Charting a bright future for

Lough Carra

Feasibility Study for a LIFE Project application

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March 2020

Report prepared by Woodrow Sustainable Solutions Ltd.

for the Lough Carra Catchment Association.

This project is part-funded by the European Union, Department of Rural and Community Development and Mayo Local Action Group (LAG) under the Rural Development Programme (LEADER) 2014 – 2020.

South West Mayo Development Company CLG
Comhlacht Forbartha Iardheisceart Mhaigh Eo CTR

Comhairle Contae Mhaigh Eo
Mayo County Council

MAYO.IE

LCDC
Coiste um Fhorbairt Pobail Áitiúil Mhaigh Eo
Mayo Local Community Development Committee

Rialtas na hÉireann Government of Ireland
Tionscadal Éireann Project Ireland 2040

LEADER

The European Agricultural Fund for Rural Development: Europe investing in rural areas

Rialtas na hÉireann Government of Ireland
Funded by the Department of Rural & Community Development

Front cover photograph by Lynda Huxley.

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1 INTRODUCTION AND BACKGROUND

1.1 BRIEF

Woodrow Sustainable Solutions Ltd. was commissioned by the Lough Carra Catchment Association to carry out a feasibility study to inform a potential LIFE project for the Lough Carra catchment. This project would aim to reverse the ecological decline and eutrophication of Lough Carra. The overall goal of the proposed project will be “restoring, protecting and conserving the biodiversity value and ecological integrity of the lake and its lakeshore and catchment habitats, and ensuring the quality of water in the lough”.

The specific objectives are as follows:

1. To maintain and enhance existing priority habitats in the SAC.
2. To ensure the protection and conservation of key species in the SPA, the SAC and the catchment.
3. To prevent and reverse eutrophication by reducing the flow of nutrients into the lough.
4. To promote and encourage truly sustainable and environmentally sensitive land use practices in the catchment.
5. To prevent the further conversion of land and intensification of agriculture in the catchment.
6. To raise awareness of the unique values of the Lough, including ecosystem services, and promote its enjoyment by local communities and all sectors of society.

1.2 APPROACH TO FEASIBILITY STUDY

This study focuses on the threats to Lough Carra, considers a range of potential solutions, and examines how these might be implemented through a LIFE project.

This includes a consideration of farming practices in the catchment, as well as other sources of nutrients, such as forestry plantations and waste water. Groundwater in the region is considered, as well as the lake’s importance as a source of drinking water. Other important

issues are also included, such as flood management, monitoring methods, and the threat to the lake's ecosystems from invasive species.

A range of potential solutions is examined and evaluated. This includes an assessment of previous projects in other areas, and solutions which have worked successfully in other situations. It also includes a consideration of the particular needs of the Lough Carra area, and how a range of solutions can be tailored to meet these needs.

The success of any changes made in management of the catchment will need to be assessed and measured; therefore, this report also considers how this can be best achieved, and proposes a comprehensive suite of monitoring techniques.

Consideration is also given to developing a long-term sustainable strategy for farmers in the region, as it is clear that the success of any agri-environmental scheme depends on the good will and participation of farmers. Suggestions are made for public engagement, such as wildlife walks, workshops, publications, and farm visits.

A projected costing for the project was drawn up as part of the 2019 application. This will need to be revised in consultation with the associated beneficiaries and partners, as part of the preparation of the concept note for the 2020 application.

1.3 LIFE PROJECTS AND REQUIREMENTS[1]

The EU LIFE Programme provides funding for a range of projects throughout the EU, in areas such as biodiversity conservation, climate action, and environmental protection. Projects are co-funded, with a proportion of the cost coming from the LIFE fund, and the remainder coming from other sources. Amounts granted from the LIFE fund are typically in the range of €1 million to €5 million.

The maximum percentage available from the LIFE fund is summarised as follows:

- 75% for projects that concern priority habitats or species as defined in the Habitats (92/43/EEC) or the Birds Directives (2009/147/EC)
- 60% in the case of projects in the Nature & Biodiversity priority area
- 55% for all other areas

[1] Some details in this section are based on the 2019 rules and guidance, and as such may be subject to alteration when the full 2020 documentation becomes available.

It is expected that the proposed Lough Carra project would fall under the Nature & Biodiversity topics. For these topics, the LIFE guidance literature states that:

"Projects will develop best practices for wider biodiversity challenges, while keeping a focus on Natura 2000. Projects can be Best Practise, Demonstration or Pilot. For Biodiversity projects, demonstration/innovation is required for certain project topics".[2]

While there is no pre-determined duration for LIFE projects, they normally last for 3 – 5 years. It is envisaged that the proposed Carra project would last for 5 years.

1.3.1 Roles of the project partners & beneficiaries

A LIFE project is managed by the **co-ordinating beneficiary**, a body which takes responsibility for the management of the project. The co-ordinator is responsible for reporting on the project, and acts as an intermediary between funders and the various stakeholders involved in the project. Payments are made to the co-ordinator, who distributes them among other parties in accordance with the project plan. The co-ordinator must also contribute financially to the project. The co-ordinator must be directly involved in the implementation of the project, and in the dissemination of the project results. Mayo County Council has agreed to be the co-ordinating beneficiary for the proposed Lough Carra project. In addition, the project would have associated beneficiaries and partners.

Associated beneficiaries are bodies or groups which contribute to the project and are responsible for one or more project actions. Associated beneficiaries are expected to contribute financially to the project, as well as using LIFE monies to carry out project actions. Associated beneficiaries are also expected to contribute to reporting obligations as part of the project.

Partners are other parties which help with the activities of the project. Partners can contribute to the work of the project but do not necessarily receive money from the LIFE fund. However, it is possible for partners to claim costs for implementing a part of the project if this is approved as part of the project plan. Such activities must be mentioned and justified in the application.

For the 2020 Lough Carra LIFE application, the following groups are proposed as associated beneficiaries:

[2] https://ec.europa.eu/easme/en/section/life/

- Lough Carra Catchment Association
- National Parks and Wildlife Service
- Geological Survey Ireland
- Environmental Protection Agency (EPA)
- Coillte

The following groups are proposed as project partners:

- Teagasc
- Office of Public Works (OPW)
- The Local Authority Waters Programme (LAWPRO)
- The Department of Agriculture, Food and the Marine (DAFM)
- Vincent Wildlife Trust
- Inland Fisheries Ireland (IFI)
- National Federation of Group Water Schemes (NFGWS)

1.3.2 What actions are eligible for LIFE funding?

The LIFE Programme has the following general objectives, as set out in EU Regulation 1293/2013.

- *to contribute to the shift towards a resource-efficient, low-carbon and climate-resilient economy, to the protection and improvement of the quality of the environment and to halting and reversing biodiversity loss, including the support of the Natura 2000 network and tackling the degradation of ecosystems*
- *to improve the development, implementation and enforcement of Union environmental and climate policy and legislation, and to act as a catalyst for, and promote, the integration and mainstreaming of environmental and climate objectives into other Union policies and public and private sector practice, including by increasing the public and private sector's capacity*

- *to support better environmental and climate governance at all levels, including better involvement of civil society, NGOs and local actors*
- *to support the implementation of the 7th Environment Action Programme*

Actions eligible for funding must be specific to the project and its aims. Therefore, actions taken by local or national bodies which are part of their normal activities, or actions required of them by law, are not eligible. For public bodies, salary costs of staff are eligible only if they relate to actions which are carried out specifically for the purposes of the project, and which would not have otherwise been carried out. In addition, activities which are already ongoing before the start of the project are not eligible.

Project activities are expected to be sustainable in the long-term, and to have long-term benefits. These benefits must be sustainable after the conclusion of the LIFE project. Research which is considered important to underpinning the project's activities, and which is specifically related to the aims of the project, can be included. However, such research must be clearly justified, should be no more than a minor element of the project, must not be already covered by existing funding from other sources, and is expected to result in scientific publications.

1.3.3 Time Schedule for 2020 LIFE applications

The following is an indicative schedule, which may be subject to slight changes:

- April 2020 – Opening of 2020 funding call
- April 30, 2020 - EU LIFE Information Day and Networking event, Brussels, Belgium.
- June 2020 – Submission of the Concept Note
- October 2020 – Applicants whose Concept Notes have been successful will be invited to submit a full proposal
- February 2021 – Submission of full proposal
- June 2021 – Results of winning proposals
- September 2021 – Start of the project

1.3.4 Previous & Current LIFE projects in Ireland

The following is a selection of Irish projects which have been successful in receiving LIFE funding:

- Burren LIFE - conserving and supporting the heritage, environment and communities of the Burren
- Aran LIFE - conservation management practices for farmers on designated Natura 2000 sites
- Kerry LIFE - sustainable land use management for the conservation of the freshwater pearl mussel
- The Living Bog - raised bog restoration project
- Raptor LIFE - managing habitats for hen harriers, merlin, Atlantic salmon and brook lamprey
- Dublin Urban Rivers LIFE - improving water quality in Co. Dublin, and promoting water quality improvement in urban areas

1.4 INTENDED OUTCOMES

This study is intended to examine the threats to the biodiversity and ecological quality of the lake and its catchment, to explore potential solutions, and to make recommendations for how these solutions could be put into action as part of a potential LIFE project. The proposed actions are intended to meet the requirements of the brief, in terms of “restoring, protecting and conserving the biodiversity value and ecological integrity of the lake and its lakeshore and catchment habitats and ensuring the quality of water in the lough”.

2 BACKGROUND

2.1 THE PROBLEM

Lough Carra, a marl lake in Co. Mayo, is celebrated for the exceptional nature and rarity of its landscape and ecological communities. It is also an important source of drinking water, and an important trout fishing lake. However, many troubling signs of deterioration have emerged, over the past three decades in particular. Comparisons of the distribution and extent of reedbeds in the lake have shown that significant changes have taken place over recent decades, particularly the spread of bulrushes *Schoenoplectus lacustris* into new parts of the lake (Shackleton, 1975; Huxley, 2007). Not only has emergent plant cover spread into previously unvegetated areas, but the vegetation has also become denser. The areas where these changes are most noticeable are at Annie's and Castleburke. The fact that tributary streams enter the lake at these two points suggests that nutrient pollution from the catchment are contributing to the spread of reeds and bulrushes.

There are also various reports of increased cloudiness and green colour in the water, due to algal blooms, and thick layers of green algal scum washing up on the shores of the lake. Local people have reported that there has been a big decrease in the number of mayflies emerging from the lake, and anglers have found that the trout population seems to have significantly declined. Huxley & Huxley (2015) noted the huge numbers of chironomids which hatch out during summer in recent times. A series of studies by researchers from Trinity College, Dublin, also found low numbers of mayflies, increasing phosphorus build-up over time in the lake sediments, and increasing phosphate concentrations in the lake water. Giles (2003) observed that wild trout spawning and nursery habitats in this area have suffered extensive damage, caused by arterial drainage schemes and intensification of agriculture, especially livestock rearing. The threat of further nutrient pollution in Lough Carra was emphasised, and the author pointed out that this "pernicious process of over-enrichment" leaves Lough Carra in danger of a sudden shift to dark, cloudy water with frequent algal blooms.

Chris Huxley has noted the increasing concentration of green colour of *Ophrydium* colonies in the lake. *Ophrydium* is an organism whose individual cells are microscopic but which forms roundish jelly-like colonies which can be seen in shallow areas of the lake. In addition to the cells' containing algal symbionts, the mucilage typically contains a large collection of 'tenants', such as green algae, diatoms, and cyanobacteria. It is likely that increased

nutrients in the lake water allow some of these tenants to flourish, causing the change in colour.

Several habitats of high priority (NPWS, 2013) are present in and around Lough Carra. The lake itself is a hard-water lake with charophyte vegetation, and the surrounding land includes both orchid-rich calcareous grassland and limestone pavement. Fen and reed-swamp habitat are found around the lakeshore, and areas of old oak woodland and blanket bog are also present in the catchment. All of these are habitats which are considered worthy of protection under the EU Habitats Directive. Unfortunately, there has been a gradual loss of important habitats over the years in the Carra catchment, due in particular to the conversion of natural or semi-natural areas to agricultural use. Huxley & Thornton (2003) and Huxley & Huxley (2015) emphasised the extent of this loss of habitats, with areas of woodland, scrub, and semi-natural grassland being cleared and turned into perennial ryegrass monocultures. Drainage efforts in the catchment over the years have also caused losses in wetland habitats, and the amalgamation of small fields has resulted in a loss of hedgerows and dry-stone walls.

Surveys of submerged vegetation over the past three decades have also shown troubling changes in important bioindicators in the lake, including the charophytes, and have shown increasing cloudiness in the water. Roden & Murphy (2013) reviewed historical accounts of Lough Carra's vegetation. Praeger (1906) reported very clear water, substantial submerged charophyte vegetation, and very sparse emergent vegetation – all characteristic of a very oligotrophic (low-nutrient) lake. Marl crusts were very extensive; Praeger had these analysed and it was found that they contained several species of cyanobacteria, as well as green algae and diatoms. By 1977, the water was still clear, and still had substantial charophyte vegetation, with a euphotic depth up to 7 m (Heuff, 1984). However, by 1996, there were notable changes in the macrophyte ecology, with large areas of *Myriophyllum verticillatum*, and shifts in the charophyte communities (King & Champ, 2000). Roden & Murphy (2013) reported decreased water transparency, a reduced euphotic zone, increased water chlorophyll content, and degraded marl crusts – all indications of nutrient pollution. It was concluded that Lough Carra was under considerable ecological stress, and that "the assumption that it is Ireland's best example of a marl lake may cease to be true in the near future" (Roden & Murphy, 2013).

Subsequent work on the marl crusts of Lough Carra showed that parts of the lake are seriously degraded, and that this damage is caused by nutrient pollution. These marl crusts contain complex microbial communities, including many species of cyanobacteria. Some of the filamentous species, especially those of the genus *Schizothrix*, bind together particles of

calcium carbonate, forming firm crusts. These crusts can grow to several centimetres in thickness over time. Doddy et al. (2019a) found a significant relationship between increasing phosphorus concentration and declining crust cover in Irish marl lakes. Doddy et al. (2019b) showed experimentally that increases in nutrients cause a change in community structure in Lough Carra's marl crusts, with green algae coming to dominate, causing declines in the filamentous cyanobacteria and eventually disintegration of the crusts.

Studies of the contents of Lough Carra's sediment are also useful in tracking changes over time in the lake's ecology. Changes in P concentrations in Lough Carra's sediments have been measured and documented (Hobbs et al. 2005; Donohue et al. 2010), and P concentration has shown a large increase over time, especially since the 1950s. The danger of a sudden shift in the lake's ecology, with a loss of much of the natural communities and biodiversity, has been emphasised, and described as an "ecological time bomb" (Irvine et al. 2003). For these reasons, the urgent need for a change in nutrient-management in the catchment cannot be over-emphasised.

In light of these changes, the Lough Carra Catchment Association (LCCA) was established, attracting interest from local people, academics, angling clubs, farmers, politicians, state agency employees and others. The LCCA has since held monthly meetings and has worked toward the establishment of a LIFE project for the region.

2.2 USES & MANAGEMENT OF LOUGH CARRA

Lough Carra is a large lake which is important to the region in several ways. It is a source of drinking water, and the local water schemes (part of the National Federation of Group Water Schemes) abstracts water to supply approximately 1100 households. It is also an important fishing lake, with a long history of angling for brown trout in particular, as well as pike and perch. The lake is used by angling clubs, including the Lough Carra Trout Anglers' Association. The main access points used for fishing boats are at Brownstown, Moorehall and Castleburke. There are also a number of private access areas, which are used with the permission of the landowners. Faherty (2004), discussing the increasing pressure on the fish stocks from angling, noted that the peak boat count in Lough Carra from angling in 2003 was 158.

The area around the lake has long been a site of human habitation, as revealed by the many archaeological features, such as ringforts and standing stones, and the crannogs which are still present in the lake. The lake and its shores are important for recreational purposes, both for local people and for visitors to the region. There are many ecological features of interest

to the visitor, including the bird populations, the butterflies and other insects, the islands and their wildlife, and the areas of limestone pavement around the shores. The lake has long been the subject of art and literature, partly due to the striking nature of the landscape and the richness of its biodiversity. Poems, stories and music have been inspired by Lough Carra.

The lake and its surrounds have been a focus for scientific researchers for many years, and many aspects of its natural features have been studied, including the geology, aquatic and terrestrial animals, lichens, plants, microbial communities, and sediments. In particular, researchers from Trinity College, Dublin and from the Galway-Mayo Institute of Technology have carried out numerous studies on Lough Carra and its catchment.

Several bodies and organisations are involved in the overall management of Lough Carra. The Office of Public Works (OPW) has responsibility for flood management and public drainage in the region. This includes a number of roadside and arterial drains, some of which empty into the lake. As these tend to fill with sediment and debris, they are occasionally emptied out, and the material spread on adjoining land. There is a weir on the Keel River, which drains Lough Carra. This weir helps maintain Lough Carra's water level since historical works to canalise the Keel River had the effect of increasing water flow out of the lake. The OPW's "benefitted lands" include a margin around the shore of the lake, in the potential flood zone, as well as other potential flooding areas.

Coillte also has a management role. Four forestry areas in proximity to the lake are owned and operated by Coillte – part of the Moorehall estate, Tower Hill, Derrinrush and Cloonee. All of these have been included in Coillte's BioClass initiative, and are henceforth to be managed for biodiversity rather than for commercial purposes. While non-native tree species have been planted on these areas in the past, the plan is to gradually convert them to native species, ensuring that planting and felling work is done in a manner that is sensitive to the vulnerability of the lake.

As the local public authority, Mayo County Council has responsibility for a number of areas, including roads, planning, housing, cemeteries, litter control, and waste management. Mayo County Council also owns part of the Moorehall site, and is developing the site as a public park in the interests of recreation, tourism, public amenity and cultural development. Given the importance of the site for wildlife and biodiversity, the county council has untaken to develop a masterplan for the site in collaboration with the National Parks & Wildlife Service (NPWS). A draft of this plan is not available at the time of writing, but it is being put together in conjunction with the Coillte BioClass plans, with a particular emphasis on conservation measures for bats at Moorehall (William Cormacan, personal communication). The NPWS

has responsibility for the protection of designated Natura 2000 sites. This includes management for wildlife and control of invasive species. As noted above, Lough Carra is both an SAC and an SPA.

