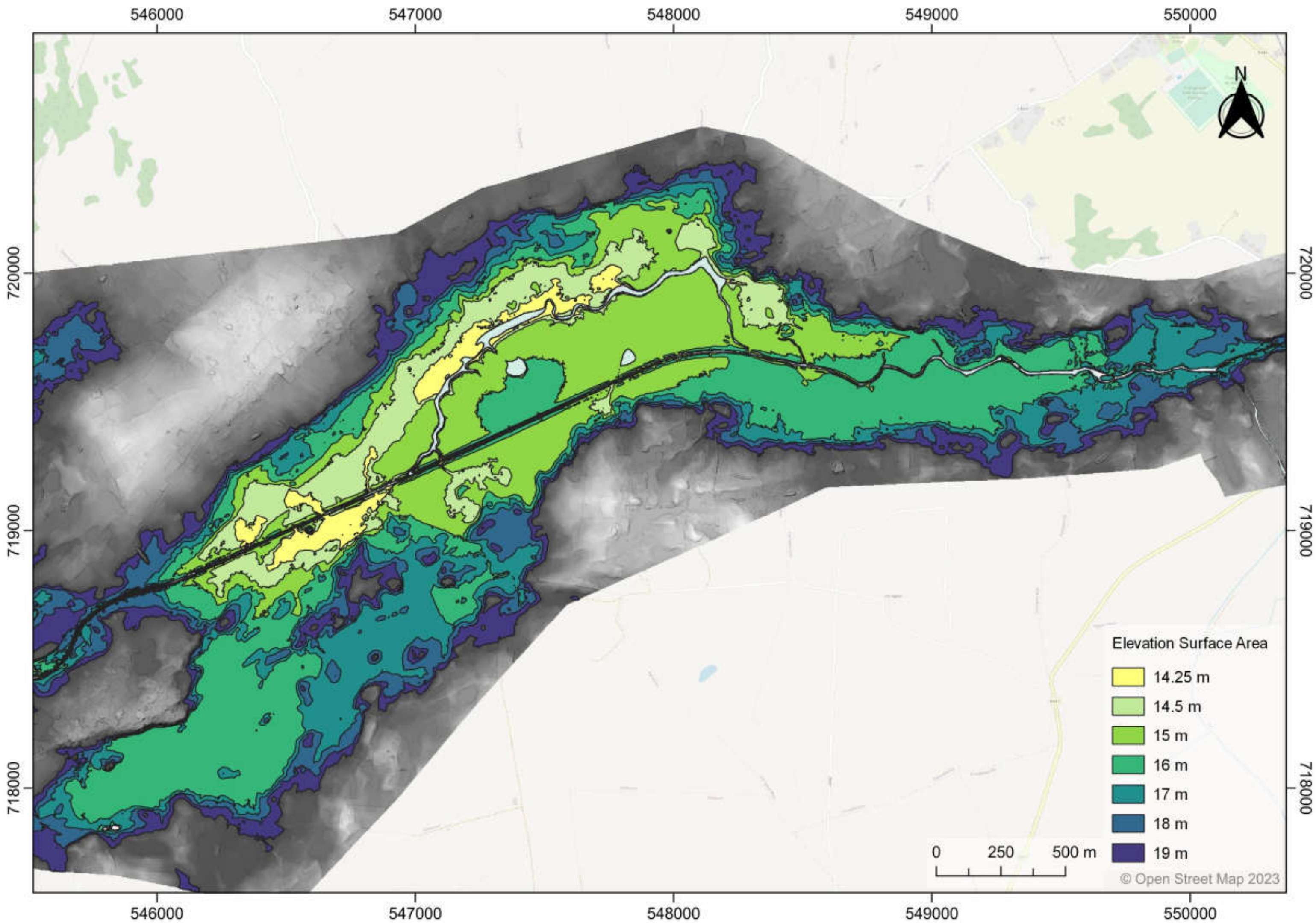

Figure 3-1: Map of areas flooded at different water levels

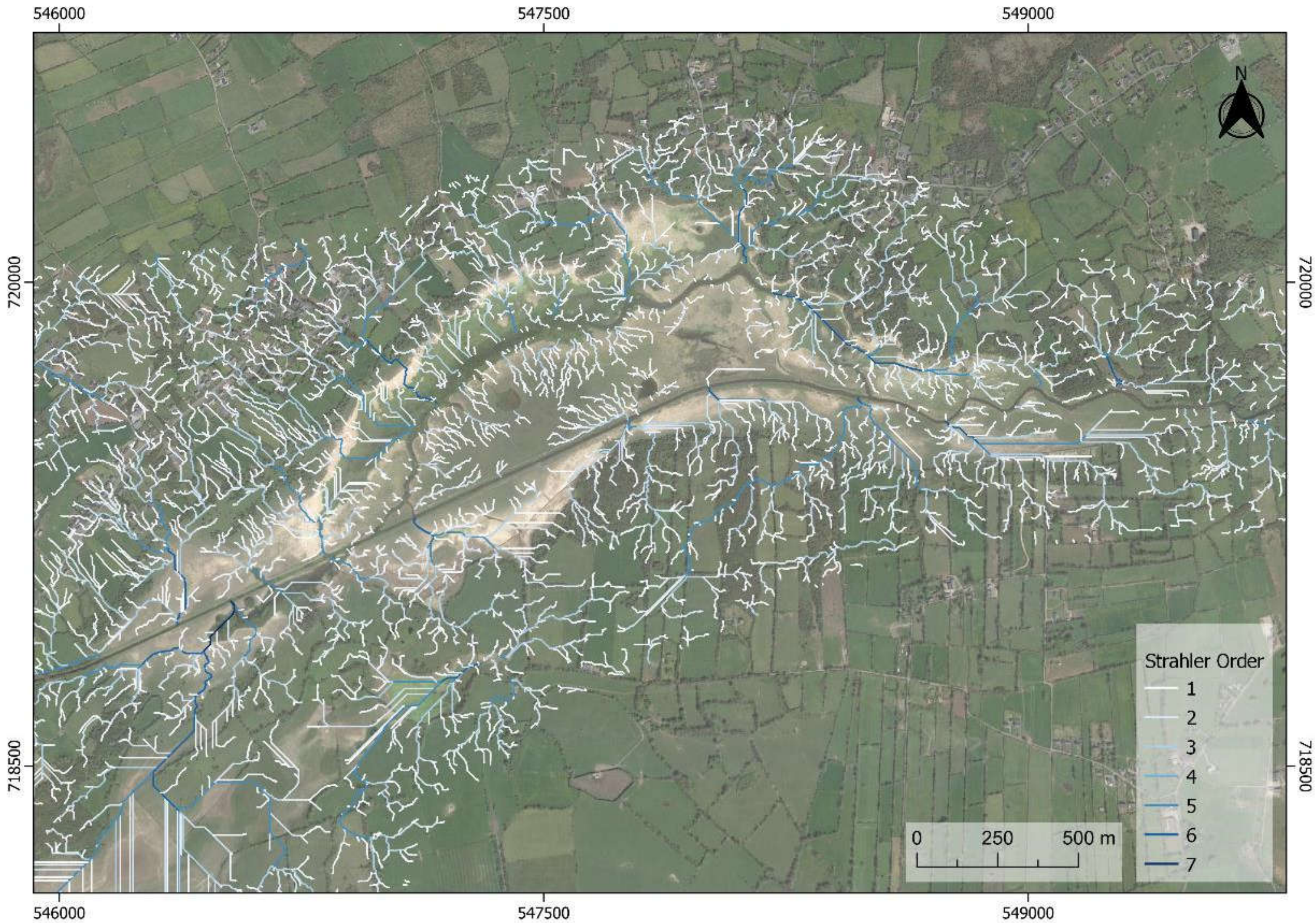

Figure 3-2: Map of drainage network overlaid on satellite imagery for the Rahasane Turlough
(Satellite imagery credit: Google Maps)

