epa Research

Evidence Synthesis Report 7

Investigating the likelihood of a Lough Neagh bloom scenario happening in the Republic of Ireland

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Rialtas na hÉireann
Government of Ireland

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EPA RESEARCH PROGRAMME 2021–2030

Investigating the Likelihood of a Lough Neagh Bloom Scenario Happening in Ireland

(FTP-2024-04)

EPA Research Evidence Synthesis Report

Prepared for the Environmental Protection Agency

by

UK Centre for Ecology & Hydrology and James Hutton Institute

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ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2021–2030. The EPA Research Programme is a Government of Ireland initiative funded by the Department of Climate, Energy and the Environment. It is administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research. This research study was funded under the EPA Research Fast-Track to Policy funding scheme, which is designed to support short-term, evidence-based research studies where an urgent policy need is demonstrated.

The authors would like to acknowledge the members of the project steering committee, namely Deirdre Tierney (EPA), Eva Mockler (EPA), Fiona Kelly (IFI), Brenda Walker (NIEA) and Stephen Prentice (NIEA).

This report is based on research carried out in 2025 using data from 2015–2025. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA RESEARCH PROGRAMME 2021–2030
Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-80009-289-1 June 2025

Price: Free Online version

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Contents

List of Figures

List of Tables

Executive Summary

This report reviews the factors that contributed to the harmful algal bloom (HAB) event in Lough Neagh, Northern Ireland, in 2023 and assesses the potential for similar events in other nutrient-enriched and nationally important lakes in Ireland. The primary objective was to gain an understanding of what factors caused the event at Lough Neagh and to evaluate the threat and potential impact of HABs on Irish lakes.

Literature reviews identified the major drivers of the Lough Neagh HAB, the likely impacts of invasive zebra mussels and management measures for lakes. The 2023 Lough Neagh HAB was chiefly attributed to a combination of eutrophication (excess nutrients, particularly phosphorus), climate change (increased temperatures and high-rainfall events) and the presence of invasive zebra mussels.

Decades of anthropogenic pollution in the Lough Neagh catchment have led to an excess of nutrients. Climate change has exacerbated the situation, with Lough Neagh's surface water temperature increasing by 1°C between 1995 and 2023. The wettest July on record, in 2023, further contributed to significant phosphorus loading from land to water.

As filter feeders, zebra mussels increase water clarity, allowing for greater light penetration and potentially promoting cyanobacteria (blue-green algae) growth. While zebra mussels can also reduce overall phytoplankton and chlorophyll-a concentrations, their selective feeding may favour population growth of blue-green algae.

To assess the risk profile of future HAB events, this study examined 35 lakes in Ireland. Data on lake and catchment characteristics, water chemistry, future climate projections, zebra mussel presence and catchment land cover/nutrient loading were collated and analysed.

Future climate projections indicate a statistically significant increase in mean temperatures (~0.05°C per year) and precipitation (~0.033 mm per year) across the study lake population as a whole. Of the lakes studied, zebra mussel presence has been recorded in 74% (26 of 35), with Lough Derg (Tipperary) having a particularly well-established population. Given the hydrological interconnectivity of the study lakes, the potential for further spread is high. Analysis of land cover characteristics revealed that pastures are the dominant land cover type in most lake catchments (covering > 70% of the land area for 31 lakes). Analysis of catchment nutrients indicated that phosphorus loading from pastures is a significant contributor to the total phosphorus load in 74% (26 of 35) of the study lakes.

A threat matrix was developed using 11 metrics related to HABs, including a water quality principal component analysis, Water Framework Directive (WFD) status, zebra mussel presence, lake depth and retention time, future precipitation and air temperature exceedance and catchment phosphorus concentrations. This matrix categorised the study lakes based on their relative threat of experiencing HABs. A public and nature amenity matrix assessed the potential consequences of HABs using eight metrics, including protected status, lake designation and recreational use.

The study concludes that 20% of the lakes in this study (7 of 35) face a high potential threat of serious HAB events due to a combination of factors like those implicated in the Lough Neagh bloom. Lakes with both a high potential threat score and a high potential public and nature amenity value are of greatest concern.

The report offers several recommendations:

- **Improve the evidence base and scientific understanding:**
  - increase monitoring of nutrients and other water quality parameters, particularly in winter, to gain a better understanding of the impact of zebra mussels and to detect early warning signs of HABs;
  - increase monitoring of zebra mussel populations to assess current numbers and gain an understanding of population changes over time, and conduct further research on zebra mussel behaviour and life cycles.
- **Update policy:**
  - improve understanding about the level of uptake of Programmes of Measures for lakes;

  - where not already included, add lakes with a high HAB risk profile to WFD priority areas for action.
- **Apply actionable responses:**
  - develop a "HAB action plan" for Irish lakes, outlining best practices for environmental responses/impact management, drawing lessons from open and transparent approaches;
  - promote and integrate citizen science tools, like the Bloomin' Algae app, to facilitate rapid reporting of and responses to HAB events.
- **Learn lessons from Lough Neagh:**
  - learn from the management of the Lough Neagh HAB event, including by establishing threat levels for surveying, and issuing alerts for, and reacting to, HABs at bathing water lakes;
  - learn from the outcomes of the ongoing Small Business Research Initiatives.

1 Introduction

Almost half of the lakes in Ireland (49.5%) are currently failing to meet environmental objectives, with one of the main problems affecting these lakes being nutrient enrichment. This can cause, among other things, algal blooms (Carvalho *et al*., 2011). Harmful algal blooms (HABs) negatively affect the ecology of a lake, as well as human and animal health, making these events particularly relevant to lakes in Ireland that are protected under the Water Framework Directive (WFD), the Drinking Water Directive, the Bathing Water Directive and/or the Habitats Directive.

In 2023, Lough Neagh, Northern Ireland, had one of the worst and longest lasting blue-green algal blooms in its history. It is vital to understand the causes of this and the possible risks of similar events happening in lakes in Ireland, so that future monitoring, potential interventions and mitigation strategies can be planned to avoid this, where possible.

In addition to nutrient enrichment, climate change poses a threat to the quality of lakes as water temperatures increase and rainfall patterns change (May *et al*., 2024). In Scotland, these factors have been shown to affect the likelihood of algal blooms on multiple scales. However, different types of lakes and reservoirs will respond differently to these threats, and sensitivity factors will affect the risk of water quality issues developing (May *et al*., 2022).

The three main factors that, together, allow algal blooms to form are warm temperatures, strong sunlight and high nutrient levels, especially high phosphorus levels (May *et al*., 2024). Reid *et al*. (2024) showed that the most likely drivers of HABs in Lough Neagh are eutrophication, climate change and invasive species (zebra mussels), although a total of 18 potential factors have been identified within the catchment. Lough Neagh is categorised as being hypertrophic; this means that it has extremely high nutrient levels, which are likely to be the result of its catchment having a high density of livestock farming. High phosphorus levels in the lake, even with reductions in nutrient inputs, can persist for many years due to the internal recycling of phosphorus from the bed sediments.

The impact of climatic change on Lough Neagh has included the surface water temperatures increasing by 1°C between 1995 and 2023. In 2023, Northern Ireland had one of its wettest spring and summer periods on record, leading to farmland becoming saturated. This heavy precipitation also led to increased flooding, washing more nutrients from the land into the lake.

Zebra mussels were first recorded in Lough Neagh in 2005. These can alter nutrient cycles and favour cyanobacteria (blue-green algae) growth, as has been observed in the Great Lakes in North America (Sarnelle *et al*., 2010). Zebra mussels graze selectively on a range of phytoplankton species, but not on blue-green algae. This reduces competition for resources and increases water clarity, enabling sunlight to penetrate further into the lake and thereby enabling the rapid growth and accumulation of blue-green algae (DAERA, 2024a). Furthermore, blue-green algae enhance the mobility of phosphorus between the bed sediments and the water column, creating a positive feedback loop that enhances bloom development even more (Reid *et al*., 2024). Changes in climate have altered water retention times through their impact on extreme weather events, such as floods and droughts.

Gaining a better understanding of how all these factors are likely to affect the risk of lakes in Ireland developing the type of prolonged HAB event that has been witnessed at Lough Neagh is vital for protecting habitats and water security into the future.

1.1 Objectives

The objectives of this work were to:

- review the factors that facilitated the occurrence of the Lough Neagh HAB as outlined in a recently published report (Reid *et al*., 2024) and associated literature;
- review the impact of invasive zebra mussels on Lough Neagh, and explore the wider literature to gain an understanding of their impact on lakes across the world;
- collate information on current Programmes of Measures and related catchment management/ nutrient reduction objectives in Ireland, and

explore how future nutrient load reductions could help mitigate the occurrence of unprecedented HAB events;

- assess the potential for prolonged HABs in a set of lakes in Ireland known to be nutrient enriched and/or of national importance (e.g. the Great Western Lakes and Shannon Lakes);
- analyse existing evidence to gain an understanding of which of these lakes are similar to Lough Neagh in terms of nutrient enrichment/conditions and in terms of the factors that may have given rise to the 2023 HAB event;
- bring together information on the environmental objectives of the study lakes and analyse how HAB events could impact people and the environment within the catchment of each lake;
- use the results of the data analysis and impact assessment to create HAB threat and public and amenity value matrices, to allow comparisons across the study lakes.

2 Overview of the Research

2.1 Literature Reviews

To inform the analysis carried out as part of this work, it was important to conduct literature reviews to ascertain three key things: (a) what the major drivers of the HAB event at Lough Neagh in 2023 were, (b) what the impacts of invasive zebra mussels on Irish lakes and lakes around the world are likely to be, and (c) what the current measures in place at the study lakes are and how they could potentially be supplemented to prepare for the eventuality of a serious HAB event.

2.1.1 Lough Neagh reports

HABs occur as a result of many factors and can vary from lake to lake. Reid *et al.* (2024) devised a conceptual model of the Lough Neagh catchment, identifying potential drivers of HABs, including prevailing wind direction; sedimentation; urbanisation; combined sewer overflows; industry; fertilisers; and commercial eel fishery. However, they attributed the 2023 Lough Neagh HAB event to a combined result of eutrophication, climate change and invasive species, in agreement with the Department of Agriculture, Environment and Rural Affairs (DAERA), the Department for Infrastructure and Northern Ireland Water (NIW) (DAERA, 2024a).

The Lough Neagh catchment has seen decades of anthropogenic pollution from point and diffuse sources, leading to an excess of phosphorus and nitrogen. Both Reid *et al.* (2024) and DAERA (2024a) argue that the 2023 event was driven by increased nutrient loading, especially phosphate loading. Provisional estimations of total phosphorus (TP) sources running into Lough Neagh attribute 56% to agriculture; 31% to wastewater treatment works; 12% to forestry and urban diffuse pollution; and 1% to septic tanks (DAERA, 2024a). These estimations reveal that agriculture and wastewater treatment works effluent are the two main phosphorus pollution sources. The agricultural sector has seen intensification and expansion over the past decade, with approximately 66% of the Lough Neagh catchment being used for agriculture, primarily for grassland grazing (Elliott *et al*., 2016). Reid *et al.* (2024) collected and analysed surface water and algal mats during the 2023 HAB event. They found bacteria that are typically associated with the activated sludge systems of human-effluent wastewater treatment plants, as well as bacteria associated with either livestock or wildfowl species.

While eutrophication is the primary cause of HAB events in Lough Neagh, the pollution is exacerbated by climate change (DAERA, 2024a). Lough Neagh surface water temperatures increased by 1°C between 1995 and 2023, making the conditions more suitable for algal blooms (Reid *et al.*, 2024). Similarly, climate change alters soil temperature patterns, which in turn affects soil nutrient dynamics (DAERA, 2024a). The lake also saw the wettest July on record in 2023, with double the July average rainfall (185.4 mm) (Met Office, 2023). Intense rainfall and flooding enable the movement of nutrients from land to waterbodies, leading to significant phosphorus loading (DAERA, 2024a).

Another key driver of HABs in the lake are zebra mussels (*Dreissena polymorpha*), which were first documented in Lough Neagh in 2005 and became abundant in the late 2010s (Reid *et al.*, 2024). This invasive species feeds selectively on existing phytoplankton species (and potentially less or not at all on blue-green algae). Zebra mussels are associated with water clarity and subsequent light penetration, enabling cyanobacteria growth and reproduction (Reid *et al.*, 2024). The increased temperatures and wetter conditions that are associated with climate change also affect the spread of zebra mussels. Zebra mussels require water temperatures of > 12°C to spawn, and, therefore, climate change may mean earlier or longer spawning periods. However, lower rainfall can deplete populations in shallow areas by freezing or drying the population (Baker, 2023).

May *et al.* (2022) highlighted several sensitivity factors for Scottish lochs and reservoirs developing water quality issues as a result of climate change. They found that shallower waterbodies are more sensitive to climate extremes than deeper waterbodies due to their higher surface-area-to-volume ratio. They added that shallow lakes with medium alkalinity levels in particular are associated with increased cyanobacteria levels. Flushing rates were also found to affect the sensitivity of lakes to environmental change.

In summary, the three main causes of HAB events in Lough Neagh are:

1. nutrient loading – phosphorus and nitrogen from agriculture and wastewater treatment works;
2. climate change – increased surface water temperatures and increased rainfall (and flooding);
3. zebra mussels – their impact on phytoplankton populations/clear water phases.

2.1.2 Invasive zebra mussels

The following review centres on the impacts of invasive (zebra) mussels, complemented by a new collection of papers published in March 2025 in the journal *Hydrobiologia* (Lopes-Lima *et al.*, 2025). The impacts of zebra mussels vary from lake to lake depending on the context of each environment (Baker, 2023). Zebra mussels have system-wide ecological effects depending on population density, distribution, water mixing rates, retention time, lake morphology and invasion time (Karatayev and Burlakova, 2025). They are suspension feeders, which affects the benthic environment on a local scale but also results in system-wide impacts on the planktonic community, trophic relationships and nutrient cycling (Karatayev and Burlakova, 2025). Zebra mussels are considered ecosystem engineers because of how they alter the environment and resources for other species.

Zebra mussels filter water then excrete waste, which concentrates nutrients at the bottom of the lake. They alter the lake nutrient cycle by reducing zooplankton and phytoplankton populations and are associated with a reduction in concentrations of phosphorus and chlorophyll-a (chl-a), which is used as an indicator of algae levels (Karatayev and Burlakova, 2025). They are also associated with increased water transparency, which must not be mistaken for higher water quality, as phosphorus levels can remain high (Baker, 2023).

The relationship between zebra mussels, nutrient content and algal bloom-forming cyanobacteria is complex (Baker, 2023). Zebra mussels are typically restricted to the littoral zone, meaning that their impacts may be greater in shallow polymictic lakes than in deeper dimictic lakes. The effects of zebra mussels are greatest in the early stages of their invasion, when the population is high and climbing. Karatayev *et al.* (2021) examined long-term ecosystem impacts of zebra mussels in six shallow lakes. They found that the strongest ecosystem impacts were most noticeable within 5–10 years of the initial invasion and the effects began to stabilise and partially recover after 10–15 years. They found that the introduction of zebra mussels was responsible for a reduction in chlorophyll and phytoplankton, and in turn, zooplankton levels.

Higgins *et al*. (2008) investigated the effects of zebra mussels on water chemistry in Lough Doon, a dual-basin lake in the west of Ireland. The lower basin had a population of 5.5×10^8 zebra mussels, whereas only three were recorded in the upper basin. Near-surface water samples collected from January to July 2007 revealed differences in the turbidity and water chemistry of the two basins. The infested lower basin had significantly lower concentrations of suspended solids and chl-a and lower phytoplankton biovolumes, and greater Secchi transparency. The lower basin also had lower TP concentrations; however, soluble reactive phosphorus (SRP) concentrations were similar in both basins. The nitrate and ammonium concentrations were also significantly higher in the lower basin. The observed reduction in turbidity and improvement in water quality in the basin with a large zebra mussel population are reflective of the filter feeding of this species. Likewise, altered nutrient cycles can be attributed to filter feeding and excretion.

Millane *et al*. (2008) studied the effects of zebra mussels in 2005 and 2006 in Lough Sheelin, a shallow alkaline lowland lake in Ireland. They observed a significant reduction in chl-a and an increase in water transparency. However, unlike findings from Higgins *et al*. (2008), TP concentrations remained high, most likely as a result of continued high phosphorus loading from agriculture. Similarly, Greene *et al*. (2015) investigated the water quality effects of a zebra mussel invasion on Lough Sheelin between 1990 and 2008. They found that TP loads were reduced but TP concentrations remained high after the invasion.

Kirsch and Dzialowski (2012) conducted mesocosm experiments on water collected from three reservoirs in Kansas, USA, that frequently experienced cyanobacterial blooms. They found that zebra mussels significantly reduced algal biomass (chl-a) and cyanobacteria biovolume. The mussels were associated with increased SRP concentrations in the eutrophic and hypereutrophic reservoirs, yet there was no effect on the mesotrophic reservoir. Zebra mussels reduced turbidity in each reservoir experiment. They found that the mussels were responsible for altered phytoplankton biomass and community structure, and general water quality conditions. However, they emphasised the variation of effects between reservoirs.

The use of zebra mussels as a biofilter tool to decrease lake eutrophication has been suggested due to their ability to reduce phytoplankton biomass and increase water quality (Karatayev and Burlakova, 2025). McLaughlan and Aldridge (2013) reviewed the use of zebra mussels as a tool for tackling eutrophication and improving water quality in reservoirs. As filter feeders, zebra mussels can improve water quality through the removal of suspended material in the water column and reduce nutrient levels. They can store large amounts of phosphorus and nitrogen, reducing nutrient loads from the water column and depositing them in the sediment through faeces.

McLaughlan and Aldridge (2013) suggested the cultivation and encouragement of zebra mussel populations in sites that have already been invaded. Creamer *et al.* (2025) applied graph analysis to lake networks in Texas and New Mexico in the USA to investigate the spread of zebra mussels. Lakes were identified as hubs, stepping stones and cut points based on factors such as the number of connections to other lakes. Network analysis was useful in identifying the connectivity of the lakes and in determining which lakes were most responsible for the spread of zebra mussels.

2.1.3 Lake and catchment measures

Lake measures

Lake measures must be considered along with catchment measures within the broader context of integrated catchment management and monitoring, partly to gain an understanding of biogeochemical variables that drive or influence lake responses but also to enable the identification of the effects of specific measures (CDM Smith, 2019). Approaches taken in various jurisdictions to address freshwater lake eutrophication and associated algal blooms in Lough Neagh include (Cave and Allen, 2023):

- reducing agricultural run-off through the use of strips of vegetation beside rivers;
- removing nutrient-rich sediment from the lakebed;
- using constructed wetlands to reduce nutrient levels within waterways;
- using selectively toxic microbes to kill zebra mussels;
- using chemicals to control blue-green algae;
- using chemicals to neutralise nutrient effects.

Many of these approaches would be challenging to deliver in Lough Neagh, given the size of the lake, the biodiversity within and around it, and the potential expense involved. This gives rise to questions as to how many of these approaches have been assessed for potential adoption by the local authorities or assessed for smaller lakes where these measures may be more feasible.

Water Action Plan 2024

The *Water Action Plan 2024: A River Basin Management Plan for Ireland* (DHLGH, 2024) outlines the new approach that Ireland will take as it works to protect and restore its rivers, lakes, estuaries and coastal waters over the third cycle of the EU WFD. With effective implementation of this plan, Ireland can expect to see actions to improve water quality in its waterbodies.

Changes in agricultural approaches and an increase in urban wastewater treatment are expected to lead to reduced pollution pressures. A number of diverse measures are required to protect and restore natural waters, which also include the implementation of 11 existing EU directives such as the Nitrates Directive and the Urban Wastewater Treatment Directive. The plan has utilised recent technical advances to place a major emphasis on establishing the “right measure in the right place” through an effective catchment-based approach. This includes selecting required mitigation measures and targeting areas where those measures need to be implemented locally to improve the status of natural waters.

Targeting agricultural measures

Given that agricultural diffuse pollution is the most important pressure on most Irish waterbodies, a "coloured flag" system has been developed to support the targeting of agricultural measures to ensure that the right measure is implemented in the right place. Flags were assigned to all sub-basins, indicating potential water quality issues to focus on. Where agricultural measures are needed to restore water quality, one or more coloured flags are used to indicate the types of water quality issues associated with that sub-basin:

- red flag: potential point source;
- orange flag: nitrate losses;
- navy flag: phosphorus/sediment losses;
- white flag: sub-basins where agriculture is not identified as a significant pressure and measures to "protect" water quality are appropriate.

These flags indicate potential impacts arising from agriculture, to facilitate the targeting of actions, and should be combined with local knowledge and evidence. To highlight this approach, the areas of coverage of different targeted agricultural measures were calculated for the study lake catchment areas, by overlaying the lake catchment boundaries with the 2023 targeted agricultural measure layer for each sub-basin (EPA, 2023) – these are shown in Table A7.1.

Gap analysis

The EPA (2024a) carried out an analysis of the water quality outcomes that are likely to be achieved as a result of the measures outlined in the recent Water Action Plan, which forecasts the number of waterbodies that are likely to achieve their 2027 status objectives, and those that are likely to show improvements, so that an assessment can be made of the gaps that need to be filled before WFD environmental objectives can be achieved. This analysis highlighted three types of gap:

1. **The measures gap:** this applies to waterbodies that are classified as "at risk" but for which no specific, targeted measures are either in place or planned to address the pressures by 2027. Of the 1649 waterbodies that are at risk, 864 (52%) are forecast to have not achieved the 2027 objectives due to this measures gap. The pressures affecting waterbodies without specific targeted measures include hydromorphological, urban run-off, urban wastewater and invasive species pressures. Note that a waterbody can have more than one of these significant pressures.
2. **The effectiveness gap:** this occurs where a measure is planned, but is not likely to be 100% effective in achieving the environmental objective in all waterbodies where the pressure applies. This type of gap arises due to uncertainties about the level of uptake and implementation of the required measures, for example where they are voluntary or where there are other external factors governing their implementation. There is a lack of information on the rate of effectiveness of many measure types, but forecast analysis suggests that medium and high rates of effectiveness are the most likely outcomes, based on the rates of improvement in water quality in response to the measures currently in place.
3. **The evidence gap:** this applies to the 583 (12% of) waterbodies that are under review, where further investigation is needed to confirm the water quality impacts, and the pressures, before the measures and their effectiveness can be assessed. The monitoring and assessment of waterbodies under review is ongoing, to gather evidence on the pressures on these waterbodies and their impact on water quality, and therefore on which measures are likely to be effective.