The Environmental Protection Agency (EPA) and Inland Fisheries Ireland (IFI) both have responsibilities for reporting on Lough Carra under the Water Framework Directive.

2.3 LAND USE IN THE LOUGH CARRA CATCHMENT

The Lough Carra catchment is almost entirely rural, and estimated to be 109 km² in area (Rolston & Ryther, 2018). The precise extent of the catchment and groundwater flow are not yet fully determined, however. In some parts of the catchment the density of dwellings is quite high, although there are no large urban centres. Soils in the catchment are predominately alkaline mineral soils, although there are also significant areas of peat.

The majority of the land in the catchment is used for farming, mainly of cattle and sheep; interspersed with this agricultural land are areas of forestry, semi-natural vegetation, bogs, limestone pavements, and wetlands. Huxley & Thornton (2003) compared land use in the catchment between 1970 and 2002. In this time, mean farm size had increased from 50.7 acres to 59.7 acres, and cattle stocking levels had increased from 0.33/acre to 0.47/acre, representing an overall increase of 42% in cattle density during the 32-year period. Sheep numbers, meanwhile, had increased from 0.28/acre to 0.66/acre (a 136% increase in density). The study also took account of pig numbers, recording an increase of 5614% from 0.02/acre to 0.99/acre, but this finding was not considered representative of the catchment.

Considering the application of chemical fertiliser, there was an increase of 186% across the 34 farms included in the study, the mean figure rising from approximately 75 tonnes to about 200 tonnes. This increase was despite the fact that, by 2002, five of the 34 farms had stopped using chemical fertilisers. While estimates of slurry and manure application were not as precise, almost a fourfold increase was estimated. This study also recorded large increases in the conversion of land from natural or semi-natural vegetation to more intensive agricultural uses, and an increase in drainage measures. Tillage was found to have decreased in the farms studied, from 50 acres in 1970 to 0.5 acres in 2002.

Of the forestry plantations in the catchment, most are owned by Coillte. In addition to the four BioClass-designated areas discussed above, there are two small, commercially managed, Coillte plantations in the catchment, one of 11.7 hectares near Ballintubber, and one of 7.7 acres at Newtown (Coillte, personal communication). Aerial maps appear to show

a few further very small areas of forest or woodland in the catchment, seemingly private-owned, but it is clear that these comprise a very small percentage of the land area.

2.4 LOUGH CARRA'S ECOLOGY

Lough Carra is a multi-basin lake, approximately 18 km² in area. While much of the lake is shallow, 1 – 4 m in depth, there are eight deeper areas of 15 – 20 m depth (Roden & Murphy, 2013). Three distinct basins can be defined within the lake (Hobbs et al. 2005), which are referred to in this report as the north basin, middle basin, and south basin (Figure 1). The lake is fed by a combination of groundwater and inflowing streams or rivers. Most of these inflowing streams approach the lake from the east. The lake drains into nearby Lough Mask via the River Keel, which exits the lake to the south-west.

Figure 1: Lough Carra, Co. Mayo. Three main basins of the lake are defined. Source: EPA maps

Lough Carra is a hard-water, marl-precipitating lake, with mean alkalinity of 136 mg/l $CaCO_3$ (Doddy et al, 2019a). A marl lake is one in which calcium carbonate ($CaCO_3$) precipitates from solution, forming a layer on the lake bed, and is defined as a lake in which calcium carbonate constitutes at least 50% of the sediment's inorganic content (Pentecost, 2009). The bedrock in the area is Carboniferous limestone, and some areas surrounding the lake are karstic in nature, similar to parts of the Burren in terms of their flora. Much of the catchment is fairly flat or gently sloped, and contains much agricultural land, as well as areas of bog, fen, marsh and turloughs (Huxley & Huxley, 2015). Some areas of planted coniferous forest are also present, and some patches of semi-natural woodland have developed in undisturbed areas, including on some of the lake's islands.

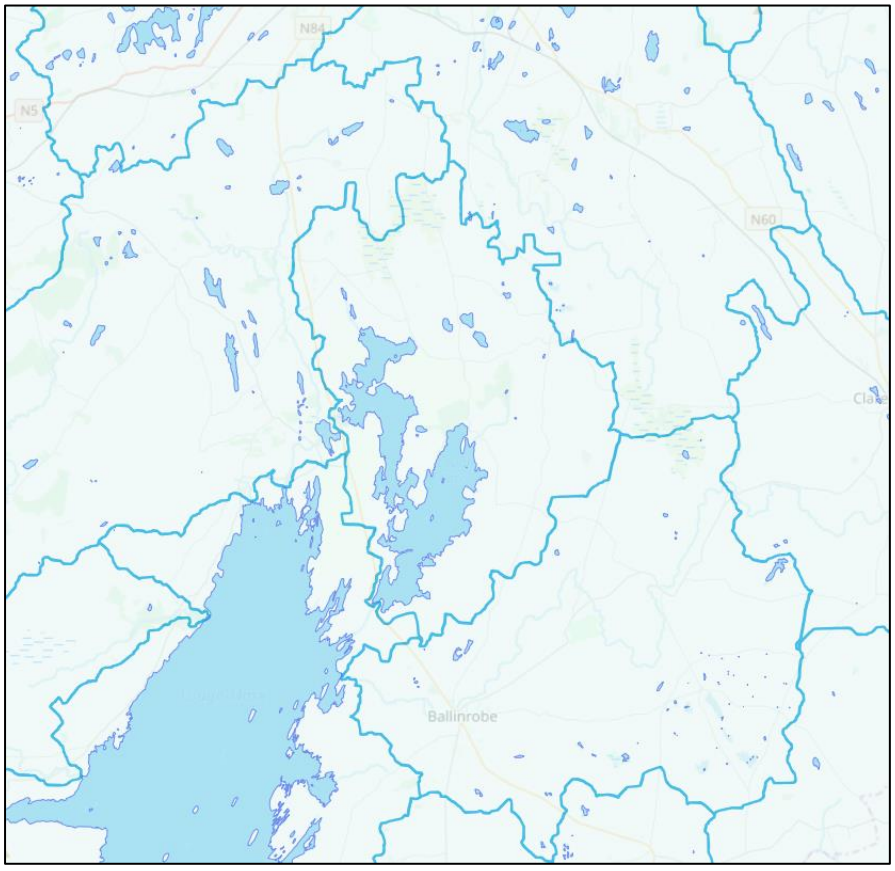


Figure 2: The Lough Carra catchment extends largely to the east and north of the lake. Shown to the south-west is Lough Mask, into which Lough Carra empties via the River Keel. Source: EPA maps.

As a shallow, oligotrophic lake, Lough Carra is of considerable rarity. Irvine et al. (2004) stated that the great western lakes, Loughs Carra, Corrib and Mask, are "of sufficiently high international status to merit particular attention to their protection. Lough Carra is one of the

few remaining examples of a high quality shallow calcareous lake in Europe. It is, however, easy to ignore the value of one's own heritage."

2.5 NUTRIENT POLLUTION IN FRESHWATERS

It is useful at this point to step back and attempt to see the changes in Lough Carra in a wider context. These changes are not surprising, and are consistent with wider trends, both nationally and globally. It is well documented that freshwater ecosystems are now among the most heavily altered and degraded ecosystems in the world, and many have suffered a major loss of biodiversity (Geist, 2011; Ulén et al. 2007). For lakes, one of the most serious problems worldwide is pollution by nutrients as a result of human activities, notably agriculture. Many lakes have been so oversupplied with nutrients, often to many times their previous concentrations, that the natural ecological communities have been largely eradicated and the system transformed to a state of green, cloudy water, floating algal scums, and devastation of the invertebrate and fish communities. Lough Carra is by no means immune from this fate.

Of the various nutrients that living organisms require, and which are therefore necessary in functioning ecosystems, phosphorus (P) and nitrogen (N) are the limiting nutrients in many natural environments (Moss, 2010) This means that these nutrients are naturally scarce, and this scarcity limits the growth and productivity that can occur in the system. An oligotrophic lake like Lough Carra is naturally very low in P and N, and the creatures and communities that live there are well adapted to these low-nutrient conditions. An increase in these nutrients in such a lake can cause abrupt, large-scale changes, removing restrictions to growth in certain organisms, such as green algae, and allowing others species - those adapted for oligotrophic conditions - to be overwhelmed and outcompeted.

Before the advent of nitrogen-fixation technology and phosphate mining, these nutrients were scarce and limited resources, and were managed and recycled accordingly (Dawson & Hilton, 2010). Since N & P fertilisers became commercially available, the freshwater habitats of much of the world have suffered an enormous influx of waste nutrients, especially since the mid-20th century (Schindler & Vallentyne, 2008). Phosphorus is generally regarded as the more crucial polluting nutrient in freshwaters, since it accumulates in sediments and cannot be easily removed or broken down. Nitrogen also contributes to eutrophication but is a more transient nutrient, which can be broken down and released into the atmosphere.

In the modern world, few lakes are unaffected by nutrient pollution, even those in protected areas (Carvalho & Moss, 1995). Agriculture is very often the primary cause, particularly in

areas of intensively-farmed land (Withers et al. 2014; Ulén et al. 2007). Sewage effluent is another source of nutrient-pollution, and the use of phosphates in detergents (now banned in some countries) has had impacts in many areas in the past (Schindler & Vallentyne, 2008).

2.6 NUTRIENTS IN MARL LAKES

In marl-precipitating lakes, such as Lough Carra, phosphorus can be co-precipitated from solution and subsequently accumulates in the form of phosphorus compounds, especially Fe:P (iron-phosphorus) compounds. This iron-bound P is stable only in aerobic conditions. In addition, P can become loosely bound (adsorbed) to benthic sediments (Moss et al. 1996). The importance of this is that large amounts of P can accumulate in lakes in an insidious manner; since the marl sediment acts as a P-buffer, the extent of the increase may not be detected by standard water-chemistry tests. However, when the buffering capacity of the sediment is exceeded, the lake can suddenly change to a murky, turbid, unvegetated, phytoplankton-dominated state (Jeppesen et al. 1991; Jensen et al. 1994; Moss et al. 1996). Such 'critical transitions' in shallow lakes are well-documented internationally, and are described by the Alternative Stable States (ASS) model of lake ecology (Scheffer, 2004; 2009). When a change of this sort has occurred, such lakes are notoriously difficult to restore.

2.7 EUROPEAN DIRECTIVES

2.7.1 Birds Directive

Lough Carra is designated as a Special Protection Area (SPA) under the EU Birds Directive (site code: 004051), and is of special conservation interest for the common gull *Larus canus*.

According to the Site Synopsis, Lough Carra also supports wintering populations of several bird species including wigeon, gadwall, teal, mallard, shoveler, pochard, tufted duck, goldeneye, little grebe, great crested grebe, and lapwing. In the past, Lough Carra supported a mallard population of national importance. Lough Carra SPA is of considerable ornithological importance for breeding gulls including a nationally important population of common gull.

Huxley & Huxley (2015) have described the importance of the lake for several species of birds, including common terns, starlings, swallows, gadwall, common gulls, jays, ravens, curlews, shoveler and teal. Unfortunately, many bird populations have been in decline in this

area over the past several decades. Mallard numbers have fallen to a fraction of their former abundance, and this trend is repeated for shoveler, teal and pochard. Other wildfowl have also seriously suffered, with breeding waders such as lapwing, ringed plover and redshank showing huge declines. These declines are likely due in part to the introduction of the invasive American mink and the loss of priority habitats.

2.7.2 Habitats Directive

Lough Carra is also part of the Lough Carra/Mask Complex SAC (site code: 001774), which is designated under the EU Habitats Directive for several habitats and species, listed in Figure 1. The Site Synopsis describes Lough Carra as one of the best examples in Ireland of a hard water marl lake, and states that the "site is of considerable conservation importance as it has good examples of nine habitats listed on Annex I of the E.U. Habitats Directive, four of which are listed with priority status. Some of these habitats are amongst the best examples of their kind in the country".

However, an NPWS study carried out by Roden & Murphy (2013), found "obvious signs of ecological stress" in Lough Carra. These included a shallowing of the euphotic zone, a change from charophyte to angiosperm dominance in the submerged communities, and degradation and disappearance of marl crusts in the vicinity of inflowing streams.

2.7.3 Water Framework Directive

The EU Water Framework Directive was adopted in 2000, with the aim of protecting and improving all surface, ground and coastal waters. The directive stresses the need for ecological assessment techniques. A range of indices, including both ecological indicators and water chemistry, are used in monitoring lakes such as Lough Carra. In Ireland, the Environmental Protection Agency (EPA) is responsible for the national coordination of all the technical aspects of the directive, as well as setting out environmental objectives, characterising river and lake catchments, putting together river basin management plans, and reporting to the EU Commission and the European Environment Agency (EEA) on the implementation of the directive in Ireland.

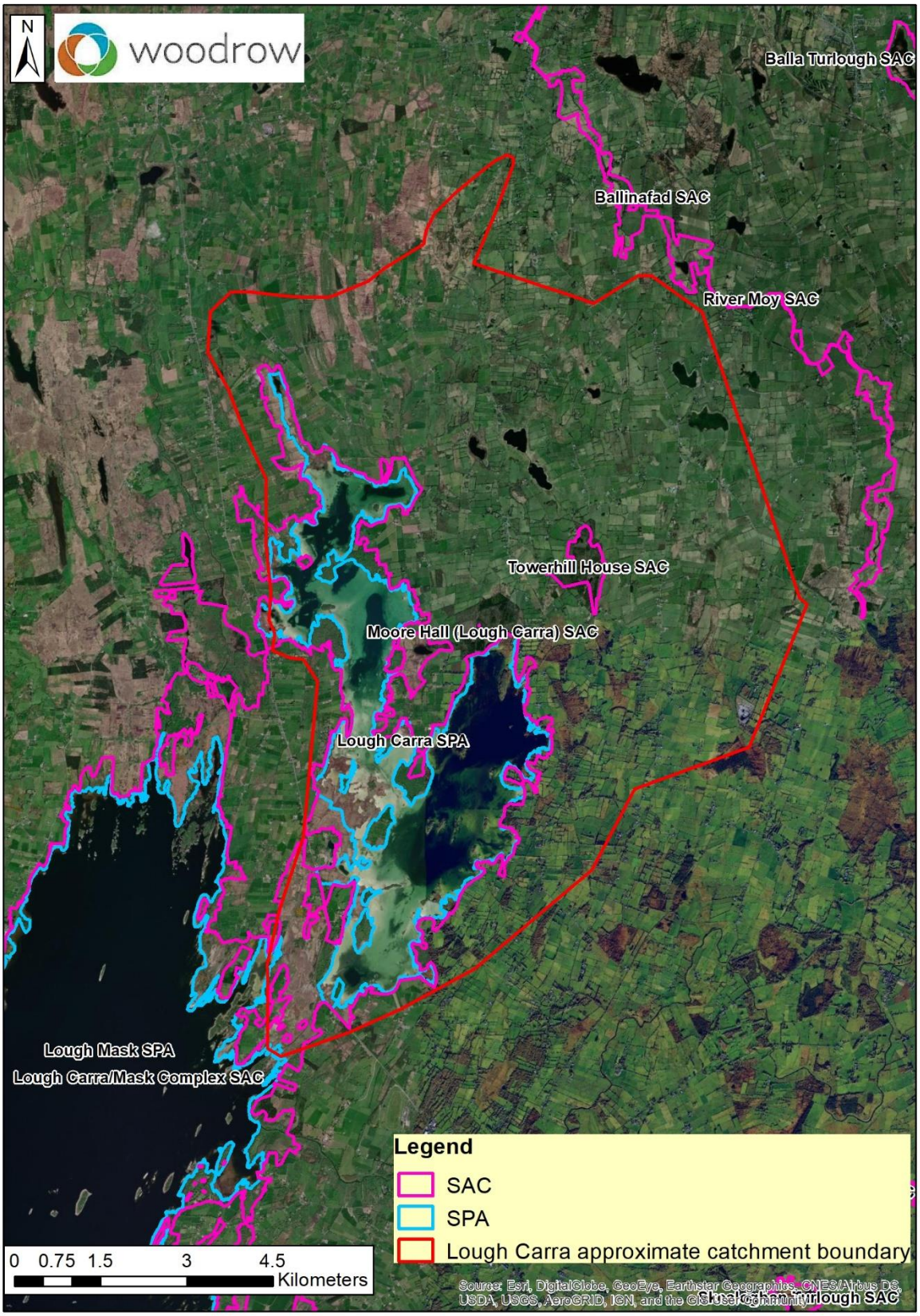


Figure 3: Designated areas for protection under the European Nature Directives

Table 1: Qualifying interests for the Lough Carra/Lough Mask Complex SAC. Priority habitats are indicated by an asterisk (*)

Natura 2000 code	Qualifying habitat/species
3110	Oligotrophic Waters containing very few minerals
3130	Oligotrophic to Mesotrophic Standing Waters
3140	Hard Water Lakes
4030	Dry Heath
6210	Orchid-rich Calcareous Grassland*
7210	*Cladium* Fens*
7230	Alkaline Fens
8240	Limestone Pavement*
91E0	Alluvial Forests*
1303	Lesser Horseshoe Bat (*Rhinolophus hipposideros*)
1355	Otter (*Lutra lutra*)
1393	Slender Green Feather-moss (*Drepanocladus vernicosus*)

2.8 GROUNDWATER IN THE LOUGH CARRA CATCHMENT

The bedrock beneath the Lough Carra catchment is almost entirely limestone, with small amounts of shale also present. Since limestone is soluble in water, such areas tend to have many underground channels, crevices and caves, which can result in complex systems of drainage and groundwater flow. The ability of water to dissolve limestone depends on the amount of carbon dioxide (CO_2) contained in the water. If the amount of dissolved CO_2 in rainwater exceeds that of atmospheric CO_2, such water tends to dissolve limestone; conversely, when the pressure of CO_2 in water is lower than that for free CO_2 in the atmosphere, calcium carbonate, the main mineral in limestone, is precipitated from solution (Sweeting, 1973). Respiration carried out in soils or sediments by bacteria, plant roots or small animals can increase the CO_2 content to many times its atmospheric concentration, causing localised underground dissolution of rock. If this supersaturated water reaches the surface, for example at a spring or in a cave, the excess CO_2 diffuses into the atmosphere, and limestone solidifies out of the water (Golubić, 1973).

