5 Years Annual Monitoring of Rahasane Turlough – Post works on FRS

Galway County Council

P6611

December 2021

Eliot Taylor, Bláithín Ní Ainín, Philip Doddy (Woodrow), Bridget Keehan (Woodrow), Jon Hunt (CDM Smith)

Client: **Galway County Council**
Address: **County Hall**
Prospect Hill
Galway
H91 H6KX

Project reference: **P6611**

Date of issue: **January 2022**

Project Director: **Dr Eliot Taylor**

Project Manager: **Dr Bláithín Ní Ainín**

APEM Ireland
C/o NSC Campus
Mahon
Cork
T12 XY2N
IRELAND

Tel: +353 (0)21 230 7100

Registered in Ireland No. 693910

Revision and Amendment Register

Version Number	Date	Section(s)	Page(s)	Summary of Changes	Approved by
V2	20.1.22	3.2	20	Deleted reference to time constraints and updated text to explain why work could not repeated as conducted in 2016, and how future surveys will be conducted	BNA
			21	‘present’ corrected to ‘[illegible]’	BNA
		3.3.2	26	Typo corrected to ‘was common in 2021’	BNA
		4.4.1	41	Removed reference to conducting separate study	MD
		5	44	Removed reference to conducting separate study	MD
	02.02.22	5	44	Inserted sentence on benefits of monitoring karst features	JH

Contents

List of Figures

List of Tables

1. Introduction

In November 2009, the flooding of the Dunkellin River and Aggard Stream caused damage and disruption to life and properties in the Craughwell and Kilcolgan areas in Co. Galway. As a result, the Office of Public Works (OPW) commissioned a study of the flooding, its causes and effects, to identify a preferred flood relief scheme (FRS) to reduce frequency and/or impact of similar future flooding. In 2011, Galway County Council commissioned an assessment of the likely environmental impacts of the proposed scheme. An agreed scheme was developed, including flood relief works (a combination of river widening, deepening, culvert upgrade and replacement, bridge improvement and replacement, and general channel maintenance). The scheme was designed to provide optimum flood relief with minimum environmental impact, whilst also satisfying cost-benefit criteria. The planning application for the scheme (07.JA0035) submitted by Galway County Council, was granted with seven associated conditions. Of these, Condition No. 4 states:

'For a period of five years following completion of all works, the local authority shall undertake annual monitoring at Rahasane Turlough, to include:

- *(a) field assessment of swallow holes and recording of natural collapse of conduits or infilling of swallow holes*
- *(b) monitoring of water level at existing river gauges up and down gradient of Rahasane Turlough, and*
- *(c) monitoring of vegetation and indicator species at Rahasane Turlough*

Reason: In the interest of the protection of the environment and to broaden scientific knowledge.'

Works on the FRS are complete and Galway County Council, wishing to fulfil its commitments under Condition 4 of the issuance of planning permission, have therefore, appointed APEM Ireland Ltd (APEM) to undertake the required field surveys and assessments for a period of five years, starting from July 2021. In each year, APEM will undertake the agreed monitoring and submit an annual findings report, followed by a final report at the end of 5-year monitoring period.

As no works implemented have directly impacted on Rahasane Turlough itself, the main concerns with regard to the site relate to any possible change in the hydrological regime that pertained/pertains to and within it on an annual basis, and in particular, whether implementation of the FRS might lead to any drying out/reduction in the extent and/or frequency of flooding. Such an impact can be detected through the monitoring proposed by ABP, as follows:

1. Reduction in number, or complete cessation, of changes to the physical structure of the Karst below the turlough, e.g. reduced/zero new incidences of collapse or infilling of swallow holes;
2. Changes in, i.e. lower, water levels and reduced flow volumes and velocity into / out of the turlough as compared to those recorded in the past;
3. Changes in composition of the vegetation, e.g. a shift away from wetland species to more dryland species, and;
4. Changes in the composition of freshwater macroinvertebrate fauna from one characteristic of a regularly flooded habitat to one of a more frequently dry habitat.

This report covers the first year of annual monitoring, conducted in August 2021.

1.1 Report Structure

The report is structured to meet the requirements of Condition No. 4 under which An Bord Pleanála granted the application (07.JA0035). Therefore, the remaining structure of the report is as follows:

- Chapter 2 (Hydrogeology and Hydrology Surveys) will report on Condition 4 part (a) '*field assessment of swallow holes and recording of natural collapse of conduits or infilling of swallow holes*' and on Condition 4 part (b) '*monitoring of water level at existing river gauges up-gradient and down gradient of Rahasane Turlough'*.

- Chapter 3 (Vegetation Survey) will report on the first part of Condition 4 part (c) *monitoring of vegetation… at Rahasane Turlough'.*

- Chapter 4 (Macroinvertebrate Survey) will report on the second part of Condition 4 part (c) *monitoring of … indicator species at Rahasane Turlough'*.

- Chapter 5 (Key Findings from Year 1) will summarise the findings of the surveys for this first year.

2. Hydrogeology and Hydrology Surveys

The ecosystem associated with the Rahasane Turlough SAC is highly dependent on the hydrological flow regime at the site. The hydrological flow regime is, in turn, defined by the karst system that underlies the turlough catchment. The surface expression of the karst system is manifested by karst features such as caves, swallow holes, estavelles (ground feature that can act as a sink or supply of water depending on surrounding hydrological and hydrogeological conditions), and springs. The key challenge is to be able to differentiate between natural changes in hydrological behaviour from those which may be attributed to the flood scheme. To meet this challenge we have undertaken the following:

- Review of previous datasets and reports;
- The first of five annual drone surveys;
- Visited and conducted a brief assessment of the four OPW hydrometric stations associated with the Rahasane Turlough;
- Collected and assessed relevant hydrometric station data; and
- Conducted a site walkover of the turlough to ground-truth and observe karst features for annual monitoring purposes over the next four years.

2.1 Review of previous datasets and reports

The following sources of site-specific data were reviewed:

- OPW – 2018 Flood Risk Management Plan – Galway Bay South East;
- OPW – 2019 Strategic Environmental Assessment Statement - Galway Bay South East;
- OPW – 2010 Preliminary Flood Risk assessments – Groundwater Flooding;
- RPS - 2014 Environmental Impact Statement (Dunkellin River and Aggard Stream Flood Relief Scheme);
- RPS – 2014 Natura Impact Statement (Dunkellin River and Aggard Stream Flood Relief Scheme);
- RPS – 2016 Preconstruction Assessment Geology and Hydrogeology; and
- OPW – Water level and flow data at gauging stations deemed relevant to the FRS, notably on the Dunkellin River near the Rahasane SAC.

The following additional sources of publicly available data and information were checked and used as appropriate:

- Geological Survey Ireland (GSI) web-based groundwater data viewer, specifically the GSI karst database;
- Ordnance Survey Ireland (Geohive) – Historic maps and aerial photography;
- Environmental Protection Agency (EPA web-based data viewer (EPA map viewer; Hydronet); and
- National Parks and Wildlife Service (NPWS) web-based data viewer (Special Areas of Conservation; Special Protection Areas).

2.2 Annual Drone Survey

The first of five annual drone surveys of the Rahasane Turlough was conducted in August 2021 to assist with the ground-truthing and monitoring of karst features. The survey was conducted using a DJI Mavic 2 Pro drone flown at a height of 125 m. The imagery captured was processed using the software programme DroneDeploy. The processed and collated imagery can be viewed here. Subsequent annual surveys will be added to this dataset to assist with the identification of changes to karst features that were ground-truthed during the walkover survey (see below).

2.3 OPW Hydrometric Stations

OPW Hydrometric Stations (gauging stations) are measurement stations installed on rivers and lakes to record water levels, temperature and/or flow, mainly for flood risk management purposes. In the context of the FRS and the Rahasane Turlugh SAC, three existing hydrometric stations on the Dunkellin River were visited in August 2021:

- Craughwell 29007
- Aggard Bridge 29010
- Rahasane Turlough 29002

These stations measure water levels upstream (29007, 29010) and downstream (29002) Rahasane Turlough. Their locations are shown on Drawing 1 in Appendix 1.

2.3.1 Craughwell 29007

Craughwell 29007, Figure 1, is a new hydrometric station on the Dunkellin River, approximately 230 m downstream of former monitoring station 29007. The latter was replaced with the new station following the construction of the FRS through Craughwell village. New station 29007 is located upstream of a bridge and is positioned to measure the river levels where the natural river course and the FRS are combined. It records the water level and temperature at 15-minute intervals using an OTT PLS sensor The data are stored in a data logger and automatically loaded to a server via solar-powered telemetry.

Figure 1 New OPW Hydrometric Station Craughwell 29007 (looking west).

The riverbed at the hydrometric station appears relatively clean (i.e. free of vegetation or other obstacles). The riverbanks are built up with rocks for stability purposes, to a level of approx. 2.7 m above the stream bed. There is a concrete structure which slopes 45° towards the stream at the base of the nearby bridge.

2.3.2 Aggard Bridge 29010

Aggard Bridge 29010 (Figure 2) records the water level and temperature on a tributary of the Dunkellin River at 15-minute intervals. Data are recorded using an OTT sensor and stored in an in-situ data logger (Figure 3). The data are automatically transmitted to a server via solar-powered telemetry.

The stream banks are heavily vegetated and the profile of the tributary changes over short distances. Downstream, the flow is channeled under a bridge.

Figure 2 Aggard Bridge 29010 Hydrometric Station (looking downstream).

Figure 3 Data logger at the Aggard Bridge 29010 Hydrometric Station.

2.3.3 Rahasane Turlough 29002

Rahasane Turlough 29002 (Figure 4) records the water level and temperature of the Dunkellin River downstream of the Rahasane Turlough SAC. Data are recorded at 15-minute intervals using an OTT sensor, and locally stored in a data logger. The data are automatically loaded to a server via solar-powered telemetry.

The riverbanks at and upstream of the monitoring station are heavily vegetated.

Figure 4 Rahasane Turlough 29002 Hydrometric Station

2.4 Hydrometric Station Data

Water level data for each of the hydrometric stations are graphed below for the third quarter of 2021 (Q3, i.e. July, August, September), since project inception. The data were provided by OPW. At present such data must be requested directly from OPW but OPW plans to add all hydrometric stations to their Hydro-Data website (www.waterlevel.ie) where historic and real-time data can be viewed and downloaded. Daily rainfall data from the Athenry weather station (www.met.ie) were added to the graphs for illustration purposes. It should be noted that the nearest rainfall station is Craughwell, but the data for Q3 are not yet available for download, hence the data available for the Athenry station were used.

Water level data for Q3 from replacement station Craughwell 29007 (Figure 5) are available from 13/07/2021, which is the date when the new station was commissioned. During the available period of record, water levels ranged between 17.1 mOD and 18.16 mOD (mean =

17.2 mOD). Water levels were at their lowest in July, corresponding with a prolonged dry period. This was followed by a sharp water level rise to 17.6 mOD at the beginning of August which is caused by a large rainfall event. Water levels also responded significantly to rainfall that occurred in late-September/early October.

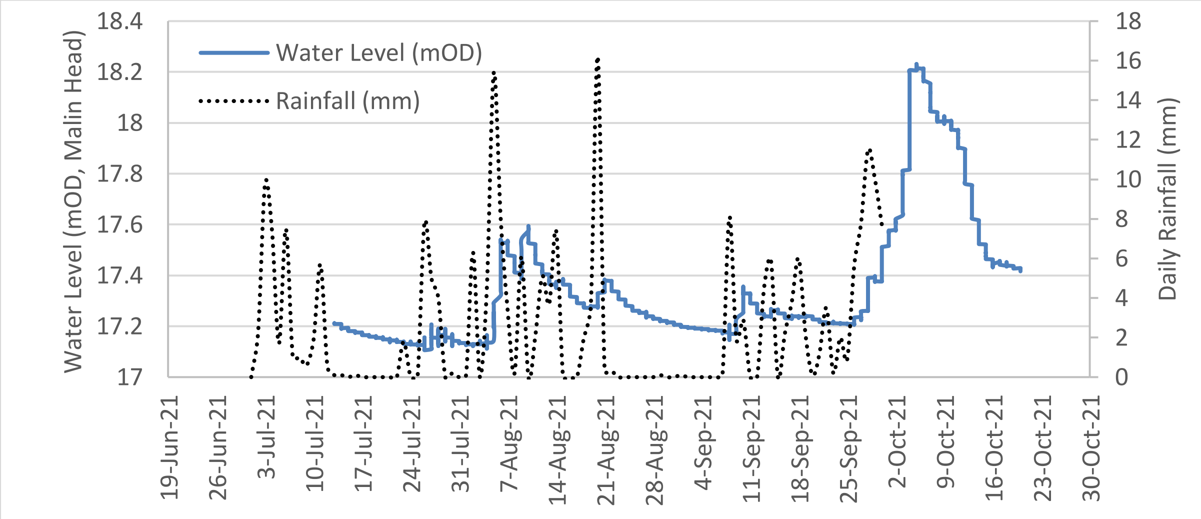


Figure 5 Craughwell 29007, Q3 2021 Water Level and Rainfall (Athenry) Data.