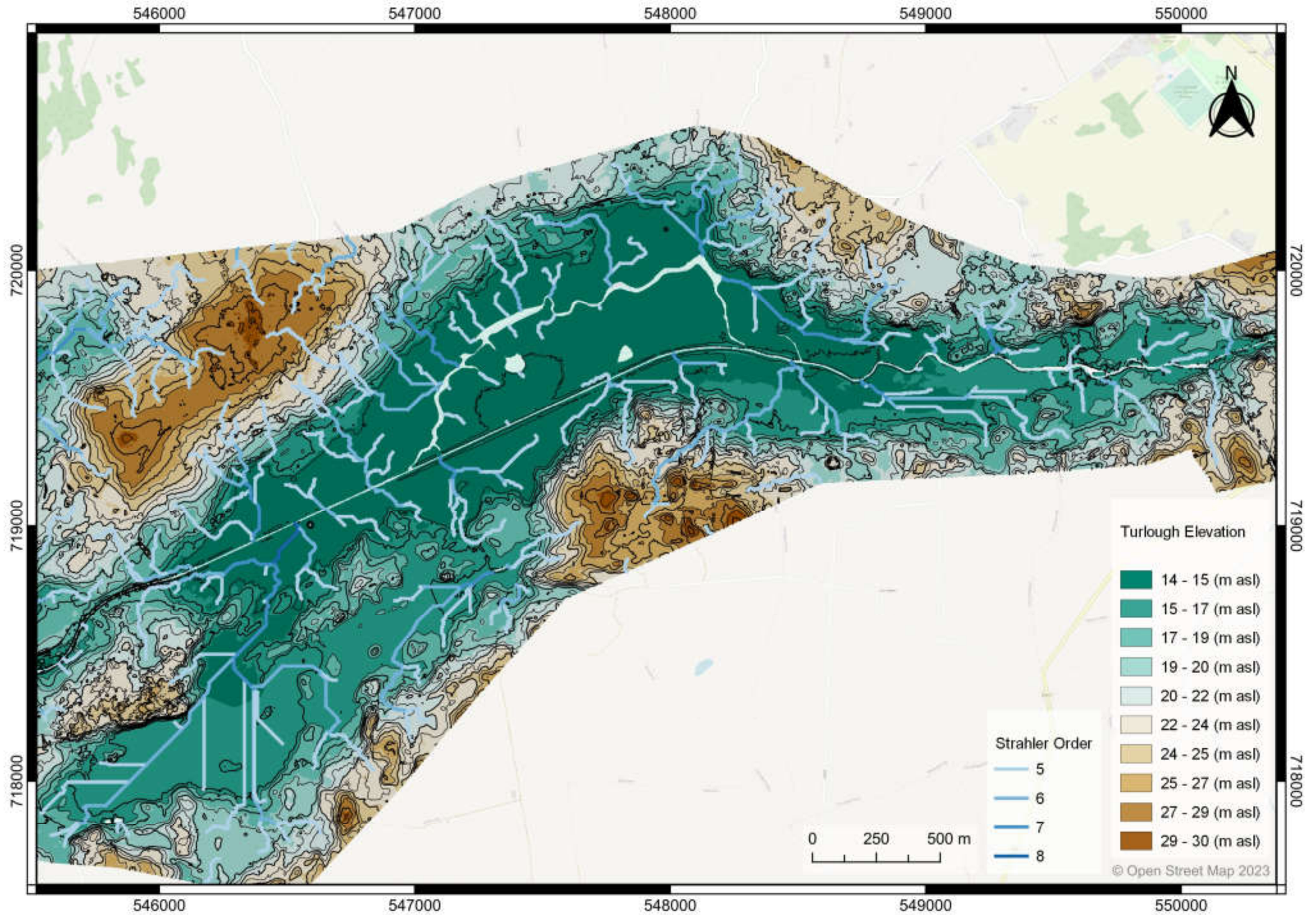

Figure 3-3: Map of key drainage network, overlain on 50 cm contours generated from the 2m lidar DEM

3.2. Walkover survey

The walkover survey of the perimeter of the Rahasane Turlough identified nine potential pollution sources (Figure 4). These sources were all localised inputs, having minimal influence in the immediate vicinity of the input (Grade 3). Most of the sources identified were livestock-related and, as the whole perimeter of the turlough, which is commonage, is available for grazing with animals able to enter the water, the periphery itself is a tenth potential pollution source. Pollution from these sources is likely to be most prominent in the summer when higher numbers of livestock are grazing, and they are likely contributing a significant quantity of nutrients in these summer months, which enter the turlough as water levels rise with wet weather.

The EPA has identified septic tanks as a potential source of water quality issues in this area (https://gis.epa.ie/EPAMaps/Water). Only one potential septic tank issue was identified (Site 1). However, as the turlough is also groundwater fed, septic tank inputs could be contributing to groundwater contamination, and through this entering the turlough.

Further details of every recorded pollution input can be found in Appendix B.

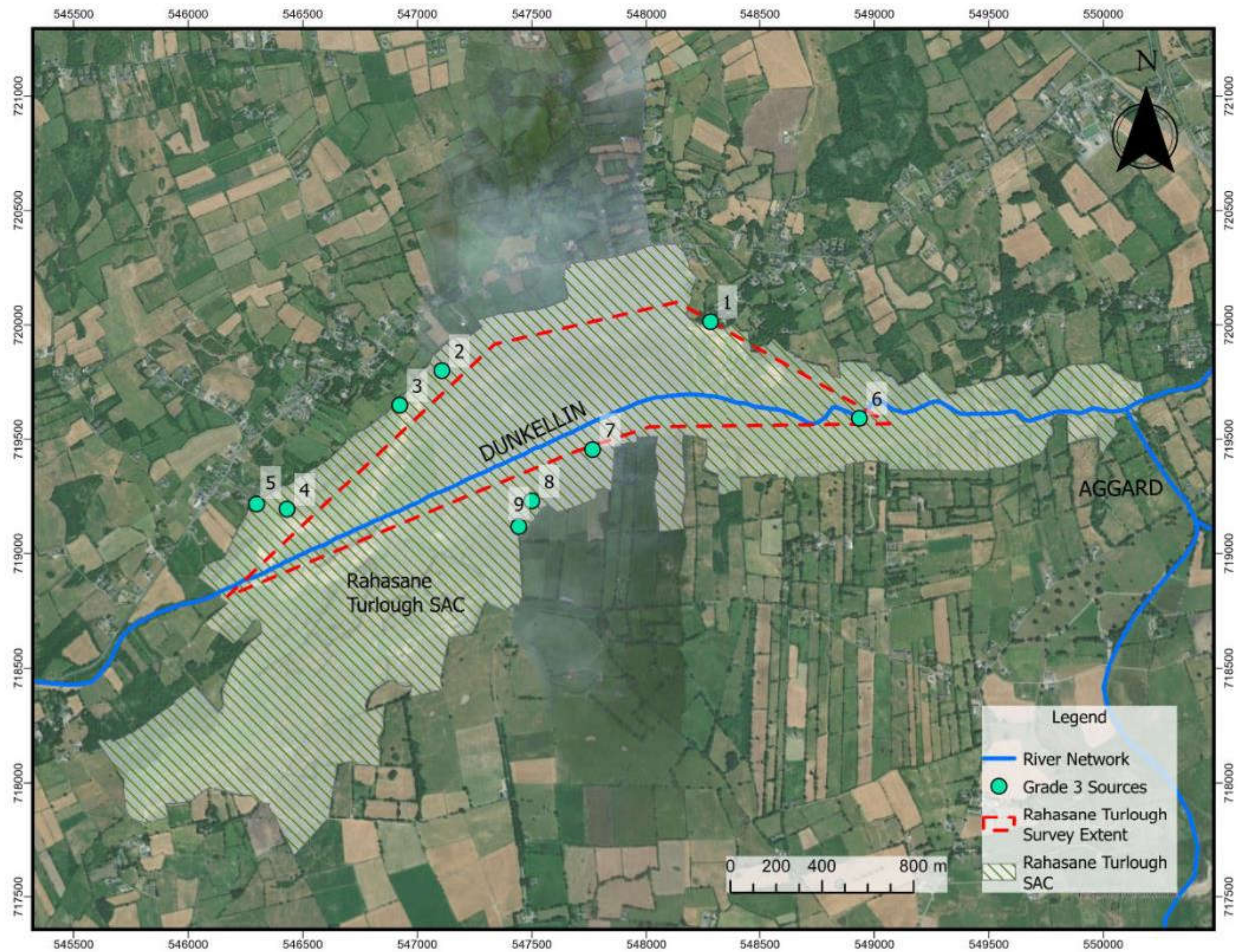

Figure 3-4: Location of all detected pollution sources recorded around Rahasane Turlough

See Appendix B for details

3.3. Water quality sampling

Full water quality results are provided in Appendix C.

There were some interesting patterns in nutrient concentration along the Dunkellin River in September 2023, moving from the upstream site immediately after the confluence with the Raford River (Site 3WQ) to the most downstream site (Site 15WQ; Figure 3-5). Concentrations of both total nitrogen and its main constituent, nitrate, remained constant upstream of the turlough, but then dropped downstream; however, while high flow increased total nitrogen concentration slightly it generally caused a drop in nitrate concentration. Orthophosphate concentrations remained relatively constant from upstream to downstream during low flow; at high flow the overall orthophosphate increased was higher upstream but similar to low flow concentration downstream; total phosphorus generally followed the same pattern, but with a low flow peak at Site 5WQ downstream of Craughwell village.

Data from the tributaries of the Dunkellin River suggest that origins of nutrients into the river vary in geography. Concentration of nitrate was relatively high in Aggard Stream during low flows, while the Raford River had high concentration of orthophosphate. Interestingly, despite the different inputs from tributaries, the main Dunkellin River showed a slight decline in phosphorus components from Site 1WQ to Site 10WQ, whereas the nitrogen components increased slightly in concentration.

In terms of concentrations, orthophosphate at the lower flow was within the High status boundary for all sites except Raford River, whereas at the higher flow concentrations exceeded the Good threshold at most locations. Nitrate, in contrast, exceeded the High threshold at several sites at low flow, but in most cases was more dilute at high flow; all readings were, however, within the Good threshold. Ammonia concentration was within the High threshold on most occasions, with the few exceedances showing no pattern.

Most chemical water quality concentrations declined in September 2023 between locations upstream of the turlough (Sites 9WQ and 10WQ) and the downstream site 14WQ, suggesting that the turlough was acting as a sink for nutrients brought in by the river; this pattern was not present in July 2024, where nutrients were very low in all samples.

Nutrient concentrations were low in all samples taken from the turlough in July 2024. Nitrate concentration was below the limit of detection at all sites apart from Site 11WQ, and here it was within the WFD High threshold. Similarly, orthophosphate and ammonia readings were all within the High threshold.