These various processes result in the karst landscape and groundwater systems typical of areas like the Carra catchment. The aquifers in the region (underground flooded areas of rock or gravel) are therefore known as karstified aquifers. Since the underlying rock tends to have many fissures and channels, water from the surface, including water from drains, can often move through the system very quickly. Groundwater in such a system can travel hundreds of metres per day (Pilmer & Duncan, 2019). Where the soil layer overlying the bedrock is quite thin, this means that there is little natural filtration of water, and so pollutants can reach the groundwater quickly as it makes its way through the catchment and into the lake (Rolston & Ryder, 2018). For this reason, such areas are particularly vulnerable to pollutants, including those which cause nutrient pollution. The areas most vulnerable are those which have little or no soil, such as the areas of limestone pavement or bare shattered limestone which surround much of the lake. Groundwater vulnerability is rated on the scale shown below in Figures 4 – 7. It is clear from these maps that much of the area around Lough Carra and in the Carra catchment has very high groundwater vulnerability. This is another reason why Lough Carra is so sensitive to nutrient pollution in the catchment, and why precautions to cut down on profligate nutrient use are so necessary if the deterioration of the lake is to be halted.

Groundwater research is one of the programmes operated by the Geological Survey of Ireland (GSI). In July 2019, a presentation given to a meeting of the Lough Carra Catchment Association by members of staff from the GSI (Pilmer & Duncan, 2019) summarised the work that they have been doing, and described some of the geological features in the area. Not much previous mapping of karst features or groundwater movements has been done in the area. The aim of the GSI's work in the Lough Carra region was defined as developing "a conceptual understanding of groundwater movement within the Lough Carra catchment", and it is hoped that work in the region will help to improve the national groundwater database, and also provide useful input into the proposed LIFE project. The key findings to date were summarised as follows:

- Many karst features or possible karst features have been recorded in the area. These include dolines, swallow holes, springs, turloughs, exposed limestone pavements, boreholes and sinking streams.
- The Ballintubber region was noted as having a particular prevalence of springs.
- The Annie's area has a series of turloughs, swallow holes and springs.
- The northern boundary at Ballyhean has a number of swallow holes and springs.

Following on from this survey work, the GSI intend to focus their mapping efforts on the boundaries of the catchment with a view to tracing water movements from the boundary and across the catchment. They also intend to continue identification work on submerged springs, and to conduct a well survey to define groundwater levels. They hope to increase their coverage and mapping of karst features in the south-east region of the catchment.

The continuation of this work is important to the long-term success of the proposed LIFE project. This is especially the case due to the karst nature of the area, the complex networks of underground channels, and how these connect the various areas of the catchment with the lake and its inflowing streams. Therefore, the involvement of the GSI as a partner in the proposed project will be a valuable and worthwhile contribution to the project's long-term success.

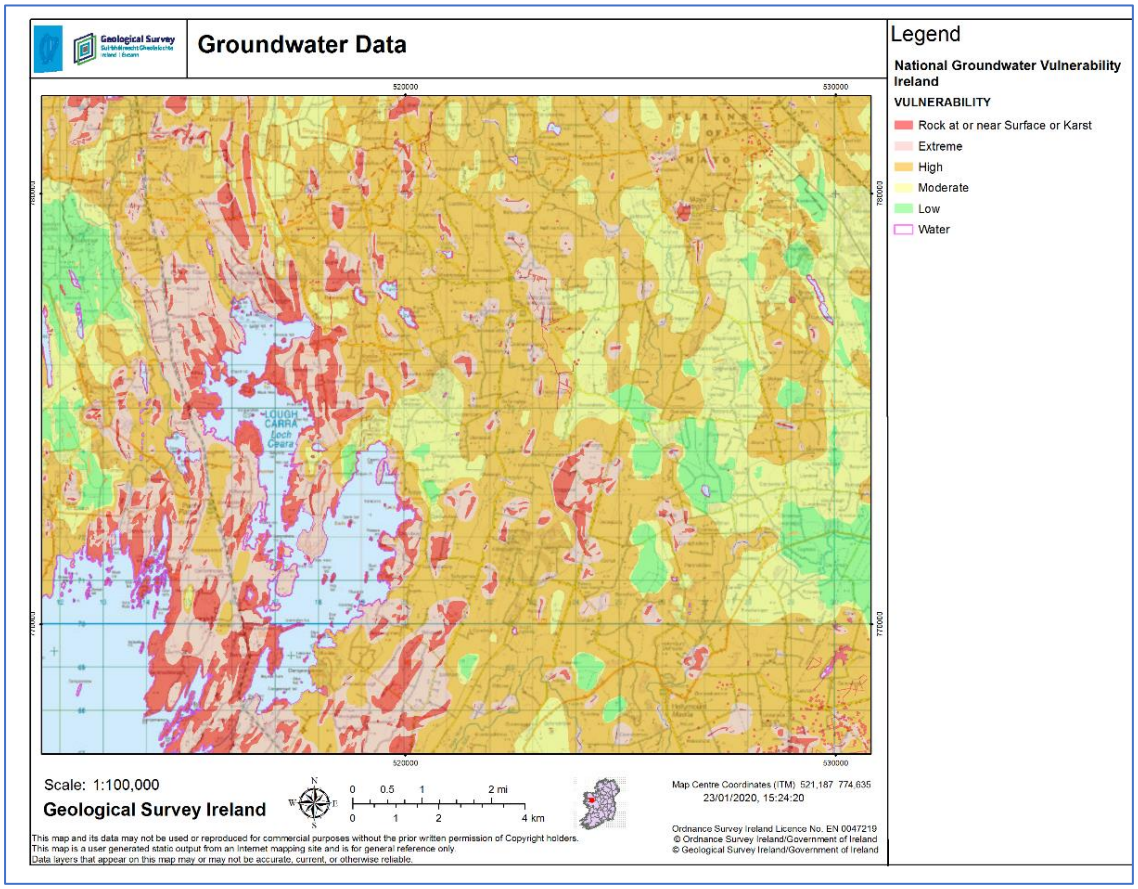


Figure 4: Groundwater Vulnerability in the Carra region

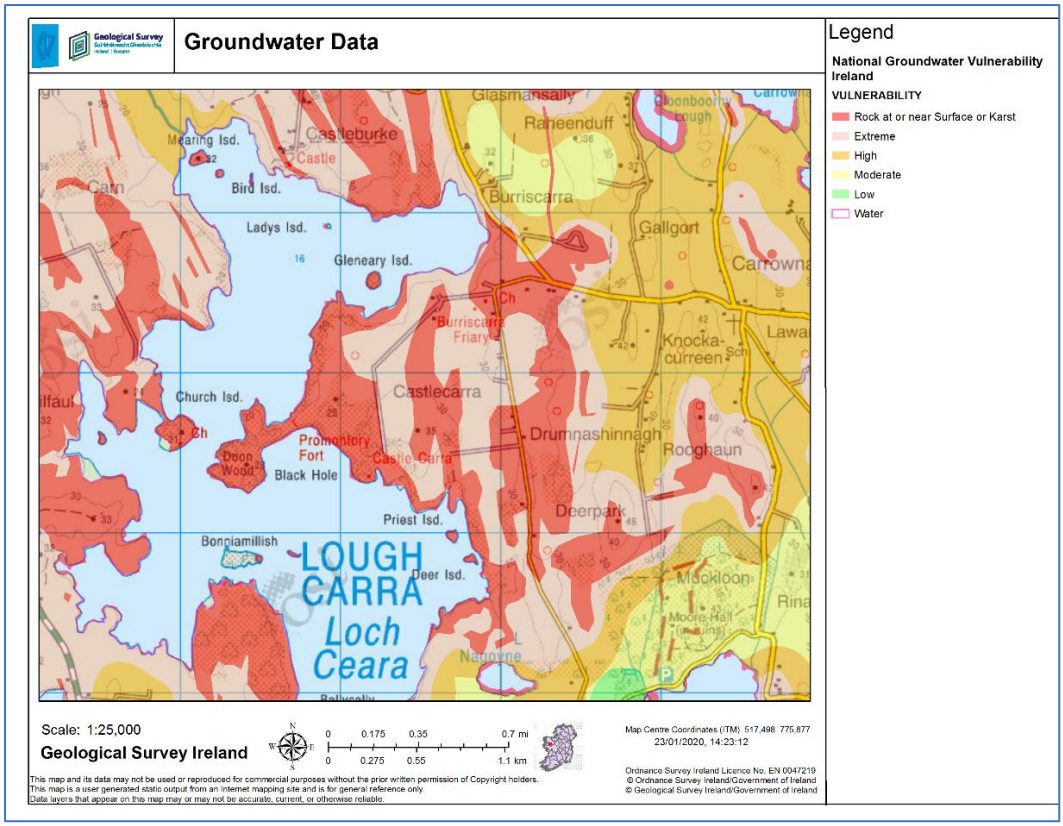


Figure 5: Groundwater Vulnerability – northern section of Lough Carra

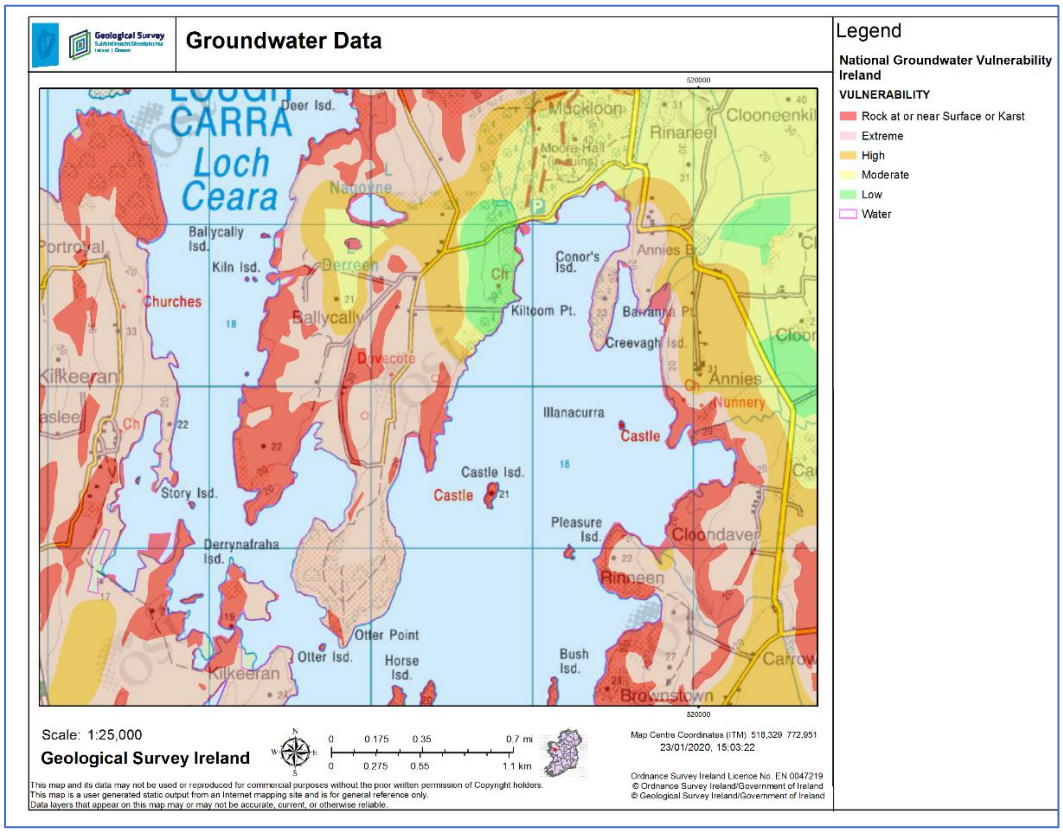


Figure 6: Groundwater Vulnerability – mid section of Lough Carra

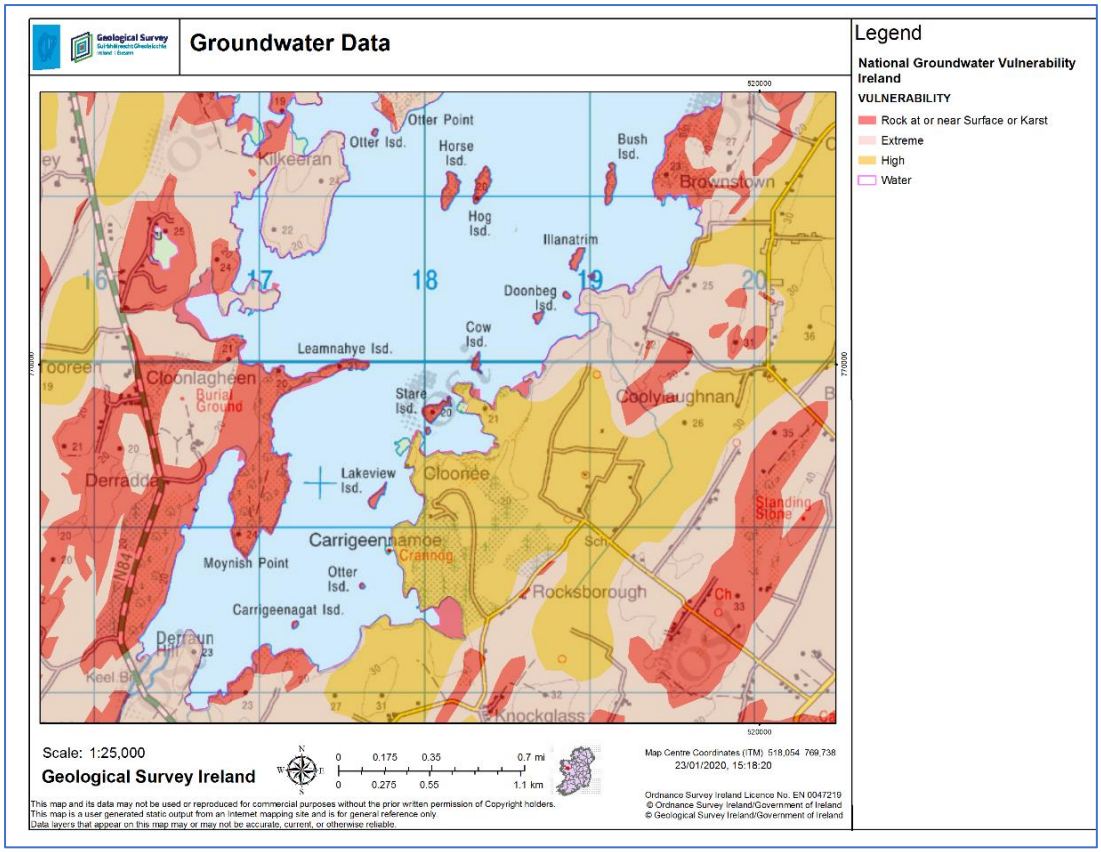


Figure 7: Groundwater Vulnerability - southern section of Lough Carra

2.9 PUBLIC WATER SUPPLY

Lough Carra is an important source of drinking water, with water being abstracted from the north basin for the Lough Carra Group Water Scheme, and from the south basin for the Robeen Group Water Scheme. Rolston & Ryder (2018) produced a report which described the Lough Carra Group Water Scheme catchment, evaluated available data on water quality, considered the impacts of land use on water quality, and gave recommendations for managing the area in the interests of maintaining a good drinking water source.

As noted above in the context of groundwater, the nature of the karst geology in the catchment, in combination with the relatively shallow soils, reduces the potential for pollutants to be filtered from surface water as it percolates through to the groundwater. This makes Lough Carra vulnerable as a drinking water source. Rolston & Ryder (2018) emphasised the need, therefore, for domestic wastewater treatment systems (mainly septic tanks) to be well installed and maintained properly, in order to minimise loss of nutrients, as well as infectious pathogens, into the groundwater and the lake. It was also noted that

dwelling density is relatively high in parts of the catchment, and that pressures from agriculture are also high, with much of the catchment used as pasture for livestock.

The general deterioration in water quality in the catchment over the past 30 years is seen as a problem for the future of the water source, and the expectation of 'significant changes to the lake's ecology' as a result of continued diffuse nutrient pollution is noted. The report acknowledges that, due to the size of the catchment, any significant source protection measures for the drinking water supply would require long-term integrated catchment management, involving a number of stakeholders. This is what the Lough Carra LIFE project must also aim to achieve, and again the need to plan for the long-term and to anticipate the subsequent 'AfterLIFE' programme is clear.

The recommendations from the report by Rolston & Ryder (2018) are summarised as follows:

- *Put Source Protection on the agenda*

Including source protection issues on the agenda of committee meetings increases the profile and awareness of source protection issues within the Lough Carra catchment and Lough Carra GWS sub-catchment and brings into focus the recommendations made within this report. Developing a protocol for dealing with potential pollution incidences would be a good first step for the committee to address.

- *Modify Trihalomethane sampling*

Although the Drinking Water Regulations (2014) parametric limit for Trihalomethanes was not exceeded on any sampling occasion, THM concentrations were occasionally high. Given than THM monitoring frequently took place outside of the period when Dissolved Organic Carbon values are typically highest (and subsequently the probability of THM formation is greatest), there is the possibility that THM concentrations during this period may be high. Therefore Lough Carra GWS should engage with Glan Agua and Mayo County Council to ensure that THM monitoring is undertaken on at least a monthly basis between July and November.

- *Engage Mayo County Council regarding wider catchment-scale issues*

The water quality issues affecting Lough Carra can only be improved through large-scale, integrated catchment management efforts. Given that Lough Carra is a drinking water source, Lough Carra GWS should be an important stakeholder in any catchment-scale management actions. By proactively engaging Mayo County Council, Lough Carra GWS can highlight the important issues impacting on drinking water source quality and subsequently be involved as a stakeholder in the development of management plans and actions aimed at improving the water quality of Lough Carra.