Water level data for Q3 from Aggard Bridge 29010 are presented in Figure 6. Water levels over this period ranged from 20.9 mOD to 21.5 mOD (mean = 21.1 mOD). The data incorporate some 'noise' but the water levels response is generally very similar to that described for replacement Station 29007.

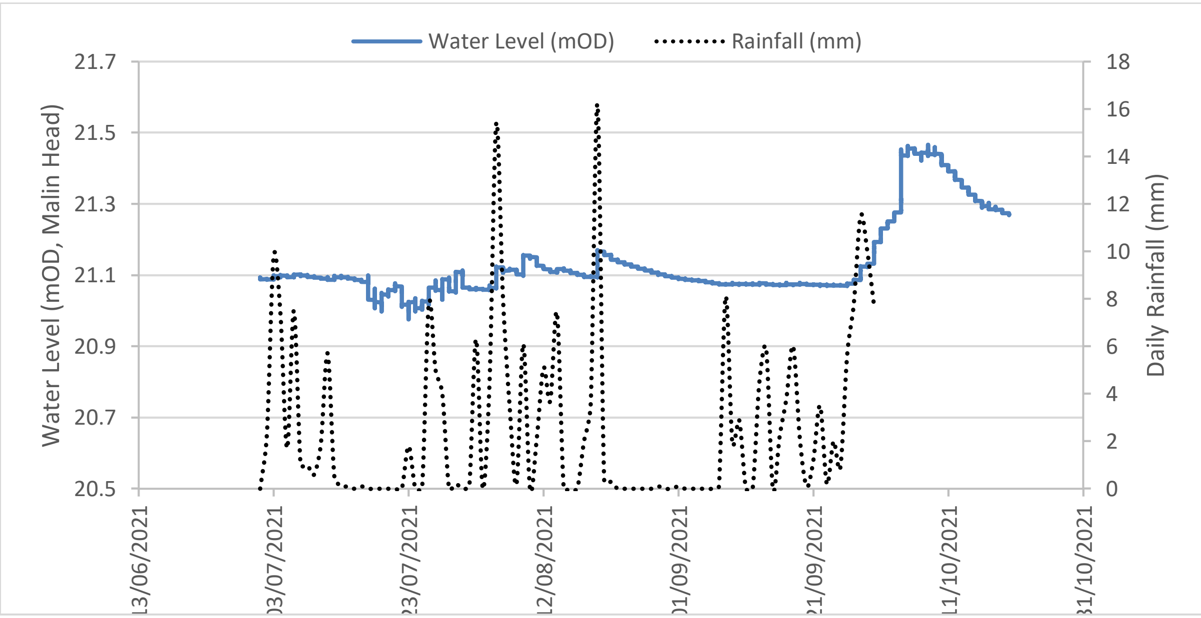


Figure 6 Aggard Bridge 29010, Q3 2021 Water Level and Rainfall (Athenry) Data.

Water level data for Q3 from Rahasane Turlough 29002 are shown in Figure 7. OPW reported problems with the recording of data at this station, which is evident in Figure 7. Data quality issues have been recently rectified and the corrected data will be presented in subsequent reporting.

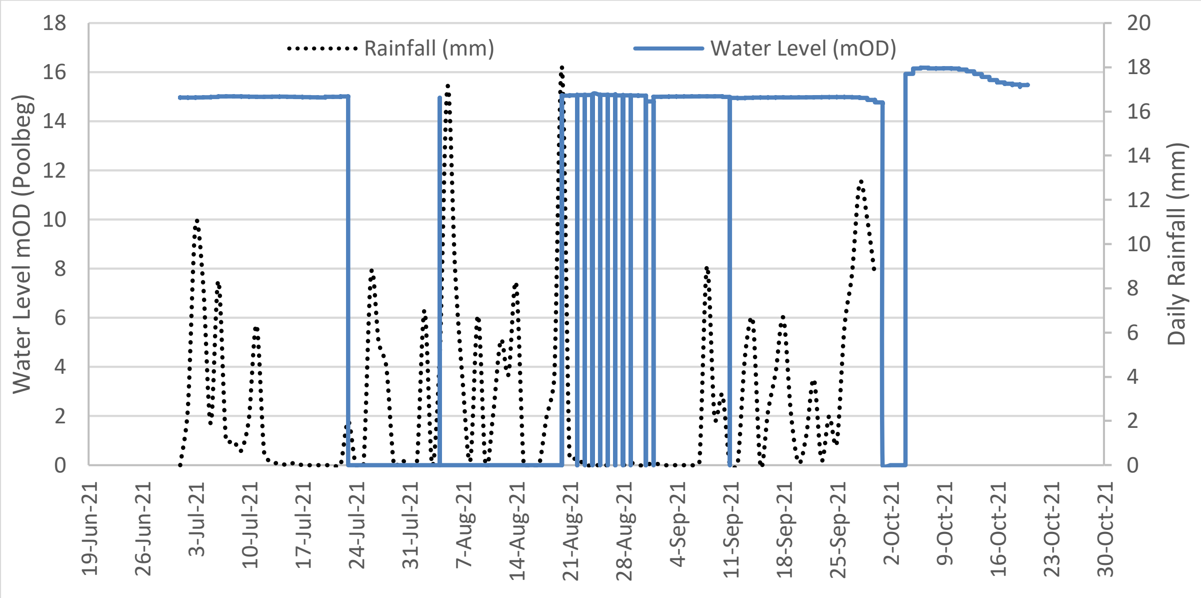


Figure 7 Rahasane Turlough 29002, Q3 2021 Water Level and Rainfall (Athenry) Data.

2.5 Walkover survey – Rahasane Turlough

The initial walkover survey took place on 20th August 2021. The purpose of the walkover survey was two-fold: a) to ground-truth karst features included in the GSI karst database; and b) to identify/verify potential additional features from those in the GSI database. The features recorded will be monitored for change on an annual basis over the next four years.

Part of the SAC was inundated on the day of the visit. Estimates from the drone survey indicate that approximately 16% of an estimated total turlough area of 3.27 km^2 (NPWS) was submerged (Drawing 1). The flooded areas were contiguous with the natural and straightened course of the Dunkellin River.

Known karst features in the Rahasane Turlough SAC are shown on Drawing 1 (Appendix 1) and listed in Table 1. These incorporate those features in the GSI database, those mapped by RPS from Lidar data during the FRS and those that were ground-truthed or identified during the site walkover survey. It is these features that will be monitored over the next four years.

Due to the standing water, it is possible that additional submerged features such as swallow holes or estavelles may exist, which are not included in Table 1; However, because the turlough has been subject to study in the past, it is inferred that the most obvious and significant features are captured in Table 1.

In the future, submergence can affect the quality of monitoring events. For this reason, the site visits in subsequent years should ideally be conducted on days when water levels are low(est).

Specific other features of interest that were noted on the site walkover survey are also summarised in Table 1. They include monitoring wells. The team checked with GSI and other researchers of turlough hydrology, but the purpose or circumstances around the presence of monitoring wells are not known. The combination of these observed features will be monitored (where possible) over the next four years.

A selection of images is provided in Figures 8 through 15.

Table 1 Summary of hydrogeological and hydrological features at the Rahasane Turlough (Points 1-12 – CDM Smith features; GSI 1-7 – GSI features; RPS 1-16 – RPS features).

ID	X (ITM)	Y (ITM)	Feature	Comment
1	546108	718854	Enclosed depression	Monitor for changes
2	546310	718914	Dunkellin River	Hydrological reference feature – observation point within turlough
3	546327	718940	10+ small scale depressions	Possible near surface expression of epikarst. Monitor for changes.
4	546325	718991	Enclosed depression	Monitor for changes
5	546570	719115	Area receiving inflow from river	Possible nearby swallow hole
6	546653	719086	Wetland vegetation	Monitor for changes – ecologist
7	546681	719110	50+ small depressions of Approx. 200 mm diameter	Possible near surface expression of epikarst. Monitor for changes.
8	546689	719158	Enclosed depression	Possible location for groundwater recharge/discharge (estavelle). Monitor for changes
9	546912	719483	Monitoring well	Condition unknown. Consider condition survey for possible monitoring.
10	547683	718724	Existing well	Condition unknown. Consider condition survey for possible monitoring.
11	547408	718725	Enclosed depression	Possible location for groundwater recharge/discharge (estavelle). Monitor for changes
12	547411	718730	Enclosed depression	Possible location for groundwater recharge/discharge (estavelle). Monitor for changes
GSI 1	547409	718761	Spring	Monitor for estimated flow
GSI 2	547732	718806	Enclosed depression	Monitor for changes
GSI 3	546483	718930	Swallow hole	Monitor for changes
GSI 4	548512	719832	Enclosed depression	Monitor for changes
GSI 5	548647	719790	Enclosed depression	Monitor for changes

ID	X (ITM)	Y (ITM)	Feature	Comment
GSI 6	549994	719655	Swallow hole	Monitor for changes
GSI 7	550433	719748	Swallow hole	Monitor for changes
RPS 1	550577	719824	Enclosed depression	Monitor for changes
RPS 2	547982	719853	Enclosed depression	Monitor for changes
RPS 3	548582	719523	Enclosed depression	Monitor for changes
RPS 4	548744	719523	Enclosed depression	Monitor for changes
RPS 5	547832	719589	Enclosed depression	Monitor for changes
RPS 6	547473	719282	10+ small scale depressions	Possible near surface expression of epikarst. Monitor for changes.
RPS 7	547372	718848	Enclosed depression	Monitor for changes
RPS 8	547041	718867	Enclosed depression	Monitor for changes
RPS 9	546943	718755	Enclosed depression	Monitor for changes
RPS 10	546994	718861	Enclosed depression	Monitor for changes
RPS 11	546920	719065	Enclosed depression	Monitor for changes
RPS 12	546509	718456	Enclosed depression	Monitor for changes
RPS 13	546205	718203	Enclosed depression	Monitor for changes
RPS 14	545843	717986	Enclosed depression	Monitor for changes
RPS 15	546277	718983	Enclosed depression	Monitor for changes
RPS 16	546459	719099	Enclosed depression	Monitor for changes

Figure 8 ID 3 - shallow depressions

Figure 9 ID 6 - wetland vegetation

Figure 10 ID 7 - shallow depressions

Figure 11 ID 8 – Enclosed depression – possible swallow hole/estavelle

Figure 12 ID 9 – Monitoring well (condition unknown)

Figure 13 ID 10 – Monitoring well (condition unknown)

Figure 14 ID 11 Enclosed depression - possible estavelle

Figure 15 ID 12 – Enclosed depression - possible estavelle

2.6 Results and Discussion

An initial drone survey, hydrometric stations visit, and walkover survey of Rahasane Turlough have been conducted as part of Year 1 monitoring of the SAC. Karst features have been identified and mapped, and aerial imagery has been obtained on a day when approximately 16% of the turlough SAC was submerged.

In subsequent years, site visits and drone surveys will be repeated by CDM Smith. The mapped karst features will be checked to see if landforms have changed, or new landforms have appeared. The future visual comparisons require that surveys be carried out when water levels in the turlough are low (as low as possible in any given year), as the submergence of features does not allow for the evaluation that is required. In addition, OPW hydrometric station data and local rainfall data will be processed and presented in a similar manner to above so that trends (where identifiable) can be discussed.

For this reason, flexibility is necessary in terms of the timing of surveys. Decisions about dates will be guided by weather conditions, weather forecasts, as well as checking the status of other turlough locations which are monitored (continuously) by the GSI as part of their Groundwater Flooding project (noting that this includes turloughs in South Galway).

Ideally, the mapping of karst features should be supplemented by review of available Lidar data. The FRS flew Lidar surveys of the Dunkellin River catchment in 2015, including the Rahasane Turlough SAC. The current project has received a copy of the raw Lidar data, but the data are unprocessed and not usable at the present time. The current project does not have the scope or financial means of running or processing the Lidar data, hence they cannot be exploited to their full potential. This would be of great value to the project, noting the tangible benefits that GSI has demonstrated with Lidar in the mapping of karst features in topographically subtle terrains.