Catchment measures

CDM Smith (2019) listed a number of recommended, relevant catchment mitigation options in poorly drained at-risk waterbodies where agriculture is a significant pressure. These are:

- maintaining negative farm-gate phosphorus balances (phosphorus uptake > phosphorus input);
- encouraging the "P-mining" of soils (limiting phosphorus application and maintaining soil phosphorus at levels as low as is practicable);
- improving advice to farmers on the timing and location of phosphorus applications in relation to predicted rainfall events;
- adjusting, where appropriate, soil pH through lime application, to reduce phosphorus dissolution from non-calcareous soils with a high clay content

and to improve soil structure (reducing particulate transport from soil);
- controlling livestock access to reduce direct nutrient loads (animal excreta) and to prevent the poaching of soils and the mobilisation of dissolved and particulate phosphorus;
- collecting and storing slurry, manure and soiled water adequately at farmyards to prevent run-off or seepage to waterbodies.

It is worth noting, though, that reducing the diffuse source load as a measure on its own is unlikely to result in improved lake water quality outcomes.

Moreover, in Northern Ireland, the consultation on the third cycle of river basin management plans lists several measures, existing and new, that aim to address water quality in Northern Ireland (Cave and Allen, 2023). These include sector-specific measures aimed at tackling diffuse and point source pollution, such as:

- reducing nutrient and pesticide pollution from agriculture;
- improving wastewater treatment plants (2021–2017);
- reforming and reviewing point source regulations;
- establishing a regulators forum for chemicals and pesticides for Northern Ireland;
- continuing joint working, e.g. the joint management by DAERA and NIW of pollution incident monitoring, etc., and the Water Catchment Partnership (NIW, DAERA and the Ulster Farmers' Union), and establishing new joint working partnerships.

Monitoring

Recommendations from CDM Smith (2019) related to lake water monitoring include the following:

- Due to the importance of internal phosphorus cycling, the characterisation of lake sediments in more lakes is needed. Collecting sediment data from individual lakes would reduce the uncertainty associated with lag (recovery) time estimation.
- Higher-resolution time series of lake water column phosphorus are needed, including stratification monitoring, to improve the understanding of lake phosphorus seasonality and durations of turnover events. It is likely that current monitoring frequencies may not capture the details of loading patterns from the principal significant phosphorus load pressures. Existing monitoring programmes can be adapted to the specific goals of identifying lag times, spatially as well as temporally.
- Wind strength and direction play a key role in sediment resuspension, particularly in shallow lakes; however, high-resolution data that can be applied on the lake scale are not available and the collection of these data should be considered for any related lake studies.

Legacy phosphorus

In lakes where catchment measures have been implemented to reduce the external phosphorus load, internal phosphorus loading from the lake sediment may prevent improvements in water quality for a period of time, and this delay in lake recovery following the implementation of measures is also referred to as the lag time (CDM Smith, 2019). The lag time associated with the internal loading of phosphorus in Irish lakes may relate to:

- water quality recovery: the time for dispersal (flushing) of phosphorus already in the sediments of the lake waterbody and, thus, already part of the hydrological system;
- recovery of hydromorphological conditions: the time for hydromorphological processes to recreate the appropriate range of habitats and substrate conditions following restoration measures in the lake;
- ecological recovery: the time for the re-establishment of species (e.g. macrophyte abundance and age structure) following a reduction in the external and internal phosphorus loads and/or recovery of hydromorphological conditions.

Calm weather conditions can result in low levels of dissolved oxygen developing at the sediment–water interface, creating anoxic conditions, thereby enhancing phosphorus release from iron compounds in the sediment, and this process was identified as a principal factor in the internal loading of Lough Neagh, Northern Ireland.

Important elements that influence lag times (due to natural conditions) are loading history (extended periods with high external phosphorus loading increase the potential for accumulation of internal phosphorus pools), lake residence time (flushing rates) and chemical characteristics of the sediment, particularly iron content.

Flushing rate. Lakes that have shorter residence times may recover more quickly than lakes with longer residence times.

Bathymetry. Lake depths are relevant in the context of phosphorus release in deeper lakes (anoxic conditions during stratification) and in the context of sediment (phosphorus) resuspension in shallow lakes (wind exposure). Lake bathymetry is considered less important than flushing rate and biological status in assessing the longevity of internal loading, but it is relevant in determining the timing (e.g. seasonal), rate and relative significance of phosphorus release.

Recovery timescales are often underestimated because external and internal phosphorus loads are not both considered (Rippey *et al*., 2021). In Lough Neagh in the long term, one cyanobacteria bloom may simply be replaced by another unless the in-lake phosphorus concentration can be greatly reduced (Elliott *et al*., 2016). Summer conditions (higher water temperatures, low oxygen conditions, high biological activity) resulted in the greatest mass of phosphorus release, with the iron-mediated release of phosphorus being the major release mechanism, which can occur in sediments that are not completely anoxic. In addition, decreasing nitrate levels and increasing water temperature can enhance SRP release from in-lake sediments (McElarney *et al*., 2021).

2.2 Study Sites

There are 35 lakes included in this study – a targeted selection provided by the EPA that covers lakes with high public and amenity value (e.g. the Great Western Lakes and Shannon Lakes) and lakes deemed to be at particular threat of future HABs, due to a history of nutrient enrichment and/or previous occurrence of HABs. These lakes and their catchments are shown in Figure 2.1, with Lough Neagh and its catchment shown in grey.

2.3 Data Collation

To analyse the threat of future HAB events at the study sites, and informed by the literature reviews above, data were sought on lake and catchment characteristics, WFD water chemistry monitoring, future climate projections on air temperature and precipitation, zebra mussel populations and catchment land cover/nutrient loading.

2.3.1 Lake and catchment characteristics

Lake polygons and the WFD river network were provided by the EPA. The former were filtered to the study lakes, whereas the river network was used to create an additional dataset of “major rivers”, filtering for stream orders 5–7. Lake catchment data were obtained from a prior extrapolation study (APEM, 2022), and, to align with the work undertaken during that study, the nested catchment dataset (version 2) was used to define any catchment statistics for the study lakes.

2.3.2 Water chemistry data

WFD data provided by the EPA (2007–2023) were merged and filtered for the 35 study lakes. The resulting dataset was merged with Lough Neagh chemistry data (Stephen Prentice, DAERA, January 2025, personal communication), to allow a direct comparison. This was then filtered to six water quality determinants associated with HABs, based on the literature review: TP, alkalinity, ammonia, total oxidised nitrogen (TON), water temperature and nitrate.

2.3.3 Projected climate data

To inform an understanding of how climate change may affect lakes in Ireland, future projections of precipitation and air temperature were sought. Data from the Irish TRANSLATE model (O’Brien *et al.*, 2024) were sought but were not openly/immediately available to the project. This model is a bias-corrected, downscaled product from the Coupled Model Intercomparison Project Phase 5 (CMIP5), and a comparative product from the EVOFLOOD project (Gebrechorkos *et al.*, 2022) was used in its place. This is similarly bias corrected and downscaled from the (more recent) CMIP6. Future projections (2015–2100) are at 0.25° horizontal resolution (~16.5 km in Ireland), compared with ~12 km resolution in TRANSLATE. Data for SSP5-8.5 were selected; this uses Shared Socioeconomic Pathway (SSP)5, where climate change mitigation challenges dominate, and

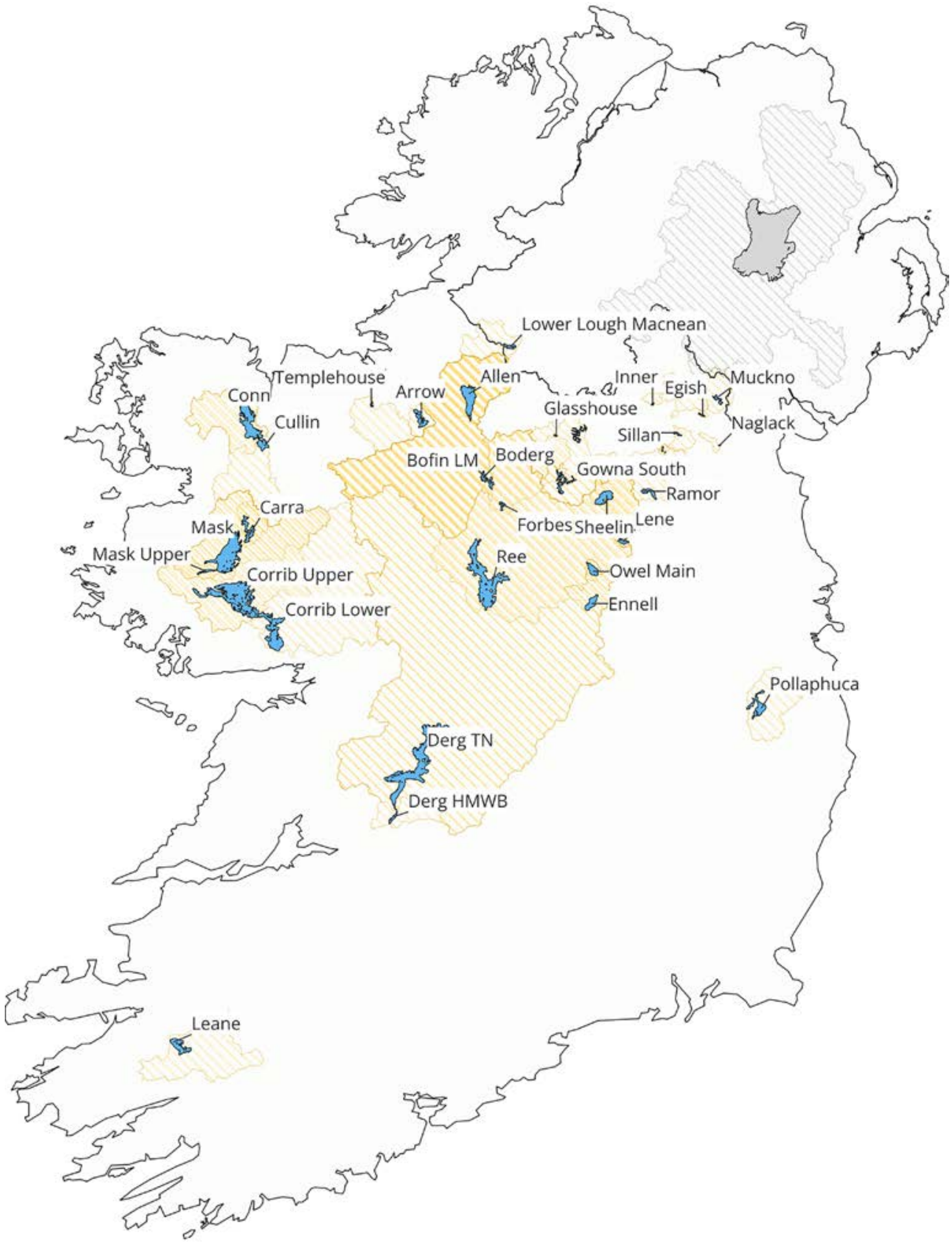

Figure 2.1. Map of the 35 lakes included in this study, with their (nested) catchments shown in orange. Lough Neagh and its catchment are also shown, in grey.

Representative Concentration Pathway (RCP)8.5, a pathway based on a radiative forcing of 8.5 W/m^2 in the year 2100. To simplify the analysis, a single global climate model was used: Hadley Centre Global Environment Model version 3 (HadGEM3) (Jones *et al.*, 2024).

Separate datasets were downloaded for precipitation, mean surface air temperature and maximum surface air temperature. These data were all cropped to a grid covering the whole island of Ireland, then monthly gridded data were used as outputs for precipitation (sum, mm) and air temperature (mean, °C). The catchment polygons were then used for the 35 study lakes to derive apportioned mean values for each lake. Please note that the precipitation data ran to only the year 2097, so this end point was used for the air temperature data also.

2.3.4 *Zebra mussels*

A dataset on zebra mussel presence for Irish lakes was provided by the EPA, then filtered down to the 35 study lakes. This dataset was reviewed by Fisheries Ireland and (first) colonisation dates were included, where known. This was supplemented with all Irish zebra mussel records from the Global Biodiversity Information Facility (GBIF, 2025) and analysed in relation to the study lakes and their catchments.

2.3.5 Catchment characterisation

Lake catchment characterisation involved assessing land cover composition, collating information regarding the WFD status of each lake and significant issues/pressures within the catchment areas, and calculating indicative population sizes within lake catchments. Land cover composition within lake catchment areas was calculated from the 2018 Corine land cover dataset (EPA, 2018). Data on lake WFD status, protected area status and significant issues/pressures were derived from the national summary information that accompanies the EPA cycle 3 catchment assessment reports (Excel file accompanying EPA, 2024b). The indicative population size within each lake catchment was calculated using the Census 2022 Small Area Population Statistics (CSO, 2022). Small area statistics were first published for Census 2011 following work undertaken by the National Institute of Regional and Spatial Analysis on behalf of Ordnance Survey Ireland (now Tailte Éireann) and in consultation with the Central Statistics Office. They were designed for the compilation of statistics on the lowest level of geography in line with data protection guidelines and typically contain between 50 and 200 dwellings. Data on the boundaries of small areas were downloaded, and polygons were selected that had the majority of their area within the boundaries of the 35 study lake catchments; this approach was used because small area and lake catchment boundaries did not align for most lakes. Statistics tables were then combined with the selected small area boundaries, and population counts were calculated for each lake catchment.

2.3.6 Catchment phosphorus

Nutrient loss, mainly of phosphorus, from land to waters has been identified as the most important terrestrial factor increasing the risk of eutrophication and algal bloom occurrence in standing waters (May *et al.*, 2024). Hence, data on the main sources of TP within the study lake catchments, and on modelled TP loads, were gathered from the EPA (APEM, 2022).

3 Examination of the Findings

3.1 Overview of the Lakes

Table 3.1 shows key lake statistics gathered, or derived, from the EPA's extrapolation study of Irish lakes (APEM, 2022). For context, Lough Neagh has a surface area of ~38,300 ha and a mean depth of 8.9 m (DAERA, 2024b), with an average retention time of 455 days (15 months) (ECN, 2025) and a volume of ~3.4 km^3 (Hughes *et al.* 2004). It has a catchment area of ~455,800 ha, with a population >400,000, and it provides drinking water for 40% of Northern Ireland's population – 760,000 people (Reid *et al.*, 2024). The lake is currently classed as hypereutrophic, with mean annual chl-a and TP concentrations of 46 µg/l and 108 µg/l, respectively, in 2014; from 1980 to 2014, mean annual chl-a values were 30–80 µg/l (Elliott *et al.*, 2016). Between 1992 and 2019, the annual TP concentration was consistently over 100 µg/l (Cave and Allen, 2023), keeping the lake's WFD classification for TP as "bad ecological potential" (EU, 2000) and therefore also affecting its overall "ecological potential".

Between 2022 and 2023, the geometric mean chl-a concentration for Lough Neagh was 8.5 µg/l and the arithmetic mean was 19.7 µg/l, while the geometric mean TP concentration was 125 µg/l and the arithmetic mean was 133 µg/l. This shows that, while chl-a values had declined notably since 2015, TP concentrations remained within the historical range (Stephen Prentice, DAERA, January 2025, personal communication). The same dataset shows 2023 peak values (on 4 September 2023) of 347.1 µg/l for chl-a and 339 µg/l for TP – both considerably higher than the historical, and 2022/23, means.

Eight lakes have a WFD chl-a status of poor or bad. Nine lakes have a WFD TP status in the same categories. All lakes are reasonably shallow, with 27 being shallower than Lough Neagh. Three lakes have longer retention times than Lough Neagh and six more have retention times of >6 months.

3.2 Analysis of Water Chemistry

To look further into the water chemistry for each lake and compare its similarity to that of Lough Neagh, principal component analysis (PCA) was carried out to summarise key water chemistry data on two principal component axes, using six determinants that represent the potential drivers and sensitivity factors of HABs from the literature review. Data for lakes in Ireland were averaged over the months April to June and the years 2021–2024. Data for Lough Neagh were averaged over the months April to June and the years 2022–2024. All data are shown in Table A1.2, and were *z*-score scaled before fitting a PCA model. The data are too limited for other months to make a reliable statistical comparison, as outliers would be dominated by a lack of frequency. The following lakes had similar PCA scores to Lough Neagh: Derg Tipperary (TN), Derg heavily modified waterbody (HMWB), Ramor, Sheelin, Sillan and Muckno. Naglack also showed some similarity, albeit being in an extreme position in the PCA (Figure 3.1).

3.3 Future Climate Projections

To analyse the climate data, histograms were plotted to assess the distribution of the mean air temperature, maximum air temperature and precipitation data for the 35 study lakes, as well as for Lough Neagh for comparative purposes. All climate variables approximated a normal distribution, allowing a linear regression for modelling trends over time. Variables were initially modelled based on an interaction between year (standardised) and lake. However, none of the interaction effects was significant for any of the variables, meaning that **rates of change** were similar across all lakes. The model was thus simplified using the structure shown in Equation 3.1, where *I(year-2015)* is an indexed variable that starts the modelling at year 0:

$$lm(variable \sim I(year\text{-}2015) + LAKE\ NAME) \qquad (3.1)$$

The model fit was demonstrated using residuals versus fitted, Q-Q residuals, scale-location and residuals versus leverage plots; all models exhibited homoskedasticity in residuals and no overly influential datapoints.

Table 3.1. Key lake statistics, calculated retention times and WFD status categories for the study lakes, with figures for Lough Neagh for reference

Identifier (Seg_CD)	Name	Lake area (ha)	Catchment area (ha)	Mean depth (m)	Volume (km³)	Ret. time (days)	Chl-a (µg/l)	Chl-a status	TP (µg/l)	TP status
NA	Neagh	38,300	445,800	8.9	3.4	455	>40	Mod.[a]/good[b]	>100	
26_716	Allen	3346	44,575	4.5	0.151	81	5.5	Good	18.2	Good
35_159	Arrow	1247	6617	11.0	0.137	974	2.7	High	11.9	Good
26_747b	Boderg	403	181,734	2.4	0.010	3	4.6	High	25.7	Mod.
26_747a	Bofin LM	490	184,188	2.4	0.012	3	4.3	High	22.4	Good
30_347	Carra	1564	10,906	2.3	0.037	117	2.9	High	7.0	High
34_406b	Conn	4704	42,254	6.9	0.326	274	1.9	High	8.3	High
30_666a	Corrib Lower	5063	302,149	1.7	0.084	13	2.0	High	8.9	High
30_666b	Corrib Upper	11,568	163,675	9.3	1.080	319	1.3	High	6.1	High
34_406a	Cullin	1024	81,891	2.2	0.022	8	2.0	High	9.9	High
25_191b	Derg HMWB	355	1,080,110	5.7	0.020	1	3.6	High	16.3	Good
25_191a	Derg TN	11,651	1,063,050	7.5	0.874	40	3.7	High	19.4	Good
07_268	Drumkeery	13	892	3.9	0.001	28	30.1	Poor	48.3	Mod.
36_671	Egish	112	651	3.7	0.004	360	24.5	Poor	165.4	Bad
25_188	Ennell	1156	16,944	6.4	0.074	253	4.5	High	18.0	Good
26_723	Forbes	298	226,055	1.7	0.005	1	4.8	High	30.8	Mod.
36_615	Glasshouse	54	12,347	4.8	0.003	10	19.1	Mod.	52.4	Poor
36_723	Gowna North	407	3933	3.4	0.014	208	33.4	Poor	45.5	Mod.
36_724	Gowna South	745	25,492	3.5	0.026	71	4.7	High	32.6	Mod.
36_526	Inner	61	15,046	2.3	0.001	5	41.3	Poor	116.3	Bad
22_210	Leane	1891	55,781	13.0	0.246	119	4.4	High	10.2	Good
07_274	Lene	416	1307	8.0	0.033	1857	2.7	High	8.3	High
36_445	Lower Lough MacNean	457	19,040	1.4	0.006	14	10.0	Good	28.0	Mod.
30_665a	Mask	7797	87,572	5.2	0.402	129	1.0	High	8.4	High
30_665b	Mask Upper	421	7807	4.1	0.017	37	3.0	High	7.0	High
06_56	Muckno	356	16,165	5.7	0.020	78	18.7	Mod.	47.0	Mod.
06_55	Naglack	11	1739	3.4	0.000	15	68.6	Bad	74.9	Poor
36_657	Oughter South	661	59,172	2.4	0.016	14	22.4	Poor	69.1	Poor
26_703	Owel Main	1022	3076	7.2	0.073	1616	1.8	High	7.3	High
09_71	Pollaphuca	1954	32,022	2.4	0.048	48	2.7	High	0.0	Good
07_275	Ramor	713	24,990	2.9	0.020	47	15.1	Mod.	56.7	Poor
26_750a	Ree	10,020	458,217	6.2	0.621	76	4.6	High	20.1	Good
26_709	Sheelin	1816	24,911	4.0	0.072	156	7.4	Good	24.3	Good
36_528	Sillan	162	5275	5.3	0.009	86	22.9	Poor	68.2	Poor
07_267	Skeagh Upper	61	531	4.6	0.003	256	40.5	Poor	57.4	Poor
35_157	Templehouse	119	27,268	1.1	0.001	2	5.4	High	53.2	Poor

[a]Overall chl-a status for phytoplankton.
[b]Chl-a class within PLUTO calculator.
LM, Leitrim; Mod., moderate; Ret., retention.
Source: Data not derived from this study were taken from APEM (2022).