- *Engage the National Federation of Group Water Schemes and Geological Survey of Ireland*

The karstic limestone nature of the underlying geology of the Lough Carra catchment indicates strong potential for groundwater influencing the water quality of Lough Carra. The geographical area from which groundwater may be delivered to Lough Carra is likely to be different to that of the surface

water catchment delineated in this report. Therefore, Lough Carra GWS should engage both the National Federation of Group Water Schemes and the Geological Survey of Ireland to attempt to fully understand the potential contribution of groundwater to the GWS abstraction point in the northern basin of Lough Carra.

- *Microbiological data collation and assessment*

No raw water microbiological data (E. coli, C. perfringens and Total Coliforms) were provided for this report. If such data exists then it should be collated and analysed to understand levels of microbiological contamination of the raw water supply. If no such data exits then E. coli, C. perfringens and Total Coliforms should be monitored within the raw water supply on a monthly basis.

- *Engage with GWS members with regard to on-site waste water treatment systems (septic tanks) maintenance*

Group Water Scheme members within the Lough Carra GWS sub-catchment should be engaged to ensure septic tanks are maintained and serviced regularly in order to reduce the potential for nutrient and other contaminants entering surface water and groundwater bodies.

Following engagement with the Geological Survey of Ireland (see above), any septic tanks that lie outside of the Lough Carra GWS sub-catchment delineated in this report, but within any delineated groundwater zone of contribution, should also be maintained and serviced regularly.

Lough Carra GWS could therefore contact residents within these geographic localities to proactively help to ensure suitable septic tank management within the region. The National Federation of Group Water Schemes is currently involved in a pilot septic tank engagement project and it may be worthwhile for Lough Carra GWS to contact the NFGWS to discuss septic tank management and engagement mechanisms.

- *Soil nutrient analysis*

Given the deteriorating water quality within Lough Carra and the likely contribution of nutrients to this deterioration, undertaking soil nutrient analysis for lands bordering the northern basin of Lough Carra and the inflow streams to this basin would be valuable. Soils with high nutrient status are most likely to result in losses to nearby waterways. Knowledge of soil nutrient status would allow farmers to match fertiliser application to their needs and to save money by not applying fertiliser to fields that do not require it. This analysis would be beneficial to both the GWS and the farmers and therefore consideration could be given to sharing the costs of undertaking soil nutrient analysis.

- *Fencing land with livestock access to local water bodies*

Restricting direct livestock access to water bodies in the vicinity of the northern basin of Lough Carra and its inflow streams will assist in reducing potential nutrient and faecal contamination of the raw water source. This action, in combination with the monitoring of faecal coliforms in the raw water, will help to identify further source protection measure required to improve water quality for the GWS and potentially reduce treatment costs in the longer term.

- *Initiate a communications drive*

Lough Carra GWS should consider undertaking a communications initiative to remind scheme members of their legal obligations with regards to nutrient enrichment practices, to recommend Good Agricultural Practices and to highlight the importance of wastewater treatment system management. Highlighting the importance of Scheme members' actions in regards to improving raw water quality could also raise awareness for facilitating improvements in environmental status of all the water bodies within the Lough Carra catchment. The location of the treatment works on the edge of Lough Carra presents an opportunity for a community open day when members of the local community and GWS members can learn more about the source of their drinking water, be informed about the treatment process, the work that is required to ensure good quality water reaches their taps and the source protection measures that need to be implemented to ensure good raw water quality. Consideration should be given to engaging local schools to take an interest in local water resource management issues and to encourage students to undertake projects that can ultimately help raise the profile of GWS and the source protection measures required to help improve the environmental status of the catchment area whilst also providing cost-savings in the water treatment process.

It is clear, looking at these recommendations, that they overlap very substantially with the aims of the Lough Carra Catchment Association, and the proposed LIFE project. Consequently, the National Federation of Group Water Schemes (NFGWS) has agreed to be a partner in the LIFE project application.

3 PRESSURES

3.1 AGRICULTURE

LaCanne & Lundgren (2018) observed that modern agricultural policy often tends to 'decouple farmer decisions from market demands', and results in less food diversity, rising pollution, loss of biodiversity, and increasing climate change. Some of these policy changes have been foisted on farmers, with little or no consultation, and have resulted in changes that damage the land, reduce biodiversity, and reduce the long-term sustainability and profitability of farms. In Ireland, this reduction in long-term sustainability and profitability of farms should not be underestimated. There are increasing problems with isolation of farmers, and some farmers say that they see no future in farming. Many of them fear for the future of their farms, as their children often do not choose to take up a career in farming, because it is not considered a long-term and sustainable profession.

Although there is an increasing tendency in some parts of the country to convert farmland to forestry plantations, many farmers are reluctant to make this change, as they would like to be able to continue farming, and are frustrated that they cannot get a reasonable price for the animals or foods they produce. There are even problems with rising levels of depression, with middle-aged farmers in Ireland at increased risk of suicide (O'Donnell & Richardson, 2018).

Farmers tend to operate within the guidelines and systems laid down for them, and in accordance with the advice they are given. Unfortunately, it is clear that these policies and guidelines have not always served the best interests of farmers or their land. These are important realities which should be considered during the planning of the proposed Lough Carra project. The project will need the participation and good will of farmers, and should therefore help them to make changes that are conducive to prosperity and sustainability of their farms, as well as helping to achieve the environmental aims of the project.

The previous sections of this report make clear that there have been major changes in land use and farming practices in the Lough Carra catchment, and that this has coincided with serious ecological decline in the lake. This decline is consistent with trends reported from around the world, which link the intensification of farming with declining ecological quality in freshwater systems. The capacity of marl lakes like Lough Carra to absorb and store large amounts of phosphorus in the sediments initially acts as a buffer, slowing the decline caused by nutrient pollution. However, when this capacity is exceeded, the lake is expected to go into rapid decline, with a loss of much of its natural habitats and biodiversity. Consequently,

the way that agriculture is currently carried out in the catchment is considered to be the most serious pressure on Lough Carra.

3.2 DOMESTIC WASTE WATER & SEPTIC TANKS

The domestic wastewater of approximately 490,000 dwellings in Ireland are treated on-site by domestic wastewater treatment systems, 90% of which are septic tanks (Gill et al. 2018). Since most of the Carra catchment is rural, many of the households in the catchment have septic tanks for the management of wastewater and sewage (Rolston & Ryder, 2018). A conventional septic tank system consists of the septic tank itself and a percolation area. In some cases, a secondary treatment system is used, which may comprise a filter of soil, sand or peat (EPA, 2013). In order to ensure the system works as well as possible, desludging of tanks should be periodically (the frequency depends on tank size and usage) carried out by a permitted waste collector. The Environmental Protection Agency has published a Code of Practice for wastewater treatment systems (EPA, 2010) which provides information and guidance on the design, operation and maintenance of septic tanks and other wastewater and sewage management systems. If septic tanks are not working optimally, nutrients can be lost into the groundwater and surrounding waterbodies. Moreover, septic tanks can be a source of both toxic chemicals and infectious pathogens. The Water Services (Amendment) Act 2012 provides for the registration and inspection of septic tanks. Under this legislation, all on-site septic tank systems or domestic wastewater treatment systems have to be registered.

An EPA report (Gill et al. 2018) evaluated the impact of domestic waste as a health issue for users of private wells, and the nutrient impact domestic waste and septic tank systems have on local water courses. While this study did not take place in the Lough Carra catchment, the part of the study focusing on private wells did include two areas of comparably high groundwater vulnerability. In these two areas, 16% and 10% of wells tested positive for *E. coli* contamination. In the same study, comparisons of nutrient concentration in streams in four catchments were measured, both upstream and downstream of clusters of houses with domestic wastewater systems, using on-site, continuous-recording equipment. A model was developed to help estimate the nutrient input from domestic wastewater systems in the catchment as a percentage of the total nutrient input. It was estimated that, in the four catchments, the percentage contributions of total phosphorus were 13.8 %, 8.5%, 1.3% and 11.3%, respectively. The corresponding contributions of total nitrogen in the catchments were 28.5%, 12.4%, 6.8% and 8.7%.

Considering the high groundwater vulnerability in much of the Carra catchment, there is a high potential for nutrient pollution from septic tanks, as well as the potential for entry of infectious pathogens to the lake. Many septic tanks in Ireland are old and quite basic in design, and many of these do not function optimally. The Lough Carra catchment is probably no exception in this regard, and this is expected to exacerbate the potential, already high, for nutrient pollution of the lake. Consideration of the percolation area is also important. Water exiting a septic tank is very high in nutrients; unless the percolation area is sufficiently extensive, this high-nutrient water can easily make its way to a water course and end up in the lake. Soil porosity is another factor, as free-draining soil allows water to pass through quickly, having little filtering capacity. Much of the Carra catchment has relatively thin and free-draining soil.

While most septic tanks receive water from the bathroom and kitchen, in some cases rainwater from the roof or other surfaces is also diverted into the septic tank. This is a particular problem, as it greatly increases the amount of water going through the system, which can result in a faster release of nutrients as well as potential flooding of the tank or percolation area during wet periods.

In light of the foregoing, domestic waste water and septic tank systems are considered a significant pressure in the Carra catchment, and a highly likely contributor to nutrient pollution in the lake.

3.3 FORESTRY

Afforestation in river and lake catchments can cause ecological problems in a variety of ways, including nutrient pollution, sedimentation of water bodies, and erosion. However, forestry can also be carried out in such a way that it enhances habitats, acts as a nutrient and carbon sink, and increases the amenity value of the area. The impact of forestry in the catchment, therefore, depends very much on how it is planned, the planting and felling regime, and the species planted.

Different issues and problems can arise at different stages during the processes of preparing the ground, planting, thinning, and felling. Preparation of the ground, often involving heavy machinery, can result in much disturbance of habitats as well as a risk of sediments or peat particles being washed into water courses. This is particularly the case when new forestry access roads are being constructed. The drainage channels which are dug, and mounding of soil in some cases, also contribute to soil erosion and sedimentation of water courses by

peat particles or sediment. These drains also hasten the flow of water through the system, thus reducing the natural flood-buffering capacity.

Fertilisers used during or after planting can lead to excessive levels of nutrients, especially phosphorus, in water courses draining the region. When clear-felling is carried out, the resulting devastation of the landscape leaves many areas of bare soil or peat, again leading to soil erosion, sedimentation in water courses, and leaching of nutrients. The use of heavy machinery at various stages of the process also causes compaction of soil, resulting in rainwater pooling or flowing across the surface, rather than percolating naturally through the soil. Many of these issues result from the large-scale, industrialised nature of how this work is carried out in commercial forestry plantations.

Forestry plantations can also increase acidification of surface waters. One mechanism is 'pollutant scavenging', whereby tree canopies capture sulphur and nitrogen pollutants from the atmosphere, although this has decreased from a high point in the 1970s due to greater controls on emissions in more recent decades (Nisbet & Evans, 2014). The build-up of an acid layer of leaf litter on the floor of coniferous forestry plantations can also increase acidification in water draining from the site (Hornung, 1985). The prevalent use of spruce and other conifers often results in a thick layer of such litter. Plantations of this sort are usually dense, and once the trees have grown to a considerable size, they allow very little light through to the forest floor. For this reason, there is little or no natural woodland floor vegetation in many commercial forests, thus greatly reducing their potential to encourage biodiversity. Plantations of native species offer a much greater benefit to a large range of species.

Another matter to be considered is the layout of forestry plantations on the landscape. Natural woodlands tend to adapt to the contours and variations in the landscape, whereas planted forests tend to follow the boundaries of particular plots of land. This latter approach often results in abrupt changes between dense coniferous forestry and open land. When this is done on high ground, where it can be seen from a distance, the arrangement of straight lines and abrupt angles on hillsides can look quite bizarre.

As mentioned above, forestry makes up only a small percentage of land use in the Carra catchment. Most of this is operated by Coillte. There are four Coillte areas in close proximity to the lake itself – Moorehall, Tower Hill, Derrinrush and Cloonee. While these have in the past been managed as commercial plantations, and planted with non-native conifers, they have now been categorised as BioClass areas by Coillte, and are henceforth to be managed for biodiversity rather than for commercial interests. Biodiversity management plans have been prepared for these areas. Clear-felling is to be discontinued, and it is intended that a

gradual change to native species will be made on these sites. As well as these BioClass-designated areas, Coillte have two small, commercially managed, Coillte plantations in the catchment, one of 11.7 hectares near Ballintubber, and one of 7.7 acres at Newtown (Coillte, personal communication).

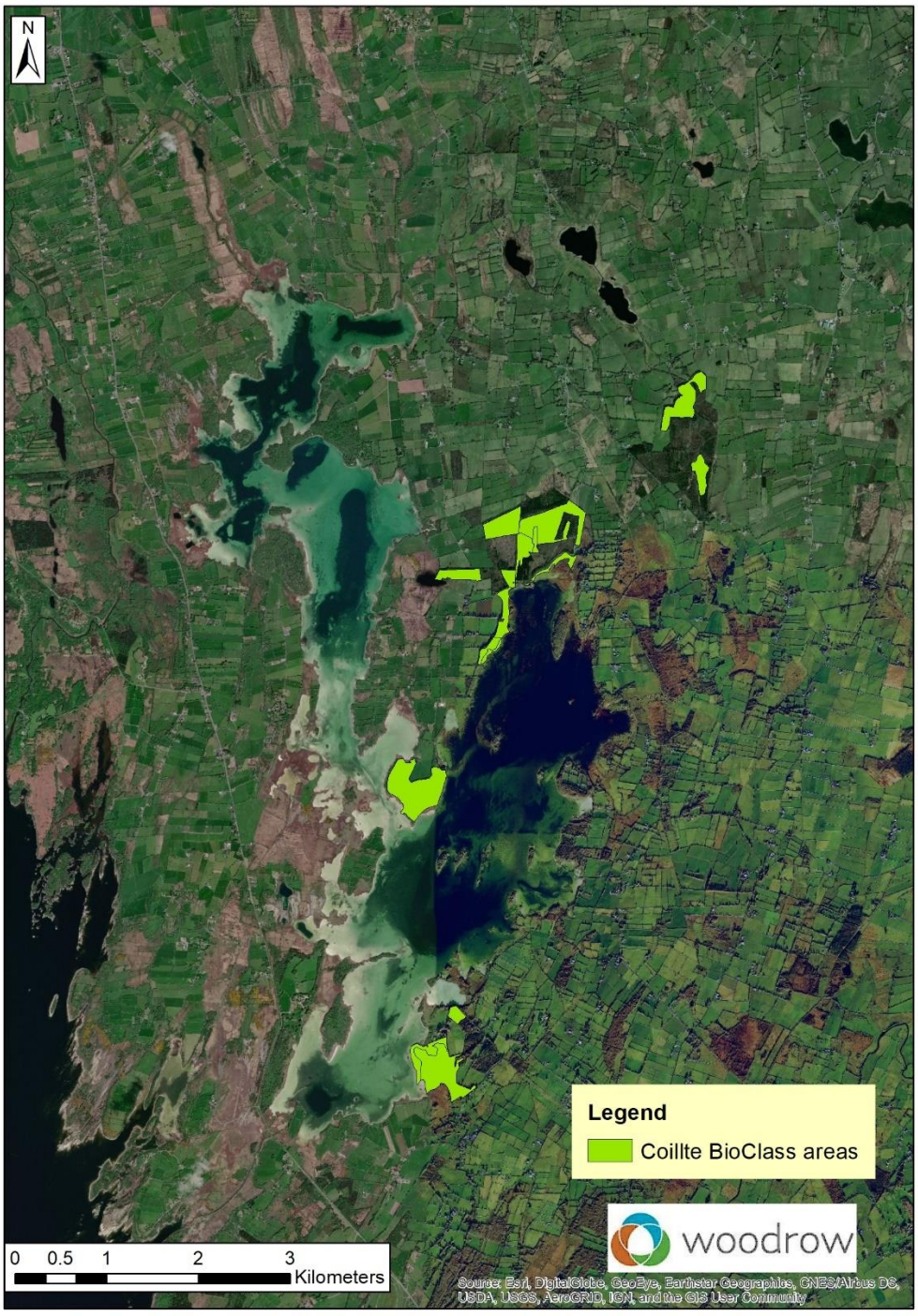


Figure 8: Coillte BioClass sites in the Lough Carra catchment.

Overall, therefore, it is considered that pressures on Lough Carra from forestry are decreasing, and likely to continue to do so as progress is made with the management of the Coillte BioClass areas. There is, however, a risk of nutrient release and sedimentation of water courses from the two remaining commercial sites, and this potential would increase if further land in the catchment were to be converted to commercial forestry plantations in the future. However, if areas within the catchment were to be converted from agricultural use to native woodland in the future, and if planting and management were done judiciously, this could act as a sink for nutrients and carbon, as well as enhancing biodiversity by providing habitats for a broad range of species.

3.4 TURF-CUTTING

Parts of the Carra catchment contain peat bogs. While aerial photographs show several areas of cutover bogs, it is difficult to give an estimate regarding how much turf-cutting takes place in the catchment at present. These areas include lands around Annie's, Clogher, and Knockaraha.

Peat bogs are generally low-nutrient systems, especially when they are mainly rain-fed (ombrotrophic) rather than receiving nutrients from groundwater. Nitrogen and other nutrients can be accumulated in *Sphagnum* bogs (Damman, 1988), although the processes of peat-formation tend to immobilise N so that it is not easily released while the accumulated peat layer is intact (Brock & Bregman, 1989). However, when bogs are drained and turf is cut, there is a high potential for peat particles and dissolved substances to be released into water courses. This is likely to cause problems with sedimentation in streams, which can have a negative effect on the breeding success of trout. There are surface water courses from the area of Clogher Bog which feed into Lough Carra, and water courses in the Annie's region which appear to pass close to areas of cutover bog. Therefore, turf cutting is considered a potential pressure on the water courses within the catchment.

3.5 INVASIVE SPECIES

Invasive species can be a threat to the natural biodiversity and ecological functioning of many habitats, and are a particular problem in freshwater systems in many countries around the world. In considering the threat of invasive species, one must consider the potential impacts of certain non-native species if they were to be introduced to Lough Carra, as well as the impacts already being caused by those species which are present.