In conclusion, it is not possible to ascertain if the hydrogeology and hydrology of the turlough has changed since the FRS at this time. This is the first time that this sort of monitoring has been undertaken at this site, and therefore there is no baseline for comparison. Furthermore, as the turlough system is complex as it is influenced by a karst system which is not possible to model, and the FRS is only one of multiple factors interacting within the system. However, the year-on-year monitoring of the karst features and gauging stations will provide input into the further characterisation of the SAC and provide insight into the possible influences and impacts of the FRS.

3. Vegetation Survey

3.1 Review of previous datasets and reports

Turlough vegetation is of high ecological interest and importance for two main reasons:

1. Turloughs are extremely rare in a European and global context, with almost all examples found in Ireland
2. The unusual and dynamic seasonal water regime facilitates an unusual range of plant species

This ecological rarity and importance is emphasised by the fact that turloughs have been listed as priority habitats in the EU Habitats Directive (EU habitat code 3180). The vegetation of turloughs reflects the fact that these habitats are transitional in nature, with a very dynamic water regime. The composition of the vegetation tends to change in accordance with the flooding gradient.

A comprehensive study of turlough vegetation in Ireland was undertaken on behalf of NPWS (Waldren, 2015). In addition, NPWS commissioned a Conservation Objectives supporting document (O'Connor, 2017) to cover forty-five SACs selected for the Annex I Priority habitat Turloughs (3180), for which individual Conservation Objectives Supporting documents had not been prepared. These documents were reviewed to inform the methodological approach to surveying.

In addition, the vegetation of Rahasane Turlough was surveyed in detail by Roger Goodwillie in 1992, as part of a study of sixty-one Irish Turloughs commissioned by NPWS (Goodwillie, 1992). This survey focussed on distinctive plant communities and specific indicator species, to ascertain the flora present and to examine any habitat variation, including variation between Rahasane and other turloughs, in order evaluate the site's ecological interest.

A further study undertaken in 2012 (Sharkey, 2012) documents the vegetation communities of 22 turloughs within Counties Galway, Clare, Roscommon and Mayo. The categorisation of turlough vegetation communities was updated by Sharkey, and this updated classification was used for the 2021 surveys at Rahasane.

The vegetation communities identified in Rahasane Turlough by Goodwillie (1992), and Sharkey (2012) were re-surveyed by RPS environmental consultants during 2014 and 2015, in order to inform the planning submission for the Dunkellin River & Aggard Stream Flood Relief Scheme (RPS, 2016). This study revisited Goodwillie's transects and examined twelve transects and 249 relevés in detail. The results of the surveys by RPS were reviewed and used to inform the site selection process.

3.2 Methodology

As described in Section 3.1, the vegetation survey undertaken by RPS (2016) was a very substantial piece of work, involving the examination of twelve transects and 249 relevés within the Rahasane survey area. The budget for the current project did not allow for this work to be repeated in its entirely; therefore, the vegetation records from the transects and relevés identified in the RPS survey were reviewed in order to inform the selection of a subset of these for assessment within the current survey, with the intention of focusing on those areas previously identified as being of botanical importance. It is proposed to use this subset of the transects and relevés for monitoring purposes in future years, throughout the current project.

For the current vegetation monitoring of Rahasane Turlough, the fieldwork methodology was adapted from Waldren (2015), in accordance with the scheduled time available, including mapping of broad vegetation zones during the dry season (mid-summer to early autumn) using transects, and focused on vegetation monitoring by recording vegetation in relevés in the locations selected.

The focus on vegetation units takes cognisance of the units specified by Goodwillie (1992) and Sharkey (2012), with the latter classification being used to produce the vegetation community maps (Appendix 2). As in previous studies of the turlough vegetation, the vegetation monitoring places particular emphasis on indicator plant species (both positive and negative), as listed by O'Connor (2017) and Waldren (2015), and considers other indicative features, such as the presence and extent of algal mats and algal paper.

Three transects were selected for resurvey from those defined by RPS (2016): Transects 2, 4 and 6. These transects are shown in Figures 16 to 19. These transects were selected in order to give as broad a coverage of the turlough as possible in the time available, and to cover a diversity of habitat types with a representative geographical spread. This selection process made use of the review of the previous datasets as described above, as well as drone footage of the region carried out by CDM Smith during the summer of 2021.

The RPS (2016) survey identified and assessed a number of 1x1 m relevés along each transect. A subset of these were selected for reassessment during the current survey, ensuring that the selected relevés demonstrated a good geographic spread incorporating the range of vegetation zones represented across the turlough area. Once transect and relevé locations had been selected, fieldwork was scheduled for August 2021, this being within both the optimum survey season for wetland habitats and the usual dry season for the turlough.

3.2.1 Details of the surveys undertaken on site

Fieldwork was undertaken by Dr Philip Doddy and Bridget Keehan of Woodrow Sustainable Solutions, part of the APEM Group. Both field surveyors are experienced ecologists with specialist skills in botanical field survey and habitat classification.

The site field survey was planned to include the following:

- Mapping of broad vegetation zones, by means of examination and recording of vegetation at the selected transect locations, identifying the points of transition to different identified vegetation zones along each transect.
- Detailed examination of each of the 1x1 m relevés selected for re-survey, along the three selected transect lines (Transects 2, 4, and 6). For each relevé this included an assessment of its physical characteristics, vegetation cover, vegetation type, dominant species, presence and abundance of positive and negative indicator species, management and observed pressures/threats.

It is noted that there were some periods of heavy rainfall in late summer 2021, and local knowledge indicated that the turlough was unseasonably high because of this. Consequently, water levels at some parts of the turlough were high, and a number of the relevés identified by RPS (2016) were covered in water at the time of the survey and therefore could not be re-assessed during the 2021 survey period. All results from the vegetation zone mapping were processed on QGIS, and maps produced showing the relevant vegetation zones.

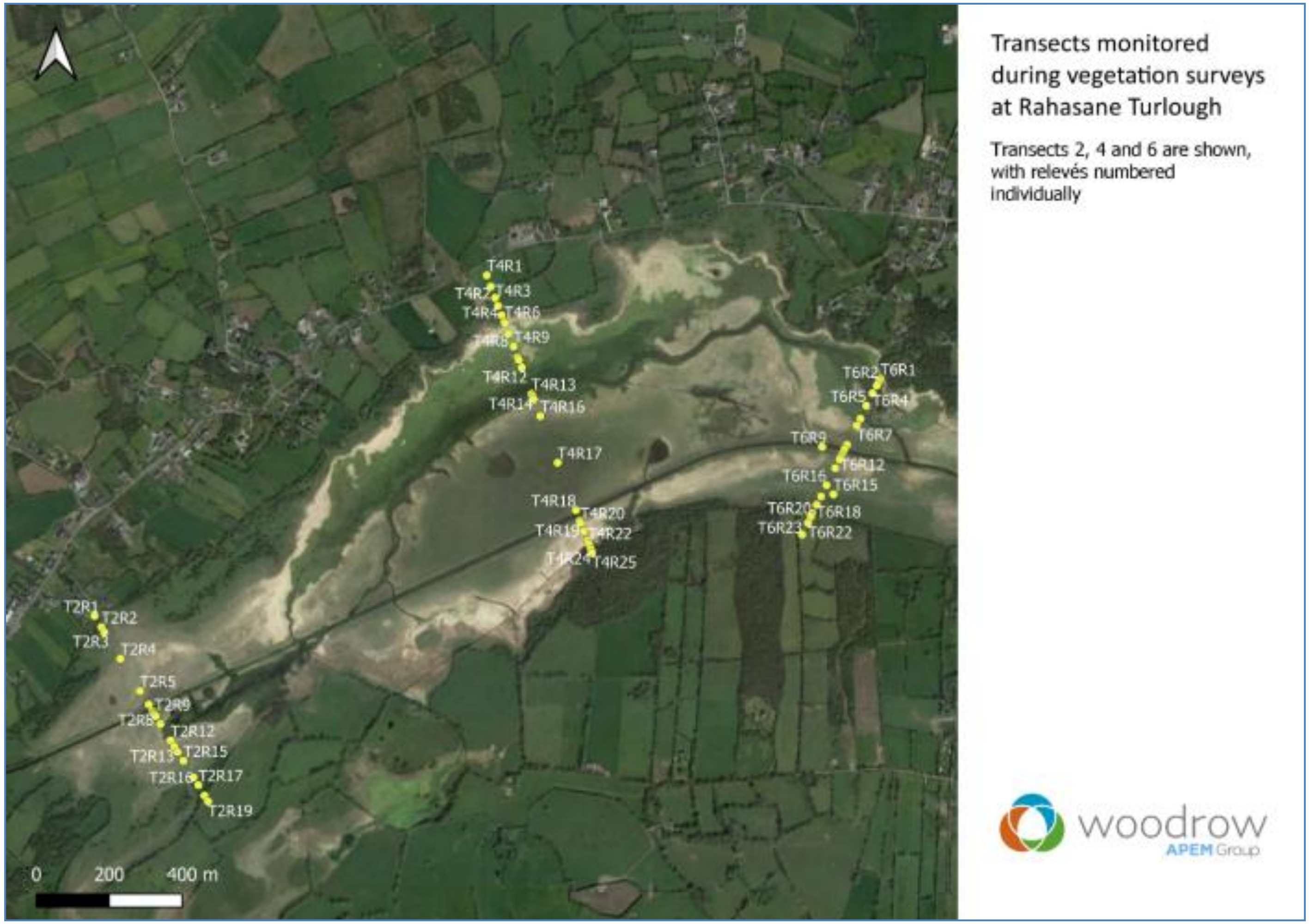


Figure 16 Three transects selected for surveys at Rahasane Turlough

Figure 17 Transect 2 and the surrounding area, Rahasane Turlough, Co. Galway

Figure 18 Transect 4 and the surrounding area, Rahasane Turlough, Co. Galway

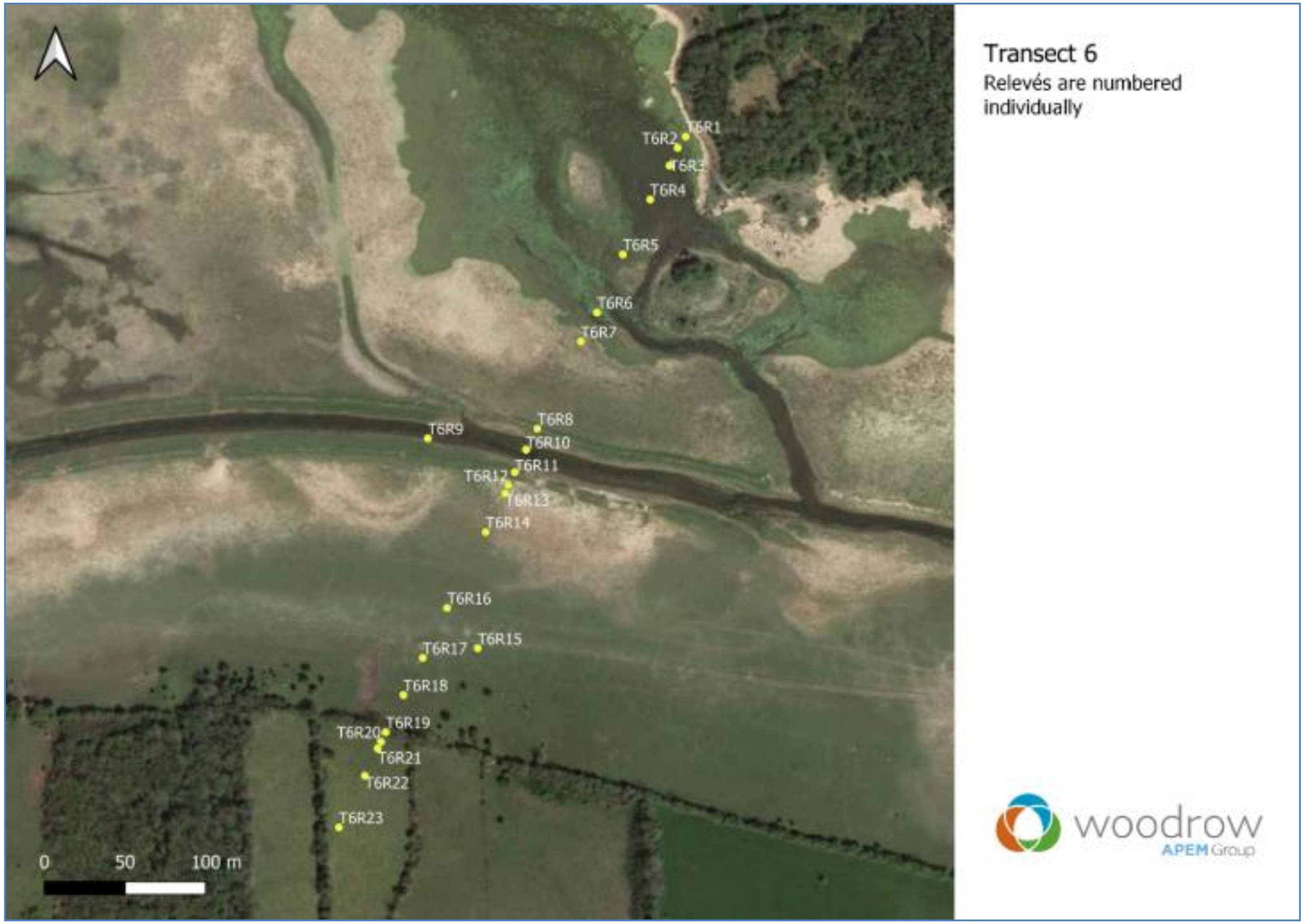


Figure 19 Transect 6 and the surrounding area, Rahasane Turlough, Co. Galway

3.3 Results and Discussion

This section presents the results of surveys conducted at Rahasane Turlough in the summer of 2021. The following summary tables provide the species lists and vegetation cover in each relevé. Vegetation maps produced from these surveys are presented in Appendix 2.