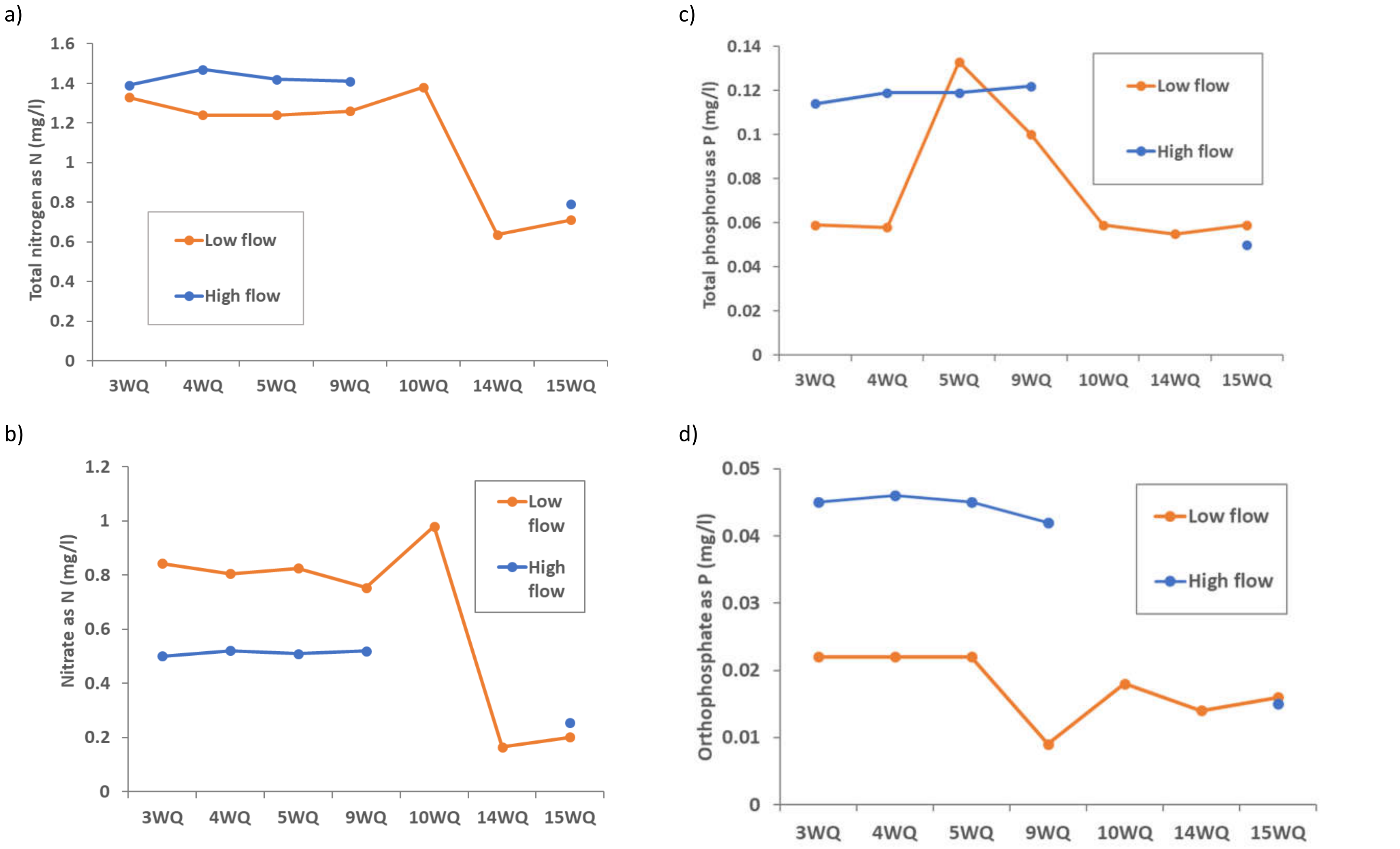

Figure 3-5: Nutrient concentrations in Dunkellin River during low and high flows, based on 2023 nutrient data

a) Total nitrogen as N; b) nitrate as N; c) total phosphorus; d) orthophosphate as P.

Site 3WQ - Dunkellin d/stream of Raford confl.; 4WQ -Dunkellin u/stream of Craughwell; 5WQ – Dunkellin d/stream of Craughwell; 9WQ – Dunkellin u/stream of Aggard confl.; 10WQ – Dunkellin d/stream of tribs., 14WQ – Dunkellin immediately d/stream of Rahasane; Site 15WQ Dunkellin 1km d/stream of Rahasane.

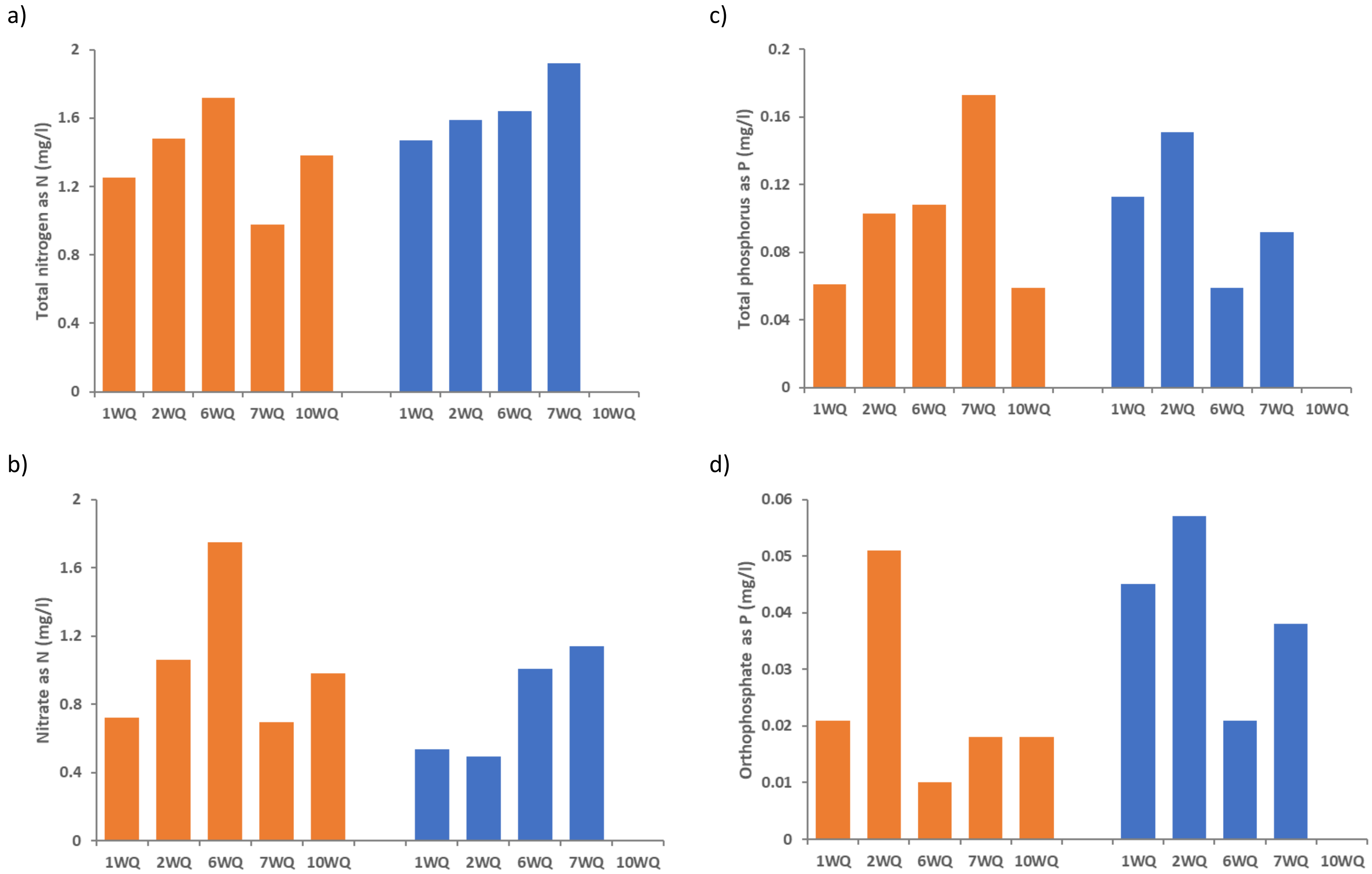

Figure 3-6: Nutrient concentrations in tributaries of the Dunkellin River, based on 2023 nutrient data

Orange = low flow; blue = high flow. Site 1WQ - Dunkellin R upstream of Raford confluence; Site 2WQ -Raford River; Site 6WQ – Aggard Stream; Site 7WQ – Killora Stream; Site 10WQ – Dunkellin River downstream of tributaries

4. Discussion

4.1. Evidence of nutrient enrichment of the turlough

The turlough has been assigned as a Groundwater Dependent Terrestrial Ecosystem (GWDTE) under the WFD. It was identified by the EPA as at risk of failing the objectives of the WFD, based on pressures from agriculture and domestic waste-water. The most recent macroinvertebrate data from the Dunkellin river (2024) indicates Moderate ecological status immediately upstream at Craughwell, and Poor ecological status downstream at Kilcolgan Bridge, indicating ecological degradation at these sites. The EPA has also identified septic tanks as a potential source of water quality issues in this area (https://gis.epa.ie/EPAMaps/Water). One potential septic tank issue was identified during the walkover survey (Site 1). However, septic tank inputs through groundwater contamination cannot be ruled out.

Nutrient concentrations have not been routinely monitored as part of the annual monitoring programme on the turlough as the focus of the annual programme is on monitoring impacts of the FRS on water levels and ecological responses in the turlough system. Nevertheless, as part of the annual monitoring, ecological data has suggested potential issues with livestock access, overgrazing and nutrient enrichment at the turlough. The vegetation surveys revisited transects surveyed by Roger Goodwillie in 1992, who found that the turlough was closely grazed by cattle, sheep and horses, and noted that the shortness of the vegetation was one of the turloughs chief features (Goodwillie, 1992). The annual vegetation surveys conducted in 2021, 2022 and 2024 also found vegetation was grazed short by livestock on each occasion, with poaching and animal dung evident along transects and a small percentage of bare ground indicating that stocking rates may be higher than optimal (the turlough was too flooded in 2023 to carry out a vegetation survey). Increased areas of closely cropped vegetation and bare ground can result in increased soil erosion and sediment runoff, resulting in increased nutrient loading where livestock dung is washed directly in after rainfall. Slimy floating algae and algal mats were noted at all sites, in 2021, 2022 and 2024. Water levels were very high in 2023, and therefore the water edge was much farther from sites annually monitored owing to the flooding. Algal mats and macrophytes were not noted in that year, as the edges were on flooded grassland, at a distance from the more permanently wet areas within the turlough.