Zebra Mussels (*Dreissena polymorpha*)

The Zebra mussel is now a major invasive pest species globally, and is present in large numbers in several Irish lakes. It is classed as a High-Impact invasive species in Ireland[3]. Zebra mussels have not yet been recorded in Lough Carra, but are present in other lakes in the region, including nearby in Lough Mask. It is crucial that Lough Carra is protected from infestation by this species. Zebras mussels are easily transferred between bodies of water on boats or fishing equipment. While there are signs in place to warn anglers about the spread of Zebra mussels, these have not been effective in other lakes and are not a realistic solution. The EPA has acknowledged that public information and biosecurity campaigns have not halted the spread of zebra mussels in Ireland (Tierney et al. 2015). There are a number of points where boats can enter Lough Carra, notably Brownstown, Moorehall and Castleburke.

If serious preventative measures are not taken, and if boats continue to be brought onto the lake having recently been in other water bodies, it is all but inevitable that zebra mussels will be introduced to Lough Carra, as they have been in so many other lakes around Ireland, and around the world. This problem is entirely foreseeable, and it can only be prevented, not cured at a later date. If zebra mussels are introduced to lough Carra, there is no way to get rid of them. This would be an ecological tragedy.

Fallow Deer (*Dama dama*)

In recent times, fallow deer have proliferated in the woodland and scrub areas around parts of Lough Carra (Huxley & Huxley, 2015). These are classed as a High-Impact invasive species in Ireland[4] and can do serious damage to woodland vegetation. Grimes (2007) showed that the presence of these animals in the woodlands around the lake was having a damaging effect on the natural woodland flora, and was leaving large areas of woodland floor almost bare of natural vegetation. In addition to direct damage to woodland plants, this stripping of vegetation can lead to soil erosion, and consequent nutrient pollution in the lake. In addition, deer drinking at streams or at the lakeshore can add nutrients directly to the water by urination or defecation. Carden et al. (2011) reported that fallow deer expanded their range in Ireland by 174% between 1978 and 2008, and can now be found in most counties. Culling has been carried out around the Lough Carra area, and fallow deer may be shot by licenced hunters during certain times of the year (1 September – 31 December for

[3] National Biodiversity Data Centre list of High Impact invasive species

[4] National Biodiversity Data Centre list of High Impact invasive species

males, 1 November – 28/29 February for females and antlerless animals). Nonetheless, they continue to persist, and are a significant pressure on parts of the Lough Carra catchment.

American Mink (*Neovison vison*)

American minks were brought into Ireland in the 1950s for commercial fur farming, and subsequently escaped, or were released, into the wild (Smal, 1988). Minks are related to stoats, pine martens and otters, and are semi-aquatic. They occur particularly around areas of freshwater, including lakes, pools or rivers. Minks are very able and effective predators, and hunt fish, invertebrates, small mammals and water birds (Deane & O'Gorman, 1969).

By the 1980s, American minks had become widespread in much of the country (Smal, 1988). They have been present in the Lough Carra region over the past few decades, where they have been observed to hunt various waterfowl and trout, and can be seen swimming from the mainland to the various islands on the lake (Huxley & Huxley, 2015). Minks in Ireland are classed as a High Impact invasive species[5]. They have found a niche in Irish habitats and their rapid spread throughout the country suggests they have few direct competitors or predators to restrict their numbers.

Greylag geese (*Anser anser*)

This is a migratory species, which overwinters in Ireland during winter (approximately November – April). However, a feral population is also present throughout the year. These geese can transfer nutrients and microbes to the water by grazing on terrestrial vegetation and later defecating by the lakeshore. This process of nutrient pollution by droppings being deposited beside or in a lake is known as guanotrophication. Dessborn et al. (2016) showed that geese could introduce significant amounts of phosphorus and nitrogen to lakes by feeding in the broader area and then returning to roost by the lake, although in farming areas the nutrient contribution from geese was thought to be a small fraction of the contribution from agriculture. Geese can also contribute to internal nutrient loading and turbidity in lakes by grubbing in the sediment and uprooting aquatic plants. Mathis & Kevern (1975) showed that geese, when present in large numbers, can also introduce chemical pollutants, such as lead and cadmium to water bodies, in their droppings.

None of this is to suggest that overwintering geese are a significant pressure on the lake, or that moderate numbers of geese are likely to do any damage; however, the feral population

5 National Biodiversity Data Centre list of High Impact invasive species

of greylag geese, because of its year-round presence, should not be allowed to increase unchecked.

Roach (*Rutilus rutilus*)

Roach have now been present in Lough Carra for some years (Huxley & Huxley, 2015), although there is a lack of information regarding their current numbers and status. Roach were recorded for the first time by IFI during the 2015 survey. Roach is regarded as a medium-impact invasive species in Ireland[6], and its presence in Lough Carra is therefore a cause for concern. A study of roach in Irish lakes (Hayden et al. 2014) found that this species is adaptable in terms of feeding strategy, altering its feeding behaviour according to the particular resources available, which likely contributes to its success in expanding its range in Irish lakes. This study found that roach showed elevated growth rates in lakes which were also most suitable for brown trout, such as Lough Ennell and Lough Corrib, and it was noted that these tended to be mainly alkaline lakes containing charophyte beds and high macroinvertebrate populations. This suggests that roach are likely to increase in Lough Carra also, particularly as they are able to achieve a fast growth rate and are capable of adapting successfully to a broad range of food types.

3.6 FLOODING & PUBLIC DRAINAGE

Flooding events can cause serious disruptions to the ecological functioning of ecosystems, as well as causing damage to property and buildings, and endangering people and livestock. Therefore, consideration should be given to flood management as part of the proposed Lough Carra project. Given the high rainfall in the area and the importance of groundwater influences on the lake, potential damage caused by flooding is a significant risk.

Flooding has the potential to exacerbate the core problem of nutrient pollution in Lough Carra, as well as the potential to increase sedimentation rates in the lake and its inflowing streams. This is because floods can greatly increase soil erosion, washing soil particles into water courses. This can result in serious influxes of nutrients to the system. This is particularly so in situations where natural habitats such as wetlands and woodlands have been removed or converted to farmland, as these ecological features can slow and contain water if they are left intact. The high permeability and groundwater vulnerability in much of

[6] National Biodiversity Data Centre list of Medium Impact invasive species

the Carra catchment means that high rainfall could result in water moving through the system very quickly.

There are also several OPW drains in the region (Figure 9), which channel water from surfaces such as roads into the lake. During heavy rainfall, this would quickly increase the flow into the lake. Such water is also expected to carry a significant sediment load, and may add to nutrient pollution. Arterial drainage is carried out under the Arterial Drainage Act (1945), which requires that drainage works are maintained in good repair and effective condition. Work carried out includes modification of natural water courses where this is considered necessary for modification of water flow. The expressed purpose of arterial drainage has been to improve land for agriculture. Drains are maintained using a standard 3 – 5 year rotational management approach. The lower stretch of Annie's River is managed by cutting of aquatic emergent vegetation by in-river machinery. Drainage channels in the region are cleared out periodically using a digger, with excavated material being spread on nearby land. OPW 'benefitted lands' includes a margin around the shore of Lough Carra. Channelisation of parts of the Cloondaver Stream and Annie's River has been identified as a significant pressure on the system (Douglas, 2019).

There is a weir on the Keel River, which drains Lough Carra, and this weir regulates to a certain degree the water level in the lake. Huxley & Huxley (2015) noted that parts of the Keel River were canalised in the 19th century, and that this resulted in a dropping of the lake's water level, as can be seen from elevated marl deposits which remain in certain places around the lake shore. The subsequent construction of the weir partly restored the water level, but not quite to its previous depth. The weir remains in place and still mitigates to an extent the effects of drainage lower down in the Mask/Corrib system.

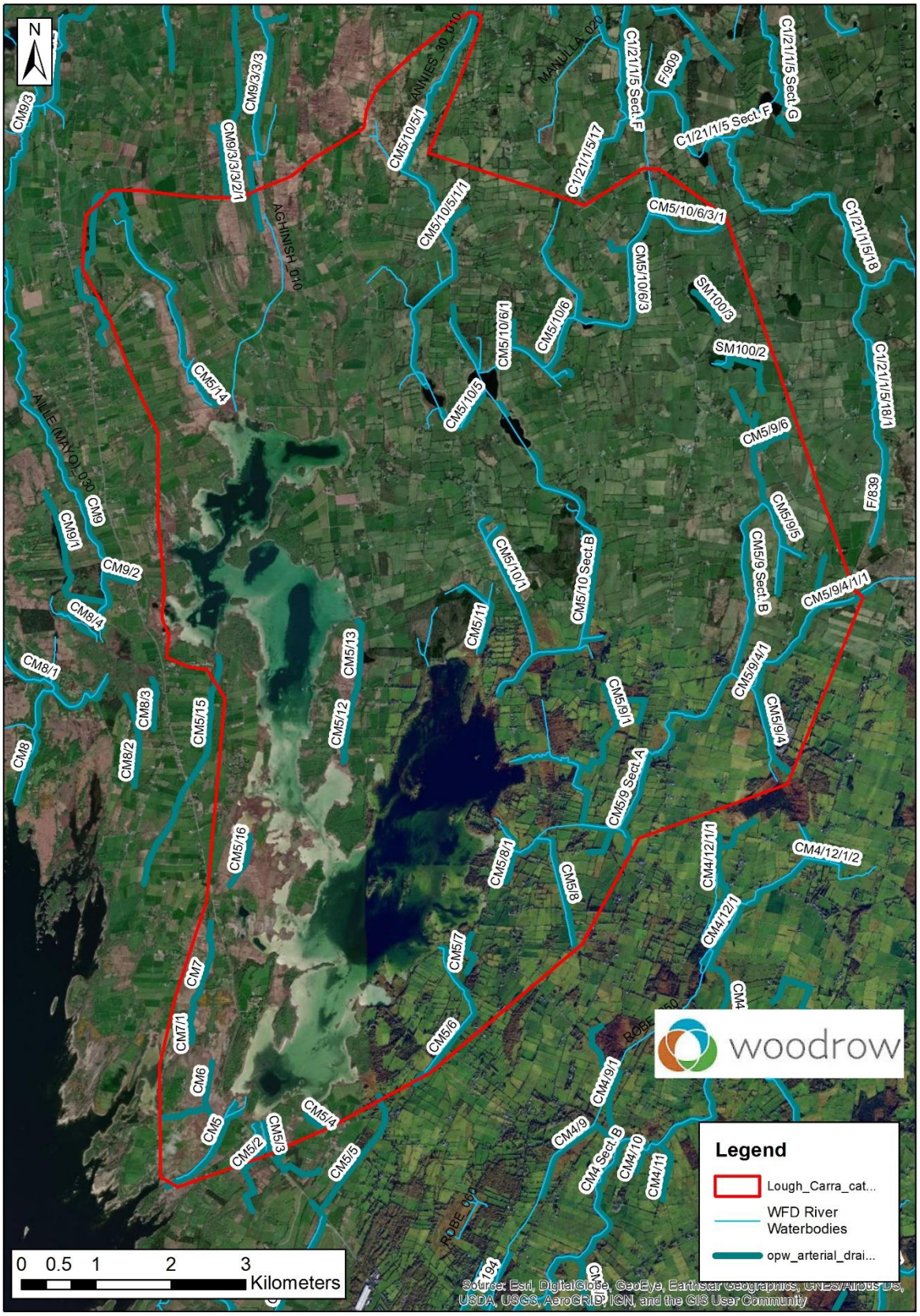


Figure 9: OPW arterial drains in the Carra Catchment, with management codes

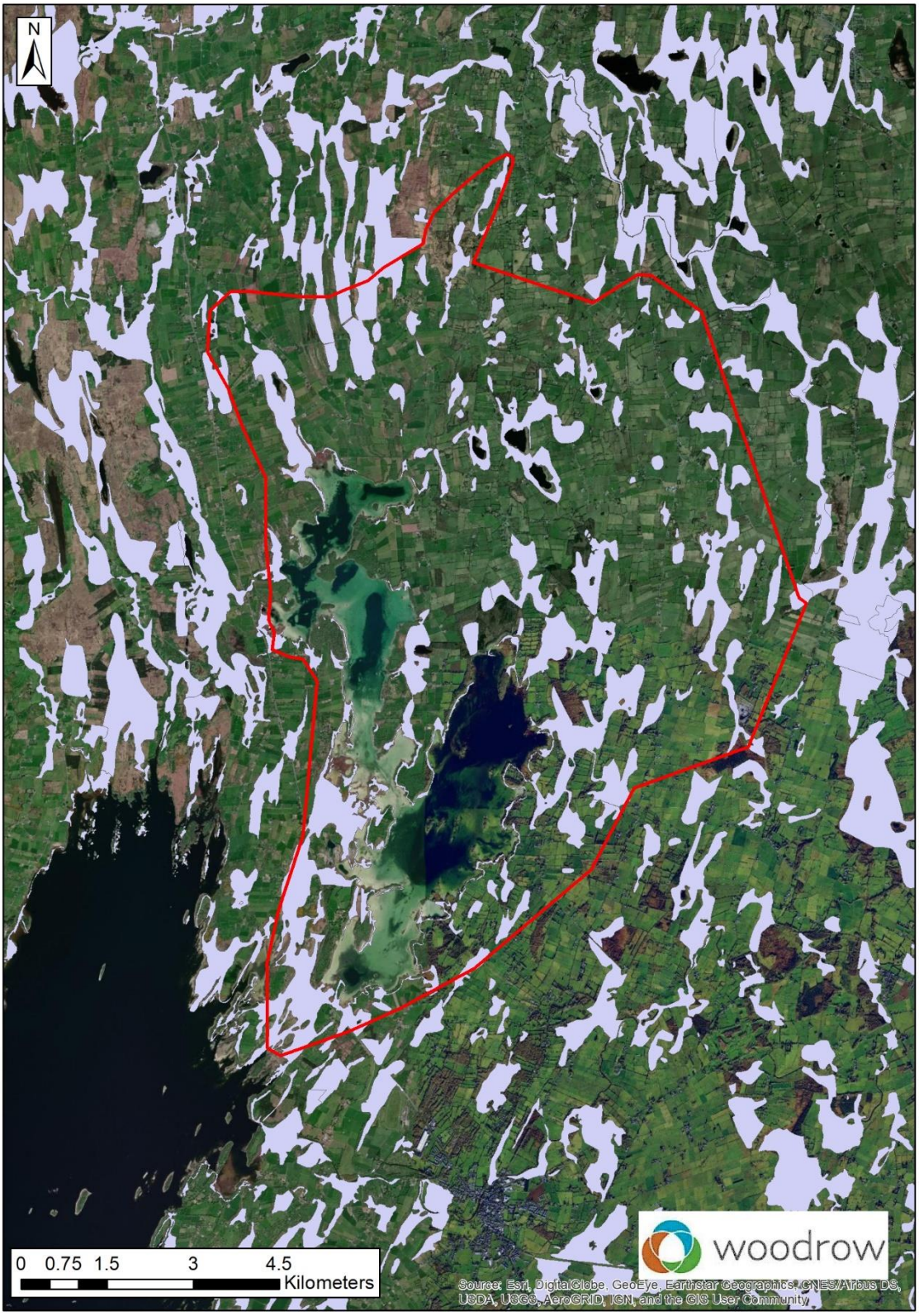


Figure 10: OPW 'benefitted lands' in the Lough Carra catchment

4 OPTIONS FOR ACTION

The following sections examine the options for action and make specific recommendations on each subject considered. In addition, a few general principles should be stated and affirmed at the outset.

1. The special habitats, landscape, and biodiversity of the Lough Carra area are the product of a long series of ancient ecological, evolutionary and geological processes. Nature has fashioned this place over an immensity of time – this richness should not now be thrown away in a brief flash of carelessness.

2. It should be acknowledged that a different model of farming is needed in the Lough Carra catchment if this project is to succeed. This is for the benefit of the lake's ecological communities, the surrounding environment, and the farmers themselves. It means moving the focus away from maximum grass production and selling products at low prices, to a system by which the natural habitats in the catchment are themselves seen as a worthwhile 'product'. It means introducing a system whereby farmers are valued as guardians and keepers of the land and its ecosystems. Food produced on these farms should be seen, and promoted, as a premium product, produced in an environmentally-sensitive manner - not as something which is churned out to be sold cheaply in supermarket chains. If farmers are to change their farming methods for the good of Lough Carra, they need to be paid properly for the food they produce. The project should help them to achieve this.

3. It should be understood and acknowledged that shallow temperate lakes, such as Lough Carra, have a complex system of interacting ecological mechanisms which can result in an abrupt change from a clear-water state with submerged vegetation to a state of phytoplankton dominance with dark, cloudy water, algal scums and impoverished benthic flora. When a change of this sort has occurred, such lakes are notoriously difficult to restore.

4. From the outset, the proposed project should be designed to be long-term, and capable of extension after the initial funding period. This involves (a) setting up bodies that can become self-sustaining, (b) building strong, long-term relationships with agencies including Teagasc, Coillte, and the National Parks & Wildlife Service (NPWS), and (c) demonstrating during the project that the efforts being made are

ambitious, scientifically informed, and competently carried out, such that they merit long-term funding from the Department of Agriculture, Food and the Marine (DAFM).

4.1 AGRICULTURE

4.1.1 AIMS

The main aim is to reduce nutrient pollution from agriculture, as part of the process of halting and reversing the ecological decline of Lough Carra. This will involve identifying and implementing means by which:

(a) the input of nutrients to the land can be reduced,

(b) nutrients can be recycled within farms rather than being lost to the waters of the catchment, and

(c) measures can be put in place to intercept nutrients before they reach water courses.

A further aim is to enhance habitats for biodiversity in the catchment, and to reduce other forms of pollution which may have a negative effect on wildlife. This will involve formulating and putting in place management plans in which the needs of wildlife are recognised, and in which the use of potentially damaging chemicals, such as herbicides, can be ended or minimised. Consideration will also need to be given to identifying means by which farms can continue to be lucrative as these changes are put in place. An additional aim is the protection of groundwater and drinking water in the region from any negative impacts caused by agriculture.

It is important to state that in order to be successful the proposed project must also be ambitious. While small peripheral changes may be initially more palatable to some stakeholders or participants, they will not be sufficient to solve the problem of nutrient pollution in Lough Carra.