3.3.1 Climate extremes

To analyse air temperature extremes, a “hot month” was defined by taking the mean across all lakes of the hottest month of each year in the time period 2015–2097, to give 82 yearly values, and then taking the mean of these values. The same was done using the maximum temperature of the hottest month of each year, ultimately resulting in a mean and

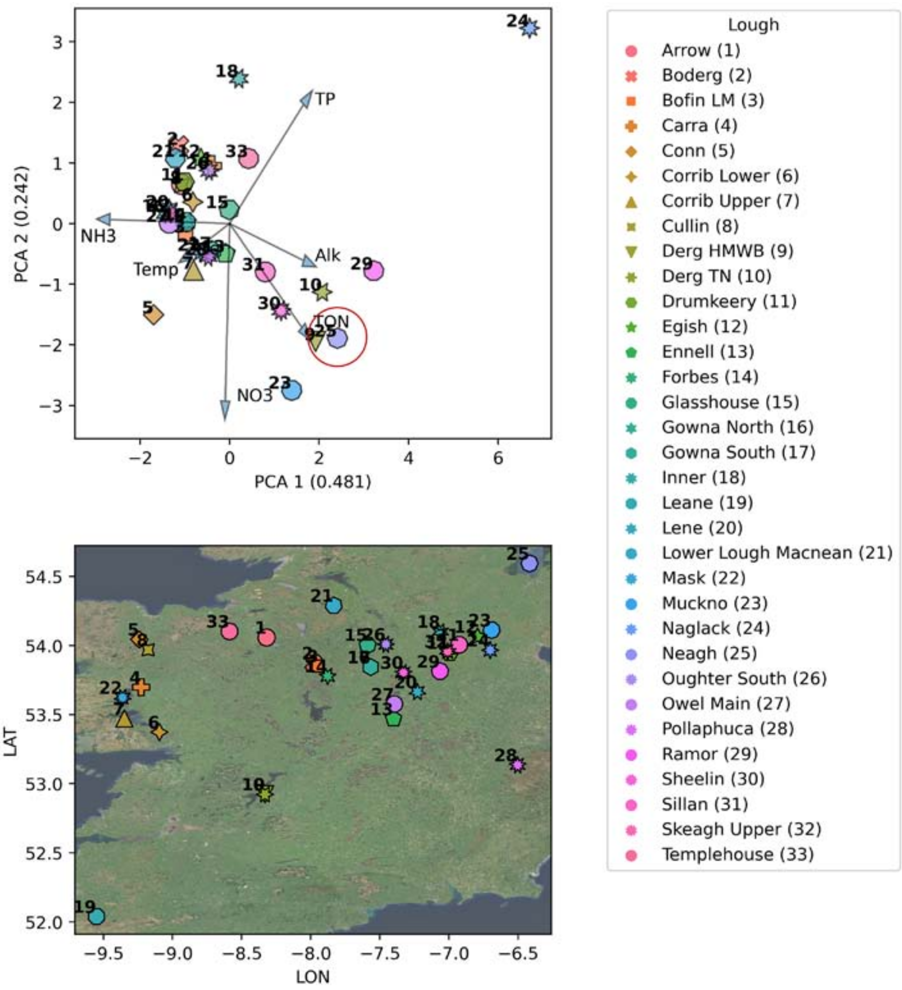

Figure 3.1. Top panel: a PCA biplot showing the first two principal component axes based on a PCA model using seven water quality variables associated with HABs: TP, alkalinity (Alk), ammonia (NH_3), TON, water temperature (Temp) and nitrate (NO_3). Lakes are given different symbols and numbers, as denoted in the legend, with Lough Neagh being circled in red. The PCA "loadings" are shown as arrows on the biplot. Bottom panel: a map showing location of the lakes in Ireland. LAT, latitude; LON, longitude.

maximum threshold for what constitutes a hot month. The mean air temperature threshold was 18.7°C, and the maximum air temperature threshold was 21.9°C.

To account for existing differences in precipitation between lakes, a method was defined for estimating a baseline "wet month". Firstly, data were filtered to include only those from 2015 to 2025 to create a baseline/reference period. An individual wet-month threshold was then defined for each lake by taking the mean of the wettest month of the year across the 10-year period. Thresholds ranged from 140.5 mm/year (Naglack) to 267 mm/year (Leane).

The numbers of months exceeding the thresholds each year were then counted. The numbers of years in which at least 1 month exceeded the air temperature or precipitation threshold were also counted for each lake, and the percentage of exceedance years was determined by dividing this value by the total number of years in the analysis time period (82).

Together, this resulted in 35 single values for each variable, one for each study lake, which described what percentage of the years in the analysis period could be defined as hot or wet.

3.3.2 Air temperature

For the period 2015–2097, a statistically significant increase in mean air temperature across all lakes of ~0.05°C each year is projected. A heat map was used to visualise how many months of the year each lake exceeded a high air temperature threshold

(Figure 3.2). The maximum number of months in a year that the threshold was exceeded was 5, and this was the case for 28 out of the 35 lakes studied (and Lough Neagh). In general, the number of months exceeding the air temperature threshold increased in later years (2050–2097), which matches the general increase in modelled air temperature with time (Figure 3.3).

Similar patterns were seen for maximum air temperature as were seen for mean air temperature. For the period 2015–2097, a statistically significant increase in maximum air temperature across all lakes of ~0.053°C each year is projected. Out of 36 lakes (the study lakes and Lough Neagh), 35 of them exceeded the maximum air temperature threshold (21.9°C) for 4 months in a given year between 2059 and 2096. Further detail on maximum air temperature is shown in Figure A2.1.

3.3.3 Precipitation

For the period 2015–2097, a statistically significant increase in precipitation across all lakes of ~0.033 mm each year is projected. Figure 3.4 shows precipitation over time for all study lakes (and Lough Neagh). With further analysis, three statistically different groups were identified that comprised:

- Lough Leane, which had the highest overall mean precipitation;

Figure 3.2. Heat map showing the number of months (shaded cells) that exceeded air temperature thresholds for each lake (*y*-axis) and year (*x*-axis).

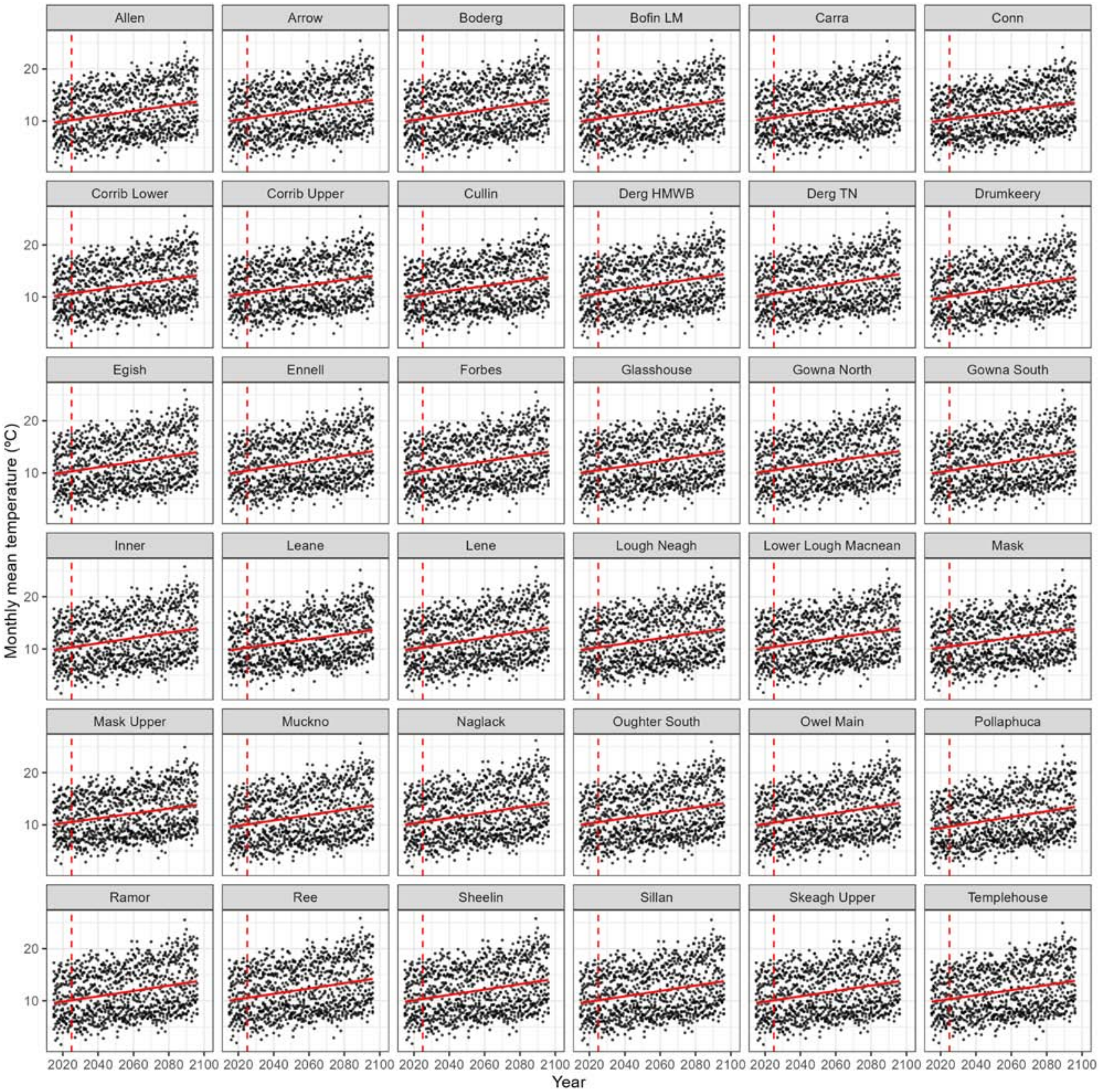

Figure 3.3. Linear regressions (linear model x ~ y and 95% confidence intervals) of mean monthly air temperature (ºC) over time and projected into the future (2015–2096). Model results: *F* = 72.72, *DF* = 36, 35,387, *p*-value < 2.2×10^{-16}, adjusted R^2 = 0.07. The dotted vertical red line represents the present year (2025). The first lake (top-left panel, i.e. Allen) was used as a model intercept. Data source: CMIP6, HadGem3.

- Lough Allen, Lough Templehouse, Lower Lough MacNean and Lough Arrow, in a middle group;
- lakes with the lowest overall mean precipitation, suggesting that the majority of the lakes in this study have similar mean precipitation levels to the group containing Lough Neagh, 2015–2097.

A heat map was used to visualise how many months of the year each lake exceeded a high precipitation threshold (Figure 3.5). The maximum number of months in a year that the threshold was exceeded was 4, and this was the case for 12 out of the 35 lakes studied (and Lough Neagh). In general, the number of months exceeding the precipitation threshold increased in later years (2050–2097), which matches the general increase in modelled precipitation with time (Figure 3.4). One notable exception to the increase happening in later years was Lower Lough MacNean,

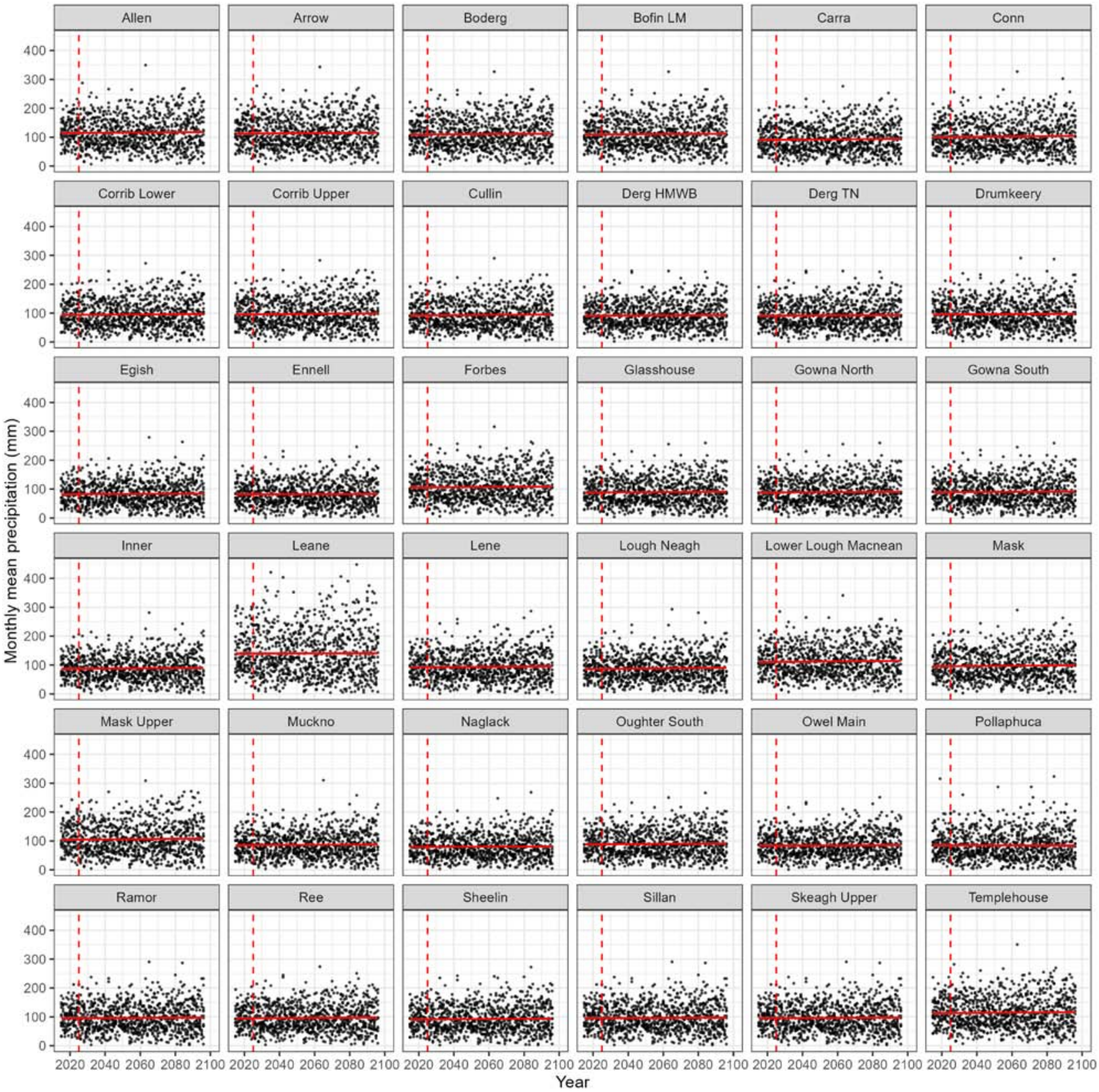

Figure 3.4. Linear regressions (linear model x ~ y and 95% confidence intervals) of monthly precipitation (mm) over time and projected into the future (2015–2096). Model results: $F = 72.72$, $DF = 36, 35{,}387$, p-value < 2.2×10^{-16}, adjusted $R^2 = 0.07$. The dotted vertical red line represents the present year (2025). The first lake (top-left panel, i.e. Allen) was used as a model intercept. Data source: CMIP6, HadGem3.

for which the precipitation threshold was exceeded in 4 months in 2022.

3.4 Zebra Mussels

Table 3.2 shows zebra mussel presence, record counts and colonisation dates for the study lakes. Of the 26 lakes known to have a zebra mussel population, 11 had GBIF records within their lake polygons and six more had records in their catchments only. One lake (Inner) was not marked with zebra mussel presence, yet had GBIF records in the lake/catchment.

Of the study 35 lakes, 26 show zebra mussel presence, and, for nine of these, colonisation occurred over 10 years ago. The records from GBIF show considerable variation across lakes and catchments, but this could be down to variations in recording efforts. Even so, six of the lakes have 200+ unique GBIF records within their catchments,

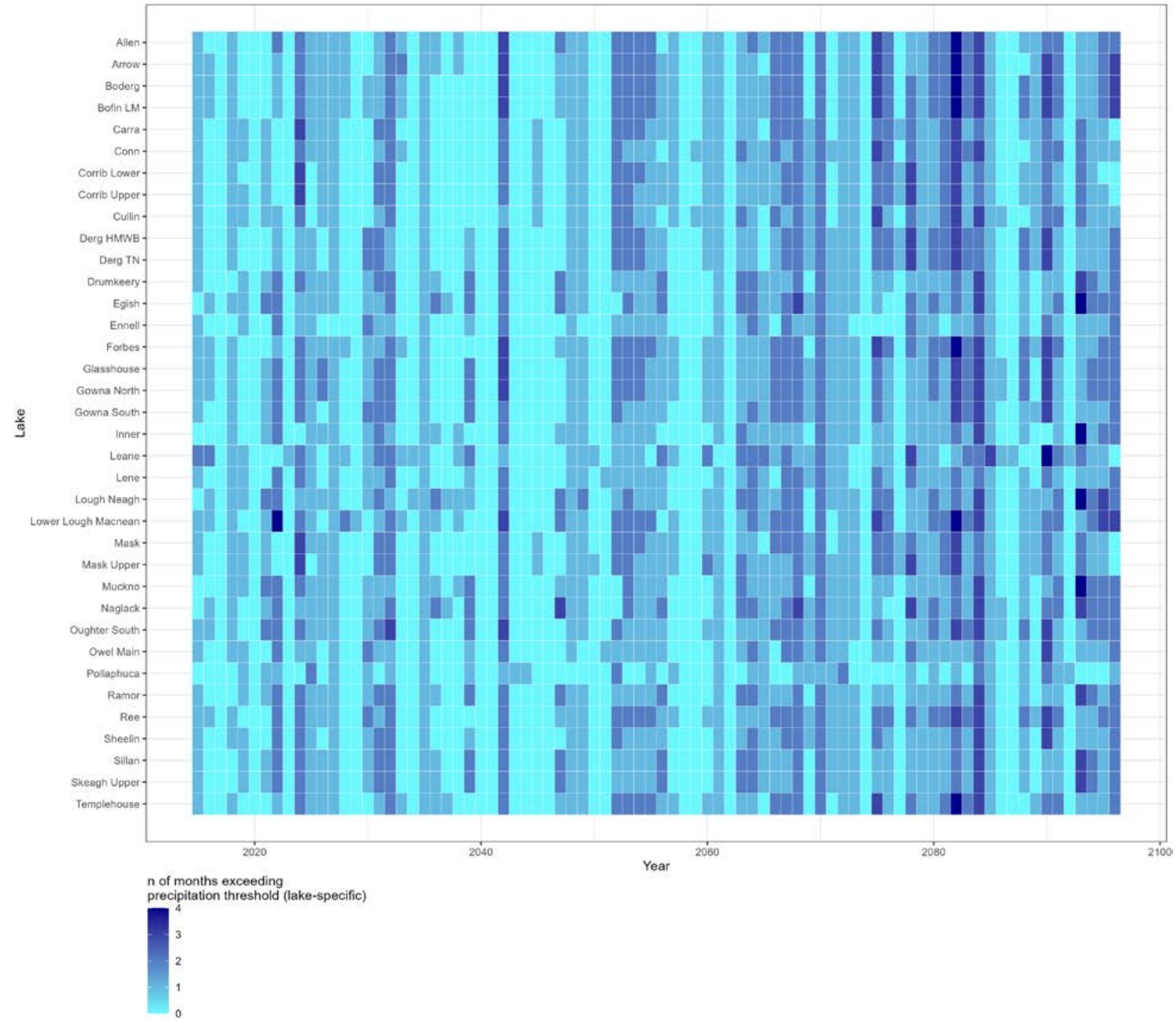

Figure 3.5. Heat map showing the number of months (shaded cells) that exceeded precipitation thresholds for each lake (*y*-axis) and year (*x*-axis).

which suggests the likelihood of large populations being hydrologically connected to these lakes. In terms of identifying risk factors, all lakes apart from Loughs Leane and Pollaphuca are at immediate risk of initial colonisation (depending on water chemistry) or population increase, but Lough Derg TN is the only lake to stand out as having a known large, and very well-established, population.

Figure 3.6 shows the GBIF records over time for Lough Derg TN – this shows that most of the recorded sightings of zebra mussels have been in the last 5 years. Again, recording effort needs to be considered to assess any risk factors.

Figure 3.7 shows all lakes other than Loughs Leane and Pollaphuca (which are not hydrologically connected to any known zebra mussel records) and their merged catchments, with lakes with known zebra mussel populations shown as striped. The figure also shows the major river network and highlights how connected most of the study lakes are.

3.5 Catchment Characteristics

Table 3.3 characterises the study lakes and catchments based on their protected status, angling activities, WFD risk status, significant issues/pressures and population. A full description of every study lake, its catchment characteristics and protected status, and an overall summary is provided in Appendix 4.

Table 3.2. Zebra mussel presence and EPA/Fisheries Ireland colonisation records for the 35 study lakes, along with the total number of GBIF records and the earliest year of GBIF-recorded colonisation for each lake and its catchment

Identifier (Seg_CD)	Name	Presence (EPA)	Colonisation (EPA)	GBIF records (lake)	GBIF colonisation (lake)	GBIF records (catchment)	GBIF colonisation (catchment)
26_716	Allen	No					
35_159	Arrow	Yes		1	2006	3	2001
26_747b	Boderg	Yes		4	2022	191	2001
26_747a	Bofin LM	Yes		4	2022	195	2001
30_347	Carra	No					
34_406b	Conn	Yes	2006				
30_666a	Corrib Lower	Yes	2007			11	2007
30_666b	Corrib Upper	Yes	2007	3	2007	10	2007
34_406a	Cullin	Yes				6	2008
25_191b	Derg HMWB	Yes				592	1997
25_191a	Derg TN	Yes	1994	235	1997	587	1997
07_268	Drumkeery	No					
36_671	Egish	Yes					
25_188	Ennell	Yes		1	2010	7	2008
26_723	Forbes	Yes		3	2022	207	2001
36_615	Glasshouse	Yes		1	2010	1	2010
36_723	Gowna North	Yes					
36_724	Gowna South	Yes				1	2024
36_526	Inner	No				3	2013
22_210	Leane	No					
07_274	Lene	Yes				1	2017
36_445	Lower Lough MacNean	Yes					
30_665a	Mask	Yes	2009	2	2007	3	2007
30_665b	Mask Upper	No					
06_56	Muckno	No					
06_55	Naglack	Yes					
36_657	Oughter South	Yes				4	2010
26_703	Owel Main	Yes		1	2017	1	2017
09_71	Pollaphuca	No					
07_275	Ramor	Yes					
26_750a	Ree	Yes		23	2018	269	1998
26_709	Sheelin	Yes	2001				
36_528	Sillan	Yes					
07_267	Skeagh Upper	No					
35_157	Templehouse	Yes					

LM, Leitrim.