It was noted that unusually high water levels in parts of the turlough, following heavy rains in late summer 2021, resulted in some locations being inaccessible. This emphasises the need to tailor site visits to rainfall and water level conditions for surveys in future years.

3.3.1 Transect 2

Along Transect 2, there were many similarities in vegetation between the 2021 results and those recorded by RPS in 2016. This applied particularly with regard to the most dominant species in relevés, such as creeping bent (*Agrostis stolonifera*) and silverweed (*Potentilla anserina*), both of which were widespread along the transect. However, in four of the five relevés surveyed along this transect, species richness was greater in 2021 than in 2016, with more bryophytes, in particular, recorded in 2021 including the moss *Cinclidotus fontinaloides*, which is a turlough specialist. Results from future years may show whether this is part of a general trend, and if it is related to management of the land within the turlough basin.

Creeping bent (*Agrostis stolonifera*), one of the most prevalent plant species in terms of percentage cover was found to vary somewhat between 2016 and 2021, but with no evidence of an overall trend. Silverweed (*Potentilla anserina*), another characteristic species, had declined in some areas compared to 2016, but was also recorded as an additional species in one relevé (T2R12), where it was not present in 2016. Creeping cinquefoil (*Potentilla reptans*), a characteristic species used in defining some turlough communities (Sharkey, 2012) was not found in any of these relevés in 2016, but was present in three of them in 2021. This may possibly indicate the broader presence of the turlough community 3 (19) - *Potentilla anserina – Potentilla reptans* (Sharkey, 2012), but further work in future years may help to establish whether this is a genuine trend.

Most of the locations examined along Transect 2 were grazed very short by sheep and horses. This appears to be a longstanding situation, as Goodwillie (1992) also found that Rahasane Turlough was closed grazed by cattle, sheep and horses during his surveys, and noted the shortness of the vegetation as one of the turlough's chief features. Photographs provided in Appendix 2 show the conditions in each relevé. Some poaching was noted, as much as 10 % in Relevé T2R4, indicating that the seasonal stocking rate may be higher than the optimal level, and as such may pose a risk to the habitat quality in the turlough.

3.3.2 Transect 4

Much of Transect 4 was inaccessible due to high water levels, although it is understood that these areas would normally be accessible in summer. Local knowledge indicated that the water level was higher than normal for the time of year, due to recent heavy rains. In the accessible area, creeping bent (*Agrostis stolonifera*) and silverweed (*Potentilla anserina*) were the most dominant species. Species richness in 2021 was higher than in 2016, although red fescue (*Festuca rubra*), which was prevalent in 2016 was not recorded in this location in 2021. In this same area, creeping bent (*Agrostis stolonifera*), not recorded in 2016, was common in 2021, while water knotweed (*Persicaria amphibia*) and greater plantain (*Plantago major*) were new additions to the species list for Relevé T4R5. However, it is difficult to make meaningful comparisons based on the 2021 data, due to much of the transect being under water and inaccessible.

As in Transect 2, slight poaching was noted, and 6% of the area recorded was bare of vegetation, again indicating that the stocking rate may be higher than optimal for this habitat.

3.3.3 Transect 6

In Transect 6, again there were similarities between the 2016 and 2021 results, although species richness was higher in each area examined in 2021. Species newly recorded in these relevés (compared to 2016) included curly dock (*Rumex crispus*), black sedge (*Carex nigra*), cuckoo flower (*Cardamine pratensis*), marsh bedstraw (*Galium palustre*) and creeping cinquefoil (*Potentilla reptans*).

Typical turlough species such as silverweed (*Potentilla anserina*), creeping bent (*Agrostis stolonifera*) and creeping buttercup (*Ranunculus repens*) were particularly prevalent. While the species richness was higher in 2021, with additional characteristic species such as creeping cinquefoil (*Potentilla reptans*) being recorded, other plants, such as meadowsweet (*Filipendula ulmaria*) were not noted in 2021, although they were present in 2016. This may be part of a pattern whereby taller plants are becoming less common over time due to tight grazing, although it appears from previous records (Goodwillie, 1992) that close grazing of the turlough basin in summer is a longstanding circumstance. Surveys in future years may indicate whether there is a pattern in this regard.

Much of the vegetation in the areas examined along Transect 6 was grazed very short, with slight poaching noted in places. This is similar to the situation noted in Transect 2 and Transect 4 and appears to be a widespread feature of the turlough.

Table 2 Summary information on relevés surveyed in Transect 2, Rahasane Turlough

Parameter	Relevé 2 (T2R2)	Relevé 4 (T2R4)	Relevé 6 (T2R6)	Relevé 12 (RT2R12)	Relevé 16 (T2R16)
Location (ITM)	X: 546294 Y: 719189	X: 546346 Y: 719102	X: 546424 Y: 718976	X: 546484 Y: 718877	X: 546547 Y: 718775
Water height (cm)	0	0	0	0	0
Vegetation zone (Sharkey)	3 (19) *Potentilla anserina – Potentilla reptans*	5 (11) *Persicaria amphibia – Mentha aquatica*	7 (15) *Lolium-Trifolium-Agrostis*	3 (19) *Potentilla anserina – Potentilla reptans*	3 (19) *Potentilla anserina – Potentilla reptans*
Vegetation height max (cm)	19,*Rumex* flowers to 31	4 cm	4	6	3, *Rumex* flowers to 25
% graminoids	30	40	33	65	38
% forbs	70	50	66	28	60
% shrubs	0	0	0	0	0
% bryophytes	<4 (DOMIN 2)	4	<1	25	<4
% bare ground	0	1 - 2	0	4	2
% poaching	0	10	0	4	2

Table 3 Summary information on relevés surveyed in Transect 4, Rahasane Turlough*.

Parameter	Relevé 5 (T4R5)	Relevé 10 (T4R10)	Relevé 16 (T4R16)	Relevé 18 (T4R18)	Relevé 22 (T4R22)
Location (ITM)	X: 547393 Y: 720048	X: 547437 Y: 719932	X: 547499 Y: 719770	X: 547597 Y: 719511	X: 547629 Y: 719427
Water height (cm)	0	Inaccessible*	Inaccessible*	Inaccessible*	Inaccessible*
Vegetation zone (Sharkey)	3 (19) *Potentilla anserina – Potentilla reptans*				
Vegetation height max (cm)	12				
% graminoids	25				
% forbs	75				
% shrubs	0				
% bryophytes	<1				
% bare ground	6 (4% rock, 2% bare earth)				
% poaching	0				

*Some locations were inaccessible due to unseasonably high water levels in 2021

Table 4: Summary information on relevés surveyed in Transect 6, Rahasane Turlough*.

Parameter	Relevé 2 (T6R2)	Relevé 6 (T6R6)	Relevé 12 (T6R12)	Relevé 16 (T6R16)	Relevé 18 (T6R18)
Location (ITM)	X: 548428 Y: 719865	X: 548378 Y: 719763	X: 548323 Y: 719656	X: 548285 Y: 719580	X: 548258 Y: 719526
Water height (cm)	Inaccessible*	Inaccessible*	0	0	0
Vegetation zone (Sharkey)			3 (4) *Agrostis stolonifera – Potentilla anserina - Festuca rubra*	3 (4) *Agrostis stolonifera – Potentilla anserina - Festuca rubra*	3 (4) *Agrostis stolonifera – Potentilla anserina - Festuca rubra*
Vegetation height max (cm)			3 - 5	7	3-4
% graminoids			55	55	30
% forbs			50	45	75
% shrubs			0	0	0
% bryophytes			<1	0	<1
% bare ground			0	0	0
% poaching			0	0	0

*Some locations were inaccessible due to unseasonably high water levels in 2021

Table 5 Species list, % cover and dominance of vegetation at relevés surveyed in Transect 2, Rahasane Turlough

Species	Relevé 2 (T2R2)		Relevé 4 (T2R4)		Relevé 6 (T2R6)		Relevé 12 (RT2R12)		Relevé 16 (T2R16)	
	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN
Achillea millefolium	6	4	40	7						
Agrostis stolonifera	23	5			33	6	65	8	38	7
Bellis perennis	<4	1			>1	1				
Brachythecium rutabulum			<4	2	<1	1-2	2	3	<4	2
Bryum sp.			<1	1						
Cardamine pratensis			<1	1-2	<1	2			<4	2
Carex nigra	5	4								
Cerastium fontanum					<1	1				
Cinclidotus fontinaloides	<4	2								
Festuca rubra	<4	2								
Galium palustre			10	4	5	4			<4	1
Gnaphalium uliginosum			<1	1						
Hydrocotyle vulgaris	<4	1							<4	1
Juncus sp.					<1	1				
Mentha aquatica			5	4			<4	3		
Myosotis scorpioides			10	4	2	3	12	5	<4	1
Nasturtium officinale							<4	1		
Persicaria amphibia			1-2	3						
Plantago lanceolata	<4	2			4	3				
Plantago major			2	3						
Potentilla anserina	32	6	15	5	25	5-6	16	5	30	6
Potentilla reptans	4	4			1-2	2			<4	2
Prunella vulgaris			<1	1						
Ranunculus repens			2-3	3	<1	2			<4	2
Rorippa sp.			<1	1			<4	1		
Rumex crispus	7	4	1-2	2	1	1			<4	2
Scorzoneroides autumnalis	<4	3			1-2	2			<4	2
Trifolium repens	18	5			30	6			26	6
Viola persicifolia			<4	1						

Table 6 Species list, % cover and dominance of vegetation at relevés surveyed in Transect 4, Rahasane Turlough*

Species	Relevé 5 (T4R5)		Relevé 10 (T4R10)		Relevé 16 (T4R16)		Relevé 18 (T4R18)		Relevé 22 (T4R22)	
	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN
Agrostis stolonifera	25	5	Inaccessible*		Inaccessible*		Inaccessible*		Inaccessible*	
Cerastium fontanum	<1	1								
Cinclidotus fontinaloides	<1	1								
Myosotis scorpioides	5	4								
Persicaria amphibia	<4	2								
Plantago lanceolata	2	2								
Potentilla anserina	50	7								
Potentilla reptans	2	3								
Ranunculus repens	10	4								
Rumex crispus	5	4								
Stellaria media	<1	2								

*Some locations were inaccessible due to unseasonably high water levels in 2021

Table 7 Species list, % cover and dominance of vegetation at relevés surveyed in Transect 6, Rahasane Turlough*

Species	Relevé 2 (T6R2)		Relevé 6 (T6R6)		Relevé 12 (T6R12)		Relevé 16 (T6R16)		Relevé 18 (T6R18)	
	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN	% cover	DOMIN
Agrostis stolonifera	Inaccessible*		Inaccessible*		50	7	48	7	20	5
Alopecurus geniculatus					2-3	2-3				
Bellis perennis									<1	1
Cardamine pratensis					<1	1	<4	3	<1	2
Carex nigra					3	3	4	4	4	3
Festuca rubra					2-3	2-3	4	4	10	4
Galium palustre					<1	1	<4	3	2	3
Myosotis scorpioides					3	3	<4	3		
Plantago major									1	2
Potentilla anserina					30	6	32	6	40	7
Potentilla reptans							<4	3	<1	2
Prunella vulgaris									2-3	3
Ranunculus repens					10	4			2-3	3
Rumex acetosa									<1	1
Rumex crispus					2-3	2-3				
Scorzoneroides autumnalis									2	3
Trifolium repens									25	5
Veronica chamaedrys							<4	3		

*Some locations were inaccessible due to unseasonably high water levels in 2021

3.4 References

Goodwillie R., 1992. *Turloughs over 10ha: Vegetation Survey & Evaluation*. A Report for the National Parks & Wildlife Service Office of Public Works.