4.1.2 FARMERS' ATTITUDES

A detailed survey of farmers in the Carra catchment was carried out in early 2020 by the Lough Carra Catchment Association, in collaboration with Woodrow Sustainable Solutions, in order to determine farmers' attitudes to a range of issues. Farmers were asked questions about their own farming activities, their level of concern for water quality and other environmental issues in the catchment, and their participation to date in other agri-

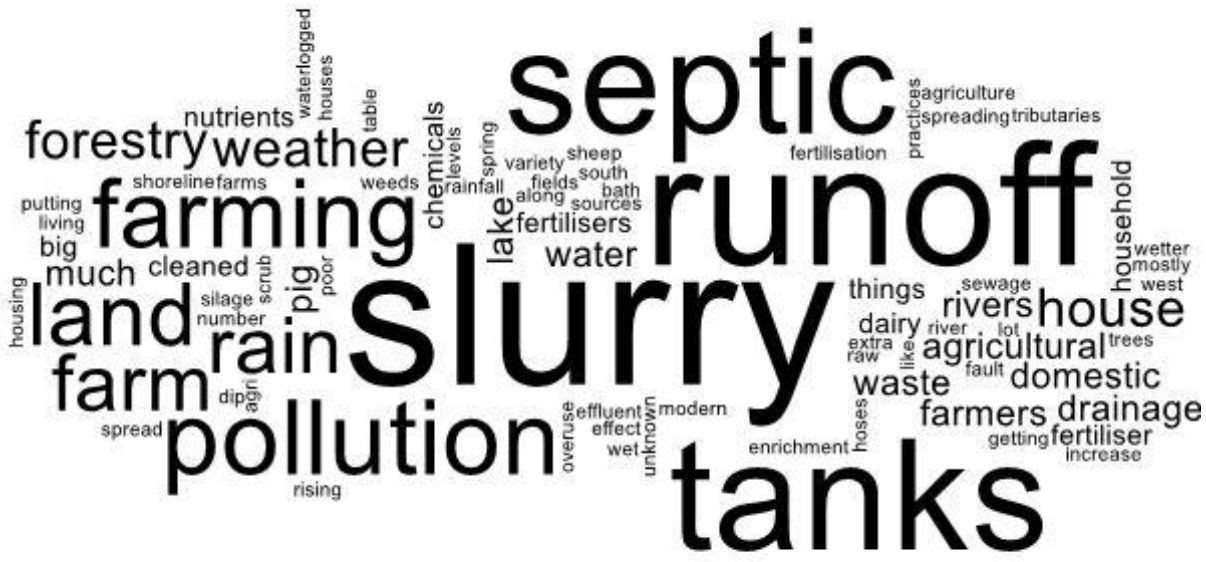
environmental schemes. Questions regarding the current models of farming in the area were included in the survey, and whether farmers felt that these were good for farmers and for the environment. Farmers were also asked about their main concerns, the sustainability and future of their farms, and their willingness to change to farming practices that would be more environmentally sensitive and sustainable in the long term. Ninety-four farmers were surveyed, representing approximately 20% of the farms in the catchment. The results of this survey are presented below in Appendix 2.

Several important conclusions can be drawn from these results. It is clear that farmers in the area are concerned about water quality, and have a good level of awareness about some of the main issues involved. When farmers were asked about the importance of maintaining high water quality standards in Lough Carra, 87% felt that this was 'very important'. When asked if farmers in the area should be concerned about the decline in the quality of water in the lake, 99% of the respondents answered 'yes'. A large number of respondents (82%) said that they had personally noticed signs of decline in the lake, such as green water, algal scum washing up on the shore, fewer mayflies, or changes in fish populations.

Farmers in the area also see the lake as an important part of the region's heritage. When asked if Lough Carra is important to the heritage and culture of this part of Co. Mayo, all 94 respondents (100%) said 'yes'. When asked if it is important for people in the area to value the lake and to keep its water in good condition, 83% said that this is 'very important', and a further 17% felt that this was 'slightly important'. Not a single respondent chose the 'not important' option. When farmers were asked about their main concerns at present, the responses showed the level of awareness that farmers have about environmental issues. When answering this question, farmers could pick from a range of potential concerns, and could also list any further concerns that they have. 'Damage to the environment' was chosen as the second most important concern, second only to 'cattle & sheep selling prices', and of higher concern than Brexit or the costs of fertilisers or chemicals. When farmers were asked how important it is for them that the natural environment of the area is maintained in good condition in the long term, 85% said that this is 'very important'.

Farmers also showed a high level of awareness when it comes to the causes of water quality in the lake. Participants in the survey were asked what they thought was the biggest threat to Lough Carra. Again, farmers could choose from a range of options as well as listing any further threats which they considered important. 'Nutrient runoff from farms' was considered the biggest threat to the lake, selected by over 87% of farmers. 'Septic tanks' were considered the second most important threat. When asked to give their own suggestions about what might be causing the decline in Lough Carra's water quality, farmers gave a

range of responses which are represented by the ‘word cloud’ below. The size of each word in the word cloud is a reflection of how often it was mentioned in the answers given to this question. Again, full details of the responses are given in Appendix 2. It is clear that slurry, nutrient runoff from land, and septic tanks are considered to be major causes of the lake’s decline.



Farmers also showed a willingness to take action to reduce environmental damage and to get involved in agri-environmental schemes. This is of crucial importance to the success of the proposed LIFE project, and the results of the survey are very positive in this regard. A large majority (95%) of farmers said that they already take some measures on their farms to protect the environment. A majority (55%) are already involved in agri-environmental schemes such as GLAS. A further 34% said that they have been involved in agri-environmental schemes in the past. A very large percentage of farmers (95%) agreed that schemes of this sort are a good way to help farmers to work in ways that are better for the natural environment. When asked if they were interested in options that could help improve the water quality in the lake, as well as providing farmers with a more sustainable and long-term way of making a living from farming, almost 77% said they were interested, with a further 22% ‘possibly’ interested. These responses, considered along with the results discussed above regarding farmers’ concerns about lake water quality, suggest that an agri-environmental scheme as part of the LIFE project would enjoy a high level of interest and participation.

Overall, the survey results portray farmers in the Lough Carra catchment as being interested in the quality of the environment in which they live, and willing to be pro-active when it comes to taking measures to protect their environment. An examination of the full survey results (see Appendix 2) shows the frustration that farmers feel when they see things being done wrongly in the area, such as slurry being spread at inappropriate times or septic tanks not being maintained well. Farmers are also aware that regulations, farming advice, and agricultural policies are not always sensible or well-informed, and that farmers themselves sometimes need to take responsibility for finding better ways to do things.

Finally, here are a few quotations from farmers who took part in the survey.

"More people should be concerned and more people should be getting involved."

"Madness spreading slurry in January, February & March when water table is high."

"Farmers obey rules, it's the rules that are not right."

"The septic tanks issue is critical and needs to be addressed immediately."

"Change farming methods."

"Public awareness & action."

4.1.3 PREVIOUS AND CURRENT AGRI-ENVIRONMENTAL SCHEMES

It is useful at this stage to consider previous projects, and to determine what useful lessons can be learned from them. Four results-based agri-environmental schemes are outlined here, to assess how they could inform a potential Carra LIFE project.

4.1.3.1 Pearl Mussel Project

This is an agri-environment programme which aims to improve the quality of watercourses, in order to conserve the endangered freshwater pearl mussel *Margaritifera margaritifera.* The programme is currently being run as a pilot scheme in eight freshwater pearl mussel catchments in Ireland. It is designed to be flexible, results-based, and adapted to specific areas. Habitat quality is assessed in various ways, and farmers are then paid in accordance with their degree of success in achieving the desired results.

The three factors assessed for habitat quality are peatland, grassland, and woodland/scrub, wherever these occur on participating farms. These are used as indicators, as it is recognised that the management of farmland has a direct influence on the streams and rivers in the catchment, and on their ecological quality. Fields or plots are graded using a scorecard, and are given points for various aspects of the habitat, such as the plant species present, soil condition, and any damaging activities that are evident. For plots that occupy floodplains, there is an additional assessment carried out for a separate payment which is intended to encourage farmers to maintain active floodplains.

A whole-farm assessment is then carried out, and an adjustment factor is calculated based on three criteria – watercourse condition, farm nutrient balance, and farmyard management. The score previously calculated based on the habitat quality assessment is then multiplied by this adjustment factor. This can increase or decrease the score.

Finally, any supporting actions carried out on the farm are considered. These are voluntary jobs which a farmer may choose to carry out, and include actions like providing good livestock drinking facilities, effective fencing, controlling invasive species, and blocking drains. Extra payments are available for these supporting actions.

The application process is designed to be simple and streamlined. Farmers express interest by filling in and submitting a single-page form. The Project Team prepares a Pearl Mussel Programme Farm Plan and issues a contract offer to the farmer, which the farmer can choose to accept. Participating farmers need to have a project advisor. A list of trained, approved advisors is provided by the project team, from which the farmer nominates an advisor. Assessment of farms is carried out annually. The advisor, working together with the

farmer, conducts a review of the habitats, farm operations, and farm management. A farm score, on which payment is based, is calculated, and recommendations are made for the future.

This Project is funded by the Department of Agriculture, Food and the Marine, as part of Ireland's Rural Development Programme 2014-2020, and has a budget of €10 million.

4.1.3.2 Burren LIFE project & Burren Programme

The Burren LIFE Project was a successful results-based agri-environmental scheme which ran from 2005 to 2009 in Co. Clare. This work is now continued by the subsequent Burren Programme. In the Burren Programme, farmers are paid both for specific actions undertaken and for environmental objectives achieved. In order to encourage maximum participation from farmers, participants are able to opt in or out of different parts of the programme, according to their own particular circumstances and the individual nature of their farms. They are then rewarded financially for the environmental benefits they deliver.

As with the pearl mussel programme, there is a panel of trained and approved farm advisors from which a farmer selects an advisor for his or her own farm. Each year, the advisor helps the farmer to prepare a short, simple farm plan for the year. The plan is tailored to the particular needs and circumstances of the farmer, and farmers can nominate particular conservation actions for their farms. Actions can include things like repairing stone walls, clearing encroaching scrub, restoring habitats, or providing improved feeding and drinking facilities for livestock. These works are co-funded by the farmer. When actions are completed and approved by the farm advisor, the farmer is paid accordingly.

In addition to payments arising from these specific actions, farmers are paid on the basis of the 'habitat health' of their land. Winterage pastures and lowland grasslands are eligible, and are scored by the farm advisor based on several factors, including grazing level, state of feeding and drinking areas, the plant communities, and the amount of bracken or scrub present. The payment made to the farmer is in proportion to the score given to the habitats on the land. Payment per hectare also varies with the area of land a farmer has in the scheme, so that small farmers are particularly incentivised.

The Burren LIFE Project and Burren Programme have resulted in many improvements in habitats and farm practices in the Burren, and have also resulted in farmers being valued for the role they now play in managing the biodiversity and wildlife on their land.

Burren LIFE was funded by the European Union LIFE Programme, and the Burren Programme now receives funding of €1 million annually from the Department of Agriculture,

Food and the Marine (DAFM), as well as extra funding or assistance from organisations including the National Parks & Wildlife Service, Teagasc, and the Heritage Council.

4.1.3.3 BRIDE Project

The acronym BRIDE stands for Biodiversity Regeneration in a Dairying Environment. This is an ongoing project in the south-west of Ireland, with a planned timescale of 2018 – 2022, and a total budget of €1,100,000. The project aims to conserve habitats and biodiversity on farmed land in the catchment of the Bride River, in counties Cork and Waterford. This is a region of the country where dairy farming is common. As dairy farming tends to be particularly intensive, there was a recognised need in the area for a project to enhance habitats for biodiversity.

The BRIDE Project was set up as a results-based agri-environmental project, which would take a 'landscape-scale' approach to biodiversity enhancement. This involves encouraging clusters of farmers in a certain area to implement a range of actions for habitat improvement. Farms which contain certain specified species or habitats, from lists prepared by the project managers, get higher priority than farms not known to contain these. The list of habitats includes Native Woodland, Reed Beds, Semi-Natural Grassland, Bog / Marsh and Ponds. The list of species includes a range of native birds, mammals and amphibians, as well as the marsh fritillary butterfly.

Farm-based actions in this project involve hedgerow management for nature, creation of biodiversity space along field margins, keeping winter stubble in place on land where cereal is grown, creating riverside buffer zones, planting and conserving areas of native woodland, and additional enhancement measures for wildlife such as installing bat boxes and nest boxes. Monitoring is carried out during the survey to measure the success or failure of these measures, by comparing the diversity of various groups – plants, vegetation groups, birds, bats and pollinators – to a baseline recorded before the commencement of the project.

In assessing success, the project uses a unit called BMA (Biodiversity Managed Area), and assigns a percentage to each farm based on how much of its area is managed for diversity. The overall objective is that all participating farms will have a BMA of at least 10% by the end of the project. A project ecologist draws up Biodiversity Management Plans for each farm, in consultation with the individual farmers. Like the Burren Programme, the BRIDE project is results-based. It also includes payments for capital costs, which are paid twice-yearly once particular approved improvement measures are put in place and inspected.

Protection of water courses is one aspect of the BRIDE project, with an emphasis on preventing slurry, fertilisers, herbicides and pesticides from reaching water courses. This is achieved partly by establishing buffer strips along water courses. However, the minimum size requirements for buffer strips in the BRIDE project are small. For rivers, a strip of at least 3 m must be used, and for streams, the buffer strip must be at least 2 m.

4.1.3.4 Danú - Project Plan for a Biological Farming Transition Programme

The Danú project is based on the concept of 'biological farming', which is described as a holistic approach to managing the soil, pastures and crops. This approach has a particularly strong emphasis on maintaining soils that are productive and have a high level of biological activity. This is in contrast to some modern conventional farming approaches, which can result in impoverished soil microbial and invertebrate communities, and physical problems such as compaction. In biological farming, an important aim is to produce high-quality, nutritious food, with minimal or no use of pesticides or herbicides. It is an approach which can be applied to both tillage and grassland farming.

The Danú project is designed as a transition programme for a group of farms in the midlands of Ireland, to help them to change over from conventional to biological farming. The project includes dairy, tillage and beef farmers. Initially, the current conventional farming practices on these farms are examined, to identify weaknesses in the way that soils, crops and pastures are being managed. A baseline is established by conducting various soil and biological tests, and control and trial plots set up on twelve farms. The new biological farming approach is used on the trial plots, whereas the control plots continue to be farmed conventionally, in accordance with guidelines and recommendations from Teagasc. Ongoing monitoring is then used to assess the changes that result from the new approach.

The Danú project is ongoing at present, with a timescale of 2018 – 2022, and a budget of €400,000. The main source of funding is the Irish Rural Development Programme (RDP), which is implemented by the Department of Agriculture, Food and the Marine.

4.1.4 OPTIONS FOR THE CARRA CATCHMENT

For the proposed Carra LIFE project to be successful, it will need the participation and good will of farmers in the catchment. The challenge, therefore, is to find a model of farming for the area which will achieve the aims of the project, while at the same time being acceptable to farmers. Ideally, the new system would help to improve and enrich the lives of farmers, as

well as improving and enriching the natural environment. A range of options is explored here, followed by specific recommendations.

4.1.4.1 Regenerative Farming

Regenerative farming is a system which has been proposed as a means of improving the natural environment as well as protecting the long-term sustainability of farms and prosperity for farmers. This approach seeks to promote good soil health, encourage biodiversity, and reduce fertiliser use, while still producing a good living for farmers. By fostering good soil quality, with organic matter added through nutrient recycling on the farm, and by encouraging natural predators of pest species, regenerative farmers spend less on expensive fertilisers and pesticides. There is also a tendency to market these products differently, as customers often see the value of high-quality produce which is produced in a safer and sustainable manner. Rhodes (2017), in a review of regenerative farming systems, emphasised the importance of nourishing and managing the soil, which in turn leads to better quality water, productivity, and biodiversity. Soil structure is maintained, and nutrients are naturally recycled back into the soil as organic matter is re-incorporated. As well as reducing the need for fertilisers, an essential component of this, in the context of Lough Carra, is preventing soil erosion and nutrient-loss through leaching.

While much of the Carra catchment consists of pasture, it is worth noting that regenerative methods also offer advantages where crops are grown, even on a small scale. The modern trend of reducing biodiversity and switching to monoculture crops allows insect pests to concentrate specifically on those crops while also removing their natural predators. This results in an increased dependency on pesticides, which in turn prevents a recovery of biodiversity. LaCanne & Lundgren (2018), in a series of crop trials on corn *Zea mays*, found that insect pest populations were very significantly higher on insecticide-treated farms compared to those managed as regenerative farms. In this study, it was found that the regenerative system was nearly twice as profitable as the conventional system; even though the regenerative trials produced a smaller yield, they were much cheaper to grow, partly because the conventional system required a large expenditure on fertilisers and pesticides.

Better flood management is another advantageous aspect of regenerative farming. As discussed later in this report, natural vegetation and humus-rich soil slows down the flow of excessive rainwater across the land and into drains and rivers, thereby preventing flooding further downstream. Rhodes (2017) noted that this natural water retention and aquifer recharge ameliorated both flooding and drought, as well as erosion of the soil, with consequent nutrient pollution.

In many ways, this approach to farming is simply common sense, and in some ways resembles the way that farming was carried out before the wide availability of fertilisers, pesticides and other chemical applications. However, by incorporating new knowledge and insights from recent research in areas like multi-species swards, this way of farming can now be done more profitably by integrating those research developments which are of most relevance to a particular situation, resulting in a more finely-tailored approach.

4.1.4.2 Multispecies swards

In recent years, research on multispecies swards has been carried out in order to see how they compare with conventional modern agricultural seed mixes. In a sense, this is not a new concept, because there was a time when all meadows and grasslands had multispecies swards, before the modern fashion for perennial ryegrass monocultures was established. Nyfeler et al. (2009) found that multispecies mixes produced much higher yields than monocultures, and that these yields could be achieved with considerably less fertiliser. This study used a mix of two grass species (*Lolium perenne* & *Dactylis glomerata*) and two clover species (*Trifolium pratense* & *Trifolium repens*). Mixtures of the four species produced up to twice the yield of the average of monocultures of the four species. Of particular relevance to the proposed Lough Carra project is that high yields could be achieved even with greatly reduced levels of nitrogen fertilisation. In some cases, it was found that mixtures could produce the same yield as grass monocultures even when nitrogen input was reduced by over 85%. It is thought that the difference can be explained by swards of higher species richness better utilising resources due to each species' ability to exploit a particular niche and by positive interactions between species. These findings are not surprising when one reflects that, in nature, natural selection drives species to efficiently exploit particular niches, and that, consequently, wild grasslands typically have mixtures of several species. An obvious conclusion from this is that grass monocultures, widely used in Irish farming today, are a major waste of money as well as being associated with nutrient pollution.