Pastures were the dominant catchment land cover type (>70% of lake catchment area) for 31 of the 35 lakes included in this study. Inland wetlands were the dominant cover for Loughs Mask Upper (65%) and Conn (36%) followed by pastures (31%), while heterogeneous agricultural areas were the dominant land cover for Lower Lough MacNean and Lough Allen, covering 73% and 62% of the lake catchment areas, respectively (Figure A6.1). Most lakes (22/35) had some form of protected area status, with 12 of these providing drinking water supplies. Apart from Lough Inner, all other lakes were important for recreational fishery. Most of the lakes (23/35) were found to have a WFD status of “at risk” in the latest

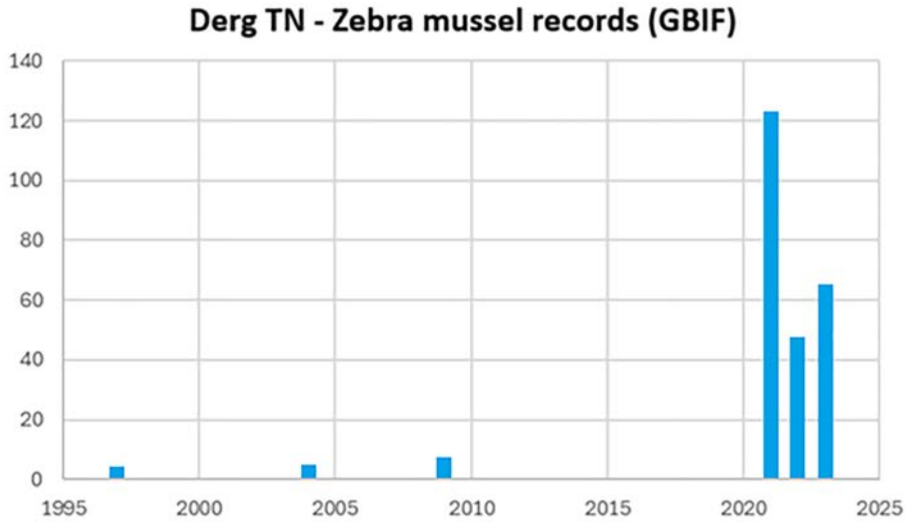

Figure 3.6. Number of records of zebra mussel in the GBIF database for Lough Derg TN, showing variation over time.

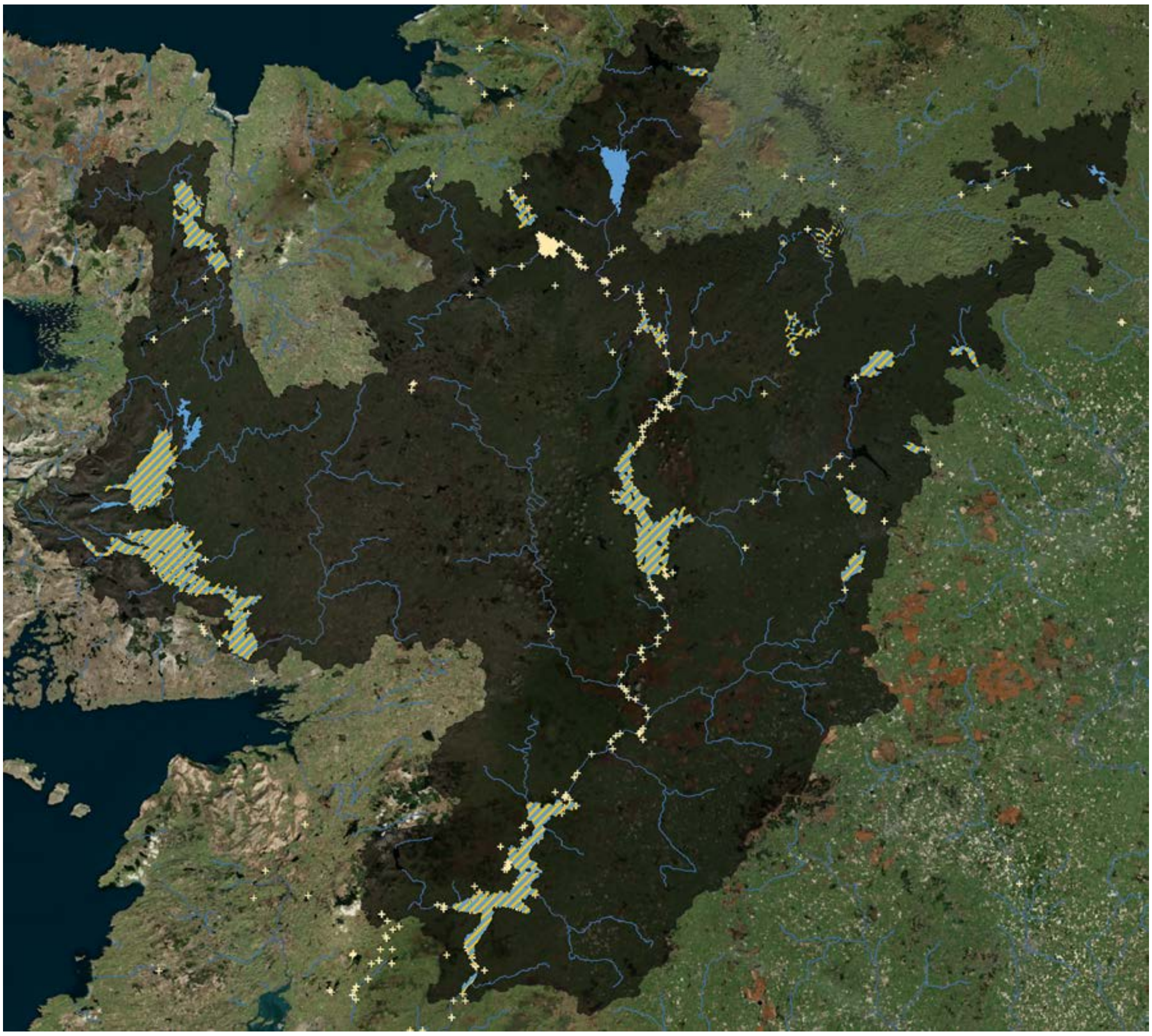

Figure 3.7. Zebra mussel presence at 33 of the 35 lakes in this study. Stripes indicate lakes that have recorded zebra mussel populations, while blue indicates lakes that have no recorded zebra mussel populations. Plus signs (+) mark GBIF zebra mussel river records, blue lines show the major rivers (stream order 5–7) and the combined lake catchments are shown in dark grey. Loughs Leane and Pollaphuca (out of view) have no recorded zebra mussel populations.

Table 3.3. Protected area type, WFD risk status, and significant issues and pressures for each study lake

Name	Protected area type	Fisheries/angling	WFD risk status	Significant issues	Significant pressures	Catchment population
Allen		Pike and coarse fish, pollan present	At risk	Morphological, nutrients	Ag, IS	3329
Arrow	DWPA; SAC; SPA	GWL	Review			735
Boderg		Popular pike and coarse fishery	At risk	Hydrological, morphological, nutrients, unknown impact type	IS, Ag	39,095
Bofin LM		Pike and coarse fish	At risk	Hydrological, morphological, nutrients, unknown impact type	IS, Ag, other	40,244
Carra	SAC; SPA	GWL	Not at risk			2273
Conn	DWPA; SAC; SPA	GWL – salmon present	Review			6229
Corrib Lower	DWPA; SAC; SPA	GWL – salmon present	Not at risk			99,353
Corrib Upper	DWPA; SAC; SPA	GWL – salmon present	Not at risk			36,111
Cullin	SAC; SPA; NSA	GWL – salmon present	At risk	Nutrients, unknown impact type	IS, Ag	32,038
Derg HMWB	SAC; NSA	Popular coarse, pike and trout fishery, pollan present	Review			372,028
Derg TN	BW; DWPA; SAC; SPA; NSA	Popular coarse, pike and trout fishery, pollan present	At risk	Hydrological, morphological, nutrients, unknown impact type	HYMO, IS, Ag	366,399
Drumkeery	DWPA	Coarse angling, competitions/angling festival	At risk	Nutrients	DWTS, Ag	215
Egish		Coarse fishery	At risk	Chemical, nutrients, unknown impact type	IS, Ag	295
Ennell	BW; SAC; SPA; NSA	Popular brown trout and coarse fishery with active brown trout angling club	Review			26,838
Forbes	DWPA; SAC; SPA	Pike and coarse fish	At risk	Morphological, nutrients	Ag, IS, Peat	51,268
Glasshouse		Pike and coarse fish	At risk	Nutrients	For, Ag	3032
Gowna North	DWPA	Active coarse and pike fishing, competitions	At risk	Nutrients	Ag	1115
Gowna South		Active coarse and pike fishing, competitions	At risk	Chemical, nutrients, unknown impact type	Ag, IS	6908
Inner			At risk	Nutrients	Ag	5343
Leane	SAC; SPA; NSA	Arctic char and Killarney shad present, important for salmon and brown trout, active angling club	Not at risk			25,501
Lene	BW; DWPA; SAC	Popular angling centre, regular stocking with rainbow trout, active angling club	At risk	Other significant impacts	IS	610
Lower Lough MacNean		Coarse fish and pike	At risk	Nutrients, organic	Unknown, UWW	1234
Mask	DWPA; SAC; SPA	GWL, Arctic char present	At risk	Nutrients	Ag, DWTS, IS	20,965
Mask Upper	SAC; SPA	GWL	Not at risk			367
Muckno	NSA	Popular for coarse fishing, regular competitions	At risk	Nutrients, organic	UWW	8407

Table 3.3. Continued

Name	Protected area type	Fisheries/angling	WFD risk status	Significant issues	Significant pressures	Catchment population
Naglack		Pike and coarse fish, history of no fish due to pollution in the 1970s, recovery after upgrade to WWTP in the 1990s	At risk	Nutrients, organic, unknown impact type	IS, UWW	3894
Oughter South	SAC; SPA; NSA	Coarse fish and pike, regular angling, prime pike angling	At risk	Nutrients	Ag, DWTS	16,909
Owel Main	BW; DWPA; SAC; SPA	Mainly brown trout, also stocked with rainbow trout	Not at risk			965
Pollaphuca	DWPA; SPA	Mainly coarse and pike angling (controlled via permit by ESB). There is also a small stock of trout. Due to proximity to Dublin, it would be considered a popular angling destination with active angling clubs (ESB also stock the lake with brown trout and rainbow trout)	Not at risk			10,696
Ramor	DWPA	Coarse and pike angling, popular angling club	At risk	Nutrients, organic, unknown impact type	IS, Ag, UWW	13,107
Ree	SAC; SPA; NSA	Trout, coarse fish and pike fishing, pollan present, small commercial brown trout fishery	Not at risk			138,322
Sheelin	SAC; SPA	GWL, active brown trout angling club, regular angling competitions	At risk	Nutrients, unknown impact type	Ag, IS	10,349
Sillan	DWPA	Coarse angling, competitions	At risk	Nutrients, unknown impact type	Ag, IS, UWW	1929
Skeagh Upper	DWPA	Coarse angling, competitions, angling festival	At risk	Nutrients	Ag, DWTS	215
Templehouse	SAC	Coarse and pike angling, private estate hosts competitions, active community group	At risk	Morphological, nutrients	Ag, For	6015

Ag, agriculture; BW, designated as a bathing water lake under the WFD; DWPA, Drinking Water Protected Area; DWTS, domestic wastewater treatment system; For, forestry; GWL, designated salmonid waters in the Great Western Lakes system; HYMO, hydromorphology; IS, invasive species; LM, Leitrim; NSA, nutrient-sensitive area; Peat, peat drainage and extraction; SAC, Natura 2000 Special Area of Conservation; SPA, Natura 2000 Special Protection Area; UWW, urban wastewater; WWTP, wastewater treatment plant.

Sources: Information on protected areas, WFD risk status and significant issues derived from EPA (2024b); fisheries/angling information provided by Fiona Kelly (Inland Fisheries Ireland, 16 April 2025, personal communication); indicative lake catchment population estimates derived from Census 2022 Small Area Population Statistics (CSO, 2022).

assessment, eight lakes were "not at risk" and four were "under review". Nutrients were one of the significant issues for all but one of the lakes at risk, while agriculture (mainly pastures) was one of the significant pressures for 18 of the 23 lakes found to be at risk.

3.6 Catchment Nutrients

Phosphorus loading is often the most significant nutrient issue affecting Irish lakes and therefore a reduction in phosphorus input is usually essential for achieving "good" ecological status (CDM Smith, 2019). Excess nutrients in water can cause the overgrowth of aquatic plants and algae, which leads to eutrophication. This excessive growth outcompetes other plants, uses up dissolved oxygen and blocks light from reaching deeper waters, leading to imbalances in the ecosystem. Both phosphorus and nitrogen play a role in eutrophication; however, the management of excess phosphorus is typically the main issue to address in rivers and lakes, and the management of excess nitrogen is typically the main issue to address in groundwater, estuaries and coastal waters.

Data provided by the EPA (APEM, 2022) were used to calculate the contributions (as percentages) of different sources to the TP load in catchment areas that is transferred to lakes (Figure 3.8). TP loads from pastures contributed at least 15% of the TP load in the catchment areas of the study lakes, and pastures were the most important contributor in 26 of the 35 study lakes. More specifically, pastures were responsible for >60% of TP loads from the catchments of Loughs Inner, Glasshouse, Drumkeery, Gowna South, Oughter South, Skeagh Upper and Ramor. Forestry was the most important contributor of TP loads from the catchments of Loughs Pollaphuca and Allen (39% and 31%, respectively), with pastures being the second most important contributor (24% and 29%, respectively). Drained peat was the most important contributor of TP load in the Mask Upper catchment area (44%), diffuse urban pollution was the most important TP source in the catchment area of Lough Naglack (55%) and atmospheric deposition to water in the catchment areas of Loughs Owel Main and Lene (both ~70%). Wastewater was the source of 13–16% of TP loads in the catchment areas of Loughs Cullin, Templehouse and Muchno, while the contributions of septic tanks to TP loads were below 5% in all lake catchment areas.

Adjusting TP loads by catchment area (Figure 3.9) revealed that Lough Ennell had the greatest TP load and was the only one of the study lakes with a TP

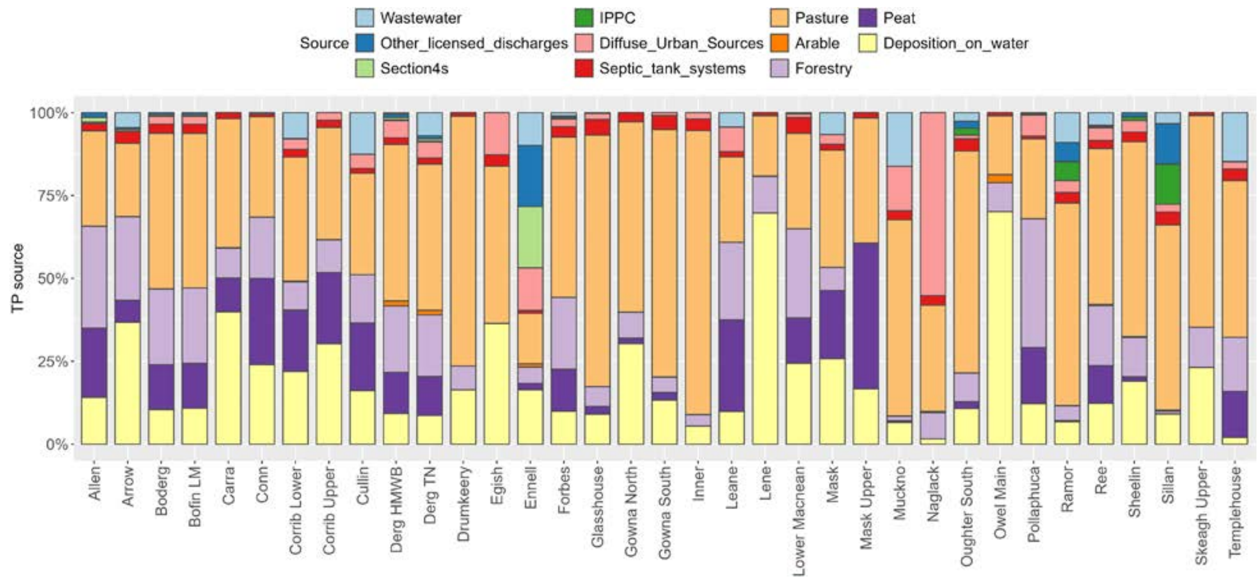

Figure 3.8. Contribution (%) of different sources to TP load in the study lake catchments. "IPPC", "Section 4s" and "Other_licensed_discharges" refer to industry pressures: the IPPC – or Integrated Pollution Prevention and Control – system covers large facilities licensed by the EPA; Section 4s cover the discharge of trade effluent (from hotels, fish farms, factories, etc.); and "Other_licensed_discharges" cover any other discharges not covered by the IPPC or Section 4s.

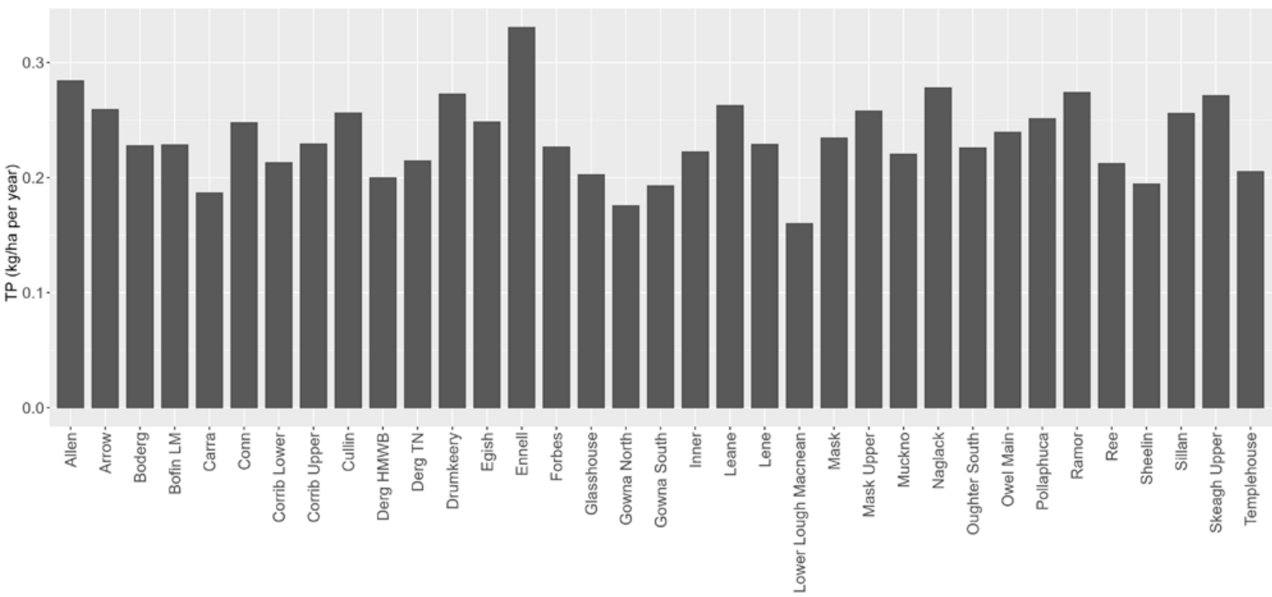

Figure 3.9. Annual TP loads (in kg/ha per year) per catchment area for the study lakes.

load greater than 0.30 kg/ha per year (at 0.38 kg/ha per year). It is worth noting that multiple sources contributed to the annual TP load (5600 kg) in Lough Ennell, with Section 4s and other discharges (see Figure 3.8 for details of these industry pressures) being the most important sources (both ~19%), followed by diffuse urban sources (~13%). Nine lakes had annual TP loads of greater than 0.25 kg/ha per year, namely Loughs Allen, Naglack, Ramor, Drumkeery, Skeagh Upper, Leane, Sillan, Arrow and Mask Upper, while four lakes had annual TP loads of less than 0.20 kg/ha per year, namely Lough Gowna South, Lough Carra, Lough Gowna North and Lower Lough MacNean. A full breakdown of catchment TP loads and sources is shown in Table A5.1.

Finally, inflow data from the Qube model were used alongside catchment TP loading data to predict inflow TP in µg/l, which can be compared with monitored in-lake TP. A comparison of catchment and predicted in-lake TP is shown in Figure A5.1.

3.7 Classifying Harmful Algal Bloom Threats

3.7.1 Harmful algal bloom threat categories

To gain a better understanding of HAB threats – defined here as the likelihood of occurrence of HABs with a similar severity to that of the 2023 Lough Neagh HAB event – across a broad set of categories related to HABs, 11 metrics were created. The creation of these metrics was informed by the data analysis presented above and can be summarised as follows:

1. similarity to Lough Neagh based on the water chemistry PCA;
2. “extended objectives” – defined for the lake based on history of nutrient enrichment;
3. WFD TP status;
4. WFD chl-a status;
5. zebra mussel presence;
6. lake depth;
7. lake retention time;
8. future climate – precipitation exceedance;
9. future climate – air temperature exceedance;
10. total modelled phosphorus per area in the catchment (in kg/ha per year);
11. total predicted inflow phosphorus (in µg/l).

For all HAB threat metrics, scores were assigned from 1 to 3 (good to bad). For water quality, these scores were informed by the PCA clusters, where lakes similar to Lough Neagh were assigned a score of 3, lakes without similarity to Lough Neagh’s overall chemistry but that had highly positive scores on principal component 1 and principal component 2 were assigned a score of 2 and all others were assigned a score of 1.