O'Connor, Á., 2017. Conservation objectives supporting document: Turloughs* and Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation. Conservation Objectives Supporting Document Series. National Parks and Wildlife Service, Dublin.RPS, 2016. Dunkellin River and Aggard Stream Flood Relief Scheme – Turlough vegetation community surveys.

Sharkey, N., 2012. '*Turlough vegetation communities : links with hydrology, hydrochemistry, soils and management*', [thesis], Trinity College (Dublin, Ireland). Department of Botany, 2012, pp 283

Waldren, S., 2015. *Turlough Hydrology, Ecology and Conservation.* Unpublished Report, National Parks & Wildlife Services. Department of Arts, Heritage and the Gaeltacht, Dublin, Ireland.

4. Macroinvertebrate and Pond PSYM Survey

4.1 Background

According to the Environmental Impact Assessment, the proposed alterations to the Dunkellin River and its bridges have been designed to have virtually no impact on the hydrological regime of Rahasane Turlough. There are very slight predicted changes to turlough water levels, but these are not significant under flood conditions. Maximum flood levels will remain unchanged and predicted surface water profiles for various flow scenarios (e.g., 5th percentile, 10th percentile) show no, or, at most, imperceptible changes between the pre- and post-works situations.

The purpose of undertaking annual monitoring of the freshwater macroinvertebrate communities and indicator species is to establish whether any changes in their composition has occurred that would indicate a transition from a habitat characteristic of being regularly flooded to one that is more frequently dry. However, it is important to note that given the ephemeral nature of a turlough, natural changes in the hydroperiod of the system occur year on year, and therefore it is important to look for changes in the community composition over a longer period to establish whether a transition in the habitat, and thus the community composition, is occurring.

With this in mind, the Predictive System for Multi-metrics (PSYM; Howard, 2002), designed for habitat survey and the assessment of standing waters, was used as a standard survey method for the turlough, allowing year on year comparison of results. This metric was developed by the Freshwater Habitats Trust and the Environment Agency in England and provides a standardised method for surveying and assessing the biological quality of standing waters, using macroinvertebrates and macrophytes. This work will potentially be a first step in making PSYM more widely useable in the Republic of Ireland as well. It could prove to be a useful standard survey method for turloughs, a view supported by Prof. Ken Irvine (pers. comm.).

Macroinvertebrate samples were identified to species level where possible, thus allowing comparison with the survey of water beetles conducted prior to commencement of the works at the site (RPS, 2016). Also examined were the presence and abundance of ephemeral taxa such as Trichoptera and Heteroptera, correlated with turloughs with longer hydroperiods, and of Gastropoda, which occur in higher abundances in turloughs with longer hydroperiods, probably owing to their limited mobility (Porst, 2009). Other standard metrics were also calculated, to provide a baseline that will assist in understanding changes in the macroinvertebrate communities present, over subsequent years of monitoring.

This report describes the first year of post-works monitoring, and the results should therefore be considered a baseline against which future surveys can be compared.

4.2 Review of previous datasets and reports

The following sources of site-specific data were reviewed:

- RPS, 2016. Dunkellin River and Aggard Stream Flood Relief Scheme: Pre-construction Aquatic Beetle Survey

- RPS, 2014. Environmental Impact Statement (Dunkellin River and Aggard Stream Flood Relief Scheme);
- RPS, 2014. Natura Impact Statement (Dunkellin River and Aggard Stream Flood Relief Scheme);

The following additional sources of relevant publicly available data and information were also reviewed:

- Environmental Protection Agency (EPA web-based data viewer (EPA map viewer; Water
- National Parks and Wildlife Service (NPWS) web-based data viewer (Special Areas of Conservation; Special Protection Areas).
- National Biodiversity Data Centre Database
- Porst, 2009. The Effects of Season, Habitat, Hydroperiod and Water Chemistry on the Distribution of Turlough Aquatic Invertebrate Communities. PhD Thesis, Trinity College Dublin.
- Relevant published peer reviewed papers associated with turlough macroinvertebrate community composition (Foster *et al.*, 1992; Lahr, 1997; Lahr *et al.*, 1999; Follner and Henle, 2006 and Williams, 2006)

4.3 Methodology

4.3.1 Macroinvertebrate Survey and Analysis

Macroinvertebrate sampling was carried out at four locations at the Rahasane Turlough on 25 August 2021 (Figure 20). The substrate at each site was comprised of semi-permanent wetted areas with grazed grassland, with submerged, emerging and floating leaved aquatic plants present.

Figure 20 The four sampling sites surveyed for macroinvertebrates and PSYM analysis

The survey was conducted by sweep netting through the submerged vegetation at all mesohabitats present at each location, using a standard pond net with 1mm mesh size for a period of 1 minute at sites 1 and 4 and 30 seconds each at sites 2 and 3 which were near one another (bringing the total to a 3-minute sample) as outlined in the PSYM method by Howard (2002). The samples were preserved in Isopropyl alcohol on site to be returned to the lab, where they were combined into a single composite sample, for as detailed an identification as possible (genus and species where possible).

Figure 21 Photo of Site 1

Macroinvertebrate samples were processed in the APEM laboratory in accordance with the methodology described in the Environment Agency's Operational Instruction 024_08 (issued 28/01/2014). This specifies the method for sorting preserved samples to ensure all invertebrate specimens are retrieved, followed by identification under a binocular microscope. Invertebrates were identified to the lowest possible level using the standard range of identification keys published by the Freshwater Biological Association, AIDGAP and others. The Operational Instruction also described quality control processes, which were followed throughout and which create auditable samples and data. A list of the macroinvertebrate taxa recorded can be found in Appendix 3 of this report. This list informed the calculation of all macroinvertebrate indices.

4.3.2 Plant Survey

Pond macrophytes were surveyed by wading the perimeter of the dry and shallow water areas at each of the four locations, with deeper areas sampled using the pond net. Species were recorded on the PSYM plant recording sheet as outlined in Howard (2002). A list of the macrophyte taxa recorded can be found in Appendix 3 of this report.

Figure 22 Photo of Site 2

4.3.3 Physico-chemical Measurements

Temperature, pH, dissolved oxygen concentration and saturation, conductivity, turbidity, salinity and Total Dissolved Solids (TDS) were measured on-site at each sample location using a multiparameter probe. Additional information on the local environment, substrate, shading, level of grazing and emergent plan cover was also recorded.

Figure 23 Photo of Site 3

Figure 24 Photo of Site 4

4.3.4 Metrics Calculation

PSYM was calculated for Rahasane Turlough based on the assessment of aquatic plant and macroinvertebrate assemblages present as well as environmental data. PSYM is a predictive tool, comparing observed species assemblages with expected composition based on the type and location of the water body, and metric scores are then combined to provide a single value which summarises the overall ecological quality of the water body. However, the reference data used to enable the prediction is currently only available for England and Wales. Instead, the survey metrics will be compared to one another over five consecutive years, to identify any changes over this time.

For the macroinvertebrate samples the metrics calculated for invertebrates in PSYM are Biological Monitoring Working Party (BMWP) score, Average Score Per Taxon (ASPT), the number of dragonfly and alderfly (Odonata and Megaloptera) families (OM) and the number of beetle families (Coleoptera); and for the macrophytes the number of submerged and emergent plant species, the Trophic ranking score (TRS) for aquatic and emergent plants and the number of uncommon species.

The BMWP and ASPT scores exploit the natural sensitivity of each taxon to organic pollution. Macroinvertebrate families which are sensitive to pollution are assigned high BMWP scores, while pollution-tolerant taxa score low. BMWP index may be altered significantly depending on whether the sampling process captures species found in some habitats but not in others. Standardisation of the BMWP score is therefore provided by the ASPT, allowing robust comparisons among sites. BMWP was developed in the UK and has since been adapted for a range of locations, including Iberia (BMWP-I) and Costa Rica (BMWP-CR); the original version works well in Ireland.

TRS is a measure of the average trophic rank for the pond, calculated by assigning each plant species with a trophic score based on its affinity to waters of a particular nutrient status. Plant scores in this system vary between 2.5 (dystrophic i.e., very nutrient poor conditions) and 10 (eutrophic, i.e., nutrient rich conditions).

An EPA Q value classification was assigned to each site. The Q-values were assigned based on the presence and relative abundance of sensitive groups and the consideration of additional qualifying criteria, as described by Toner *et al.* (2005), and in Feeley *et al.* (2020), outlined in more detail in Appendix 4. Also calculated were the Whalley Hawkes Paisley Trigg (WHPT) NTAXA (number of taxa) and WHPT-ASPT, The WHPT is an enhancement of BMWP, now used in the UK for monitoring, assessing and classifying rivers in accordance with the requirements of WFD.

The Q value and WHPT metrics are designed for use on samples collected from rivers, and so have limitations when applied to samples from standing waters, particularly as these are often naturally subject to low oxygen concentrations and have a different assemblages of taxa to rivers. Many of the metrics incorporating macroinvertebrates as bioindicators use a species or overall community's response to levels of dissolved oxygen to assess impact. This makes their use in standing waters less robust, so other measures of ecological health or value are needed, such as the presence/absence of particular species. In addition, given that much of Rahasane Turlough is ephemeral, the samples collected are likely have quite distinct assemblages. However, the metrics can still be useful as a means of comparison of samples taken from the same water body over time and were calculated here on that basis. However, in the case of the Q value assigned, a corresponding WFD Ecological Status was not assigned, given that this metric is being used as a means of comparison among years, and is not designed for use in still waters, as previously stated.

4.3.5 Assessment using beetles

Foster *et al* (1992) identified that aquatic Coleoptera as a group possess a range of attributes required to evaluate the conservation status of wetlands. They found that there were ten distinct assemblage types of Irish water beetles and developed a classification system for habitats typical of these assemblages. The Rahasane Turlough was identified as Community Type F, described as 'turloughs and more permanent, large, shallow, water bodies on base-rich substrata' (Foster *et al.*, 1992).

This research also devised a classification system to assess water beetle assemblages, ranking sites by community significance using a simple metric that can demonstrate the quality of different wetland habitat types and identify sites of highest ecological value (Foster *et al.*, 1992). This involves calculating Individual Species Quality Scores (SQS) assigned based on how commonly or rarely the species occurred in certain habitat types. Then a Mean Quality Score (MQS) for a site is calculated by dividing the total of individual SQS by total number of scoring species. This method was followed here.

The water beetle community of the Rahasane Turlough has been surveyed several times in the past by Bilton (1989), O'Connor (2001), Waldron (2003/ 2004) and RPS (2016) most recently. A summary of the results from these previous surveys was presented in the report by RPS (2016). Using the MQS from each of these studies enables a comparison to be made over time.

4.4 Results and Discussion

All sampling sites were inundated grazed pastures, with grassy substrates and light to moderate siltation. Among the 4 sites surveyed, 25 species of macroinvertebrate from 21 genera were identified, with a total of 35 taxa recorded, identified to varying levels of resolution (Appendix 3). The majority of the macroinvertebrates collected were various taxa of aquatic gastropods including *Bithynia tentaculata, Lymnaea stagnalis, Planorbis carinatus, Ampullaceana balthica* and *Valvata cristata*. There were also a high number of Corixidae (*Sigara sp*) and aquatic beetles (*Haliplus sp*) in the samples. Twenty-four taxa of aquatic plants were also recorded among sites, 19 of which were identified to species (Appendix 3).

Key water chemical parameters were recorded and are summarised below (Table 8). Due to technical issues with equipment, results from Site 6 were not included. Water temperature was relatively high, reflecting the warm summer weather and the standing waters. Dissolved oxygen levels were low, but within an expected range for standing waters. Conductivity levels may also be raised due to the presence of calcium carbonate in the catchment. Total Dissolved Solids (TDS), Conductivity and Turbidity levels reflected the moderately silted nature of the water.

The slightly acid pH of the water at all sites (ranging from 6.3 to 6.7) was interesting, given the Karst nature of the catchments and the turlough, and this will be monitored closely in future. There are a number of possible reasons for this. This result could be owing to the breakdown of vegetation-based substrate at the bottom of the more permanent part of the Turlough increasing water acidity and forming an impenetrable barrier at the base of the water body, which could be having a greater effect on the water chemistry owing to the low water levels in the summer months. Another possibility is that nutrient enrichment from a concentrated nutrient source (such as silage/livestock feed) is increasing acidity in the water column, connecting the source with water through perhaps groundwater conduits, or through the complex hydrology of the turlough system.