The walkover survey indicated that the although localised inputs were evident, the whole perimeter of the turlough acts as a potential pollution source, owing to the availability of it to grazing livestock, with animals able to enter the water, with higher numbers grazing in summer, and likely contributing a significant quantity of nutrients in these months, entering the turlough as water levels rise with wet weather.

Nevertheless, despite indications of ecological impact at the turlough, water quality data presented in Appendix C, collected under different flow conditions in different years, does not indicate excessive nitrogen or nitrates at or upstream of the turlough, with all readings within the Good status thresholds recognised by the EPA. However, orthophosphate concentrations exceeded the Good status thresholds (Surface Water Regulations, 2009) at many upstream sites in high flows in September 2023, contrasting with the low flow data which had only one exceedance of the threshold on the Raford river. No exceedance of these thresholds occurred at the sites sampled in July 2024. It is difficult to draw conclusions from this data, as it only provides a snapshot in time, and more routine water quality monitoring of the surface waters would provide better understanding of any patterns and pulses occurring over time within the turlough and its catchment.

Observations made under low flows in the summer of 2024 found that nutrient concentrations within the turlough were very low at the time of sampling. However, the macroalgal assessment conducted at the same time and locations (Appendix D) identified microalgae and cyanobacteria taxa that suggest some evidence of nutrient enrichment. There is also some evidence of decomposing organic matter towards the outflow of the turlough under the low flow conditions.

4.2. Direct sources of nutrients

This study looked directly at two potential surface water sources of nutrients: direct inputs via runoff and land use activities, and inputs via the Dunkellin River. Observations made immediately after heavy rainfall confirmed that storms do not create any temporary runoff channels into the turlough, the water going instead straight to ground. In this respect, therefore, it differs from standard lakes, in which sudden heavy rain can wash large quantities of nutrients into the water from the surrounding catchment. Instead, inputs via livestock moving freely from the fully terrestrial to the seasonally dry turlough areas may be an important source of nutrients.

Among potential nutrient pollution sources identified around the perimeter of the turlough, livestock farming was the dominant source, owing to open access to the water for livestock on the commonage land surrounding it, and a number of conduits (tracks). This meets expectations, as livestock farming is the primary land use within the catchment. While direct runoff is not important, livestock moving from higher elevation feeding areas to lower elevation areas would provide an active source of nutrients, although this process could also work in reverse. There was a possible contribution from septic tanks identified at one location, and EPA mapping suggests that this could be a more widespread issue. Septic tank contamination of groundwater from the village of Killeeneen is outside the scope of this work but should be considered for more detailed investigation. It was originally proposed that the potentially contaminated site identified be included in the water sampling programme, but the very wet summer meant that the turlough was flooded at this time and much of the area was inaccessible.

All potential nutrient input features identified were Grade 3 or lower (categorised as minimal observed inputs).

4.3. Catchment inputs

No truly low flow periods could be sampled in 2023, as river levels remained high throughout the summer, but the preliminary water quality data would suggest no major pollution from the river water. The results from the limited water quality data collected under low flows in the summer of 2024 also indicated low nutrient concentrations within the turlough as well as immediately upstream and downstream of it.

No firm conclusions should be drawn from such a small dataset, but there were three points of note:

- Among the tributaries sampled, there appeared to be differences in concentrations of nutrients, suggesting localised sources.
- There were no obvious changes in water quality along the Dunkellin River upstream of the turlough, apart from a peak in total phosphorus at Site 5WQ downstream of Craughwell village during low flow, which persisted until the confluence with Aggard Stream.
- The water quality results from 2023 suggest that the turlough itself was apparently acting as a nutrient sink, with nutrient concentrations higher in the river upstream than downstream.

Initial indications from high flow data suggested that the turlough itself was apparently acting as a nutrient sink, with nutrient concentrations higher in the river upstream than downstream. However, under low flow conditions in 2024, nutrient concentrations were lower immediately upstream and within the turlough than they were immediately downstream. These results suggest that further water quality sampling is required to fully understand the role of the river and of the turlough itself, and will allow for the capture of episodic pulses and annual variation. Ideally samples should be taken at least monthly over a full annual cycle, as there can be important seasonal differences in inputs.

While the preliminary data suggest the tributaries may be acting differentially as sources of nutrients, this needs further data, both in terms of a larger number of water quality samples and also calculation of discharge, so that total loads can be estimated.

4.4. Summary of pathways

The first walkover survey confirmed that there were no clear point sources (e.g. farm slurry runoff, broken drains) around the periphery of the turlough, although it did find one location where there was possible input from a septic tank. Later visits, including immediately after very heavy rain, confirmed that there was no surface runoff from the surrounding higher land. Therefore, while there may be a small number of direct inputs (Pathway 1), these are unlikely to be enough to have more than very localised impacts on water quality. Based on these surveys, multiple and/or widespread point sources (Pathway 2) could be eliminated as a source of nutrients, as could direct catchment runoff (Pathway 3c).

The absence of runoff from higher ground, combined with the water quality readings from the river (Pathway 3a) and assumed groundwater quality (Pathways 3c; based on borehole readings from upstream), suggested that these were not an issue, albeit with the caveat that definite conclusions should not be drawn from a small number of water quality sample dates. However, it is noted that the EPA classifies the turlough at risk from Groundwater Domestic Waste Water Pressures and River Domestic Waste Water in its modelling, likely owing to a high water table connecting the surface and groundwaters within the turlough. Therefore, without further targeted investigation of groundwater, it is not possible to rule out contamination of the groundwater from septic tanks at one or more locations.

Unusually high water levels over summer 2023 meant locations where algal growths had been observed previously were inaccessible, and thus water quality samples could not be taken nor could localised inputs be observed in that year. No excessive algal growths were observed that year. This may have been as a result of the level of flooding in that year, with the growths related to the process of summer drying (higher temperatures and more light) and less dilution of nutrients, or because nutrient inputs were lower than in previous years.

The big unknown is the livestock (Pathway 4), and the extent that they are importing nutrients from the surrounding catchment and/or remobilising those already present in the vegetation. Again, however, their impacts may be localised and not a major issue across the site as a whole, but this would require research to determine.

In summary, therefore, the study managed to remove some potential issues (direct runoff, multiple surface point sources of pollution), and has a few unanswered questions relating to role of livestock and extent of sites showing clear evidence of enrichment. The data available suggested low impact of river and groundwater inputs, but these require further investigation. Phosphorus concentrations in the river were low at the lower flow but increased with the higher flow, so the role of the river as a source of nutrients may be determined by flow, and potentially it may have a greater effect at other times of year. Groundwater data are derived from a borehole some distance from the turlough and so this requires a more localised study to find out: a) if groundwater is contaminated closer to the turlough and, if so: b) what the potential sources may be.

5. A nutrient budget for Rahasane Turlough

5.1. Draft nutrient budget

A nutrient budget is a means for determining inputs of nutrients to a site, normally with the aim of identifying the largest sources and, if there is an issue with excessive nutrient input, prioritising measures to target their control. It is well established for conservation of lakes undergoing eutrophication. However, to our knowledge it has not been applied in this way to turloughs.

Turloughs add complications to the standard method. First, their water derives mainly from groundwater, and both water quality and movement of groundwater is often the least well understood part of the hydrological system. Second, they spend time as terrestrial systems, with terrestrial ecological processes and often extensive livestock grazing, in which nutrient dynamics may be dominated by recycling within the system rather than import or export. Third, the wetting and drying is likely to create a cycle of nutrient deposition and remobilisation.

However, with these caveats in mind, an attempt has been made here to produce an outline nutrient budget, in order to better understand sources of nutrients. While there are still major data gaps, it is possible at this stage to provisionally determine potential sources of nutrients and their relative scale, bearing in mind that a more complete dataset may change this fundamentally. In order to calculate a nutrient budget for the site, the following inputs are assumed:

- Inflow river load;
- Groundwater load;
- Direct rainfall load;
- Bird load;
- Grazing livestock load;
- Direct runoff load; and
- Internal load (release of nutrients from sediment).

Estimating these will give an idea of gross nutrient inputs and their sources. Note at this stage however that determining nutrient movement, recycling within the system and loss is not possible, although the following are of key relevance and will need to be considered.

a) Livestock are grazed on the site during low water periods. Much of their nutrient production through faeces and urine will therefore be internal recycling of nutrients in the vegetation, rather than imports, although the nutrients will be converted from slowly decomposing vegetation to more labile forms.
b) Birds will be important, some of which will feed externally and then import nutrients onto the site. However, others will remain on the turlough and therefore simply recycle nutrients while some may export nutrients by feeding onsite and then roosting elsewhere.
c) Internal load refers to nutrients that are released after having been incorporated into bed sediments. In a standard lake the sediment is expected to be a sink for nutrients as particulate matter is carried into the lake and then settles on the bed. In this way nutrients are locked out of the ecological cycle, but they can be released by physical perturbation or, under some circumstances, chemical processes. As a turlough has a natural flooding and exposure cycle, sediment build up in this way during flood periods will be followed by remobilisation during dry periods, so it is assumed not to be an important net source.

The methods by which nutrient inputs were estimated are provided in Appendix E.

From these preliminary figures the source apportionment of nutrients to Rahasane Turlough is as shown in Table 5-1, and illustrated in Figure 5-1.