For zebra mussel presence, those with a prolonged history of zebra mussel presence were given a score of 3; those with a known, but not a long history of, zebra mussel presence were assigned a score of 2; and those without zebra mussels were assigned a score of 1.

For the WFD TP and chl-a statuses, poor/bad was assigned a score of 3, moderate a score of 2 and good/high a score of 1.

For all other metrics, scores were assigned based on being below the 33rd percentile (a score of 1, or 3 for depth), above the 66th percentile (a score of 3, or 1 for depth) or between the 33rd and 66th percentiles (a score of 2). It is worth noting that this assignation is based on the 35 study lakes only and will not reflect lakes in Ireland as a whole, but this method was chosen to show which of the study lakes – all of which have been included in this study due to either their existing HAB threat or the public and amenity value that the lake provides – are most/least at threat.

3.7.2 Harmful algal bloom threat matrix

The threat categories and scores for all study lakes are shown in Figure 3.10. Lakes have been grouped based on their similarity to Lough Neagh in the water chemistry PCA (see metric explanation above and Figure 3.1), with Group 1 having the highest HAB threat. The matrix is first ordered by these groups, then, within these, lakes with defined extended objectives due to a history of nutrient enrichment are presented first, and, finally, the matrix is ordered by the total number of high threat categories for each lake. This total number is used here as a sorting tool for presentation, but should not be interpreted as a **total** HAB threat score, as no weight has been placed on the categories that make up this total, and these categories will naturally have different weights (and weighting will depend on the current condition of each lake). The purpose of the matrix, therefore, is to make a general assessment of the variation in HAB threats across the 35 study lakes.

3.8 Classifying Public and Nature Amenity Value

3.8.1 Public and nature amenity value categories

Based on the information presented in Table 3.3, eight public and nature amenity value categories were assessed:

1. designated bathing water lakes;
2. designated drinking water lakes;
3. salmon/trout fishing importance;
4. navigable waters (by boat);
5. Natura 2000 Special Areas of Conservation (SACs);
6. Natura 2000 Special Protection Areas (SPAs);
7. catchment population;
8. lake surface area.

Four of these categories (1, 2, 5 and 6) are based on specific designations of the waterbody or surrounding area. The majority of the lakes are known for angling of some kind, but salmon and trout anglers tend to be highly aware of water quality issues and a HAB event would likely have more significance for this group than for a coarse fishery. Navigable waterways will be more connected for boat traffic and a HAB event might have more impact on tourism associated with this use. Catchment population is used as a metric of the population likely to be affected by a HAB event, whereas lake surface area is used to quantify the potential size of a HAB event and the number of lake users (recreation, fishing, etc.) that could be affected – public value is greater for lakes with many users.

Lakes protected by bathing water, drinking water, SAC and SPA designations were given scores of 1. For salmon/trout fishing importance, data from Fisheries Ireland were used to assign a score of 1 to lakes that were well known for this type of angling. For lake surface area and catchment population, lakes above the median values of the study lakes were assigned scores of 1. For navigable waters, a spatial dataset of Irish navigable waterways (Heritage Council, 2025) was used (with a small buffer) to define the study lakes as being connected (1) or not (0).

Figure 3.10. HAB threat matrix for the 35 study lakes, showing HAB threat factors from low to high (green to red), sorted by PCA group, nutrient-enrichment history and number of high threat categories.

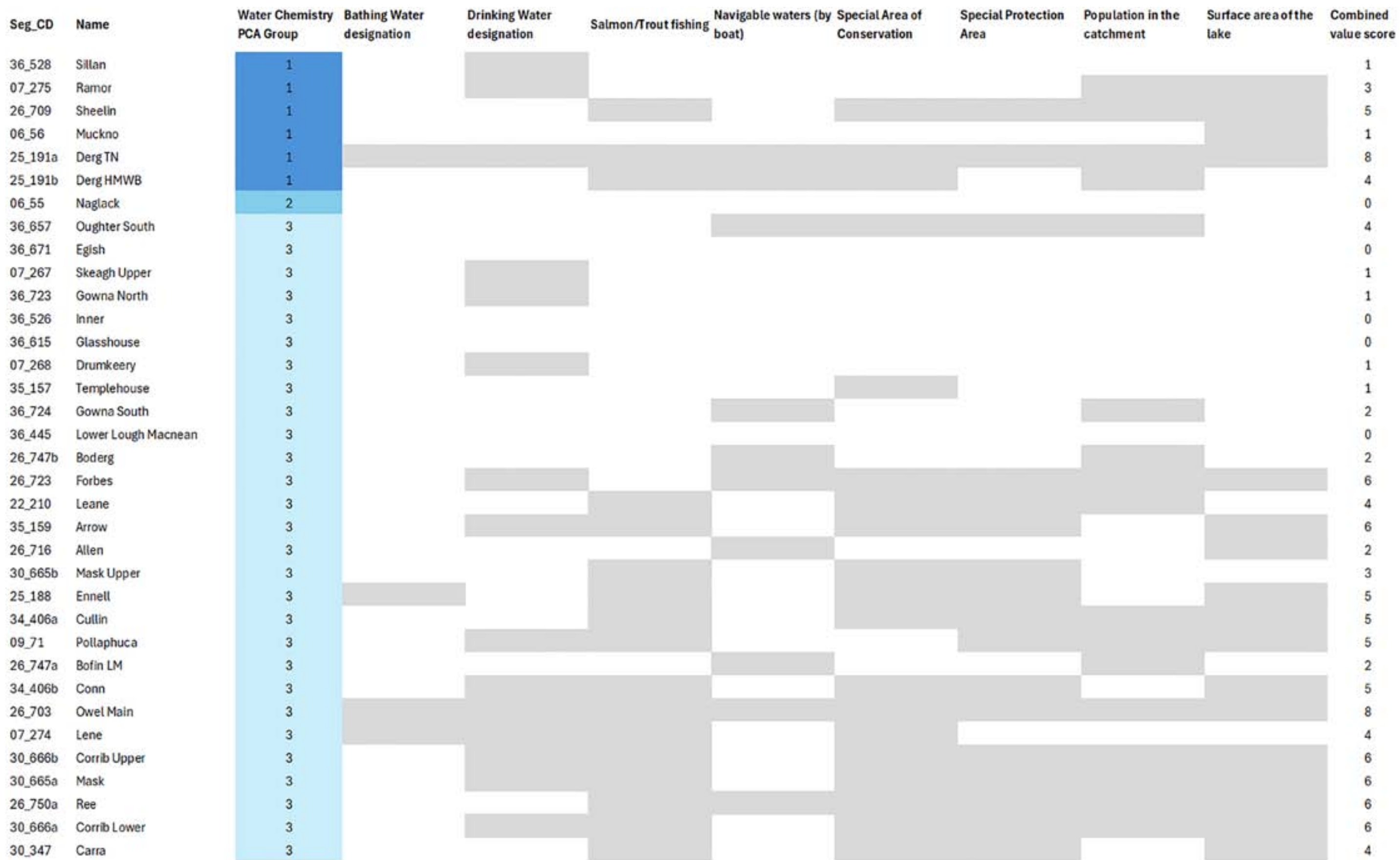

Figure 3.11. Public and nature amenity value matrix for the 35 study lakes, showing value shading (grey = high value), sorted by the order of the HAB threat matrix.

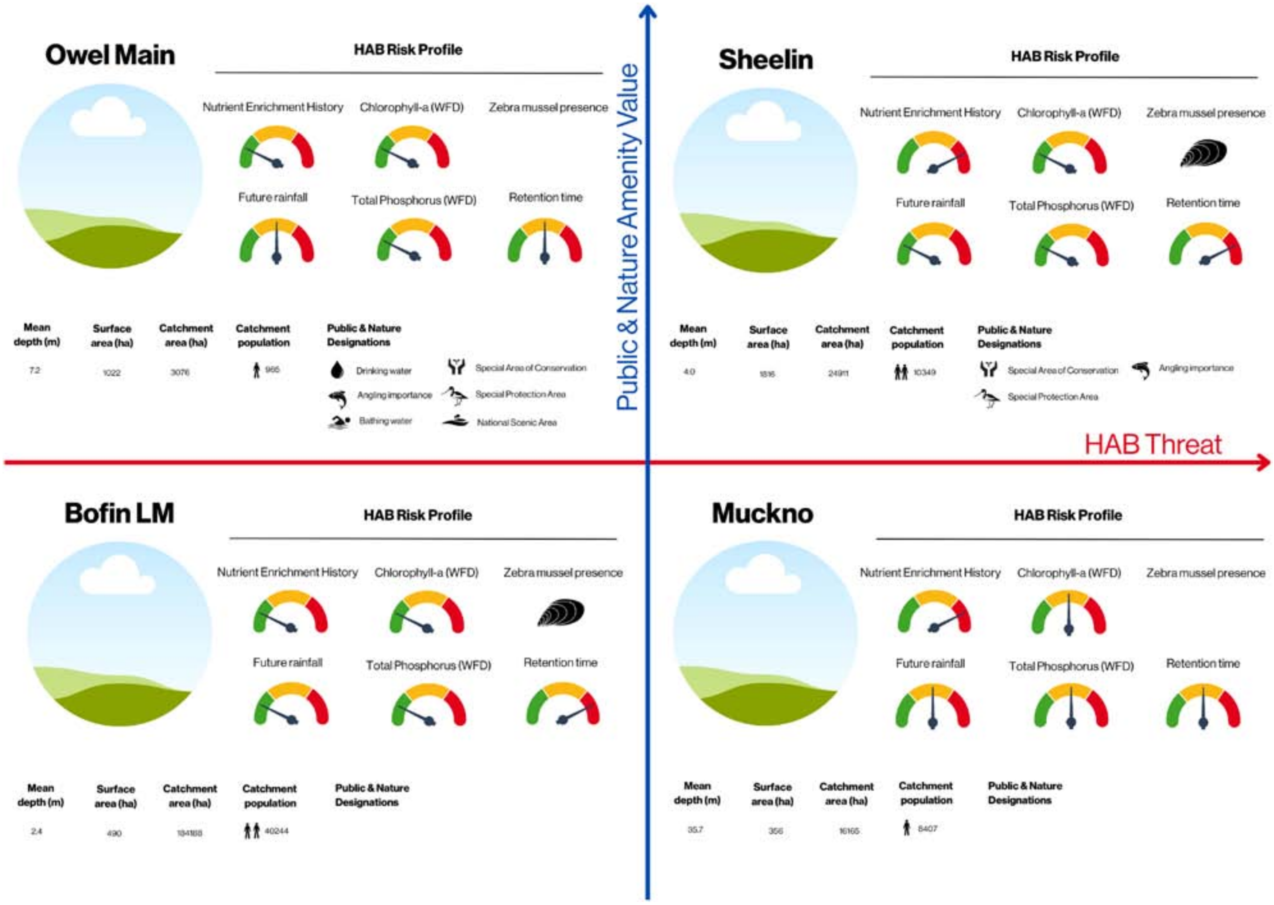

Figure 3.12. Infographic showing study lakes at different ends of the HAB threat and public and nature amenity value spectra.

3.8.2 Public and nature amenity value matrix

The public and nature amenity value categories and scores for all study lakes are shown in Figure 3.11.

3.9 Harmful Algal Bloom Threat/ Public and Nature Amenity Value Infographic

To help gain an understanding of the differences between the study lakes in terms of HAB threat and public and nature amenity value, an infographic was created showing four lakes classified as being at different ends of these spectra – an overall “HAB risk profile” is shown for each lake, combining factors from the two matrices (Figure 3.12).

4 Conclusions and Policy Recommendations

This study shows that many lakes in Ireland are at potential threat of serious HAB events, with high catchment phosphorus levels, high in-lake phosphorus levels, zebra mussel presence, rising temperatures and increases in extreme precipitation events all affecting the study lakes to varying extents. At Lough Neagh, it was the scale of the HAB event **and its impact** that made it such a serious issue. Therefore, the assessment of the public and nature amenity value of the study lakes is as important as the assessment of the HAB threat level, and lakes with a high HAB risk profile (a high HAB threat level and a high public and nature amenity value) should be of most concern. It is important to note that the exact causes of the 2023 Lough Neagh event are still being investigated, and the role of zebra mussels, often seen as phosphorus reducers in Ireland, is yet to be fully understood. However, lessons can be learned from this event, not only in terms of the potential warning signs to look out for in Irish lakes, but also in terms of how this HAB event was managed and continues to be managed.

4.1 Recommendations

1. **Improve the evidence base and scientific understanding:**

   (a) Comparisons of water quality data between the study lakes and Lough Neagh were made difficult due to a sparsity of monitoring data, particularly for winter. Increased monitoring, particularly of nutrients and water transparency, would allow a better understanding of the impact of zebra mussel populations on the lakes in which they are present. Increased monitoring would also allow a more rapid response to future HABs, as it would allow changes in nutrient levels, chl-a concentrations and water transparency (Lough Neagh saw a dramatic increase before the 2023 HAB event) to be picked up early, enabling these changes to be used as predictors of HAB events.

   (b) Data on the sizes of zebra mussel populations within Irish lakes are also currently limited, with only presence/absence information being available for most lakes. Increased monitoring of populations is recommended, to increase understanding of current population sizes and enable changes to be monitored into the future. Further research on zebra mussel behaviour (e.g. life cycles, filtering capacity, recruitment) would also help increase understanding of their likely impact on Irish lakes.

   (c) Due to the importance of internal phosphorus cycling, it would be advantageous to monitor and characterise phosphorus in lake sediments, as this could reduce the uncertainty associated with lag (recovery) time estimation.

2. **Update policy:**

   (a) Targeted measures are in place in all catchments of the study lakes, especially for agricultural pollution, which should provide context for reducing the threat of HABs due to nutrient loads. However, there is a lack of information about the level of uptake of the measures or the scale of their implementation, resulting in uncertainties in relation to determining effectiveness rates and potential ways of improving water quality if the measures currently being implemented are not likely to be 100% effective in achieving the environmental objectives in the respective waterbodies. Forecasts of measure effectiveness need to be refined on the catchment scale by collating appropriate evidence from local authorities and via the development of catchment plans. This should enhance the credibility of assessments of lake water quality improvements and help inform the development of measures aimed at reducing the HAB threat level.

(b) Where not already included, lakes with a high HAB risk profile should be added to WFD priority areas for action.

3. **Apply actionable responses:**

(a) Due to the high catchment load from agricultural sources and the slow rate of change expected in terms of addressing these sources – because of the effectiveness rates of the mitigation measures available – future threats are likely to come from the impacts of climate change and zebra mussel populations, factors that will most likely see significant change over time and both of which, realistically, are outside the control of human influence in the short term. It is recommended that a "HAB action plan" be created for Irish lakes, to outline best practice for dealing with future HAB events, in terms of both the environmental response and managing impacts. Learning lessons from the Lough Neagh HAB event (detailed below), such as the importance of taking an open and transparent approach to action, is recommended. Despite being known as a highly eutrophic lake, the 2023 HAB event at Lough Neagh still took people by surprise. In combination with using the HAB risk profiles developed by this study, an action plan would help reduce the likelihood of future Irish HAB events coming as a surprise.

(b) Data on algal blooms in Ireland are limited, and it is possible that smaller lakes are already prone to serious HABs but haven't entered the wider public consciousness. Use has been made of the Bloomin' Algae app (https://www.ceh.ac.uk/our-science/projects/bloomin-algae) to record possible HAB sightings at Lough Neagh and to inform local authorities of potential problems. The use of this app increased during and after the 2023 HAB event, as its presence was advertised in the media. If information from the app is integrated with information from environmental agencies and local authorities (as in the UK), it could be a valuable tool for knowledge transfer and facilitating a rapid response to HAB events, and its use and integration is recommended in Ireland. The data from this app could also plug the gap in algal bloom data in Ireland into the future.

4. **Learn lessons from Lough Neagh:** following the Lough Neagh HAB event, DAERA (Northern Ireland) published the *Inter-Agency Blue-Green Algae Monitoring Protocol* (DAERA, 2024c), from which lessons should be learned and applied to future responses to HABs in Ireland. The key actions that will be relevant to decision- and policymakers for mitigating and managing HABs in Ireland are summarised in section 4.2.

4.2 Lessons from Lough Neagh

4.2.1 Water sample analysis

A five-tiered approach for water sample analysis is recommended (DAERA, 2024c). In summary, this should involve:

1. bathing water staff reporting any visual signs of blue-green algae for verification;
2. a visual assessment being carried out to identify if blue-green algae are forming dense scums or mats at a bathing water site;
3. a rapid test for microcystins (a microcystin strip test and/or anatoxin strip test) being carried out;
4. water samples being taken for laboratory analysis;
5. where microcystins are present based on rapid tests and water sample analysis, periodic reference samples being taken for full cyanotoxin analysis and complete microscopic quantitative analysis at a suitable accredited laboratory.

4.2.2 Use of public health guideline values

Based on international toxic cyanobacteria guidelines (WHO, 2021), recreational bathing waters should not contain > 24 µg/l of total microcystins or the biovolume equivalent of > 4 mm^3/l for the combined total of all blue-green algae, where a known toxin producer is dominant in the total biovolume or where blue-green algae scums are consistently present. Moreover, a guideline value of 10 µg/l for microcystin-LR concentration was adopted by NIW in 2024.

4.2.3 Monitoring frequency and alert level

Three threat levels are presented for surveying, issuing alerts for and reacting to HABs at bathing water lakes (DAERA, 2024c) as follows:

1. **Green level – surveillance mode:** this involves fortnightly visual assessments, rapid test kit trialling, water sample enzyme-linked immunosorbent assay (ELISA) analysis and/or biovolume analysis to establish a baseline.
2. **Amber level – alert mode:** this involves weekly visual assessments, rapid test kit trialling, water sample ELISA analysis and/or biovolume analysis. Cyanotoxin concentration is corroboration at an accredited laboratory. The public should be advised to be aware of the presence of blue-green algae.
3. **Red level – action mode:** this involves weekly visual assessments, rapid test kit trialling, water sample ELISA analysis and/or biovolume analysis. Cyanotoxin concentration is corroboration at an accredited laboratory. Bathing water operators should be informed, so that they can advise the public against bathing, even if a dense scum is not yet visible. If visible thick scum covers most of the water surface, then advice against all water sports should be issued by the relevant landowner/manager/operator.

4.3 Small Business Research Initiative

During this project, DAERA was in the process of undertaking Phase 1 of two blue-green algae Small Business Research Initiatives (SBRIs) for Lough Neagh: a £450 k initiative launched to explore solutions to treat, reduce and suppress the growth of blue-green algae (DAERA, 2024d); and a £360 k initiative, in collaboration with the UK Space Agency and NI Space, to seek potential satellite applications and remote-sensing solutions for predicting, detecting and monitoring the extent and movement of blue-green algae in Lough Neagh (DAERA, 2024e). Phase 1 was intended to demonstrate the technical feasibility of proposed concepts and their viability as solutions for DAERA. A total of eight projects were selected (five for the in-lake and three for the space-based solutions) and these ran until the end of March 2025. This first phase of the blue-green algae SBRIs was developed (a) to explore solutions to treat and reduce blue-green algal blooms without having a negative impact on the natural environment of Lough Neagh and associated waterways in Northern Ireland; and (b) to harness the combined capability of satellite- and space-based technologies and services and aquatic applications to observe and forecast “blooms” and inform the development of strategic thinking and initiatives to protect the lake. Due to data sensitivity, limited information is available about the specifics of the successful suppliers, but what information is available on the in-lake SBRI projects suggests that, in summary, they involve:

- the natural restoration, detection, management and mitigation of blue-green algae using innovative technologies, including autonomous surface vessels and advanced water treatment solutions;
- harnessing the power of emerging technologies such as artificial intelligence, the internet of things and data platforms;
- developing technologies including those for algae removal and various types of *in situ* treatment.

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Appendix 1 Principal Component Analyses

Water Chemistry Principal Component Analysis

The first axis of the PCA model represented 48.1% of variation in the dataset, and high values on this axis corresponded to higher TP, TON and alkalinity levels, and lower water temperature and ammonia concentrations. The second PCA axis represented 24.2% of variation in the dataset, and high values on

Table A1.1. Data used for the water chemistry PCA models

No.	Name	Total phosphorus (as P) (mg/l)	Total oxidised nitrogen (as N) (mg/l)	Water temperature (°C)	Alkalinity total (as $CaCO_3$) (mg/l)	Ammonia total (as N) (mg/l)	Nitrate (as N) (mg/l)
1	Arrow	0.00978	0.1065	15.125	115.2	0.0125	0.1
2	Boderg	0.015	0.1	16.225	67.75	0.01	0.1
3	Bofin LM	0.026	0.16	14.05	107	0.01275	0.22
4	Carra	0.00657	0.18161	16.225	125.054	0.01366	0.31429
5	Conn	0.00557	0.15972	12.1083	100.667	0.01039	0.15519
6	Corrib Lower	0.01025	0.22833	15.0563	114.313	0.01265	0.16167
7	Corrib Upper	0.00523	0.34031	14.0938	92.625	0.01177	0.35583
8	Cullin	0.01194	0.12313	15.4188	76.9375	0.01831	0.1925
9	Derg HMWB	0.01825	0.9	14.7625	175.75	0.01575	1.2
10	Derg TN	0.01621	0.90691	15.7953	186.641	0.01568	1.0875
11	Drumkeery	0.039	0.18	15.4833	44.3333	0.01	0.205
12	Egish	0.10588	0.1	14.7563	76.9375	0.014	0.1
13	Ennell	0.01215	0.398	14.235	163.1	0.0232	0.348
14	Forbes	0.03533	0.135	14.1667	102.5	0.01567	0.205
15	Glasshouse	0.0455	0.39	15.7333	58.3333	0.023	0.535
16	Gowna North	0.02878	0.10833	14.4075	42.5167	0.02667	0.125
17	Gowna South	0.03322	0.30611	14.4167	88.2222	0.02078	0.47167
18	Inner	0.16133	0.1	16.0667	93.1667	0.01733	0.1
19	Leane	0.00741	0.35844	15.5125	24.4063	0.01059	0.31438
20	Lene	0.00671	0.1	14.5833	95	0.01283	0.1
21	Lower Lough MacNean	0.02863	0.1	15.7875	55	0.01	0.1
22	Mask	0.00593	0.37982	14.6375	92.0714	0.01	0.35321
23	Muckno	0.03679	0.9725	13.825	70.2396	0.02938	1.23188
24	Naglack	0.25983	0.91333	17.0167	261.167	0.3985	0.775
25	Neagh	0.11763	1.065	13.9167	92	0.06325	1.12333
26	Oughter South	0.06751	0.15583	15.2119	80.6441	0.03343	0.23375
27	Owel Main	0.00605	0.11589	14.3375	96.3393	0.01039	0.13179
28	Pollaphuca	0.00886	0.50469	15.2422	38.2813	0.01254	0.49406
29	Ramor	0.06599	1.0475	14.9931	67.3375	0.29082	0.97125
30	Sheelin	0.03035	0.774	14.2875	145.45	0.03753	0.7925
31	Sillan	0.05502	0.61188	15.2052	53.4271	0.03789	0.89667
32	Skeagh Upper	0.03571	0.13729	14.4583	31.2083	0.03713	0.15167
33	Templehouse	0.04425	0.24438	15.675	206.5	0.02094	0.2775

The coloured shading represents a continuous scale from low values (light yellow) to high values (red). Data for lakes in Ireland were averaged over the months April–June and the years 2021–2024. Data for Lough Neagh were averaged over the months April–June and the years 2022–2024. LM, Leitrim.

this axis corresponded to high TP and lower nitrate, TON and alkalinity levels. Lough Neagh had a high PCA1 and a low PCA2 score. The following lakes had similar PCA scores to Lough Neagh: Lough Derg TN, Lough Derg HMWB, Lough Ramor, Lough Sheelin, Lough Sillan and Lough Muckno. The data used for the water chemistry PCAs are shown in Table A1.1, where Lough Naglack can be seen as having high values of across all determinants, which explains its extreme position in the PCA model. Figure A1.1 shows the results of a PCA with Lough Naglack removed from the analysis, allowing an assessment of those lakes shown to be similar to Lough Neagh.