Recent research in Ireland, carried out as part of SmartGrass Project, has explored the benefits and effects of multi-species swards. Grace et al. (2018a) examined how mixed swards compared to grass monocultures for sheep farming in Ireland. This study used combinations of up to nine species (perennial ryegrass, timothy, cocksfoot, white clover, red clover, birdsfoot trefoil, plantain, chicory and yarrow), and also varied nitrogen input. Mixed swards resulted in better performance of both ewes and lambs. Ewes grazing on mixed swards maintained higher weight, including at the end of lactation, and higher Body Condition Score (BCS) than ewes on monocultures. Lambs grazing a mixed sward of six

species were heavier than lambs on monocultures (weighed at 14 weeks). Sheep grazing on mixed swards also had a reduced requirement for anthelmintics (drugs to treat flukes and tapeworms).

In a related study, Grace et al (2018b) examined the yield from mixed swards compared to grass monocultures, in terms of harvested dry mass (DM). Again, these plots were grazed by sheep. As in the study by Nyfeler (2009), it was found that the same yield (DM) could be obtained with reduced N-input. In addition, Cranston et al. (2015) reported that mixed swards that included chicory, plantain and clover had a higher nutritional value and were able to support higher rates of animal production than grass monocultures, in both cattle and sheep. Murphy et al. (2018) found that there were additional advantages to mixed swards in terms of greenhouse gas emissions. Nitrous oxide emissions were greatly reduced, while maintaining high yield (measured in terms of DM), in mixed swards with clover species, compared to grass monocultures.

"SMARTSWARD: Future Proofing Irish livestock sustainability"[7] is an ongoing project on the subject of multispecies grasslands, which is supported by the Department of Agriculture, Food and the Marine (DAFM) and others. The objective of this project is to further examine the potential role of multispecies swards in raising cattle and sheep in Ireland, in terms of reducing the input of nutrients applied to the land. The project is comparing the production potential of swards containing forage herbs, legumes and grasses to conventional agricultural swards which are based on perennial ryegrass. In addition to considering the production potential, the project aims to examine any effects the mixed sward might have on the quality of meat and milk produced, as well as on the amounts of greenhouse gasses emitted. Also included is a consideration of animal health effects, such as reduced worm burden. As this research is ongoing, it is expected that further details on the potential benefits of using swards of mixed herbage on Irish farms will be published over the next few years.

It is clear from the findings discussed above that mixed swards offer very substantial benefits in terms of nutrient reduction, with extra benefits from reduced cost of fertiliser, healthier animals, and lower greenhouse gas emissions. The fact that much of this research has been done in Ireland, and that most of the species involved are native to Ireland, gives extra confidence that this system would be successful on a broader scale in this country. Therefore, it is recommended that mixed swards, of the types used in the SmartGrass

[7] DAFM - SMARTSWARD: Future Proofing Irish livestock sustainability. Available online at: https://www.agriculture.gov.ie/research/fundedprojects/agriculture/grasscloverforagecropsfoodhorticulture/smartswardfutureproofingirishlivestocksustainability/

Project, be utilised in the proposed Lough Carra project, at least on a trial basis in some of the participating farms. Farmers should be informed about the benefits to be gained from this change, and advised on how best to carry it out. This can be done on a phased basis, as farmers may be understandably reluctant about trying a new system. Each participant could begin with a particular field or plot of land in the first year, and the relative success of this, compared with the rest of the farm, can be assessed along with the project farm adviser after the first year. The change to a multi-species sward will involve reseeding, and therefore will need to be subsidised significantly, as reseeding is a relatively expensive process. The seed mixtures trialled in the SmartGrass Project should be used, at least initially, as these have a proven track record in Irish conditions. If successful, as expected, it is likely that the benefits will be noted by other farmers in the region, who may wish to adopt the same practice. As a further benefit, the increased species diversity in the mixed swards will encourage biodiversity, and will be useful to insects such as bees.

A few precautions should be taken into account here. Glyphosate weed killers are widely recommended by Teagasc to kill existing vegetation in advance of reseeding. However, there are several problems with the use of glyphosate, including a potential risk of cancer. In 2015, the International Agency for Research on Cancer classified glyphosate as "probably carcinogenic to humans"[8]. It is worth noting that, at the time of writing, Bayer AG, the company which produces Roundup, is facing a fourth jury trial over allegations that Roundup causes cancer in humans. Three previous juries have already found the company liable for causing cancer, with damages of tens of millions of dollars awarded in each case. Bayer has now been served with many thousands of further claims relating to cancer in humans[9]. As discussed above, the Lough Carra region has generally very high groundwater vulnerability, and a high capacity for pollutants to move quickly through the catchment. Considering that Lough Carra is also a drinking water source, it should not be recommended that glyphosate be used to kill large areas of vegetation in the catchment.

However, Teagasc has also explored other options for reseeding without the use of weed killers. Clavin et al. (2017) described a series of trials carried out in Kilbeggan, Co. Westmeath, in which reseeding without the use of herbicides was carried out. These trials also investigated the use of both ploughed plots and minimum-cultivation plots. This is an important distinction, since ploughing of land can increase the risk of soil erosion if not carried out carefully and at an appropriate time. The report noted that minimum-cultivation

8 IARC Monograph on Glyphosate. Available at: https://www.iarc.fr/featured-news/media-centre-iarc-news-glyphosate/

9 https://www.nytimes.com/reuters/2020/01/25/business/24reuters-bayer-glyphosate-lawsuit-trial.html

approaches also offer other benefits – the most fertile soil remains at the surface where nutrients are needed, a faster return to grazing is possible after reseeding, it is usually cheaper than ploughing, and is particularly suitable in stony ground or on thin soils. However, ploughing and harrowing should not be ruled out as an option, as there may be circumstances in which a minimum-cultivation approach is not suitable. When good buffer zones are established, these would help to minimise the risk of soil runoff and nutrient loss. Individual, tailored advice will need to the given in each case by the project management team or farm advisor, regarding the optimal approach for each farm.

4.1.4.3 Stock Numbers

Most of the agriculture taking place in the Carra catchment involves livestock, especially cattle, with much of the area classed as pasture (Rolston & Ryder, 2018). An essential part of the project should be to reduce livestock numbers to sustainable levels which can be supported by the biomass produced locally on each farm, while also ensuring sufficient land is set aside for buffer zones and habitats for native species. Stocking rates should not exceed the sustainable carrying capacity of the land. This means not buying in extra feed for adult livestock (an exception is made for calves on dairy farms). The purpose of this is to minimise the nutrient intake from external sources, to cycle nutrients efficiently within the system, and to lose as little as possible into the water courses draining the land. Part of the effect of this will be to reduce the amount of slurry which is produced and which then needs to be spread. The particular stocking rate will depend to an extent on the individual farm, and the characteristics of the soil, so specifically-tailored advice will need to be given to participating farmers, and individual farm plans formulated, by the project management team or farm advisor, working along with the farmer. While a reduction in stocking numbers will reduce the nutrient input to the land, the resultant drop in soluble nutrient output is not expected to be immediate, as studies have shown that a lag period can ensue if soils are already high in nutrients, especially phosphorus (Capece et al. 2007).

4.1.4.4 Nutrient Planning

As noted above, the aim should be to encourage farmers to conserve and recycle nutrients within the system as much as possible. While many farmers already follow nutrient management plans prepared by Teagasc, it is clear that these are not effective in preventing nutrient pollution in Lough Carra. Therefore, the project management team or project farm advisors would provide tailored advice to participating farmers and put in place a specific plan for each farm, effectively replacing the existing Teagasc nutrient management plans.

Since Teagasc will be a partner in the proposed project, it is hoped that this transition can be done in partnership and co-operation with Teagasc, so that farmers are not given conflicting advice. The extensification measures proposed above will help reduce the amounts of slurry and manure to be spread. In addition, the following actions should be taken:

- Sampling and nutrient analysis of farm soils is a useful and economical procedure which should be the first step in putting together farm nutrient-management plans. This is already done in many cases when nutrient management plans are being prepared by Teagasc. The pH should also be measured in a range of locations on each farm, as this has implications for nutrient leaching (see below).

- Strict standards should be put in place regarding when and how manure and slurry can be stored and spread, and monitoring should be conducted throughout the project for compliance with these rules. Seasonal bans (which already have a legal basis in Ireland) are not sufficient, since leaching of nutrients can take place at any time of year. Before any spreading takes place, farmers should inspect their land to assess the soil water content, and fill in a short checklist. The weather forecast for the week ahead should also be checked, as spreading should only occur in dry weather. The amount of material to be spread at any one time should also be regulated, with specific limits set for each farm. Modern application methods for slurry (trailing shoe and injection systems) are better at minimising ammonia release than the older splash-plate method, but such machinery is expensive, and it would not be realistic to insist that these newer methods be used during the Carra project, unless the work is being done by a contractor. The recent farmers' attitudes survey (Appendix 2) shows that many farmers in the area are already aware of the problems associated with slurry, and are keen for changes to be made regarding slurry management in the catchment.

- The use of synthetic fertilisers (ammonium nitrate, superphosphate etc.) should be kept to an absolute minimum in the farm management plans, and phased out where possible. In addition to reducing nutrient run-off, this will encourage the re-establishment of semi-natural meadows and pastures, which are far more biodiverse than swards of agricultural grasses. In order to facilitate this, farmers who mow grass for hay or silage should be offered an incentive for taking only one cut per year, and doing so in late summer if possible. On land which is grazed, it is possible to develop very good species-rich grasslands if grazing pressure is kept to an appropriate level. In the Burren LIFE project, and the ensuing Burren Programme, the use of a "habitat health" checklist was found to be useful for assessing the development of species-rich grasslands, and payments to farmers

were proportional to the quality of the habitat. This method should be adopted and adapted for the Carra project.

- Lime (calcium carbonate in the form of powdered limestone) is often applied to agricultural land to increase the pH, and consequently to increase P-availability to plants (Haynes, 1982). In the Lough Carra context, there are pros and cons to this. If soil tests show that soil in a particular area has a combination of high-P and low-pH, liming could be used in the short term to increase P uptake and incorporation into plant biomass, leaving less to be leached from the soil. However, this practice would be phased out as P-concentration in the soil decreases, as liming has other environmental effects, including the release of carbon dioxide to the atmosphere. In addition, liming has different effects on different soil types, and does not always increase P-uptake (Tunney et al. 2010), and so any use of lime would have to be planned and monitored carefully. Once P levels in soil are reduced, and semi-natural grasslands established, no further liming would be carried out.

4.1.4.5 Buffer Zones & Fencing

In this report, a ‘buffer zone’ is a fenced-off area of natural or semi-natural vegetation bordering a stream, drain, river or the lake shore. When established in areas that are naturally wet, perhaps along a river or the lakeshore, a buffer zone may resemble a wetland, in terms of appearance and function. However, in much of the Lough Carra catchment, the natural waterside vegetation is likely to be composed of native trees (alder, birch, hawthorn, willow, rowan), herbaceous undergrowth, and low-growing bryophytes.

It is important to note that this concept of a buffer zone is very different from that used by many farm advisers, including some involved in Teagasc’s ASSAP initiative. For these, a buffer zone or ‘buffer strip’ is simply a narrow strip of grass at the edge of a field, to which slurry or fertiliser is not applied. These are not usually planted with native vegetation, and are not usually fenced off from the rest of the field. Indeed, under the current European Union Common Agricultural Policy (CAP), farmers lose out on subsidy payments if they take land out of agricultural use, and so the ‘buffer strip’ continues to be used for farming, often being grazed by livestock. This type of buffer strip is virtually useless for nutrient interception.

The use of buffer zones (in the sense of “fenced-off areas of natural or semi-natural vegetation bordering a stream, drain, river or the lake shore”) offers multiple benefits for the proposed project:

- They prevent livestock from entering the water, trampling the soil along the shore, and damaging shoreside vegetation. Restricting direct access by livestock is important to prevent nutrient contamination of the water. Regeneration of natural vegetation in buffer zones, after grazing is discontinued, will also contribute to the following buffer zone functions.
- They reduce the entry of sediment and soil particles to the lake. This includes soil particles which may be washed off adjacent cultivated land, as well as direct erosion of the lakeshore which occurs when the natural vegetation is removed for agricultural or other purposes.
- They prevent slurry and manure being spread close to water courses.
- They intercept nutrients which would otherwise enter the water from surrounding land. This is most effective when buffer zones have a cover of natural vegetation, especially trees and bushes. The size requirements for buffer zones, in order to be effective nutrient interceptors, are discussed below.
- Buffer zones, when well-planned, also provide wildlife corridors, refuges for wild animals, nesting sites for birds, and habitat space for plants, invertebrates and small mammals.

For buffer zones to be effective in performing these functions, they must be of a sufficient size. This has been an active area of research; reviews of the relevant literature are provided by Moss et al. (1996), Hickey & Doran (2004), and Correll (2005). The following useful principles, which should inform the Carra LIFE project, emerge from the various studies:

- Narrow buffer zones (5-10m wide) can be effective at removing sediment, but are not very effective at intercepting nutrients.
- Buffer zones which are fully covered with natural vegetation, especially native woody species, are best for removing both nutrients and sediment.
- Buffer zones are generally more successful at removing nitrogen than phosphorus, since they promote denitrification.
- Some studies have reported P-removal rates of over 80%, where buffer zones were > 13 m wide, but removal rates tend to be much lower when narrow buffer zones are used (Grismer et al. 2006; Dillaha et al. 1989).

- The ratio of buffer zone area to source area is important; there is no general consensus on the appropriate ratio, except that large source areas need large buffer areas, and some degree of proportionality should be applied.
- Buffer zones can get clogged with sediment and saturated with phosphorus if input rates are high, especially if the buffer area is a low percentage of the source area.
- Buffer zones are not very effective on steep land and are not recommended on slopes > 15° (Grismer et al. 2006).
- On slopes of > 8°, buffer zones should be a minimum of 15 m wide in order to be effective.
- While buffer zones around the lakeshore are important, it is at least as important to have adequate buffer zones along feeder streams and rivers.
- It is helpful to plant native tree saplings in a newly-established buffer zone to accelerate the reversion to natural vegetation.
- Fencing of buffer zones is important, not only to exclude livestock but also naturalised herbivores such as deer.

There is clearly a strong case for using buffer zones as part of the Carra LIFE project. However, this is not a substitute for reducing nutrient application to land, but an additional measure.

Taking these considerations into account, and also considering the practical needs of farmers for flexibility, it is proposed that the Carra LIFE project would offer the following two possibilities to participants in the scheme. Use of 'Prime' buffer zones would earn the farmer a higher rate of payment than 'Basic' buffer zones. Payments should be proportional to the length of buffer zones established, both to assist with fencing and planting of zones, and also to compensate for the loss of grazing/hay/silage land. Recommendations on the native species to be planted would be made by the Project Management Team, on a case by case basis, according to local conditions. All buffer zones should be effectively fenced against grazing animals, and planted with the recommended species.

1. Basic buffer zones – 12 m wide (or 15 m wide if overall slope is > 8°)
2. Prime buffer zones – 25 m wide

The Native Woodland Establishment Scheme offers payments to landowners for planting areas of native woodland, and this could act as an additional incentive for planting buffer zones with native trees. However, even if circumstances arise in which a buffer zone is not planted, it is still important that watercourses be fenced off from cattle and other livestock,

since the entry of animals to rivers and streams can lead to erosion of the banks, siltation of the watercourse, and nutrient pollution either by defecation/urination into the water, or by nutrients being released from eroded soil.

4.1.4.6 Cattle Breeds & Housing

In the Carra region, a mixture of beef and dairy cattle are raised. Dairy farmers primarily use Holstein-Friesian cows for high milk production. However, while these can give more milk per cow, their fodder-to-milk conversion rate is no higher than traditional breeds, so higher yields can only be sustained by feeding them energy-rich diets and concentrate supplements (Weller & Bowling, 2007). Modern continental cattle breeds, whether raised for beef or for dairy products, generally need to be housed during winter, unlike traditional breeds. The slatted sheds which are commonly used for indoor overwintering can have multiple issues. These include increased ammonia emissions (Swierstra et al. 1995), infectious disease (Madsen & Neilsen, 1985), reduced animal hygiene (Lowe et al. 2001), behavioural problems, and animal discomfort (Tuyttens, 2005). Of particular relevance in the present context is the problem of large quantities of liquid slurry building up in tanks, which then needs to be spread on the land (not always at appropriate times). The overwintering of cattle outdoors avoids this large build-up of concentrated nutrients. Another option is traditional dry-bedding, where straw is used; the resulting farmyard manure is more easily stored than liquid slurry (DAF, 2008). It has also been found that less intensive dairy farms, with lower rates of supplement concentrates being fed to cows, result in lower emissions of greenhouse gases (Casey & Holden, 2005).

In considering which breeds to choose, it would be worthwhile considering Irish cattle breeds. As part of the intensification of Irish farming, there has been a change to continental breeds in particular. Irish breeds, having been bred for Irish conditions, are generally hardier and require less housing, and often calve easier than more highly-bred, specialised breeds. These Irish breeds include Dexter, Moiled, and Kerry cattle (NRN, 2019) as well as Droimeann cattle. These are generally dual-purpose animals, used for both milk and beef, although the Kerry Cow, a relative of the Dexter, is considered primarily a milking breed. These cattle, particularly Dexter, are also less demanding in terms of fodder, often eating rushes and other plants which more specialised breeds find unattractive. In addition to savings in terms of housing and fodder, there are also subsidies available in the form of the Rare Breeds Preservation Grant and the Kerry Cattle Premium Scheme[10]

10 https://www.agriculture.gov.ie/farmingsectors/animalbreeding/

Where changes in breeds and changes in housing for livestock are concerned, it must be realised that these are substantial and long-term changes for a farmer, and would take time to implement, even when the will is there to make the change. Some farmers will have invested quite heavily in building slatted sheds and slurry tanks and, naturally, will want to see some return on that investment. In addition, there may be a lack of knowledge when it comes to alternative housing options and alternative cattle breeds, including any expected changes in veterinary and nutritional requirements. Even where a farmer is keen to introduce different breeds, this would likely be done gradually, on a phased basis.