Table 8 Summarised physicochemical data at Rahasane Turlough, August 2021

Parameter	Unit	Site 1	Site 2	Site 3	Average
Temperature	ºC	23.4	24.1	21.2	22.9
pH		6.7	6.3	6.3	6.4
DO	% Saturation	48	50.9	29	42.6
DO	Mg/L	4.1	4.3	2.5	3.6
Conductivity	µS/cm	656	577	659	631
TDS	Mg/L	424	375	429	409
Turbidity	NTU	6	6.4	5.7	6.0
Salinity	psu	0.27	0.24	0.28	0.26

4.4.1 PSYM Results

The Pond PSYM metrics are described in Tables 9 and 10. There were 19 of the PSYM macroinvertebrate taxa present, which represents a relatively diverse sample (Table 9). The ASPT score, which can range from 0 to 10, was relatively low, but this is typical of standing water bodies, particularly those with high aggregations of organic matter. There were two Coleoptera taxa (Haliplidae and Dytiscidae) and only one OM taxon (Coenagrioniidae) present. The OM number is a good indicator of water quality in British ponds (Biggs *et al.*,

2000) and the taxonomic richness of beetles is negatively correlated with nutrient enrichment in standing waters. Therefore, these results suggest potential nutrient impact at the site. Slimy floating algae was visually observed at all sites, but with increased coverage at Site 3 (Figure 23), as were livestock and horses, providing further evidence of nutrient impact.

The aquatic plant metrics associated with PSYM are recorded in Table 10. Twenty-four macrophyte species were recorded among sites, of which 21 were either emergent or submerged. Unlike the floating-leaved species, the number of emergent and submerged species are known to decline with increasing degradation of a water body.

Table 9 Pond PSYM macroinvertebrate metrics calculated at Rahasane Turlough

Metric	Result
BMWP	78
No. of PSYM Taxa (NTAXA)	19
ASPT	4.11
No. of Odonata & Megaloptera Taxa (OM)	1
No. of Coleoptera Taxa	2

The number of uncommon species present was calculated based on those species that can be described as 'local', nationally scarce' or 'Red Data Book'. Twelve species fitting these criteria were found at the site, although eleven of these were considered 'local' and only one of them was considered 'nationally scarce' in the UK (*Najas flexilis*) according to the Pond PSYM method and has an 'Endangered' status in Ireland. The Trophic Ranking Score (TRS) for the site was high at 8.3, aligning with the macroinvertebrate scores and indicating a nutrient impact at the site.

Table 10 Pond PSYM aquatic plant metrics calculated at Rahasane Turlough

Metric	Result
No. of Emergent & Submerged species	21
No. of uncommon species (Rarity Score of $\geq$2)	12
Trophic Ranking Score	8.35

As previously stated, the standard metrics used for freshwater macroinvertebrate surveys recorded below in Table 11 are designed for use on samples collected from rivers, and so have limitations when applied to standing waters. Nevertheless, these metrics were calculated for the Rahasane Turlough as an additional comparative tool, providing a baseline against which the results from subsequent years can be compared (Table 11). The relatively high number of taxa recorded likely reflects the unique assemblage of taxa found in ephemeral ecotone environments like this. In contrast, the Q value classification, the ASPT score, the % EPT and the WHPT-ASPT are all low, indicating the absence of sensitive taxa and possible pollution stress. The BMWP score was high, likely reflecting the high number of taxa present, given the low ASPT score, which indicates the presence of more tolerant taxa. Therefore, all recorded metrics scores suggest a potential nutrient impact at the site, as well as the visual observation of slimy green algae in rafts on the water surface, and the presence of livestock and horses at all sites. It is not possible to say whether the slight acidity of the water at all sites is as a result of nutrient enrichment or the natural breakdown of vegetative matter, without further investigation.

Table 11 Standard macroinvertebrate metrics calculated at Rahasane Turlough

Metric	Result
Total number of Taxa	35
Q Value	Q3
BMWP	93
ASPT	4.23
% EPT	0.2
WHPT ASPT	3.4
WHPT NTAXA	24

A previous study of Irish turloughs showed that Trichoptera and Heteroptera have a significant positive correlation with the hydroperiod of the turlough (Porst, 2009). These macroinvertebrate groups are ephemeral residents of temporary waters and need more permanent habitats to complete their life cycles (Lahr, 1997; Lahr *et al.*, 1999). Porst (2009) hypothesized that higher abundances of ephemeral taxa occur in more permanent turloughs, because in turloughs with longer habitat permanence there is a greater possibility of colonisation. The survey recorded high numbers (>150) of *Sigara* sp (Heteroptera, Nepamorpha, Corixidae) and two different families of Trichopterans (Limnephilidae and two genera of Leptoceridae), albeit in low numbers (Appendix 3). The composition and abundance of these two orders will be examined and compared in the coming years to assist in understanding if a transition in the habitat has occurred.

The association of higher abundances of Gastropoda in Turloughs with longer hydroperiods concurs with their limited mobility (Follner and Henle, 2006). Despite possessing adaptations to drought (Williams, 2006), the limited mobility of molluscs seems to permit greater survival in sites inundated for longer periods. The high abundance (>2,000 specimens) and diversity of gastropods at the site (8 species, 10 genera and 6 families) suggests that they are not subject to drought pressure. However, this community will also be monitored over the coming years to assess whether any compositional change is occurring post works.

4.4.2 Beetle survey comparison

Three species of beetle were identified within the combined sample at the Turlough: *Haliplus ruficollis group, Haliplus lineolatus* and *Ilybius fuliginosus*. A large number of larval specimens of *Haliplus spp.* that could only be identified to genus were also found, as well as a single weevil (semi-terrestrial, identified to family level – Curculionidae). Previous surveys in 2016 and in 1989 recorded *Ilybius fuliginosus* at the site; however, neither *Haliplus ruficollis* group or *H. lineolatus* have been previously recorded. The MQS Score for the site was calculated as 7 despite the low number of species found, based on the presence of *Haliplus lineolatus* which has a high SQS of 16 (Table 12).

Table 12 Mean Quality Score (MQS) calculated for the water beetle community and number of aquatic beetle species surveyed at the Rahasane Turlough, in this survey (bold) compared with previous years

Year	MQS Score	No of species	Surveyor
2021	**7**	**3**	**APEM**
2016	6	17	RPS
2004	10	13	Waldron
2003	8	12	Waldron
2002	7	10	O'Connor
1992	3	11	Foster
1989	3	11	Bilton

Beetle diversity in the samples collected were low when compared with the previous studies. However, all previous studies were conducted with the express purpose of gathering water beetles, and if conducted according to the method outlined by Foster (1992) is continued until no new species are detected. In contrast, the Pond PSYM method was time constrained and did not specifically target beetles in its methods. Therefore, the level of effort is likely to have differed among studies. Nevertheless, the Mean Quality Score was consistent with that recorded in previous years (Table 12). The Environmental Impact Statement (EIS) noted that several beetle species which are sensitive to hydrological alterations had been identified in the turlough previously. These were the turlough species *Agabus nebulosus, Hygrotus quinquelineatus* and *Hygrotus impressopunctatus*, and the moss dwelling species *Graptodytes bilineatus. G. bilineatus* is listed as Near Threatened on the Irish Waterbeetle Red List (Foster *et al.*, 2009) and is considered likely to be vulnerable to disturbance and sensitive to alterations in flooding (Sheehy Skeffington *et al.*, 2006). None of these species were recorded in this survey. Therefore, monitoring in subsequent years should maintain a focus on the beetle communities, and assess whether the absence of these species is an anomaly or whether a longer-term pattern of change in the aquatic beetle community is occurring at the Turlough, and whether a hydrological change has prompted this.

4.5 References

Biggs, J., P. Williams, M. Whitfield, G. Fox and P. Nicolet (2000). *Biological techniques of still water quality assessment. Phase 3. Method development.* Environment Agency R&D Technical Report E110. Environment Agency, Bristol.

Feeley, H.B., Bradley, C., Free, G., Kennedy, B., Little, R., McDonnell, N., Plant, C., Trodd, W., Wynne, C., and O'Boyle, S., 2020. A national macroinvertebrate dataset collected for the biomonitoring of Ireland's river network, 2007–2018. Sci Data 7, 280.

Follner K, Henle K. 2006. The Performance of Plants, Molluscs, and Carabid Beetles as Indicators of Hydrological Conditions in Floodplain Grasslands. *International Review of Hydrobiology* **91**: 364-379.

Foster GN, Nelson BH, Bilton DT, Lott DA, Merritt R, Weyl RS, Eyre MD. 1992. A classification and evaluation of Irish water beetle assemblages. *Aquatic Conservation: Marine and Freshwater Ecosystems* **2**: 185-208.

Howard, S., 2002. *A guide to monitoring the ecological quality of ponds and canals using PSYM.* Environment Agency, West Midlands and Freshwater Habitats Trust.

Lahr J. 1997. Ecotoxicology of Organisms Adapted to Life in Temporary Freshwater Ponds in Arid and Semi-Arid Regions. *Archives of Environmental Contamination and Toxicology* **32**: 50-57.

Lahr J, Diallo A, Ndour K, Badji A, Diouf P. 1999. Phenology of invertebrates living in a sahelian temporary pond. *Hydrobiologia* **405**: 189-205. Porst, G., 2009. *The Effects of Season, Habitat, Hydroperiod and Water Chemistry on the Distribution of Turlough Aquatic Invertebrate Communities.* PhD Thesis, Trinity College Dublin.

RPS, 2016. Dunkellin River and Aggard Stream Flood Relief Scheme Pre-construction Aquatic Beetle Survey. Prepared on behalf of Galway County Council.

Toner, P., Bowman, J., Clabby, K., Lucey, J., McGarrigle, M., Concannon, C., Clenaghan, C., Cunningham, P., Delaney, J., O'Boyle, S., MacCarthaigh, M., Craig, M. and Quinn, R., 2005. Water Quality in Ireland: 2001– 2003. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland.

Williams DD. 2006. *The biology of temporary waters.* Oxford University Press, Oxford, New York.

5. Key Findings from Year 1

Hydrogeology and Hydrology Survey:

- In this first year of monitoring of the SAC, an initial drone survey, hydrometric stations visit, and walkover survey of Rahasane Turlough was conducted. Karst features were identified and mapped, and aerial imagery was obtained on a day when approximately 16% of the turlough SAC was submerged.
- It is not possible to ascertain if the hydrogeology and hydrology of the turlough has changed since the FRS at this time. This is the first time that this sort of monitoring has been undertaken at this site, and therefore there is no baseline for comparison. Furthermore, as the turlough system is complex as it is influenced by a karst system which is not possible to model, and the FRS is only one of multiple factors interacting within the system. However, the year-on-year monitoring of the karst features and gauging stations will provide input into the further characterisation of the SAC and provide insight into the possible influences and impacts of the FRS.
- These site visits and drone surveys will be repeated by CDM Smith for the next four years when water levels in the turlough are low. The mapped karst features will be checked to see if landforms have changed, or new landforms have appeared. In addition, OPW hydrometric station data and local rainfall data will be processed, and trends (where identifiable) will be discussed.
- The overall benefits of the identification and monitoring of karst features includes the collection of data for long term studies of this dynamic hydrogeological system.