The first axis of the PCA model represented 39.9% of variation in the dataset, and high values on this axis corresponded to higher TP, TON and alkalinity levels, and lower water temperature and ammonia levels. The second PCA axis represented 21.8% of variation in the dataset, and high values on this axis corresponded to high TP and lower nitrate, TON and ammonia levels. The same lakes come out as showing similar water chemistry to Lough Neagh as did in the PCA when Naglack was included.

Physical Characteristics Principal Components Analysis

Figure A1.2 shows the results of a PCA of physical characteristics of the study lakes: surface area, catchment area, mean depth and retention time. Table A1.2 shows the data used in the PCA.

The first axis of the PCA model represented 43% of variation in the dataset, and high values on this axis corresponded to higher mean depth and lake area,

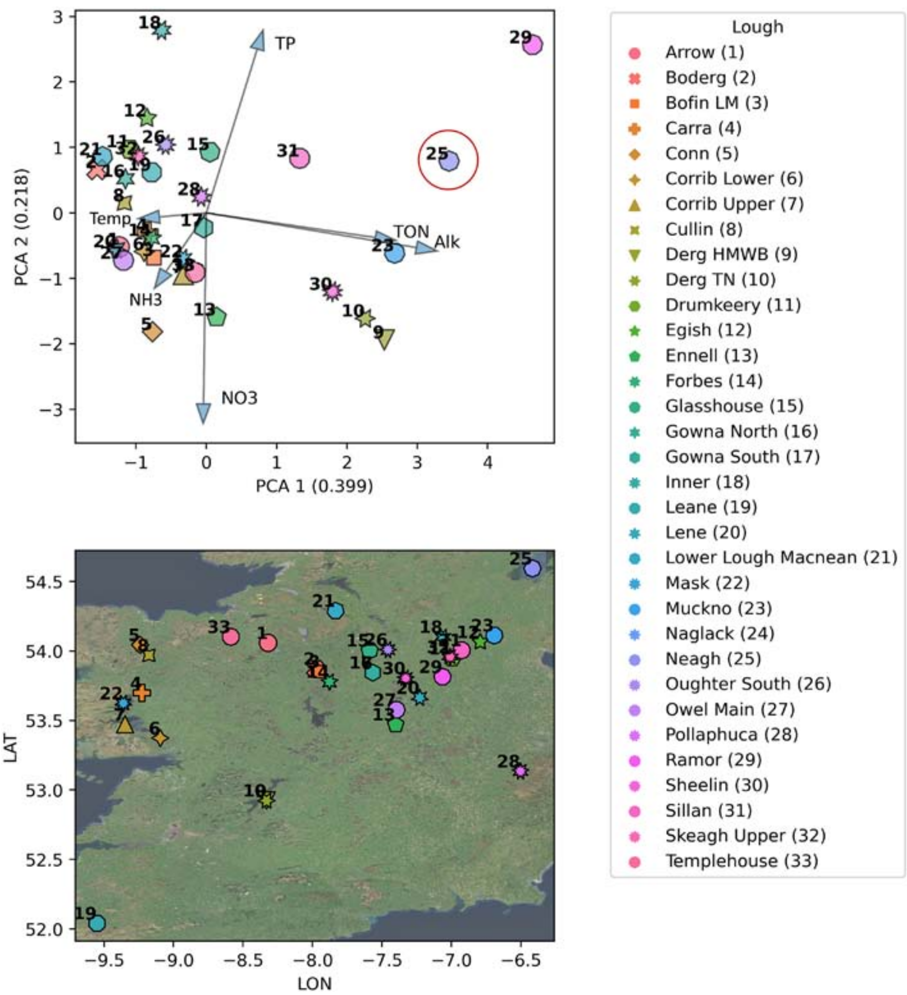

Figure A1.1. PCA biplot of lake water chemistry data (TP, alkalinity (Alk), ammonia (NH_3), TON, water temperature (Temp) and nitrate (NO_3)) following removal of Lough Naglack. Lough Neagh is circled in red. LAT, latitude; LON, longitude.

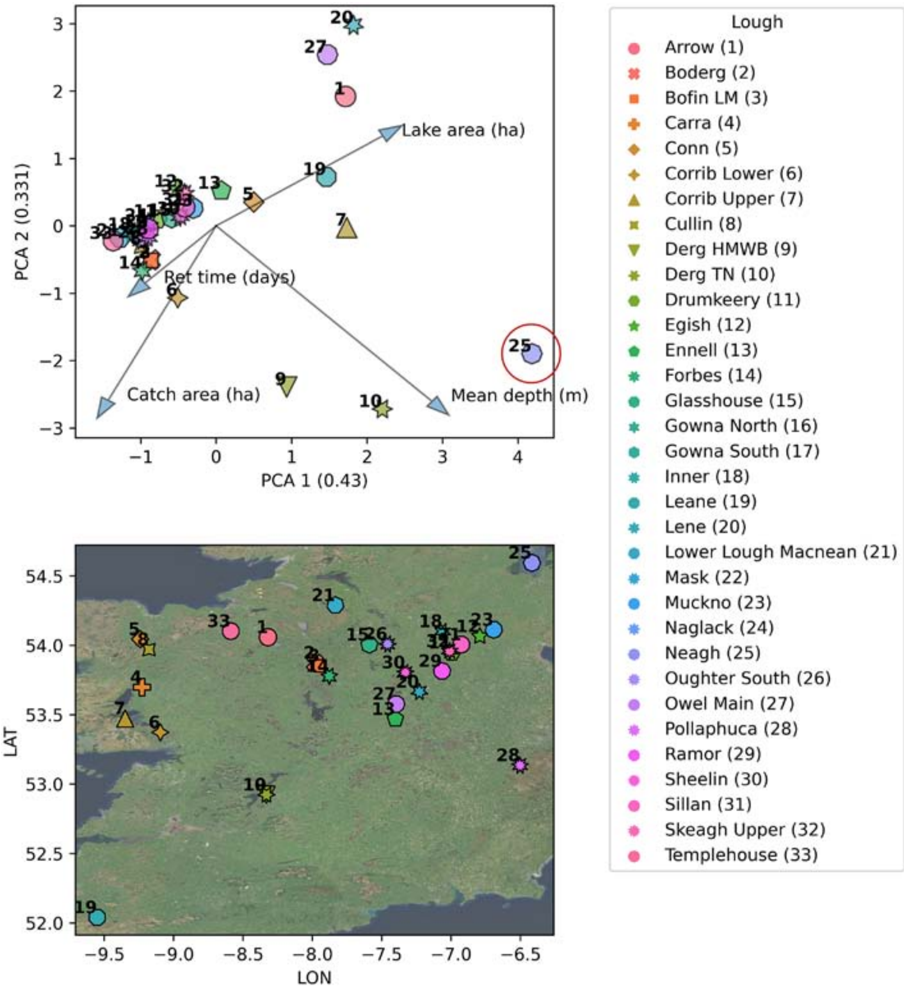

Figure A1.2. PCA biplot of lake physical characteristics: mean depth (m), catchment (Catch) area (ha), retention (Ret) time (days) and lake area (ha). Lough Neagh is circled in red. LAT, latitude; LON, longitude.

and lower catchment area and retention times. The second PCA axis represented 33% of variation in the dataset, and high values on this axis corresponded to high lake area and lower retention time and catchment area. No lakes were found to be similar to Lough Neagh based on the PCA; however, the following lakes had the most similar PCA scores to Lough Neagh: Lough Derg TN, Lough Derg HMWB and Lough Corrib Upper.

Table A1.2. Data used for the physical characteristics PCA model shown in Figure A1.2

No.	Name	Lake area (ha)	Catchment area (ha)	Mean depth (m)	Ret. time (days)
1	Arrow	1247	6617	11	973.816
2	Boderg	403	181,734	2.4	2.67915
3	Bofin LM	490	184,188	2.4	3.06204
4	Carra	1564	10,906	2.3	117.017
5	Conn	4704	42,254	6.9	274.242
6	Corrib Lower	5063	302,149	1.7	12.6857
7	Corrib Upper	11,568	163,675	9.3	318.808
8	Cullin	1024	81,891	2.2	8.28733
9	Derg HMWB	355	1,080,110	5.7	1.09522
10	Derg TN	11,651	1,063,050	7.5	39.7879
11	Drumkeery	13	892	3.9	27.6581
12	Egish	112	651	3.7	359.813
13	Ennell	1156	16,944	6.4	253.037
14	Forbes	298	226,055	1.7	1.07216
15	Glasshouse	54	12,347	4.8	10.3964
16	Gowna North				
17	Gowna South				
18	Inner	61	15,046	2.3	4.87656
19	Leane	1891	55,781	13	118.679
20	Lene	416	1307	8	1857.16
21	Lower Lough MacNean	457	19,040	1.4	14.1591
22	Mask				
23	Muckno	356	16,165	5.7	77.8388
24	Naglack	11	1739	3.4	14.9274
25	Neagh	38,300	455,800	8.9	455
26	Oughter South	661	59,172	2.4	14.1926
27	Owel Main	1022	3076	7.2	1615.59
28	Pollaphuca	1954.28	32,022	2.4	47.9602
29	Ramor	713	24,990	2.9	46.7764
30	Sheelin	1816	24,911	4	155.709
31	Sillan	162	5275	5.3	86.0302
32	Skeagh Upper	61	531	4.6	256.107
33	Templehouse	119	27,268	1.1	2.23727

The coloured shading represents a continuous scale from low values (light yellow) to high values (red). LM, Leitrim; Ret., retention.

Appendix 2 Air Temperature (Maximum)

Future projections of maximum air temperatures are shown in Figure A2.1.

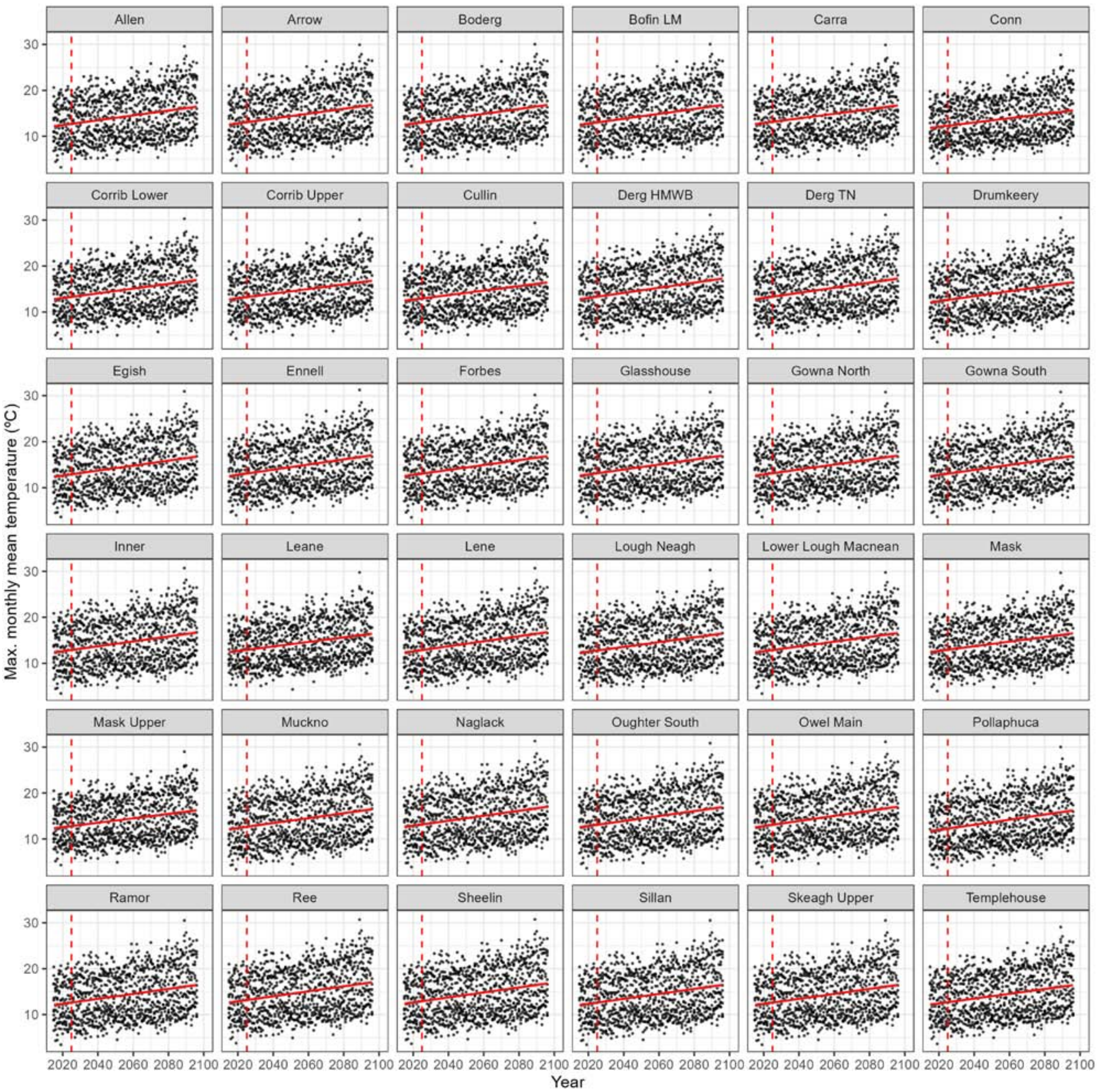

Figure A2.1. Linear regressions (linear model x ~ y and 95% confidence intervals) of maximum monthly air temperature (ºC) over time and projected into the future (2015–2096). Model results: $F = 69.07$, $DF = 36, 35{,}387$, p-value $< 2.2 \times 10^{-16}$, adjusted $R^2 = 0.06$. The dotted vertical red lines represent the present year (2025). First lake on top left (Allen) used as model intercept. Data source: CMIP6, HadGem3.

Appendix 3 Threat Classification

Precipitation

Based on percentage exceedance quantiles, lakes with 30.5% or less wet years were categorised as having a "low" exceedance threat. Lakes with between 30.5% and 46.8% wet years were categorised as having a "medium" exceedance threat. Lakes with above 46.8% wet years were categorised as having a "high" exceedance threat – these included Lough Boderg, Lough Bofin Leitrim (LM), Lough Forbes, Lough Glasshouse, Lough Gowna North, Lough Leane, Lough Neagh, Lower Lough MacNean, Lough Oughter South and Lough Ree (Table A3.1). This suggests that these lakes have a higher probability of precipitation extremes than the other study lakes, and notably this group includes Lough Neagh.

Air Temperature (Mean)

As shown in Table A3.2, based on percentage exceedance quantiles, lakes with 46.34% or less hot years were categorised as having a "low" exceedance threat. Lakes with between 46.34% and 50.1% hot years were categorised as having a "medium" exceedance threat. Lakes with above 50.1% hot years were categorised as having a "high" exceedance threat – these included Loughs Derg HMWB, Derg TN, Egish, Ennell, Glasshouse, Gowna North, Gowna South, Naglack, Oughter South, Owel Main, Ree and Sheelin. This suggests that these lakes have a higher probability of high air temperature extremes than the other study lakes.

Air Temperature (Maximum)

Lakes with 44.6% or less hot years were categorised as having a "low" exceedance threat. Lakes with between 44.6% and 46.5% hot years were categorised as having a "medium" exceedance threat. Lakes with above 46.5% hot years were categorised as having a "high" exceedance threat – these included Loughs Derg HMWB, Derg TN, Egish, Ennell, Glasshouse, Gowna North, Gowna South, Inner, Naglack, Oughter South, Owel Main and Ree. This suggests that these lakes have a higher probability of high air temperature extremes than the other study lakes.

Table A3.1. Threat of exceedance of lake-specific precipitation threshold for each lake

Lake name	Percentage exceedance (%)	Exceedance threat
Allen	63.41	Medium
Arrow	63.41	Medium
Boderg	64.63	High
Bofin LM	64.63	High
Carra	60.98	Low
Conn	63.41	Medium
Corrib Lower	58.54	Low
Corrib Upper	60.98	Low
Cullin	60.98	Low
Derg HMWB	60.98	Low
Derg TN	60.98	Low
Drumkeery	62.20	Medium
Egish	63.41	Medium
Ennell	50.00	Low
Forbes	65.85	High
Glasshouse	65.85	High
Gowna North	65.85	High
Gowna South	62.20	Medium
Inner	57.31	Low
Leane	65.85	High
Lene	58.54	Low
Lough Neagh	69.51	High
Lower Lough MacNean	65.85	High
Mask	60.98	Low
Mask Upper	63.41	Medium
Muckno	62.20	Medium
Naglack	63.41	Medium
Oughter South	64.63	High
Owel Main	57.32	Low
Pollaphuca	40.24	Low
Ramor	62.20	Medium
Ree	64.63	High
Sheelin	59.76	Low
Sillan	62.20	Medium
Skeagh Upper	62.20	Medium
Templehouse	60.98	Low

Exceedance threat is based on percentage exceedance quantiles: high > 46.8% (0.66 quantile), 30.5% < medium ≤ 46.8% (> 0.33 and ≤ 0.66 quantiles), low ≤ 30.5% (≤ 0.33 quantile).

Table A3.2. Threat of exceedance of mean air temperature threshold (18.7ºC) for all lakes

Lake name	Percentage exceedance (%)	Exceedance threat
Allen	41.46	Low
Arrow	46.34	Low
Boderg	46.34	Low
Bofin LM	46.34	Low
Carra	45.12	Low
Conn	32.93	Low
Corrib Lower	46.34	Low
Corrib Upper	45.12	Low
Cullin	39.02	Low
Derg HMWB	54.88	High
Derg TN	54.88	High
Drumkeery	46.34	Low
Egish	51.22	High
Ennell	52.44	High
Forbes	47.56	Medium
Glasshouse	53.66	High
Gowna North	53.66	High
Gowna South	52.44	High
Inner	50.00	Medium
Leane	35.37	Low
Lene	48.78	Medium
Lough Neagh	50.00	Medium
Lower Lough MacNean	46.34	Low
Mask	42.68	Low
Mask Upper	40.24	Low
Muckno	50.00	Medium
Naglack	53.66	High
Oughter South	53.66	High
Owel Main	52.44	High
Pollaphuca	35.37	Low
Ramor	46.34	Low
Ree	53.66	High
Sheelin	52.44	High
Sillan	46.34	Low
Skeagh Upper	46.34	Low
Templehouse	41.46	Low

Exceedance threat is based on percentage exceedance quantiles: high > 46.8% (0.66 quantile), 30.5% < medium ≤ 46.8% (> 0.33 and ≤ 0.66 quantiles), low ≤ 30.5% (≤ 0.33 quantile).

Appendix 4 Catchment Characterisation

This section gives broad descriptions of lake catchment characteristics extracted from WFD assessments (Cycle 3, 2016–2021: https://www.catchments.ie/data), along with information about lake WFD status, protected area status, significant issues and significant pressures, population within lake catchment areas, modelled TP loads and source contributions, and coverage of targeted agricultural measures within lake catchments. These are organised and presented at the WFD catchment level.

Muchno and Naglack

Table A4.1. Lake catchment

Lake name	Catchment
Muckno	06 Newry, Fane, Glyde and Dee
Naglack	06 Newry, Fane, Glyde and Dee

Loughs Muchno and Naglack lie within the Newry, Fane, Glyde and Dee catchment, which includes the area drained by the Newry, Fane, Glyde and Dee rivers, and by all streams entering tidal water between Murlough Upper and the Haven, County Louth. This is a cross-border catchment with a surface area of 2125 km², 1390 km² of which is in Ireland. The largest urban centre is Dundalk. The other main urban centres are Carrickmacross, Ardee, Kingscourt, Dunleer and Castleblaney.

Agriculture is the top significant pressure, impacting 67% of the 49 at-risk waterbodies within the Newry, Fane, Glyde and Dee catchment, followed by 24% being impacted by hydromorphological pressures and 22% by urban run-off. The issues resulting from these pressures are mainly nutrient pollution, organic pollution and altered morphological condition (habitat) for surface water, and nutrient pollution and chemical quality diminution for surface water and groundwater.