Table 5-1: Provisional source apportionment figures for nutrient input to Rahasane Turlough, based on 2023 nutrient data

Source	Total P		Total N	
	Input (kg/y)	% of total	Input (kg/y)	% of total
River	2563	49.2%	83,216	51.3%
Groundwater	1427	27.4%	66,336	40.9%
Rainfall	232	4.4%	3644	2.2%
Birds	139	2.7%	565	0.3%
Livestock	851	16.3%	8581	5.3%
Total (kg/yr)	**5212**		**162,341**	

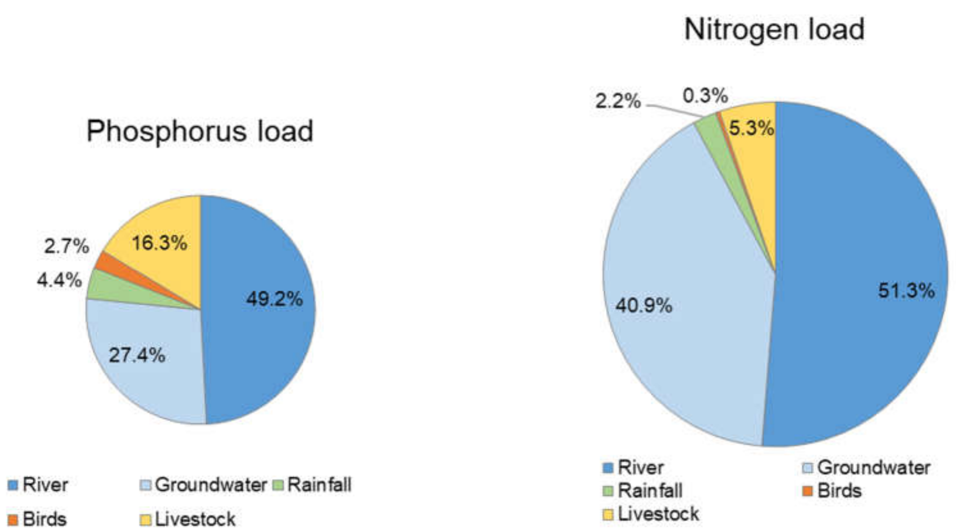

Figure 5-1: Visual representation of provisional source apportionment figures for nutrient input to Rahasane Turlough, based on 2023 nutrient data

This preliminary source apportionment is a gross oversimplification, relying on a range of assumptions and with various nutrient sources not yet included; it also takes no account of the internal recycling described above, and so may inflate the role of livestock in particular. It also cannot at this stage incorporate the two-way flow via groundwater. However, it does provide a basis for considering the data needs to overcome these issues and to work towards a more accurate nutrient budget in future.

5.2. Data needs for a full nutrient budget

5.2.1. Rivers

The Dunkellin River inflow to Rahasane Turlough is well understood, with both discharge data and water quality data available (albeit with total phosphorus not monitored). However, the flow monitoring station is upstream of Aggard Stream, whose contribution is therefore unknown. Measures of flow in Aggard Stream, along with a detailed monitoring of water quality, are needed in order to calculate loads from this source. There is a stage (depth) monitor in Aggard Stream, from which it is assumed estimates of flow can be made without having to take direct measurements.

Downstream of Rahasane Turlough there is a stage monitor, but no flow monitoring, and no water quality data. Monitoring these close to the turlough outflow is important, in order to understand the role of the turlough as a sink for inputs from upstream. Key questions are as follows:

- Does outflow volume match inflow, or is the turlough a net sink for water, as it may have been before the artificial channel was built?
- Does outflow change in tandem with inflow, or does flow increase downstream during turlough flooding periods and decrease during drying periods?
- Is the apparent reduction in nutrient concentration identified from the spot sampling carried out here a consistent pattern?

These questions could be answered with a simple regular monitoring programme, described below and summarised in Table 5-2. In addition, during at least one reflooding period, it would be useful to take water samples on multiple occasions: grazing animals will have turned much of the vegetation into highly labile faeces and urine, which may then cause a downstream flush of nutrients as the turlough refloods.

It is important to emphasise that, while the data needs described here are the ideal situation, a reasonable nutrient budget may be possible with more limited data.

5.2.2. Groundwater

A key requirement for a full understanding of the role of groundwater in nutrient dynamics is to monitor the extent to which the turlough is flooded, ideally at least weekly. As there is a clear relationship between depth and volume, a series of permanent water depth gauge boards, with measurements made at frequent intervals, would be both robust and adequate for this role. The preliminary source apportionment exercise assumed a regular pattern of autumn-winter filling and spring-summer drying, but this is unrealistic because:

- This pattern does not always occur. In 2023, for example, the water level in August was similar to typical winter depths; and
- The turlough may fill and empty rapidly rather than over the course of several months.

Furthermore, using this cycle limited the amount of groundwater nutrient data that could be used. In the period 2016-22 there were 19 groundwater quality readings taken, of which only five overlapped with the assumed filling cycles for the turlough; a more accurate indication of turlough filling and emptying would enable better use of the existing data.

Net inflows and outflows from groundwater can then be calculated from the extent to which the turlough is flooded. The nearest groundwater monitoring station within the subcatchment is at New

Inn No. 1, ca. 20 km to the northeast, and a more local station may give a better idea of nutrient contributions from groundwater.

It would be informative, if possible, to measure nutrient concentrations in the turlough as it fills, so the extent to which groundwater is a source or sink of nutrients is understood.

5.2.3. Rainwater

There are good data on rainfall volumes. The nutrient concentrations used in the source apportionment exercise above derive from data collected in northwest England and may therefore not be valid for this site. Precipitation and dust collectors could be installed to collect local data, although unless the direct atmospheric inputs are considered to be important (for example if the surrounding catchment is extensively ploughed), then this will probably have little effect on the overall pattern.

5.2.4. Birds

There are good bird data collected monthly from September to May. This could be analysed further to consider realistic lengths of time each species is likely to spend on the turlough site versus elsewhere.

5.2.5. Livestock

Livestock numbers and movements are an important determinant of nutrient dynamics in the turlough. The preliminary source apportionment used some guesses on numbers, based on local livestock data, but actual numbers that use the site, when and for how long, is unknown. Furthermore, horses were not included.

The following is needed in relation to livestock:

- Numbers of each species that graze the site, and when they are present;
- The area of grazing land they use that is flooded and the accessible area outside the flooding zone; and
- Details of any supplementary feeding: food type, amount, timings.

The data above may be relatively easily accessible, through farmer questionnaires, direct counts and map analysis. More complex, but also very useful information, would be direct observations of animal behaviour, in order to understand where they mainly graze and whether this is different from main defecating areas. This would enable an understanding of whether the animals simply recycle nutrients in situ, or whether they move them from floodable to non-flooding areas or vice versa.

5.2.6. Direct runoff

Observations made on site and the geology of the catchment confirm that this is unlikely to be an important source of inputs. The exception is if there are any concentrated point sources of nutrients that may leak into the turlough area, such as poorly maintained septic tanks or slurry stores. Mapping such features would be a useful first step in identifying if they are likely to be an important source of nutrients.

Table 5-2: Summary of monitoring recommendations for nutrient budget calculation

Element	Monitoring Recommendations	Frequency
Surface Water	1. Additional flow data under different flow conditions - Aggard Stream - Dunkellin River downstream of the turlough	Minimum of five occasions
	2. Routine water quality monitoring of surface waters at sites previously monitored as part of the study	Ideally monthly for at least one year
	3. Targeted water quality monitoring - At the turlough - At low flows at sites previously monitored as part of the study	Before, during and after reflooding period Low flows
Groundwater	4. Monitor extent of turlough using a series of permanent water depth gauge boards	Ideally monthly for at least one year
	5. Monitor boreholes closer to turlough if possible - Monitor nutrients - Monitor human input indicator (e.g. caffeine) to indicate source (domestic wastewater or livestock)	Ideal minimum seasonally for at least one year
Livestock	6. Numbers of each species grazing and when present (e.g. routine drone flight)	Ideal minimum monthly for at least one year
	7. Supplementary feeding food type, quantity and timing (farmer survey?)	Ideal minimum one full grazing season
	8. Animal movements within the site, identifying main grazing and defecating areas	Ideal minimum monthly for at least one year

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7. Appendix A: Categorisation of catchment pollution sources

The categorisation of potential pollution sources identified during a walkover survey is set out in APEM's walkover survey handbooks, which were developed based on the Rural Sediment Tracing Project carried out by APEM, in collaboration with the Environment Agency for England, between 2009 and 2011 (APEM 2010; 2011). This translates readily to Irish geography and facilitates standardised analysis of the types of land use practice that may be causing elevated levels of nutrients, into watercourses and in the area as a whole.

The perceived threats posed by inputs of pollution sources are classified on a scale of Grade 1 to Grade 3, where Grade 1 is the most severe. Potential aquatic pollution sources are identified using the 'source, pathway receptor' approach with agricultural, as well as non-agricultural pollution sources and urban run-off identified. The criteria by which the grades are defined for diffuse organic pollution and fine sediment inputs are provided in Table 7-1. To ensure consistency, walkover survey staff receive initial training in aquatic pollutants, their pathways and sources. In addition, field handbooks, which clearly define the different types of aquatic pollution found in rural environments, are provided to each field worker with standardised explanation of the classification and grading systems to be applied.

The categorisation of pollution sources is shown in

Table 7-2. This facilitates analysis and source apportionment of the types of land use practice that are causing potentially elevated levels of aquatic pollutants.