Vegetation Survey:

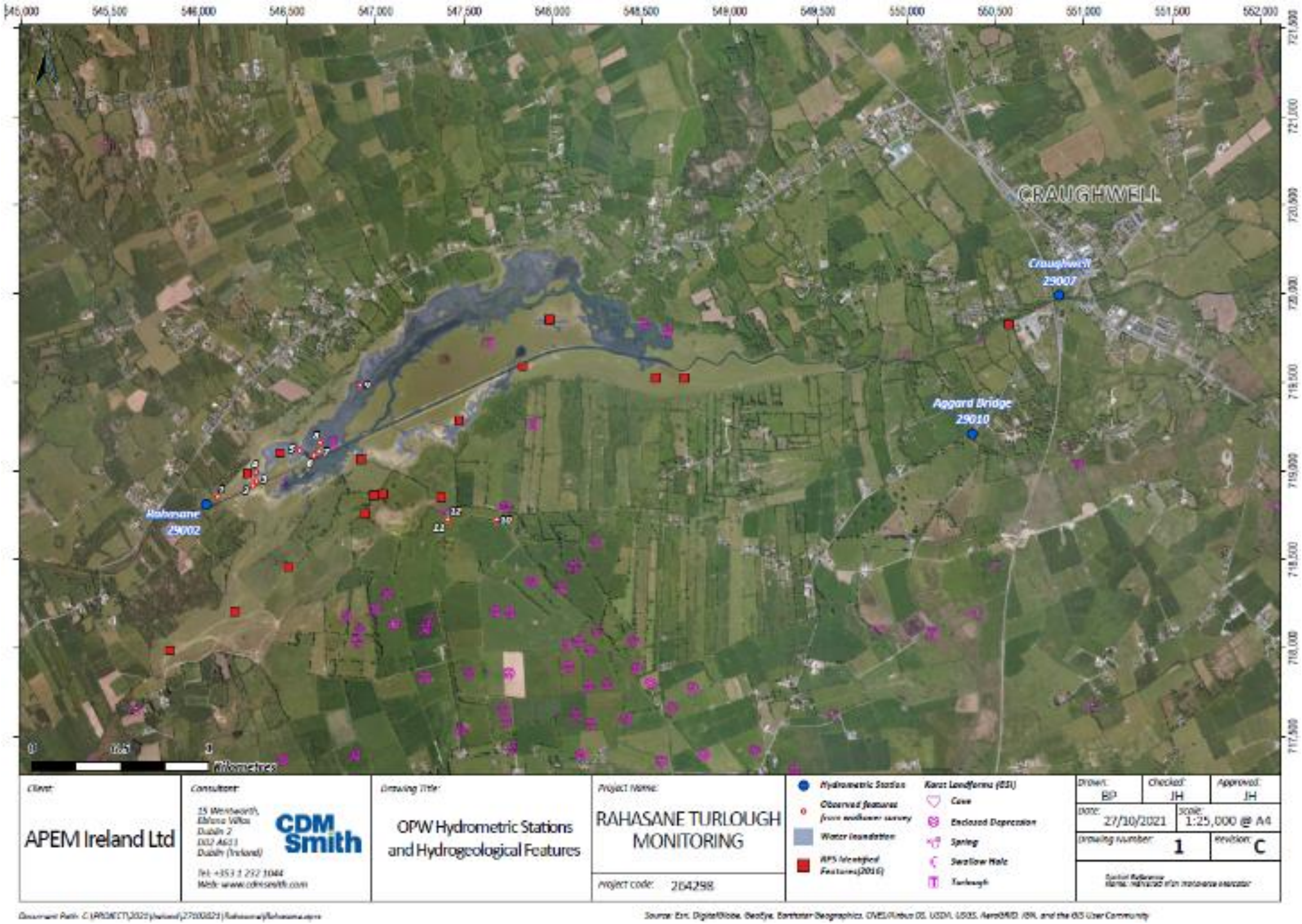
- Vegetation in almost all areas examined was tightly grazed by sheep and horses, and some poaching of the ground was noted in places. This may indicate that the stocking rate of these animals is higher than optimal for the habitats present.
- High water levels in late summer of 2021 made some areas inaccessible. While vegetation was broadly similar to that recorded in 2016, species richness was higher in several areas examined, including a higher prevalence of bryophytes.

Macroinvertebrate and PSYM Survey:

- A total of 35 macroinvertebrate taxa were recorded, principally gastropods, corixids and beetles. Of interest was the slightly acid pH of the water at all sites, given the Karst nature of the catchment. This could be as a result of the natural breakdown of vegetative matter at the bottom of the more permanent Turlough acidifying the water with 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. It is not possible to say what has caused it without further investigation.
- Pond PSYM metrics suggested potential nutrient impact at the site, corroborated by the Q3 classification, and low ASPT and WHPT-ASPT scores, a visual observation of slimy green algae in rafts on the water surface, and the presence of livestock and horses grazing next to the turlough.

- The high abundance (>2000 specimens) and diversity of gastropods at the site (8 species, 10 genera and 6 families) suggests that this group are not subject to drought pressure.
- Beetle diversity in the samples collected were low when compared with the previous studies. However, the Mean Quality Score was consistent with that recorded in previous years.
- Results such as the PSYM scores, community structure, abundance of ephemeral taxa (positively correlated with more permanent turloughs), gastropod community and beetle MQS scores, recorded here, will be considered a baseline against which future surveys will be compared, to establish whether a transition has occurred from a habitat characteristic of being regularly flooded to one that is more frequently dry.

Appendix 1 Drawing 1 – Hydrometric Stations and Recorded Hydrogeological Feature Locations



Appendix 2 Relevé Results & Vegetation Maps

Table 13 Notes and photo from Relevé 2, Transect 2 (T2 R2), Rahasane Turlough

Comments, notes, or threats: Fairly level, with vegetation grazed short by sheep and horses. Several rocks on the surface nearby. The vegetation is dominated by creeping bent (*Agrostis stolonifera*), silverweed (*Potentilla anserina*) and white clover (*Trifolium repens*).


Table 14 Notes and photo from Relevé 4, Transect 2 (T2R4), Rahasane Turlough

Comments, notes, or threats: An area that is level overall but locally undulating. It is grazed by sheep and ponies, with some dunging and poaching evident. The ground was dry underfoot at the time of the survey. The vegetation at this location is dominated by creeping bent (*Agrostis stolonifera*) and silverweed (*Potentilla anserina*), with abundant common marsh-bedstraw (*Galium palustre*) and water forget-me-not (*Myosotis scorpioides*). Water-pepper (*Persicaria amphibia*) and water mint (*Mentha aquatica*) also featured significantly in the vegetation. Some yellow cress (*Rorippa* sp.) was noted in the quadrat.


Table 15 Notes and photo from Relevé 6, Transect 2 (T2R6), Rahasane Turlough

Comments, notes, or threats: Grazed grassland, which is close-cropped by sheep and a few horses. The relevé is located on a slight rise by the river. The ground in this area was dry underfoot at the time of the survey. No bare ground was observed; the vegetation though short was quite dense with some overlapping of layers observed. The vegetation was dominated by silverweed (*Potentilla anserina*), white clover (*Trifolium repens*) and creeping bent (*Agrostis stolonifera*) and appeared somewhat improved in character.


Table 16 Notes and photo from Relevé 12, Transect 2 (T2R12), Rahasane Turlough

Comments, notes, or threats: An area that was 3 metres from standing water at the time of the survey. The vegetation was grazed very short by sheep, with some bare ground and poaching by sheep. There was also some poaching observed in the general area outside the quadrat. The ground in this area is level and was firm and dry underfoot at the time of the survey.


Table 17 Notes and photo from Relevé 16, Transect 2 (T2R16), Rahasane Turlough

Comments, notes, or threats:
This relevé is located on a slight north-facing slope, near some hawthorn trees. The ground was very firm and dry. The general area around the quadrat has occasional mossy rocks. The area was tightly grazed by sheep at the time of the survey, posing a threat from overgrazing and poaching.

Table 18 Notes and photo from Relevé 5 Transect 4 (T4R5), Rahasane Turlough

Comments, notes, or threats:
The ground in this area has a slightly undulating surface and the relevé is located approximately 30 metres from the water's edge. No poaching was recorded within the quadrat, but some slight poaching was noted in the surrounding area. Autumn hawkbit (*Scorzoneroides autumnalis*) was present in some of the surrounding area but not recorded within the quadrat.

Table 19 Notes and photo from Relevé 12 Transect 6 (T6R12), Rahasane Turlough

Comments, notes, or threats: This relevé is located within an area of level ground, at the margin of the rise up to the central channel. This area is grazed by sheep and cattle, and some dung was present at the time of the survey. The ground was dry and firm underfoot at the time of surveying. The vegetation is dominated by silverweed (*Potentilla anserina*) and creeping bent (*Agrostis stolonifera*). Common sedge (*Carex nigra*), creeping buttercup (*Ranunculus repens*), water forget-me-not (*Myosotis scorpioides*), red fescue (*Festuca rubra*), curled dock (*Rumex crispus*) and common marsh-bedstraw (*Galium palustre*) are all quite abundant in the vegetation.


Table 20 Notes and photo from Relevé 16, Transect 6 (T6R16), Rahasane Turlough

Comments, notes, or threats: This area was closely grazed by sheep and cattle, both of which were present at time of survey. The ground was very firm and dry underfoot at the time of the survey. The relevé is located in a very flat area, which is almost fully vegetated. Some very slight poaching was noted in the vicinity, outside the relevé.


Table 21 Notes and photo from Relevé 18 Transect 6 (T6R18), Rahasane Turlough

Comments, notes, or threats: This relevé is located in a quite level area, fully vegetated with a continuous sward. The area is grazed by sheep and cattle; some dung was present, but no poaching was evident. The ground was dry and firm underfoot at the time of the survey.