Table A4.2. Lake protected area type, WFD status and population

Lake name	Protected area	WFD status	Population
Muckno	NSA	At risk	8407
Naglack	–	At risk	3894

NSA, nutrient-sensitive area.

Table A4.3. WFD lake TP status, TP load and proportion (%) of TP load by main source type

Lake name	Lake TP status	Catchment TP load	Wastewater	Septic tanks	Diffuse urban	Pasture	Forestry	Deposition
Muckno	Moderate	3559	16.2	2.8	13.3	59.1	1.4	6.5
Naglack	Poor	484	0.0	2.9	55.2	32.1	7.9	1.6

Lough Muckno is at risk due to biological and nutrient conditions. Throughout the lake catchment, diffuse agriculture (notably pasture) is a significant pressure. Urban wastewater treatment is also a significant pressure on Lough Muckno and may also affect receiving river waterbodies.

Lough Naglack is also at risk. Urban wastewater treatment is a significant pressure on the lake, possibly impacting nutrient conditions and, in turn, biological conditions; Lough Naglack is also inhabited by zebra mussels.

Table A4.4. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Muckno	67	0	0	17	15	1
Naglack	0	0	41	0	0	59

Drumkeery, Lene, Ramor and Skeagh Upper

Table A4.5. Lake catchment

Lake name	Catchment
Drumkeery	07 Boyne
Lene	07 Boyne
Ramor	07 Boyne
Skeagh Upper	07 Boyne

The Boyne catchment includes the area drained by the River Boyne and by all streams entering the tidal waters between the Haven and Mornington Point, County Meath, amounting to a total area of 2694 km². The largest urban centre in the catchment is Drogheda. The other main urban centres are Navan, Trim, Kells, Virginia, Bailieborough, Athboy, Kinnegad, Edenderry and Enfield.

Agriculture is the top significant pressure, impacting 66% of the 87 at-risk waterbodies within the Boyne catchment, followed by 39% being impacted by hydromorphological pressures and 16% by domestic wastewater.

Table A4.6. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD status	Population
Drumkeery	DWPA	At risk	215
Lene	BW; DWPA; SAC	At risk	610
Ramor	DWPA	At risk	13,107
Skeagh Upper	DWPA	At risk	215

BW, designated as a bathing water lake under the WFD; DWPA, Drinking Water Protected Area.

Table A4.7. WFD lake TP status, TP load and proportion (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Other discharges	Diffuse urban	IPPC	Pasture	Forestry	Deposition
Drumkeery	Moderate	243	0.0	0.0	0.0	0.0	75.3	7.2	16.4
Lene	High	299	0.0	0.0	0.0	0.0	18.1	11.0	69.7
Ramor	Poor	6845	9.0	5.7	3.6	5.7	61.1	4.4	6.8
Skeagh Upper	Poor	144	0.0	0.0	0.0	0.0	63.9	12.1	23.1

IPPC, Integrated Pollution Prevention and Control.

Table A4.8. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Drumkeery	0	0	0	100	0	0
Lene	0	0	0	0	100	0
Ramor	47	0	1	28	24	0
Skeagh Upper	0	0	0	100	0	0

Loughs Skeagh Upper and Drumkeery are both at risk: Skeagh Upper due to “bad” fish status (in addition to “poor” macrophyte and chlorophyll status, “moderate” phytobenthos and phytoplankton status and elevated phosphate) and Drumkeery due to “moderate” macrophyte, chlorophyll and phytoplankton statuses and elevated phosphate. Diffuse agriculture and septic tanks were identified as significant pressures for these at-risk lake waterbodies.

Lough Lene is not at risk, but the Lough Lene-Adeel Stream_010, which drains to the lake, is at risk due to “poor” biological status. Agriculture (notably cattle access) and channelisation were identified as significant pressures within Lough Lene.

Lough Ramor is at risk due to “bad” biological status (driven by macrophytes and a “moderate” status for chlorophyll and phytoplankton) and elevated phosphate. Diffuse agricultural pollution was also highlighted as a significant pressure for Lough Ramor. Urban wastewater treatment and licensed facilities are also likely to affect Lough Ramor, in addition to the presence of zebra mussels.

Pollaphuca

Table A4.9. Lake catchment

Lake name	Catchment
Pollaphuca	09 Liffey and Dublin Bay

The Liffey and Dublin Bay catchment includes the area drained by the River Liffey and by all streams entering tidal water between Sea Mount and Sorrento Point, County Dublin, draining a total area of 1616 km². The largest urban centre in the catchment is Dublin City. The other main urban centres are Dun Laoghaire, Lucan, Clonee, Dunboyne, Leixlip, Maynooth, Kilcock, Celbridge, Newcastle, Rathcoole, Clane, Kill, Sallins, Johnstown, Naas, Newbridge, Athgarvan, Kilcullen and Blessington. Agriculture is the top significant pressure, impacting 39% of the 59 at-risk waterbodies within the Liffey and Dublin Bay catchment, followed by 34% being impacted by urban run-off and 24% by hydromorphological pressures. The issues resulting from these pressures are mainly nutrient pollution, organic pollution, altered morphological condition (habitat) and chemical quality diminution for surface water, and nutrient pollution and chemical pollution for groundwater.

Table A4.10. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Pollaphuca	DWPA; SPA	Not at risk	10,696

DWPA, Drinking Water Protected Area.

Table A4.11. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Diffuse urban	Pasture	Forestry	Peat	Deposition
Pollaphuca	Good	8045	6.3	24.1	38.8	16.9	12.2

Peat, peat drainage and extraction.

Table A4.12. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Pollaphuca	0	0	0	0	0	100

Significant pressures in the subcatchment are associated upstream with IE_EA_09_53 Golden Falls, where ESB has an impoundment/reservoir. This waterbody was designated an HMWB in the first cycle river basin management plan. ESB regulates the flow regime at the reservoir, and this is likely to act as a reservoir for nutrients that are released downstream. EPA biologists indicate that the flow in the river may not be sufficient to support ecology. Blessington wastewater treatment plant should also be investigated to see if it is a source of pressure. Elevated pH downgraded the ecological status of Pollaphuca reservoir to moderate; however, the elevation in pH might be a single occurrence, and the extent of the elevated pH needs to be assessed in terms of frequency and sampling location (if taken at the shore).

Leane

Table A4.13. Lake catchment

Lake name	Catchment
Leane	22 Laune-Maine-Dingle Bay

The Laune-Maine-Dingle Bay catchment includes the area drained by the Laune and Maine Rivers and all streams entering tidal water between Glanearagh Head and Clogher Head, County Kerry, draining a total area of 2036 km². The largest urban centre in the catchment is Killarney. The other main urban centres in this catchment are Cahersiveen, Kilorglin, Castleisland and Dingle.

Agriculture is the top significant pressure, impacting 54% of the 44 at-risk waterbodies within the Laune-Maine-Dingle Bay catchment, followed by 32% being impacted by hydromorphological pressures and 14% by forestry. The issues resulting from these pressures are mainly altered morphological condition (habitat), nutrient pollution, altered hydrological condition (flows/levels) impacts and chemical quality diminution for surface water, and chemical pollution and nutrient pollution for groundwater.

Table A4.14. Lake protected area type, WFD status and population

Lake name	Protected area	WFD.Risk.16.21	Population
Leane	SAC; SPA; NSA	Not at risk	25,501

NSA, nutrient-sensitive area.

Table A4.15. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Diffuse urban	Pasture	Forestry	Peat	Deposition
Leane	Good	14,651	4.4	7.4	25.7	23.4	27.6	9.8

Peat, peat drainage and extraction.

Table A4.16. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Leane	0	0	18	0	0	82

Lough Leane has good water quality status.

Ennell and Owel Main

Table A4.17. Lake catchment

Lake name	Catchment
Ennell	25A Lower Shannon
Owel Main	25A Lower Shannon

The Lower Shannon catchment covers an area of 1248 km² and is characterised by relatively flat topography, with much of the low-lying areas in the catchment covered in thick deposits of peat. The majority of the catchment is underlain by impure limestone, with some purer karstified limestone located between Tyrrellspass and Kilcormac. There are extensive sand and gravel deposits running through the catchment from Moate to Tyrrellspass and in isolated pockets in the south of the catchment that form productive groundwater aquifers. The southern tip of the catchment comprising part of the Slieve Bloom Mountains is underlain by old red sandstone.

Agriculture is the top significant pressure, impacting 60% of the 35 at-risk waterbodies in the Lower Shannon catchment, followed by 43% being impacted by hydromorphological pressures and 14% by urban run-off. The issues resulting from these pressures are mainly nutrient pollution, altered morphological condition (habitat), organic pollution impacts and chemical quality diminution for surface water, and quantitative dependent terrestrial ecosystem damage and nutrient pollution for groundwater.

Table A4.18. Lake protected area type, WFD status and population

Name	Protected area type	WFD.Risk.16.21	Population
Ennell	BW; SAC; SPA; NSA	Review	26,838
Owel Main	BW; DWPA; SAC; SPA	Not at risk	965

BW, designated as a bathing water lake under the WFD; DWPA, Drinking Water Protected Area; NSA, nutrient-sensitive area.

Table A4.19. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Other discharges	Section 4s	Diffuse urban	Pasture	Forestry	Deposition
Ennell	Good	5600	9.9	18.5	18.5	12.9	15.2	4.9	16.4
Owel Main	High	736	0.0	0.0	0.0	0.0	17.7	8.7	70.1

Table A4.20. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Ennell	0	31	4	0	0	65
Owel Main	0	100	0	0	0	0

Lough Ennell has improved in status and is deemed to be not at risk. Lough Owel Main is also of good status and not at risk. It should be noted that Inland Fisheries Ireland has identified Lough Ennell and Dysart Stream as high-value sites based on fish, and they should therefore be considered a high priority when prioritising the development and implementation of improvement measures.

Derg TN and Derg HMWB

Table A4.21. Lake catchment

Lake name	Catchment
Derg TN	25C Lower Shannon
Derg HMWB	25D Lower Shannon

The Lower Shannon (Lough Derg) catchment covers an area of 1820 km² and comprises Lough Derg and its catchment. The catchment is characterised by flat limestone plains, a small proportion of which are karstified to the east of Lough Derg, and the uplands of the Devil's Bit Hills in the south-east, the Slieve Aughty Mountains in the west and the Slieve Bearnagh and Arra Mountains in the south, between which the Shannon escapes to the south from Lough Derg. All of these upland areas are underlain by old red sandstone, with metamorphic and volcanic rocks in the higher summit areas. This catchment can be divided into two regions, the areas draining into the western and eastern sides of Lough Derg.

The Lower Shannon catchment covers an area of 1041 km² and includes the lower reaches of the River Shannon to Limerick City and the catchment of the Mulkear River. The catchment is underlain by mostly impure limestone in low-lying areas and the sandstone and metamorphic uplands of the Slieve Bearnagh and Arra Mountains in the north-west and the Silvermines and Slieve Feilim Mountains in the east. The River Shannon flows into the catchment from Lough Derg before branching into the Old River Shannon channel and the Ardnacrusha headrace at Parteen Weir. The Mulkear River and its main tributaries, the Dead, Bilboa and Kileengarrif Rivers, drain most of this catchment.

Agriculture is the top significant pressure, impacting 60% of the 35 at-risk waterbodies within the Lower Shannon and Mulkear catchment, followed by 26% being impacted by hydromorphological pressures and 11% by forestry. The issues resulting from these pressures are mainly nutrient pollution, altered morphological condition (habitat), organic pollution impacts and chemical quality diminution for surface water, and nutrient pollution and chemical pollution for groundwater.

Table A4.22. Lake protected area type, WFD status and population

Name	Protected area type	WFD.Risk.16.21	Population
Derg TN	BW; DWPA; SAC; SPA; NSA	At risk	372,028
Derg HMWB	SAC; NSA	Review	366,399

BW, designated as a bathing water lake under the WFD; DWPA, Drinking Water Protected Area; NSA, nutrient-sensitive area.

Table A4.23. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Septic tanks	Diffuse urban	Pasture	Forestry	Peat	Deposition
Derg TN	Good	227,965	7.0	1.9	4.9	44.1	18.6	11.7	8.7
Derg HMWB	Good	215,763	0.0	2.0	5.2	47.2	20.0	12.4	9.2

Peat, peat drainage and extraction.

Table A4.24. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Derg TN	2	7	24	1	1	66
Derg HMWB	2	7	24	1	1	66

Lough Derg TN (SH_25_191a) is one of the largest lakes in Ireland and it occupies most of the area of this subcatchment. Lough Derg is currently of “poor” ecological status (2010–2015). There are many pressures on the lake, principally diffuse agriculture, hydromorphology and fish passage issues, invasive species (approximately 14 species, including zebra mussel), urban wastewater and the inputting river, the Lower Shannon.

The WFD risk status of Lough Derg HMWB is under review.

Allen

Table A4.25. Lake catchment

Lake name	Catchment
Allen	26A Upper Shannon

The Upper Shannon (Lough Allen) catchment covers an area of 604 km² and is characterised by the Brefine upland areas including the karst area of the Geevagh Hills, location of the Arigna Coalfield; the karstic southern slopes of Cuilcagh Mountain; and the western flanks of Slieve Anierin (literally meaning “the Iron Mountain”), which is rich in iron ore. These surround the lowland area containing the large source of the River Shannon (Shannon Pot) and Lough Allen.

Agriculture is the top significant pressure, impacting 44% of the nine at-risk waterbodies within the Upper Shannon (Lough Allen) catchment, followed by 33% being impacted by hydromorphological pressures and 22% by forestry. The issues resulting from these pressures are mainly altered morphological condition (habitat), nutrient pollution, sediment impacts and chemical quality diminution for surface water, and nutrient pollution for groundwater.

Table A4.26. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Allen	–	At risk	3329

Table A4.27. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Septic tanks	Pasture	Forestry	Peat	Deposition
Allen	Good	12,666	2.3	28.8	30.8	20.9	14.1

Peat, peat drainage and extraction.

Table A4.28. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Allen	0	0	11	0	0	89

Lough Allen is at risk overall and has a moderate water quality status. Lough Allen had a moderate ecological status in 2013–2015. Several waterbodies flow in to this lake from outside the subcatchment. One of these rivers, at the southern end of the lake, receives effluent from a wastewater treatment works and is of poor status. Lough Allen also has pollan (an endangered fish species) present in it and was previously impacted by a landslide (approximately 8–10 years ago).

Boderg, Bofin LM and Forbes

Table A4.29. Lake catchment

Lake name	Catchment
Boderg	26C Upper Shannon
Bofin LM	26C Upper Shannon
Forbes	26C Upper Shannon

The Upper Shannon catchment covers an area of 1500 km² that is characterised by karstified lowland areas, including much of the western half of the catchment and the area underlying the main Shannon channel north of Lough Ree. The upland areas in the catchment are underlain variously by sandstone and metamorphic rocks.

Agriculture is the top significant pressure, impacting 72% of the 39 at-risk waterbodies in the Upper Shannon catchment, followed by 36% being impacted by hydromorphological pressures and 15% by both invasive species and peat. The issues resulting from these pressures are mainly nutrient pollution, altered morphological condition (habitat) and organic pollution impacts for surface water, and nutrient pollution impact for groundwater.

Table A4.30. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Boderg	–	At risk	39,095
Bofin LM	–	At risk	40,244
Forbes	DWPA; SAC; SPA	At risk	51,268

DWPA, Drinking Water Protected Area.

Table A4.31. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Septic tanks	Diffuse urban	Pasture	Forestry	Peat	Deposition
Boderg	Moderate	41,367	2.8	2.3	46.9	22.8	13.6	10.4
Bofin LM	Good	42,056	2.8	2.4	46.6	22.7	13.6	10.8
Forbes	Moderate	51,206	3.1	2.3	48.4	21.6	12.7	9.9

Peat, peat drainage and extraction.

Table A4.32. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Boderg	0	6	23	0	0	71
Bofin LM	0	6	23	0	0	72
Forbes	0	6	24	0	0	70

Lough Forbes is at risk due to biological conditions. Diffuse agriculture and local turf cutting were highlighted as significant for Lough Forbes. Zebra mussels were also identified within Loughs Boderg, Bofin LM and Forbes, and may be masking nutrient issues.

Loughs Boderg and Bofin are at risk due to moderate ecological status (driven by macrophytes). Zebra mussels are present within Loughs Boderg and Bofin and may mask nutrient issues. Karst areas are present within the subcatchment, indicating the possible dilution of orthophosphate due to groundwater contribution.

Ree

Table A4.33. Lake catchment

Lake name	Catchment
Ree	26E Upper Shannon

The Upper Shannon (Lough Ree) catchment covers an area of 581 km² and is characterised by a flat landscape underlain by impure limestone to the east and purer, karstified limestone under and to the west of Lough Ree. There are extensive sand and gravel deposits to the east and north-east of Athlone that form a productive groundwater aquifer.

Hydromorphological pressure is the top significant pressure, impacting 75% of the eight at-risk waterbodies within the Upper Shannon (Lough Ree) catchment, followed by 50% being impacted by agriculture and 38% by urban run-off. The issues resulting from these pressures are mainly nutrient pollution, altered morphological condition (habitat) and organic pollution impacts.

Table A4.34. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Ree	SAC; SPA; NSA	Not at risk	138,322

NSA, nutrient-sensitive area.

Table A4.35. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Septic tanks	Diffuse urban	Pasture	Forestry	Peat	Deposition
Ree	Good	97,246	3.8	2.5	3.8	47.0	18.1	11.3	12.3

Peat, peat drainage and extraction.

Table A4.36. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Ree	0	6	25	0	0	68

Urban wastewater treatment within the Lough Ree subcatchment is likely to be a significant pressure impacting Lough Ree. Zebra mussels are also present within this waterbody. In addition, a licensed facility within an inputting river waterbody in the northeastern part of the lake, Shannon (Upper)_100, has an impact on water temperature due to the hot water outflow, which Asian clams favour and in which they are present in very large numbers. This may also impact the lake. A disused piggery within the subcatchment may also represent a significant pressure for the lake due to the storage of slurry.

Sheelin

Table A4.37. Lake catchment

Lake name	Catchment
Sheelin	26F Upper Shannon

The Upper Shannon catchment includes an area of 1229 km². It is characterised by a south-western region of flat, boggy land, an eastern region containing swarms of isolated relatively steep-sided hills, and a northern section composed of more undulating topography entering the southern part of the Drumlin belt.

Agriculture is the top significant pressure, impacting 73% of the 30 at-risk waterbodies within the Upper Shannon catchment, followed by 23% being impacted by hydromorphological pressures and 13% by both peat and urban wastewater. The issues resulting from these pressures are mainly nutrient pollution, organic pollution, altered morphological condition (habitat) impacts and chemical quality diminution for surface water, and nutrient pollution and chemical pollution for groundwater.

Table A4.38. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Sheelin	SAC; SPA	At risk	10,349

Table A4.39. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Septic tanks	Diffuse urban	Pasture	Forestry	Deposition
Sheelin	Good	4840	2.9	3.5	58.7	11.8	19.0

Table A4.40. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Sheelin	1	22	38	0	0	40

Lough Sheelin has moderate ecological status based on its plant and fish communities. Zebra mussels are also present in the waterbody. Pressures that impact the waterbody are likely to be from the inputting waterbodies and surrounding land use, including pressures from agriculture and peat harvesting.

Carra, Corrib Lower, Corrib Upper, Mask and Mask Upper

Table A4.41. Lake catchment

Lake name	Catchment
Carra	30 Corrib
Corrib Lower	30 Corrib
Corrib Upper	30 Corrib
Mask	30 Corrib
Mask Upper	30 Corrib

The Corrib catchment includes the area drained by the River Corrib and all streams entering tidal water between Renmore Point and Nimmo's Pier, Galway, draining a total area of 3112 km². The largest urban centre in the catchment is Galway City. The other main urban centres in this catchment are Tuam, Ballinrobe, Claremorris and Ballyhaunis.

Hydromorphological pressure is the top significant pressure, impacting 60% of the 35 at-risk waterbodies within the Corrib catchment, followed by 49% being impacted by agriculture and 11% by invasive species. The issues resulting from these pressures are mainly altered morphological condition (habitat), nutrient pollution, altered hydrological condition (flow/level) impacts and chemical quality diminution for surface water, and nutrient pollution for groundwater.

Table A4.42. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Carra	DWPA; SAC; SPA	Not at risk	2273
Corrib Lower	DWPA; SAC; SPA	Not at risk	99,353
Corrib Upper	DWPA; SAC; SPA	Not at risk	36,111
Mask	DWPA; SAC; SPA	At risk	20,965
Mask Upper	SAC; SPA	Not at risk	367

DWPA, Drinking Water Protected Area.

Table A4.43. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Septic tanks	Pasture	Forestry	Peat	Deposition
Carra	High	2036	0.0	1.8	38.9	9.0	10.2	39.9
Corrib Lower	High	64,329	7.8	2.4	37.3	8.4	18.5	21.9
Corrib Upper	High	37,505	0.0	2.2	33.8	9.8	21.5	30.3
Mask	High	20,526	6.6	1.8	35.3	7.0	20.6	25.8
Mask Upper	High	2013	0.0	1.6	37.7	0.0	44.0	16.6

Peat, peat drainage and extraction.

Table A4.44. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Carra	0	63	37	0	0	0
Corrib Lower	0	6	28	0	0	67
Corrib Upper	0	8	36	0	0	56
Mask	0	11	44	0	0	46
Mask Upper	0	0	22	0	0	78

Loughs Carra, Corrib Lower, Corrib Upper and Mask Upper are all not at risk.

Lough Mask is at risk. The significant issue is likely to be nutrients, possibly related to agriculture and septic tanks. Zebra mussels are present within this waterbody and may mask nutrient issues.

Conn and Cullin

Table A4.45. Lake catchment

Lake name	Catchment
Conn	34 Moy and Killala Bay
Cullin	34 Moy and Killala Bay

The Moy and Killala Bay catchment includes the area drained by the River Moy and all streams entering tidal water in Killala Bay between Benwee Head and Lenadoon Point, County Sligo. This drains a total area of 2345 km². The largest urban centre in the catchment is Castlebar. The other main urban centres are Ballina, Tubbercurry, Kiltimagh, Swinford, Foxford, Enniscrone and Crossmolina.