Table 7-1: Definitions and examples of sediment, nutrient and organic pollution sources of Grades 1 to 3
As classified during the walkover surveys

Grade	Definition	Example
1	Observed (or potential for) widespread pollution causing localised and widespread impacts more than 100m from the point or diffuse source.	• Fields with major erosion gullies • Fields with evidence of large-scale overland flow • Extensively poached and trampled fields • Farm tracks with evidence of overland flow • Sewage pipe discharging into river • Slurry or manure run-off directly into river via ditch • Sewage fungus present in river or ditch flowing into river • Change in river profile around the point source, i.e. large pool • Widespread change in in stream vegetation and increased algal growth downstream of source • Discolouration of water or substrate downstream of a point source
2	Observed (or potential for) local pollution causing noticeable impacts within 100m of the point or diffuse source.	• Fields with evidence of localised run-off • Localised poaching • Drains and ditches discharging small quantities of effluent • Run-off from farmyard track into river, where organic material observed on track • Manure heap situated in riparian area, with evidence of run-off into channel • Localised change in in stream vegetation • Drains and ditches discharging moderate discharges
3	Minimal observed (or potential for) pollution with localised impacts in the immediate vicinity of the input.	• Active land drains • Road drains and other pipes • Minor stocking drinking areas and other points of livestock access • Livestock feeding area adjacent to channel • Muck spreading on land with potential for overland flow into channel • Minor land drains and small gauge pipes with very localised impacts to in stream habitat • Historical evidence of inflows from minimum risk sources such as road surface run-off

Table 7-2: Categories of pollution sources

Category	Source	Type	Abbreviation
A	Arable	Overland runoff (cropland)	OR
		Arable field drain	FD
		Arable drainage pipe	ADP
		Spreading	ASP
B	Livestock	Farmyard surface runoff	FR
		Farmyard discharge (infrastructure)	FD
		Poaching – direct input	PO
		Overland runoff (Grassland)	POR
		Drainage ditch	PDD
		Over-grazing	OG
		Spreading	LSP
C	Conduits	Road	RR
		Track	TR
		Drainage ditch (non-agricultural)	DD
		Footpath	FP
		Pipe	PI
D	Domestic & Industrial	Sewage treatment works	STW
		Combined Sewage Overflow	CSO
		Urban run-off	UR
		Septic tank	ST
		Industrial Effluent	IE
		Construction site	CS
		Dredging	DR
E	Other	Spoil heap	SH
		Unknown	UK
		Bank erosion	BE
		Other	OT

8. Appendix B: Walkover pollution source identification scorecards

A total of nine Grade 3 pollution sources were recorded during the walkover survey around the perimeter of the turlough, dominated by livestock (pasture) sources with pathways to the receptor using conduits (tracks) and overland flow.

The individual scorecards for each are provided below.

Site Number	**1**	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4831819984
Pollutant type	Microbial/pathogenic and nutrients	**Priority**	**Low**
Source category	Anthropogenic (D)	**Source type**	Potential septic tank input (ST)
Land use	**LHB:** Pasture (commonage)		**RHB:** Pasture (commonage) with rural housing adjacent
Vegetation	**LHB:** Grass/herbs, occasional trees and low plants		**RHB:** Grasses/herbs
Synopsis: Potential septic tank input via small depression near residential area.			

Site Number	**2**	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4714519770
Pollutant type	Bacterial and nutrients	**Priority**	**Low**
Source category	Livestock (B)	**Source type**	Poaching (PO)
Land use	**LHB:** Pasture (commonage)	**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs	**RHB:** Grass/herbs, occasional trees and low plant	

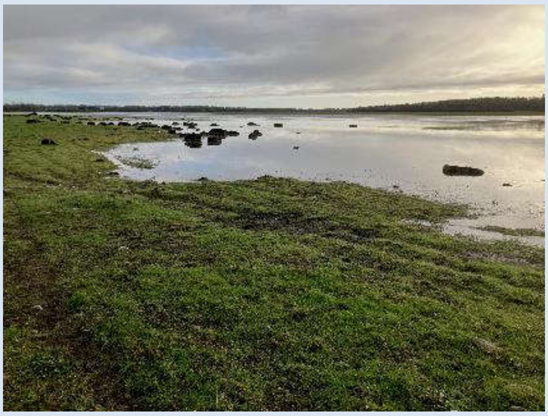
Synopsis:

Small area of minor poaching. May be more significant during summer months when stocking levels increase.

Site Number	3	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4696119619
Pollutant type	Bacterial and nutrients	**Priority**	**Low**
Source category	Livestock (B)	**Source type**	Poaching (PO)
Land use	**LHB:** Pasture (commonage)	**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs	**RHB:** Grass/herbs, occasional trees and low plant	

Synopsis:

Gated access - potential for livestock drop off location. Damage could be worse during spring months, when potentially large numbers of livestock may be dropped off via the gated access.




Site Number	**4**	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4696119619
Pollutant type	Bacterial, sediment and nutrients	**Priority**	**Low**
Source category	Livestock (B)	**Source type**	Livestock track / Poaching (PO)
Land use	**LHB:** Pasture (commonage)	**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs	**RHB:** Grass/herbs, occasional trees and low plant	

Synopsis:

Livestock track

Site Number	**5**	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4633619185
Pollutant type	Bacterial, sediment and nutrients	**Priority**	**Low**
Source category	Conduits (C)	**Source type**	Minor track (TR)
Land use	**LHB:** Pasture (commonage)	**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs	**RHB:** Grass/herbs, occasional trees and low plant	

Synopsis:

Minor track with vehicle access, suggesting likely drop-off location for livestock.

Site Number	**6**	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4897319562
Pollutant type	Bacterial, sediment and nutrients	**Priority**	**Low**
Source category	Livestock (B)	**Source type**	Minor poaching on watercourse (PO)
Land use	**LHB:** Pasture (commonage)	**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs	**RHB:** Grass/herbs, occasional trees and low plant	

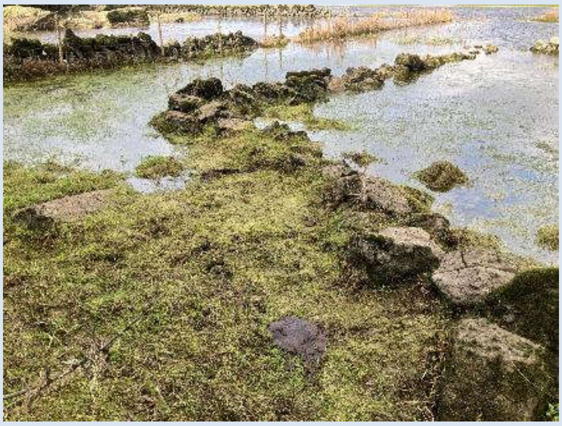
Synopsis:

Minor poaching on watercourse

Site Number	**7**	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4780319425
Pollutant type	Bacterial, sediment and nutrients	**Priority**	**Low**
Source category	Livestock (B)	**Source type**	Poaching (TR)
Land use	**LHB:** Pasture (commonage)	**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs	**RHB:** Grass/herbs, occasional trees and low plant	

Synopsis:

Livestock faeces (sheep and cattle) present in and around water.



Site Number	**8**	**Water body**	Rahasane Turlough
Date	22/02/2023	**NGR**	M4753719199
Pollutant type	Bacterial, sediment and nutrients	**Priority**	**Low**
Source category	Livestock (B)	**Source type**	Poaching (TR)
Land use	**LHB:** Pasture (commonage)	**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs	**RHB:** Grass/herbs, occasional trees and low plant	
Synopsis: Cattle poaching			

Site Number	9		**Water body**	Rahasane Turlough
Date	22/02/2023		**NGR**	M4748119087
Pollutant type	Bacterial, sediment and nutrients		**Priority**	**Low**
Source category	Livestock (B)		**Source type**	Poaching (TR)
Land use	**LHB:** Pasture (commonage)		**RHB:** Pasture (commonage) with rural housing adjacent	
Vegetation	**LHB:** Grasses/herbs		**RHB:** Grass/herbs, occasional trees and low plant	
Synopsis: Cattle poaching				

9. Appendix C: Water quality data

Site	Water body	Location	BOD mg/l			Total Nitrogen as N mg/l			Nitrate as N mg/l			Ammonia as N mg/l			Orthophosphate (filtered) as P mg/l			Total Phosphorus as P mg/l		
			Sep 2023 Low flow	Sep 2023 High flow	Jul 2024 Low flow	Sep 2023 Low flow	Sep 2023 High flow	Jul 2024 Low flow	Sep 2023 Low flow	Sep 2023 High flow	Jul 2024 Low flow	Sep 2023 Low flow	Sep 2023 High flow	Jul 2024 Low flow	Sep 2023 Low flow	Sep 2023 High flow	Jul 2024 Low flow	Sep 2023 Low flow	Sep 2023 High flow	Jul 2024 Low flow
1WQ	Dunkellin R	Upstream of Raford River confluence	<1	2		1.25	1.47		0.720	0.535		0.016	0.068		0.021	0.045		0.061	0.113	
2WQ	Raford River		<1	3		1.48	1.59		1.060	0.494		0.022	0.161		0.051	0.057		0.103	0.151	
3WQ	Dunkellin R	Downstream of Raford River confluence	<1	2		1.33	1.39		0.842	0.500		0.015	0.033		0.022	0.045		0.059	0.114	
4WQ	Dunkellin R	Upstream of Craughwell Village	<1	2		1.24	1.47		0.805	0.521		0.015	0.036		0.022	0.046		0.058	0.119	
5WQ	Dunkellin R	Downstream of Craughwell Village	<1	2		1.24	1.42		0.825	0.510		0.014	0.012		0.022	0.045		0.133	0.119	
6WQ	Aggard Stream	Upstream of Killora Stream confluence	<1	<1		1.72	1.64		1.750	1.010		0.047	0.028		0.010	0.021		0.108	0.059	
7WQ	Killora Stream		<1	1		0.98	1.92		0.698	1.140		0.021	0.026		0.018	0.038		0.173	0.092	
8WQ	Aggard Stream	Downstream of Killora Stream confluence	<1	<1		1.68	1.64		1.690	1.030		0.022	0.027		0.009	0.022		0.077	0.064	
9WQ	Dunkellin R	Upstream of Aggard Stream confluence	<1	2		1.26	1.41		0.753	0.519		0.013	0.023		0.009	0.042		0.100	0.122	
16WQ	Dunkellin R	Immediately upstream of turlough			<1			<0.33			<0.100			0.027			0.010			<0.050
10WQ	Dunkellin R	Immediately upstream of turlough	<1			1.38			0.979			0.015			0.018			0.059		
4A	Rahasane Turlough	Within turlough (annual monitoring site)			1			<0.33			<0.100			0.037			<0.010			<0.050
11WQ	Rahasane Turlough	Within turlough / walkover Site 1	2			0.89			0.672			0.010			0.016			0.055		
12WQ	Dunkellin R	Within turlough	<1			1.24			0.873			0.050			0.009			0.042		
13WQ / 3A	Rahasane Turlough	Within turlough / Walkover Site 7 / Site 3A (annual monitoring site)	3		<1	0.75		Error	<0.100		0.427	0.148		0.025	0.021		0.013	0.069		<0.050
2A	Rahasane Turlough	Within turlough (annual monitoring site)			1			<0.33			<0.100			0.028			0.015			<0.050
1A	Rahasane Turlough	Within turlough (annual monitoring site)			2			0.37			<0.100			0.040			0.024			<0.050
14WQ	Dunkellin R	Immediately downstream of turlough	<1			0.64			0.165			0.038	0.021		0.014			0.055		
15WQ	Dunkellin R	1 km downstream of turlough	<1	1	2	0.71	0.79	0.58	0.202	0.256	<0.100	0.043		0.037	0.016	0.015	0.013	0.059	0.050	<0.050