Figure 25 Vegetation communities recorded at the northern section of Transect 2

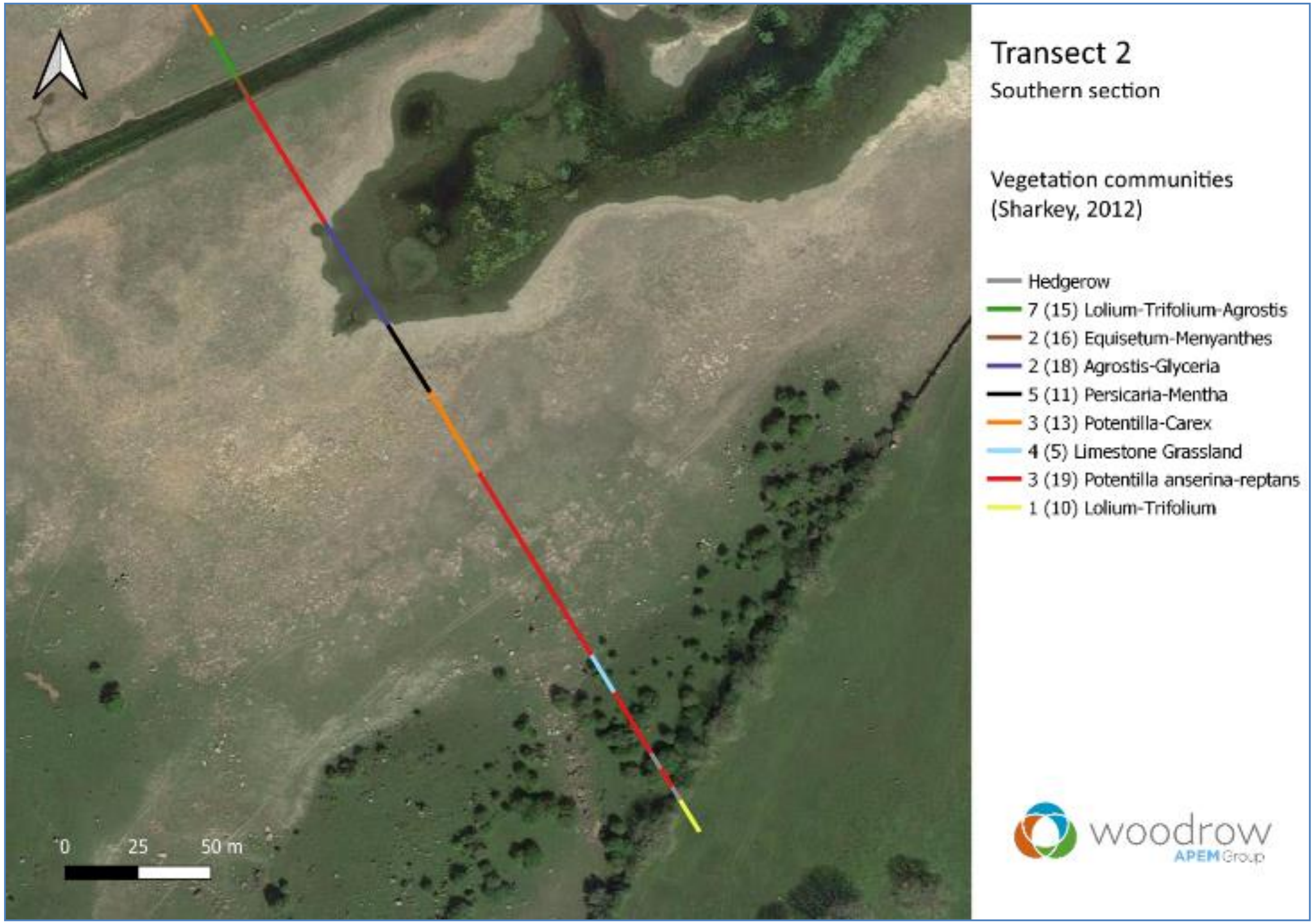


Figure 26 Vegetation communities recorded at the southern section of Transect 2

Figure 27 Vegetation communities recorded at the northern section of Transect 4

Figure 28 Vegetation communities recorded at the northern section of Transect 6

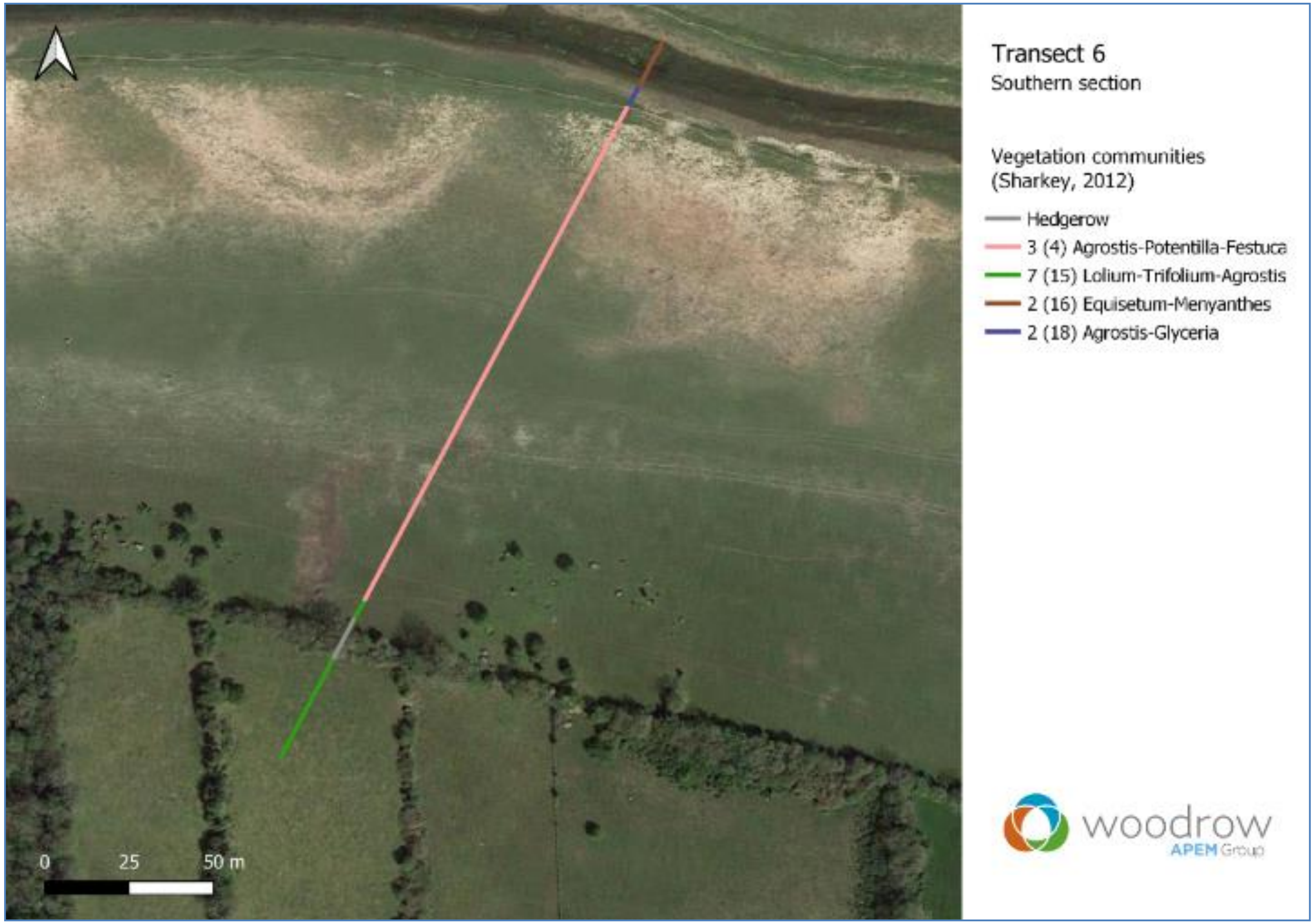


Figure 29 Vegetation communities recorded at the southern section of Transect 6

Appendix 3 Macroinvertebrate and Aquatic Plant Species Lists

Table 22: **Taxa list and abundance of each macroinvertebrate taxa recorded at the Rahasane Turlough**

Order/Group	Family	Species/genus	Abundance
Tricladida	Planariidae	*Planaria torva*	3
		Polycelis nigra/tenuis	1
	Dendrocoelidae	*Dendrocoelum lacteum*	1
Gastropoda			1
	Valvatidae	*Valvata cristata*	179
	Valvatidae	*Valvata piscinalis*	44
	Hydrobiidae(Bithyniidae)	*Bithynia tentaculata*	945
	Physidae	*Physa fontinalis*	79
	Lymnaeidae		17
	Lymnaeidae	*Lymnaea stagnalis*	837
	Lymnaeidae	*Stagnicola sp.*	58
	Lymnaeidae	*Ampullaceana balthica*	226
	Planorbidae	*Planorbis sp.*	1
	Planorbidae	*Planorbis carinatus*	404
	Planorbidae	*Planorbarius corneus*	8
	Succineidae		2
Bivalvia	Sphaeriidae	*Pisidium sp*	18
Oligochaeta			22
Hirudinea	Glossiphoniidae	*Helobdella stagnalis*	1
	Erpobdellidae	*Erpobdella octoculata*	2
Ostracoda			1
Isopoda	Asellidae	*Asellus aquaticus*	24
Crustacea	Gammaridae		2
		Crangonyx pseudogracilis	6
Ephemeroptera	Baetidae	*Cloeon simile*	1
Odonata	Coenagrionidae		36
		Ischnura elegans	24
Hemiptera	Gerridae		1
	Corixidae	*Sigara dorsalis*	29
		Sigara dorsalis/striata	164
		Sigara distincta gp (falleni & fallenoidea)	3
		Sigara fossarum	1
		Sigara fossarum/scotti	3
Coleoptera	Haliplidae	*Haliplus sp*	199
		Haliplus ruficollis group	20
		Haliplus lineolatus	1

	Dytiscidae	*Ilybius fuliginosus*	1
	Curculionidae		1
Trichoptera	Limnephilidae		2
	Leptoceridae	*Athripsodes albifrons* group (*bilineatus* & *commutatus*)	2
		Athripsodes aterrimus	1
		Mystacides sp.	1
Diptera			7
	Culicidae		3
	Chironomidae		32

Table 23: Aquatic plant species recorded at the Rahasane Turlough

Type of Macrophyte	Species Recorded	Rarity Score	Trophic Ranking Score
Emergent Plants	*Agrostis stolonifera*	1	LP
	Berula erecta	2	10
	Glyceria fluitans	1	LP
	Lythrum salicaria	1	
	Myosotis scorpiodes	1	9
	Phalaris arundinacea	1	8.5
	Schoenoplectus lacustris	2	7.7
	Typha latifolia	1	8.5
	Mentha aquatica	1	7.3
Floating Leaved Plants	*Lemna sp*	1	
	Nuphar lutea	*2*	8.5
	Potamogeton natans	*1*	LP
Submerged Plants	*Callitriche sp*	*1*	
	Chara sp	*2*	7.3
	Elodea canadensis or E. nuttallii	*1*	8.65
	Hippuris vulgaris	*2*	7.7
	Myriophyllum spicatum	*2*	9
	Najas flexilis	*4*	
	Potamogeton lucens	*2*	10
	Ranunculus aquatilis	*2*	10
	Ranunculus trichophyllus	*2*	8.5
	Sparganium angustifollium	*2*	3
	Sparganium emersum	*1*	10
	Utricularia sp	*2*	
Aquatic plants not on PSYM recording sheet	*Alisma sp.*		
	Persicaria amphibia		
	Platyhypnidium riparioides		
	Pleurozium schreberi		
	Scirpis lacustris		

Appendix 4 Macroinvertebrate Metrics

Q-Value Assessment

The EPA Q-value classification is assigned based on the assessment of the macroinvertebrate sample, which involves first of all recording the taxa present at a suitable and attainable (under field conditions) taxonomic resolution and their categorical relative abundance determined using approximate counts (as described in Feeley *et al.*, 2020). From this, the number of taxa present and categorical relative abundance of sensitive (Group A), less sensitive (Group B), tolerant (Group C), very tolerant (Group D) and most tolerant (Group E) taxa to organic pollution is examined. Additional Qualifying Criteria are also considered, consisting of recording the abundance of *Cladophora* spp, Macrophytes, and slime growths / sewage fungus, as well as the Dissolved Oxygen Saturation % and the level of substratum siltation. Then, based on the combination of number of taxa and relative abundance of the sensitive or tolerant groups present a Q-value is assigned. Details on the assignment of the scores can be found in Toner *et al.*, (2005).

In Ireland, macroinvertebrates are the main Biological Quality Element (BQE) determining the ecological status in rivers (required by the Water Framework Directive; WFD) and are based on the Q-value. The WFD requires BQE scores to be expressed as an Ecological Quality Ratio (EQR) to standardize and provide a common scale of ecological quality across participatory Member States using differing national methods. Intercalibration of the Q-value with the EQR and the corresponding ecological status are described in Table 24.

Table 24 EPA water quality status summary, comparing the Q-value, ecological quality ratio (EQR), corresponding Water Framework Directive (WFD) status and pollution gradient resulting from anthropogenic pressures (Feeley *et al.*, 2020).

Q value Score	EQR	Pollution Gradient	WFD Ecological Status
Q5	1.0	Unpolluted	High
Q4-5	0.9	Unpolluted	High
Q4	0.8	Unpolluted	Good
Q3-4	0.7	Slightly Polluted	Moderate
Q3	0.6	Moderately Polluted	Poor
Q2-3	0.5	Moderately Polluted	Poor
Q2	0.4	Seriously Polluted	Bad
Q1-2	0.3	Seriously Polluted	Bad
Q1	0.2	Seriously Polluted	Bad

BMWP and ASPT

The Biological Monitoring Working Party (BMWP) index that was designed to identify the degree of organic pollution based on the natural sensitivity of taxon to the pollution. Aquatic organisms respond to chemical changes in water, in particular, to the changes in dissolved oxygen concentrations. As pollution levels increase, the microbial oxygen demand rises, resulting in a decline in available oxygen concentrations. Many stream organisms require high dissolved oxygen concentration and are therefore not found in water bodies with lower oxygen concentrations. Macroinvertebrate families which are sensitive to pollution are assigned high BMWP scores, while pollution-tolerant taxa score low. In the BMWP system, benthic invertebrate taxa are assigned a score between 1 (tolerant to organic pollution) and 10 (intolerant to organic pollution). The BMWP score is the sum of the values for all families present in the sample. The number of BMWP-scoring families is typically recorded alongside the BMWP score, as is the Average Score Per Taxon (ASPT), which can be determined by dividing the BMWP score by the number of scoring taxa present. The BMWP score may vary significantly depending on whether the sampling process captures species found in some habitats but not in others. Standardisation of the BMWP score is therefore provided by the ASPT, with the average BMWP score per taxon allowing robust comparisons among sites.

WHPT and WHPT-ASPT

The Whalley Hawkes Paisley Trigg (WHPT) metric is used in the UK for monitoring, assessing and classifying rivers in accordance with the requirements of WFD based on assessing the ecological quality of the macroinvertebrates present when sampled. It is a revised version of the original BMWP index. Empirical data was used in the development of the WHPT index to assign abundance related sensitivity weights to taxa. The taxa included in the index are modified from those used for the BMWP index and a number of taxa were removed due to insufficient data; some additional families were included where sufficient data were available, and some existing BMWP composite taxa were split into their constituent families. The WHPT-ASPT values typically range from 1 (indicative of sites with high organic pollution and degradation) to 13 (indicative of sites with very low organic pollution and degradation). The WHPT-ASPT score standardises the WHPT score to an average per taxa to allow a robust comparison among sites.

In the UK, a WFD macroinvertebrate classification for a river site is generated by calculating the number of abundance weighted WHPT scoring families found during sampling (WHPT NTAXA), and the WHPT-ASPT, and comparing these values to the values that might be expected under undisturbed or reference conditions for that site. These undisturbed or reference scores are predicted by statistical models produced by the River Invertebrate Classification Tool (RICT) – as RICT predicts invertebrate communities at reference conditions. The observed values of WHPT ASPT and WHPT NTAXA are compared to the predicted values to generate an Environmental Quality Ratio (EQR). EQRs close to 1.0 indicate that invertebrate communities are close to their natural state.