Hydromorphological pressure is the top significant pressure, impacting 70% of the 44 at-risk waterbodies within the Moy and Killala Bay catchment, followed by 34% being impacted by agriculture and 14% by forestry. The issues resulting from these pressures are mainly altered morphological condition (habitat), nutrient pollution, sediment impacts and chemical quality diminution for surface water, and nutrient pollution for groundwater.

Table A4.46. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Conn	DWPA; SAC; Fish; SPA	Review	6229
Cullin	SAC; Fish; SPA; NSA	At risk	32,038

DWPA, Drinking Water Protected Area; Fish, salmonoid waters; NSA, nutrient-sensitive area.

Table A4.47. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Diffuse urban	Pasture	Forestry	Peat	Deposition
Conn	High	10,465	0.0	0.4	30.3	18.4	26.0	24.0
Cullin	High	20,975	12.6	4.3	30.6	14.5	20.4	16.1

Peat, peat drainage and extraction.

The WFD status of the larger of the two lakes, Lough Conn, is under review, while the smaller lake, Lough Cullin, is at risk. Nutrient concentrations appear to be low in Lough Cullin; however, EPA biologists have determined that the presence of zebra mussels could be keeping phosphate and chlorophyll concentrations artificially low.

Table A4.48. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Conn	0	24	0	0	0	76
Cullin	0	19	1	0	0	81

Arrow and Templehouse

Table A4.49. Lake catchment

Lake name	Catchment
Arrow	35 Sligo Bay and Drowse
Templehouse	35 Sligo Bay and Drowse

The Sligo Bay and Drowes catchment includes streams entering tidal water in Sligo Bay and between Lenadoon Point and Aughrus Point, County Donegal. The catchment area is 1866 km². The largest urban centre is Sligo. The other main urban centres are Ballymote, Collooney, Ballysadare and Manorhamilton.

Agriculture is the top significant pressure, impacting 49% of the 37 at-risk waterbodies within the Sligo Bay and Drowes Catchment, followed by 19% being impacted by forestry and 16% by hydromorphological pressures. The issues resulting from these pressures are mainly nutrient pollution, altered morphological condition (habitat), organic pollution impacts and chemical quality diminution for surface water, and nutrient pollution impacts for groundwater.

Table A4.50. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Arrow	DWPA; SAC; SPA	Review	735
Templehouse	SAC	At risk	6015

DWPA, Drinking Water Protected Area.

Table A4.51. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Septic tanks	Pasture	Forestry	Peat	Deposition
Arrow	Good	1715	4.5	3.7	22.1	25.2	6.7	36.7
Templehouse	Poor	5597	14.7	3.5	47.3	16.3	13.9	2.0

Peat, peat drainage and extraction.

Lough Arrow's WFD status is under review, with no major pressures identified. Lough Templehouse is at risk due to bad biological status (driven by macrophytes and fish) and elevated concentrations of TP. Zebra mussels, which are an invasive species that are likely to affect the river ecology, were recorded in 2006 and 2009 in Owenmore(Sligo)_060.

Table A4.52. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Arrow	0	0	0	0	0	100
Templehouse	0	16	53	0	0	32

Egish, Glasshouse, Gowna North, Gowna South, Inner, Lower Lough MacNean, Oughter South and Sillan

Table A4.53. Lake catchment

Lake name	Catchment
Egish	36 Erne
Sillan	36 Erne
Glasshouse	36 Erne
Gowna North	36 Erne
Gowna South	36 Erne
Inner	36 Erne
Lower Lough MacNean	36 Erne
Oughter South	36 Erne

The Erne catchment includes the area drained by the River Erne and all streams entering tidal water between Aughrus Point and Kildoney Point, County Donegal. This is a cross-border catchment with a surface area of 4415 km², 2512 km² of which is located within Ireland. The largest urban centre is Cavan Town. The other main urban centres are Bundoran, Ballyshannon, Clones, Ballybay, Cootehill and Belturbet.

Agriculture is the top significant pressure, impacting 85% of the 100 at-risk waterbodies within the Erne catchment, followed by 15% being impacted by hydromorphological pressures and 9% by urban run-off. The issues resulting from these pressures are mainly nutrient pollution, organic pollution, sediment impacts, chemical quality diminution and chemical pollution.

Table A4.54. Lake protected area type, WFD status and population

Lake name	Protected area type	WFD.Risk.16.21	Population
Egish	DWPA	At risk	295
Glasshouse	–	At risk	3032
Gowna North	DWPA	At risk	1115
Gowna South	–	At risk	6908
Inner	–	At risk	5343
Lower Lough MacNean	–	At risk	1234
Oughter South	SAC; SPA; NSA	At risk	16,909
Sillan	DWPA	At risk	1929

DWPA, Drinking Water Protected Area; NSA, nutrient-sensitive area.

Table A4.55. WFD lake TP status, TP load and proportions (%) of TP load by main source type

Lake name	TP status	TP load	Wastewater	Septic tanks	Diffuse urban	IPPC	Pasture	Forestry	Peat	Deposition
Egish	Bad	162	0.0	3.4	12.7	0.0	47.4	0.0	0.0	36.4
Glasshouse	Poor	2499	0.0	4.7	1.8	0.0	75.9	6.0	2.3	9.0
Gowna North	Moderate	690	0.0	2.8	0.0	0.0	57.4	7.8	1.7	30.3
Gowna South	Moderate	4913	0.0	4.3	0.9	0.0	74.6	4.6	2.3	13.3
Inner	Bad	3343	0.0	3.5	1.9	0.0	85.6	3.4	0.0	5.5
Lower Lough MacNean	Moderate	3045	0.0	4.8	1.1	0.0	28.8	26.9	13.7	24.4
Oughter South	Poor	13,355	2.6	3.7	1.1	2.1	66.9	8.7	2.1	10.7
Sillan	Poor	1349	3.3	3.9	2.3	12.0	55.9	0.8	0.0	9.1

IPPC, Integrated Pollution Prevention and Control; Peat, peat drainage and extraction.

Table A4.56. Proportions (%) of lake catchments covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Egish	0	100	0	0	0	0
Glasshouse	0	57	15	0	0	28
Gowna North	0	0	100	0	0	0
Gowna South	0	30	52	0	0	18
Inner	0	11	54	0	0	35
Lower Lough MacNean	0	16	31	0	0	53
Oughter South	0	37	44	0	0	19
Sillan	0	0	100	0	0	0

Loughs Sillan and Egish are at risk due to their biological conditions and elevated phosphate concentrations. Diffuse agriculture is the most significant pressure throughout the subcatchment. In addition, licensed facilities and wastewater treatment may affect Sillan and Egish. Zebra mussels are present within Sillan and Egish. Lough Glasshouse is at risk due to less than good ecological status due to impacted biological conditions and elevated phosphate. Diffuse agriculture is the dominant significant pressure throughout the subcatchment.

Loughs Gowna North and Gowna South are at risk due to biological and nutrient conditions. Diffuse agriculture was identified as a significant pressure throughout the subcatchment. In addition, Lough Gowna South is inhabited by zebra mussels.

Lower Lough MacNean is at risk due to bad water quality status, with the main pressure being urban wastewater. The subcatchment is covered by wet soils, with some peaty soils present, so potential issues arise from agriculture, forestry, wastewater and possibly the effectiveness of septic tanks under these conditions. Based on the information that is available, the main pressures throughout the subcatchment are agriculture and forestry. This is coupled with a recognised problematic wastewater facility and septic tanks. The area is popular for tourism, and there are plans to further promote it for tourism.

Four of the five lakes in the Erne_080 sub-basin have less than good ecological status and agriculture is the most significant pressure.

Appendix 5 Catchment Phosphorus Sources

Table A5.1. TP by catchment and breakdown of sources (%) for all study lakes

Lake name	TP (kg/y)	Wastewater	Other discharges	Section 4s	Septic tanks	Diffuse urban	IPPC	Arable	Pasture	Forestry	Peat	Deposition
Allen	12,666	0.0	1.4	1.4	2.3	0.4	0.0	0.0	28.8	30.8	20.9	14.1
Arrow	1715	4.5	0.5	0.5	3.7	0.0	0.0	0.0	22.1	25.2	6.7	36.7
Boderg	41,367	0.0	0.6	0.5	2.8	2.3	0.1	0.0	46.9	22.8	13.6	10.4
Bofin LM	42,056	0.0	0.6	0.4	2.8	2.4	0.1	0.0	46.6	22.7	13.6	10.8
Carra	2036	0.0	0.0	0.0	1.8	0.0	0.0	0.2	38.9	9.0	10.2	39.9
Conn	10,465	0.0	0.0	0.0	0.8	0.4	0.0	0.0	30.3	18.4	26.0	24.0
Corrib Lower	64,329	7.8	0.1	0.0	2.4	3.1	0.1	0.3	37.3	8.4	18.5	21.9
Corrib Upper	37,505	0.0	0.0	0.0	2.2	2.3	0.0	0.1	33.8	9.8	21.5	30.3
Cullin	20,975	12.6	0.0	0.0	1.4	4.3	0.0	0.0	30.6	14.5	20.4	16.1
Derg HMWB	215,763	0.4	1.0	0.7	2.0	5.2	0.3	1.5	47.2	20.0	12.4	9.2
Derg TN	227,965	7.0	0.9	0.7	1.9	4.9	0.2	1.4	44.1	18.6	11.7	8.7
Drumkeery	243	0.0	0.0	0.0	1.1	0.0	0.0	0.0	75.3	7.2	0.0	16.4
Egish	162	0.0	0.0	0.0	3.4	12.7	0.0	0.0	47.4	0.0	0.0	36.4
Ennell	5600	9.9	18.5	18.5	0.9	12.9	0.0	1.0	15.2	4.9	1.9	16.4
Forbes	51,206	1.0	0.5	0.4	3.1	2.3	0.1	0.0	48.4	21.6	12.7	9.9
Glasshouse	2499	0.0	0.1	0.1	4.7	1.8	0.0	0.0	75.9	6.0	2.3	9.0
Gowna North	690	0.0	0.0	0.0	2.8	0.0	0.0	0.0	57.4	7.8	1.7	30.3
Gowna South	4913	0.0	0.0	0.0	4.3	0.9	0.0	0.1	74.6	4.6	2.3	13.3
Inner	3343	0.0	0.0	0.0	3.5	1.9	0.0	0.1	85.6	3.4	0.0	5.5
Leane	14,651	4.4	0.0	0.0	1.6	7.4	0.0	0.0	25.7	23.4	27.6	9.8
Lene	299	0.0	0.0	0.0	1.0	0.0	0.0	0.1	18.1	11.0	0.0	69.7
Lower Lough MacNean	3045	0.0	0.2	0.2	4.8	1.1	0.0	0.0	28.8	26.9	13.7	24.4
Mask	20,526	6.6	0.0	0.0	1.8	2.9	0.0	0.1	35.3	7.0	20.6	25.8
Mask Upper	2013	0.0	0.0	0.0	1.6	0.0	0.0	0.1	37.7	0.0	44.0	16.6
Muckno	3559	16.2	0.0	0.0	2.8	13.3	0.0	0.1	59.1	1.4	0.5	6.5
Naglack	484	0.0	0.0	0.0	2.9	55.2	0.0	0.4	32.1	7.9	0.0	1.6
Oughter South	13,355	2.6	2.1	0.0	3.7	1.1	2.1	0.0	66.9	8.7	2.1	10.7
Owel Main	736	0.0	0.0	0.0	1.0	0.0	0.0	2.5	17.7	8.7	0.0	70.1
Pollaphuca	8045	0.0	0.4	0.4	0.9	6.3	0.0	0.0	24.1	38.8	16.9	12.2
Ramor	6845	9.0	5.7	0.1	3.2	3.6	5.7	0.1	61.1	4.4	0.3	6.8

Table A5.1. Continued

Lake name	TP (kg/y)	Wastewater	Other discharges	Section 4s	Septic tanks	Diffuse urban	IPPC	Arable	Pasture	Forestry	Peat	Deposition
Ree	97,246	3.8	0.4	0.3	2.5	3.8	0.1	0.4	47.0	18.1	11.3	12.3
Sheelin	4840	0.0	1.2	0.1	2.9	3.5	1.1	0.3	58.7	11.8	1.4	19.0
Sillan	1349	3.3	12.2	0.1	3.9	2.3	12.0	0.3	55.9	0.8	0.0	9.1
Skeagh Upper	144	0.0	0.0	0.0	0.9	0.0	0.0	0.0	63.9	12.1	0.0	23.1
Templehouse	5597	14.7	0.1	0.1	3.5	2.1	0.0	0.0	47.3	16.3	13.9	2.0

IPPC, Integrated Pollution Prevention and Control; Peat, peat drainage and extraction.

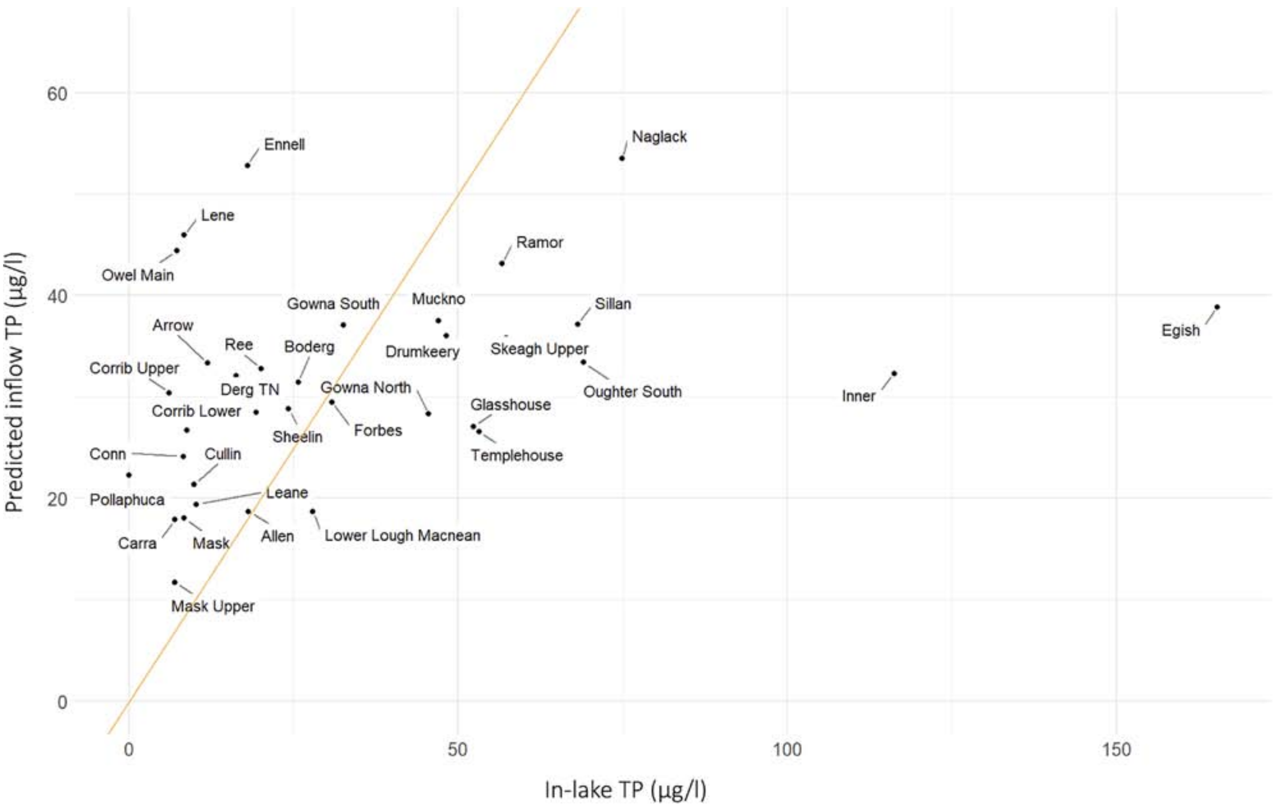

Figure A5.1. Comparison of in-lake monitored TP (data years) with predicted inflow TP using the catchment-loading values and Qube-modelled inflows (lakes falling below the line have a higher in-lake TP than predicted).

Appendix 6 Catchment Land Cover

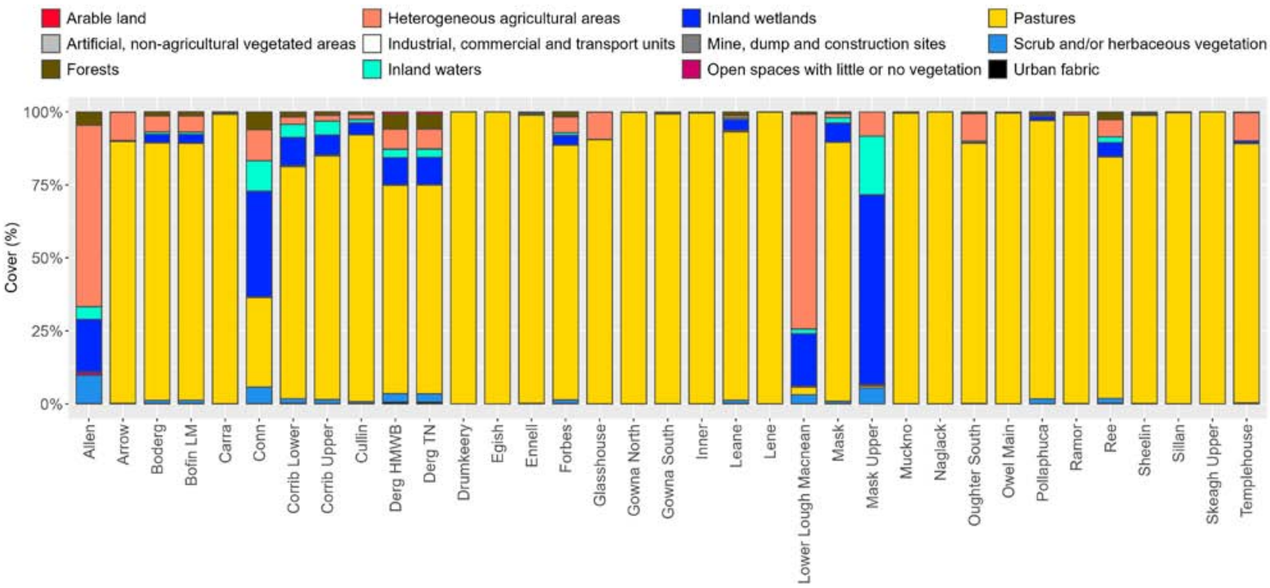

Figure A6.1. Proportion (%) of land cover types in the study lake catchments.

Appendix 7 Targeting Agricultural Measures

The flags used to target agricultural measures are as follows:

- red flag: potential point source;
- orange flag: nitrate losses;
- navy flag: phosphorus/sediment losses;
- white flag: sub-basins where agriculture is not identified as a significant pressure and current measures to "protect" water quality are appropriate.

Table A7.1. Proportions (%) of lake catchment areas covered by different types of targeted agricultural measures

Lake name	Navy and orange flags	Navy and red flags	Navy flag	Navy, red and orange flags	Orange flag	White flag
Allen	0	0	11	0	0	89
Arrow	0	0	0	0	0	100
Boderg	0	6	23	0	0	71
Bofin LM	0	6	23	0	0	72
Carra	0	63	37	0	0	0
Conn	0	24	0	0	0	76
Corrib Lower	0	6	28	0	0	67
Corrib Upper	0	8	36	0	0	56
Cullin	0	19	1	0	0	81
Derg HMWB	2	7	24	1	1	66
Derg TN	2	7	24	1	1	66
Drumkeery	0	0	0	100	0	0
Egish	0	100	0	0	0	0
Ennell	0	31	4	0	0	65
Forbes	0	6	24	0	0	70
Glasshouse	0	57	15	0	0	28
Gowna North	0	0	100	0	0	0
Gowna South	0	30	52	0	0	18
Inner	0	11	54	0	0	35
Leane	0	0	18	0	0	82
Lene	0	0	0	0	100	0
Lower Lough MacNean	0	16	31	0	0	53
Mask	0	11	44	0	0	46
Mask Upper	0	0	22	0	0	78
Muckno	67	0	0	17	15	1
Naglack	0	0	41	0	0	59
Oughter South	0	37	44	0	0	19
Owel Main	0	100	0	0	0	0
Pollaphuca	0	0	0	0	0	100
Ramor	47	0	1	28	24	0
Ree	0	6	25	0	0	68
Sheelin	1	22	38	0	0	40
Sillan	0	0	100	0	0	0
Skeagh Upper	0	0	0	100	0	0
Templehouse	0	16	53	0	0	32

Abbreviations

Chl-a	Chlorophyll-a
CMIP	Coupled Model Intercomparison Project
DAERA	Department of Agriculture, Environment and Rural Affairs
ELISA	Enzyme-linked immunosorbent assay
GBIF	Global Biodiversity Information Facility
HAB	Harmful algal bloom
HadGEM3	Hadley Centre Global Environment Model version 3
HMWB	Heavily modified waterbody
LM	Leitrim
NIW	Northern Ireland Water
PCA	Principal component analysis
SAC	Natura 2000 Special Area of Conservation
SBRI	Small Business Research Initiative
SPA	Natura 2000 Special Protection Area
SRP	Soluble reactive phosphorus
TN	Tipperary
TON	Total oxidised nitrogen
TP	Total phosphorus
WFD	Water Framework Directive

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

> Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;

> Sceitheadh fuíolluisce uirbigh;

> Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;

> Foinsí radaíochta ianúcháin;

> Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

> Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;

> Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;

> Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;

> Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú

> Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;

> Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;

> An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

> Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;

> Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;

> An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;

> Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

> Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;

> Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

> Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;

> Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;

> Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

> Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;

> Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;

> Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;

> Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;

> Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

> Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;

> Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

> Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;

> Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;

> Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;

> Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

> Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;

> An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;

> Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;

> Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

> Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

epaResearch

Evidence Synthesis Report 7

Investigating the likelihood of a Lough Neagh bloom scenario happening in the Republic of Ireland

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