Figure 9-1: Water quality data from samples taken in September 2023 and July 2024

Sites were re-ordered starting upstream and continuing downstream. Yellow highlighting represents exceedances of the High status threshold (e.g. >0.9 mg/l Nitrate (as N) as recognised by the EPA) and red highlighting represents exceedance of the Good status threshold (>0.065 m/l Ammonia; >0.035 mg/l Molybdate Reactive Phosphorus as per Surface Water Regulations 2009)

10. Appendix D: Macroalgal Assessment

10.1. Introduction

The surveys conducted in 2024 included a survey of algal mats at the four locations within Rahasane Turlough that are annually monitored for macroinvertebrates (Figure 2-2), identifying the microalgae and cyanobacteria taxa present to further understand the nutrient status of the turlough. Accompanying this survey, nutrient concentrations in the water at each location were determined (Appendix C; Sections 3.3.2 and 4).

10.2. Method

Algal mats were collected on 24 July 2024. The survey followed a rapid loch assessment protocol, adapted from the RAPPER method (Rapid Assessment of PeriPhyton Ecology in Rivers; Kelly et al., 2016a and b) based on the guidance of Dr Martyn Kelly.

A 10 m wide quadrat ('hab-plots'), extending out to knee-depth, was established at each of the four annually monitored sites. The assessment involved conducting (i) a substratum composition and siltation assessment using a modified Wentworth scale (Table 2-2) and (ii) an algal cover assessment on a four-point scale (Table 2-3). These assessments were done from the shore at the edge of each hab-plot at each site, as wading was not possible owing to unstable substrates (clay, mud and silt).

Samples of algal growths and mats were collected from each site, placed in vials and sent to Dr. Martyn Kelly (Bowburn Consultancy) for identification to the finest possible resolution. Their composition and percentage cover were recorded using a DAFOR (Dominant-Abundant-Frequent-Occasional-Rare) scale, based on the examination of five subsamples per site.

Table 10-1. The Wentworth Scale (modified form, following CEN, (2011))

Name	Size and Comments
Bedrock	Exposure of underlying solid rock
Boulder	Loose rocks >256 mm diameter (roughly the size of a large head)
Cobble	Loose rocks >64 $\leq$ 256 mm diameter (roughly the size of half fist to a large head)
Pebble	> 64 $\leq$ 256 mm ("conker" to half fist size)
Gravel	> 2 $\leq$ 64 mm
Sand	Particles > 0.06 $\leq$ 2 mm (gritty when rubbed)
Silt	Particles > 0.004 $\leq$ 0.06 mm, very fine smooth material
Clay	$\leq$ 0.004 mm, sticky, cohesive (can be rolled without crumbling)
Peat	Organic matter derived from decaying vegetation, usually dark brown or black
Marl	Fine calcareous material deposited in hard water lakes (crumbles when rolled)

Table 10-2. Four point scale used to record algal cover

Category	Description

0	No obvious filamentous algae
1	Filamentous algae present, percent cover = low (< 5% of littoral bed)
2	Filamentous algae present, percent cover = moderate (≥ 5, < 25% of littoral bed)
3	Filamentous algae present, percent cover = high (≥ 25 % of littoral bed)

10.3. Results

The assessment of algae, and the results of the analysis of algal growths and mats collected at each of the four hab-plots are recorded in Table 10-3. Figures 10-1 to 10-4 feature photos of the hab-plot at each site.

The percentage of algal cover varied widely among sites, ranging from 5-90%. *Cladophora glomerata* was the dominant macroalgal species at each site, and the only macroalgal taxa present at Sites 1A and 3A. Site 2A and 4A also had abundant *Mougeotia* sp and *Chroococcus turgidus* respectively, and *Oedogonium* sp were present at both of these sites. Macroalgal mats at Site 1A were bleached, heavily colonised by diatoms and cyanobacteria, whereas Site 2A had only one diatom taxa recorded. Sites 3A and 4A had relatively few diatoms, with cyanobacteria and other bacteria instead at Site 3A and Site 4A with cyanobacteria (*Chroococcus* sp) around the *Cladophora*.

Table 10-3: Assessment and taxa list of macroalgae at each site on the turlough

Site	Algal Cover (%)	Macroalgal taxa	DAFOR	Notes on macroalgae and other taxa present (e.g. diatoms / bacteria / cyanobacteria)
1A	5	*Cladophora glomerata*	D	Mostly narrow and sparsely branched, heavily colonised by diatoms: *Gomphonema, Rhoicosphenia* and *Cocconeis* and a narrow filamentous bacterium / Cyanobacterium. The filaments all appeared to be bleached
2A	50	*Cladophora glomerata* *Mougeotia* (~ 20 µm diameter) *Oedogonium* (~10 µm diameter) *Oedogonium* (~30 µm diameter)	D A F R	*Epithemia* was the most conspicuous epiphyte, in contrast to Site 1A.
3A	75	*Cladophora glomerata*	D	This sample was less bleached than the others, relatively few diatom epiphytes – mostly narrow filamentous Cyanobacteria or other bacteria.
4A	90	*Cladophora glomerata* *Chroococcus turgidus* (?) *Bulbochaete* (hair only) *Oedogonium* (~ 10 µm diameter)	D A R R	Fewer epiphytes than in samples 1 and 2. *Chroococcus* seems to be living in and around the *Cladophora* matrix.

Figure 10-1: Photos of the hab-plot at Site 1A

Figure 10-2: Photos of the hab-plot at Site 2A

Figure 10-3: Photos of the hab-plot at Site 3A

Figure 10-4: Photos of the hab-plot at Site 4A

10.4. Discussion

The following interpretation of the algal data has been provided by Dr Martyn Kelly.

Many filamentous algae can form floating mats; the abundance of Cladophora suggests nutrient enrichment combined with a relatively rapid turnover of water (i.e. a low residence time, too quick to allow phytoplankton to develop and compete for nutrients). This is consistent with the spring-fed and ephemeral nature of turloughs. The genus *Epithemia* contains nitrogen-fixing organelles, so suggests localised nitrogen limitation in this part of the Turlough.

Two qualifications are needed, however, in order to understand the present observations:

1. Low nutrient concentrations were recorded from the sampling sites and also in the inflow and outflow. However, these are the results of a single sampling campaign and will not capture annual variations, or episodic pulses.

2. Nutrients are not the only factor promoting algal growth and, in a shallow lake in summer, high temperatures and light levels will also encourage growth (the bleaching observed may be a consequence of photo-oxidation due to intense light levels at the water surface)[6].

If nutrient concentrations were consistently low, then I would expect some of the algae recorded as "rare" (e.g. *Bulbochaete, Mougeotia*) and other genera (e.g. *Spirogyra*) to be more abundant.

The reasons for *Epithemia* growth are difficult to discern as key nutrient concentrations are at or below detection limit. Warm weather will promote denitrification which will remove combined nitrogen cycle from the water column, as will growth of macrophytes (which may have structural components which require more nitrogen than algae). It was only abundant in one of the four samples, suggesting some spatial variability in the turlough.

The cyanobacterium genus *Chroococcus* is not one usually regarded as indicating malign features of an ecosystem, although it belongs to the same order as the toxin-producing cyanobacterium

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[6] The author, Martyn Kelly has written a blog post is part of a series explaining the role factors other than nutrients play in determining quantities of filamentous algae in rivers (but similar principles will apply to a high turnover lake/lough): [Understanding verdant rivers (V) – microscopesandmonsters (wordpress.com)]

Microcystis. There is some evidence of nitrogen-fixation in this order, which may explain its presence here, but this cannot be stated with certainty. It is important to remember that Cyanobacteria are important components of natural ecosystems, across a wide trophic gradient, so we should not draw too many conclusions from a single record.

11.Appendix E: Nutrient budget approach

The following components were considered for determining total nutrient inputs:

- Inflow river load;
- Groundwater load;
- Direct rainfall load;
- Bird load;
- Grazing livestock load; and
- Direct runoff load.

1) River inflows

Data for the Dunkellin River at Craughwell was derived from the following sources:

Flow volume was from OPW data collected at station 29007 (Craughwell) Daily discharge data from January 2010 to July 2023 were accessed from waterlevel.ie.

Nutrient concentration was from EPA data collected from station RS29K010400 (Old Road Bridge Craughwell). Nutrient samples are taken 4-6 times per year from this station. Data from 2016-22 were accessed from data www.catchments.ie. Where concentrations were below limit of detection (LoD), a value of 0.5 x LoD was used in the calculations, following standard EPA practice.

Two nutrient parameters were considered:

- Total nitrogen, determined by adding total ammonia as N, nitrite as N and nitrate as N; and
- Phosphate as P. It was assumed that phosphate P comprised the majority of total P.

The flow volume dataset for the period had extensive gaps. Therefore, the following calculation was carried out. Actual daily data for the period 1 January 2016 to 31 December 2022 was plotted and used to calculate mean monthly discharge. The actual values and the calculated values were similar (see Figure 11-1), so modelled values were used throughout.

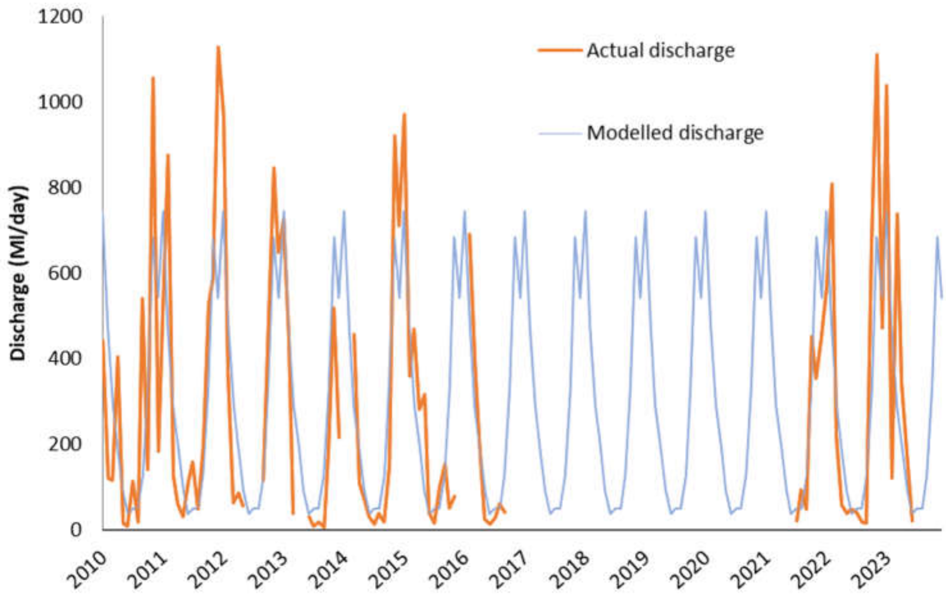

Figure 11-1: Dunkellin River – actual versus modelled discharge

Nutrient concentrations were assumed to be typical for the month in which they were measured and mean daily loads for each of these months was calculated using the modelled flow. The mean of all the daily load calculations was then used to create an annal mean load.

Between the Craughwell gauging station and Rahasane turlough is a tributary (Aggard Stream) entering the Dunkellin River from the south, whose flow is not measured by the Craughwell station and which is not monitored for water quality. This has not yet been accounted for in the model.

2) Groundwater

Groundwater quality was derived from borehole data at New Inn No.1, in the GWDTE-Rahasane Turlough (station no.: SAC000322). Data collected between 30 March 2016 and 26 October 2022 were accessed from data www.catchments.ie. Where concentrations were below limit of detection (LoD), a value of 0.5 x LoD was used in the calculations, following standard EPA practice.

Two nutrient parameters were considered:

- Total nitrogen, determined by adding total ammonia as N, nitrite as N and nitrate as N; and
- Total phosphorus.

There are no data on actual water depth of the turlough, and so an assumption was made that the turlough filled on a regular cycle, as shown in Table 3-1. From The LiDAR data available a detailed depth-volume profile could be created, giving the volume of water at each depth (Table 11-1).

Table 11-1: Assumed volume of Rahasane Turlough each month

Month	Surface elevation (m)	Volume (mL)	Change in Volume (mL)	Turlough status
Jan	19.08	12600.93	0	Stable
Feb	19.58	14766.55	2165.62	Filling
Mar	18.08	8704.12	-6062.43	Draining
Apr	17.08	5374.50	-3329.62	Draining
May	15.08	637.59	-4736.9	Draining
Jun	14.08	0.14	-637.46	Draining
Jul	14.08	0.14	0	Stable
Aug	14.58	128.01	127.88	Filling
Sep	15.08	637.59	509.58	Filling
Oct	17.08	5374.50	4736.90	Filling
Nov	18.08	8704.12	3329.62	Filling
Dec	19.08	12600.93	3896.81	Filling

The nutrient load was calculated for each month based on the change in volume of water in the turlough. Months where the turlough was in Draining or Stable status were assumed to equate to net loss of nutrients and so nutrient gain was set at zero. This gave nine occasions in which water quality readings were available for a filling turlough, and the mean of these was calculated to provide an average monthly input, which was then multiplied by 12 to give a total annual input.

3) Direct rainfall

Rainfall data were derived from Met Éireann data from Craughwell weather station (Grenage; Station number 2521; https://www.met.ie/climate/available-data/historical-data) for the period January 2020 to December 2022. For each month a mean daily rainfall was calculated.

The estimated surface area of the turlough on each month is shown in Table 11-2. The volume of water entering the lake directly was determined by multiplying the area by the mean daily rainfall (in mm). Nutrient concentrations in rainwater were derived from Allen et al. (1968); this study measured rain in various parts of England in the 1960s and the values used were from readings in the Lake District, as these are assumed to be relatively unpolluted by urban and industrial emissions and so equivalent to those in the west of Ireland. The concentrations assumed were fixed at 0.07 mg/l for TP and 1.1 mg/l for TN.

By calculating an estimated mean daily input for each month and then multiplying by 365, a total annual input was derived.

Table 11-2: Assumed area of Rahasane Turlough each month

Month	Elevation (m)	Area (ha)
Jan	19.08	418.6
Feb	19.58	447.9
Mar	18.08	359.5
Apr	17.08	308.0
May	15.08	138.6
Jun	14.08	0.5
Jul	14.08	0.5
Aug	14.58	62.9
Sep	15.08	138.6
Oct	17.08	308.0
Nov	18.08	359.5
Dec	19.08	418.6

4) Birds

Bird data were based on data from the Irish Wetland Bird Survey (I-WeBS) monitoring data for the Rahasane Turlough (https://irishwetlandbirdsurvey.ie), provided via data request, for the period August 2015 to September 2021. Bird counts were made from August to April, although with various gaps during which no counts were carried out. From the 30 monthly counts available a mean number of individuals was calculated for each month of the year, assuming zero for May to July. From these an overall annual mean count per species was determined.

The counts for each species were then fed into Boros's Generalised Method for determining bird-derived nutrient inputs (Boros 2021). This allocates a net production of N and P in grams per individual per day, and then applies a correction factor based on the proportion of each day each species is expected to be present in the turlough. By multiplying by the number of individuals and number of days in the year, a total annual load per species can be estimated.

5) Grazing livestock

Numbers of livestock registered in 2020 in each of the two electoral districts covering Rahasane Turlough – Killeely and Rahasane – was derived from the Census of Agriculture 2020 (Central Statistics Office: https://ws.cso.ie/public/api.restful/PxStat.Data.Cube_API.ReadDataset/AVA42/XLSX/2007/en), the numbers of which are shown in Table 11-3.

Table 11-3: Livestock numbers in the vicinity of Rahasane Turlough, 2020 (source: CSO)

District	Number of livestock	
	Sheep	Cattle
Killeely	923	3147
Rahasane	2401	1982

It was estimated that, of these, 10% of Killeely animals and 15% of Rahasane animals would be put to graze on the turlough each year, and that they would graze for 120 days per year. From this, a total number of livestock days per year could be calculated, for both cattle and sheep.

Nutrient production for each of the two species of livestock was derived from the following sources:

Cattle: data from Orr et al. (2012), relating to beef cattle in south west England. This study considered semi-natural grassland pasture and two grazing intensities: one which was designed to utilise herbage growth for optimum livestock production (Moderate), and the second to increase biodiversity by not fully utilising herbage growth (Lenient). Outputs from the Lenient option were considered most appropriate and used here. The study was carried out in May and September, with September producing the highest concentrations of nutrients, those this month was used for the calculations.

Sheep: data in Smith and Frost (2010), quoted in Ogejo et al. (2010), relating to sheep in England and Wales. The data in these two references only cover faecal inputs, whereas urine is an important source of nitrogen in particular. However, the TN output per animal per day is close to the mean TN value (of production by growing, lactating and dry [non-lactating] sheep) quoted by Decandia et al. (2011), which is derived from both faeces and urine; this latter source was not used as it does not cover TP.

The numbers used in the calculations are shown in Table 11-4.

Table 11-4: Estimates of daily nutrient production by livestock, as described in the text
The values used in the calculations are highlighted in bold.

Nutrient type and origin	Units	Cattle		Sheep	Source
		May	September		
Faecal N alone	(g/animal/day)			23.23	Decandia et al. (2011)
Faecal and urine N	(g/animal/day)	96.40	**122.00**	**26.65**	Orr et al. (2011) Smith & Frost (2010)
Faecal and urine P	(g/animal/day)	7.03	**9.42**	**4.63**	Orr et al. (2011) Smith & Frost (2010)

6) Direct runoff

This is assumed to be negligible, as rainwater goes direct to ground in the immediate catchment.