Any changes in this regard would therefore have to be seen as part of a broader, long-term change in farming methods in the region. The first step would be for the LIFE project management team to provide information and advice to farmers on these options. Visits to farms where these alternative arrangements are already in place should be organised for farmers, to give them an opportunity to see for themselves how these changes can be made, and to chat to other farmers about the options. Talks and presentations should be organised for farmers in the Carra catchment, in which they can hear of the potential financial benefits of these changes, and where they can also be informed about the existing available payments, such as the Rare Breeds Preservation Grant.
A list of preferred breeds would then be drawn up by the project management team, and an additional payment made available to participating farmers to assist in the changeover to these breeds. This would be an optional change, as part of the proposed agri-environmental scheme, and should be available in a stepwise manner so that farmers have the flexibility to try out these changes and see how they work for them on their own farms, before committing to any larger-scale change-over. For those who do choose to phase out the use of slatted sheds, it should be remembered that these existing sheds can be converted to other uses, and therefore would not necessarily be a lost investment.

4.1.4.7 Native Woodland Areas

The establishment of native woodland areas on parts of existing farms would be beneficial in three important ways in the Carra catchment:

1. The establishment of native forests would lock up nutrients and carbon in the long term;
2. The forested areas would provide habitats for many species, including birds, mammals, invertebrates and plants;

3. The establishment of forested areas would result in less of the land being used for agriculture, and so would help with stock reduction and nutrient management, including a reduction in the amount of slurry produced on farms.

As there is currently a funding scheme available to assist land-owners in planting areas of native woodland, the Carra project should provide information about this scheme to landowners in the catchment, and encourage them to become involved. Educational endeavours are also important in informing farmers and land-owners about how to establish and manage areas of woodland. Workshops and short courses would be useful in this regard.

Some farmers have a negative attitude toward forestry because they equate it with large blocks of Sitka spruce *Picea sitchensis* or other non-native conifers. It should be emphasised, therefore, during educational events and in promotional literature, that an area of native woodland is very different in appearance and character to commercial coniferous forestry, and can include glades and paths. It should also be stressed that areas of woodland do not have to be extensive to be beneficial, and that even one hectare or less is worth planting. It should also be emphasised that, in order to be most successful, the mixture of species planted in a particular landholding should be appropriate for the local conditions in terms of soil moisture content, drainage, pH etc. The natural vegetation occurring in old hedgerows, nearby natural/semi-natural woodlands, or patches of semi-wild vegetation is often a good guide in this regard.

Sample or demonstration areas would be useful in showing land-owners the attractions and advantages of planting a small area of woodland. Educational guided walks would be especially useful in pointing out the intrinsic interest of the biodiversity that even a small patch of woodland can contain, as many people are quite unaware of this, and often think of woodland as closed and monotonous blocks of trees.

Approachable literature on native trees and woodland biodiversity, such as booklets, leaflets or posters would be useful for promotional purposes if given out in schools, at local meetings, and at talks or workshops. Visits to schools by a local biodiversity officer or other woodland enthusiast would be useful in encouraging children to become interested, especially if combined with nature walks. A scheme whereby each child in a school is presented with a small native sapling for planting at home would be an additional way to cultivate interest, and could perhaps be sponsored by a local business or organisation.

4.1.4.8 Technological Solutions

A useful solar-powered water pump, manufactured by SPS (Solar Pump Solutions), Co. Tipperary, was presented at the June 2019 Lough Carra Catchment Association meeting. This allows water to be pumped from the lake (or a river), across a buffer zone, to a drinking trough for livestock. The device can also power an electric fence. Different variants of the pump are available, depending on the gradient of land and required capacity. One of these pumps has already been installed as a demonstration model on a farm in the Lough Carra Catchment. In cases where provision of water for animals is required as a result of the new buffer zones, a once-off payment should be available to farmers to assist with the cost of buying a solar pump.

4.1.4.9 Nutrient Removal by Aquatic Plant Harvesting

The concept of removing nutrients from aquatic systems by harvesting plants has been discussed and researched as a means of remedying eutrophication (Livermore, 1954; Peterson et al. 1974; Quilliam et al, 2015). Since nutrients from lake water and sediments are taken up by aquatic plants and become incorporated into plant tissue, harvesting these plants and removing them should take nutrients out of the system. In the case of reeds such as *Phragmites australis*, which are now increasingly prevalent in Lough Carra, the foliage dies back in winter, with nutrients from these leaves returning to the root systems of the plants, and some nutrients also being released into the water from the decaying foliage (Mason & Bryant, 1975). As these emergent plants are rooted in the sediment, they can take up nutrients which have accumulated in the lake bed, rather than just taking nutrients from the water. This is particularly relevant in Lough Carra, because of the accumulated phosphorus in the lake sediments (Hobbs et al. 2005), which can become a nutrient source via internal loading, thus potentially slowing down restoration measures in the lake.

Mason & Bryant (1975) studied nutrient content and decomposition of *P. australis* and *Typha angustifolia* in the Norfolk Broads. *Phragmites* leaves began to yellow and die back in August, as flowering began. Dead stems were quite persistent, often remaining for at least two years. *Typha* produced leaves and flowered earlier in the year than *Phragmites*, and dead stems were less persistent, mostly disappearing within one year. Peak biomass for both *Phragmites* and *Typha* was reached in early August. Peak shoot density was reached by *Phragmites* in July, and by *Typha* in May. Total nitrogen content in *Phragmites* peaked during May, and again in August-September, reaching 40 – 45 mg/g (dry mass). Total phosphorus in *Phragmites* remained high from March to August (approximately 2 – 4 mg/g dry mass), and dropped very sharply after that. These figures indicate that the optimal time

for harvesting reeds (in order to maximise nutrient removal) would be July – August, assuming that reeds in Lough Carra are comparable to those in the Broads. Obviously, the harvested material would need to be removed, and could be composted elsewhere.

Peterson et al. (1974) experimented with large-scale plant harvesting to remove nutrients from a nutrient-polluted lake in Minnesota. The entire littoral zone of the lake, which comprised about one-third of the lake's surface area, was cut over repeatedly from June to September and emergent plant material removed. This vegetation contained 0.27 % P and 2.34 % N (mean values per unit dry mass). Information on the plant species involved is not available. Bartodziej et al. (2017) also did experimental work on another lake in Minnesota to examine phosphorus-removal by harvesting aquatic plants. In this case, cutting was done down to a depth of 30 cm underwater, and vegetation included *Chara* sp., *Nitella* sp., *Potamogeton pusillus, Ceratophyllum demersum* and *Elodea* sp. A total of 3600 kg of vegetation (dry mass) was removed during July and August, and amounted to an estimated 16.4 kg of total phosphorus. Modelling of nutrient pathways in the lake indicated that this equated to 53% of the TP inflow to the lake during the year of the study (2014). Nitrogen and other nutrients were not measured in this study. All harvested material was removed and composted.

Quilliam et al. (2015) pointed out that global shortages of nutrients used in synthetic fertilisers are expected by 2050, and that fertiliser prices have been progressively rising since the early 1990s due to the increasing scarcity and cost of ingredients. The authors proposed that the harvesting of aquatic vegetation can not only help to mitigate the effects of nutrient pollution on aquatic systems, but that the harvested material, when composted, can be a valuable resource by which nutrients can be recycled, and which can make farming more sustainable. The authors also noted that any harvesting system which would uproot aquatic plants has the potential to cause a sudden worsening of the effects of eutrophication by mobilising nutrients from the sediment, and also may result in pollutants being washed downstream. Leaving plants in place while regularly harvesting the emergent material also allows for ongoing nutrient removal, as rooted plants use up nutrients from the sediment. The harvested material can be shredded and composted for re-use as a soil conditioner, assuming that no troublesome invasive species are present.

In the Lough Carra context, the Office of Public Works (OPW) already has equipment which is used on Lough Carra for cutting vegetation in the Annie's region. Given that the OPW is a partner in the proposed LIFE application, a pilot project could be included in the proposal, to trial the harvesting of aquatic vegetation in Lough Carra. This would be done in consultation with the NPWS. The aims of the pilot study should include the following:

- selection of harvesting areas which are not considered of primary importance to birds or other wildlife; the extent of harvested areas should also be considered
- analysis of nutrient (especially P) content in harvested vegetation, preferably with a breakdown per species
- establishing a conveniently-located yard for the composting of harvested material, with concrete base, and no runoff outflow to water courses (composting can be done outdoors by stacking material in windrows with occasional turning and mixing done by a machine such as a JCB)
- as a precautionary measure, harvested material should be analysed for toxins - any accumulated pesticide residues as well as cyanotoxins which may result from cyanobacterial blooms in the lake or growth of periphyton on the plants
- as well as composting the material, it is possible for shredded aquatic vegetation to be fed directly to livestock (assuming no toxins are present); while this would not be palatable to some cattle, some traditional Irish breeds may well be prepared to eat it, as well as other animals such as goats. A trial of the use of harvested aquatic vegetation as a supplement to regular fodder would therefore be useful.

4.1.4.10 Existing Agri-Environmental Schemes

Farmers who are already part of the GLAS (Green Low-Carbon Agri-Environment Scheme) or ASSAP (Agricultural Sustainability Support and Advisory Programme) may already have made some progress toward some of the goals described above. The recent farmers' attitudes survey (Appendix 2) showed that 55% of those surveyed are presently part of such schemes. It is hoped that these farmers will also join the LIFE project, which would give them an extra financial incentive to continue making positive changes in their farming practices.

The Native Woodland Establishment Scheme offers substantial payments to landowners for planting areas of native woodland. Greater involvement by farmers in this scheme would be beneficial in three important ways in the Carra catchment, as outlined above. The Carra project should provide information about this scheme to landowners in the catchment, and encourage them to become involved.

4.1.4.11 Supporting Farmers Through Green Branding & Marketing

If farmers are willing to make these changes, and to produce food in an environmentally responsible manner, they deserve in turn to be paid well for what they produce, and the proposed project should help them to achieve this.

Some of the necessary changes, such as establishment of buffer zones, will result in less land area being available for grazing, hay, or silage. Others, such as the revised nutrient plans, may in some cases result in land being somewhat less productive in terms of harvested biomass. Farmers should be compensated through the proposed project for making these changes, and for the nature benefits achieved, as in previous results-based programmes.

However, there are also widespread concerns among farmers about the sustainability of their farms and the low prices they receive for their produce. Some farmers feel disrespected by retailers and consumers who, it is believed, concentrate purely on low prices rather than the quality of the food being sold. Some farmers are also worried at present about the prospect of competition from cheap meat being imported from other countries, and some are worried that Brexit might result in reduced markets for their products.

In order to gain the long-term trust and good will of farmers, and to encourage them to produce high-quality food in an environmentally responsible manner, it is proposed to develop a marketing strategy to maximise the value of their produce. As part of the proposed project, a farmers' co-operative group should be established, in order to create and promote a premium brand for marketing the food produced on farms which are part of the project. The brand would be given a name which emphasises the high quality and local origin of the food – something like "Carra Master Food Producers".

Thus, all locally-grown food, provided it is grown on farms which are fully compliant with the rules of the project, could be sold and promoted under a common brand, with shared labelling and packaging, which would therefore become recognised and regarded as a high-quality, "green" brand. It is hoped that this will also result in farmers feeling more respected and valued, as producers of healthy and locally-grown food.

The Carra food brand should be sold mainly in outlets in Co. Mayo, especially independent shops, cafes, restaurants and markets. The emphasis should not be on exporting products or selling them in large supermarket chains. Rather, they should be promoted as local, fresh foods, produced in quite small quantities, for local consumption, and it should be emphasised that the farmers are being paid a fair price for them. This will also allow customers in the area to enjoy supporting the local environment and the Carra project,

without having to make major behavioural changes. It is expected that these products would be (very broadly speaking) 30-40% more expensive than the “budget” versions sold in large supermarket chains. Premium brands are already sold by supermarkets (Tesco Finest Range, Super Valu Signature Range etc.) and are significantly more expensive than the cheaper versions. There is clearly a market for food that is presented as high-quality, or a bit more special than the standard product. Some Marks & Spencers products are seen in this way, and are accordingly rather expensive. The Carra products would have the extra appeal of being locally-produced, in an environmentally sensitive way.

In order to be eligible for participation in the co-operative group, farms should be registered as part of the proposed agri-environmental scheme, should be participating fully, and beginning to show measurable and observable results (e.g. buffer zones established, increased meadow biodiversity). After the initial set-up of the group, and the design of packaging and labels with financial assistance from the project, the group should gradually become self-financing. This should also allow the group to continue after the proposed project has concluded, and will therefore encourage farmers to continue farming in a responsible manner and to make high nature value farming their normal way of operating.

Local premium food brands have been successfully established elsewhere. Laois Partnership Company, with funding from LEADER, set up “Glenbarrow Farms”, with the intention of helping local farmers to receive better prices for their products by marketing them as a premium brand, and selling them locally. Agreements were made with local food processors in which high quality was assured, and farmers would receive a guaranteed price. Standards were defined, training was organised where needed, and inspection systems were put in place. While this project did not have environmental aims, a similar approach could be adapted to the Lough Carra situation. The Glenbarrow Farms group has set up farm walks to demonstrate best practice and to assure customers of the quality production methods. They have also worked with local cattle markets and cattle breeders to help farmers change over to breeds which are especially suitable for the local conditions. This approach could be especially worthwhile in the Carra region, as a change to hardier cattle breeds, which can be overwintered outdoors, would reduce the need for slatted sheds, with the associated problem of large quantities of liquid slurry building up in tanks, which then needs to be spread on the land.

Finally, it is proposed that enthusiastic farmers, who are already members of the LCCA, would themselves be involved in setting up and running the proposed group, again in an attempt to show that it is in the interests of farmers to be involved, and to encourage as much participation as possible.

4.1.5 RECOMMENDATIONS FOR THE CARRA CATCHMENT

An agri-environmental scheme should be established in the region, along the following lines:

1. A Project Management Team should be appointed, consisting of three people who will work on the project full-time for the five years of the LIFE project. This team should have expertise and experience in (a) groundwater management, (b) surface water and drainage, (c) farming for nature and agri-environmental projects, (d) the biodiversity and habitats of the Lough Carra region.

2. The project team should appoint approved farm advisors, ensuring that these are suitably trained and qualified, and sufficiently familiar with the range of land and farm types in the catchment. Since these advisors will work with farmers for the duration of the project, they should co-ordinate in taking a similar approach when assessing habitat quality or approving farm actions, and should apply the same standards across all farms in the project. The advisor's job is to work with farmers in an effort to achieve the aims of the project, in particular the reduction of nutrient pollution. Any potential conflicts of interests should be ruled out before an advisor is appointed.

3. Annual farm plans should be drawn up jointly by the farm advisor and the farmer. This allows for planned improvements year-on-year, and will encourage the farmer to successively improve farm practices in order to earn higher payments in subsequent years. It also allows for actions to be updated and adjusted if necessary, and adapted to the specific circumstances of each farm or each plot of land. Thus, the farmer and advisor can effectively deal with any issues as they arise.

4. A fundamental issue, which must be included in the annual farm plans, is animal stocking levels on farms. The aim should be to keep stocking numbers sufficiently low that nutrients can be cycled within the system as much as possible. The farm advisors will need to consider the particular farm, and its characteristics, in order to determine the appropriate stocking level in each case.

5. The project should be results-based, with farmers being paid a subsidy in accordance with the results they achieve. The range of potential results, how they are measured, and the financial rewards available for each, should be clearly and realistically defined at the outset. This gives the farmer clear goals to work toward, and a clear incentive for achieving these goals. From the point of view of the participating farmers, the protection of Lough Carra and its catchment should be seen as a 'product' from which they earn an income.

6. The project should be flexible. In order to facilitate farmers' involvement, it is important to provide them with options and opportunities, such as nominating particular actions for their farms, using their own skills and abilities, and deciding how much of their land they want to include in the scheme. It is important to foster an image of flexibility for the project, so farmers will feel they can become involved and achieve good results without needing to change everything about their working practices.

7. The grading systems used on farm plots should be explained clearly to each participant at the outset, and should be set out in a simple and straightforward fashion, avoiding unnecessary jargon. Thus, farmers will understand what should be accomplished, and will be able to notice for themselves when changes occur on their land, and how these are related to changes in farming methods.

8. Payments to farmers should be based on stepwise increases in scale, rather than an all-or-nothing system. This means that greater improvements in farming practices will be rewarded with larger payments. Thus, farmers who achieve the best results get the highest payments, but all participants are incentivised to make at least some improvements, even if they feel unable to attain the highest level.

9. The project should be progressive, in terms of helping participants to increase and develop their skills and abilities. Workshops and training courses should be organised, and farmers should be able to nominate training topics which they feel would help them achieve better results on their farms. These could include things like installing solar pumps, maintaining drinking tanks for livestock, planting buffer zones, building and maintaining stone walls, installing reed beds, or learning to identify plants, birds or insects. All training should have a strong practical element of fieldwork, and should not consist only of talks or lectures.

10. In addition to different levels of pay for different standards achieved, consideration should be given to setting different per-hectare payments depending on the area of land a farmer has, so that small farms achieve a higher per-hectare payment than large farms. This should help to make it worthwhile even for owners of small plots to become participants, while making the pay-outs more equitable overall.

11. The project should be non-bureaucratic. Farmers are generally discouraged by the idea of excessive form-filling and laborious bureaucracy. Paperwork should be brief, easy to understand, direct and to-the-point. If a participant has a particular question or concern, he or she should be able to telephone the farm advisor or project team to get a clear and straight answer, rather than having to trawl through copious documents.

12. The project should be area-specific; that is, it should be tailored to the specific habitats and issues of the Lough Carra catchment, and farm management plans should be drawn up with this in mind. Since reducing nutrient-pollution is the most important issue here, the assessment methods used for scoring farms in the project should have a strong focus on things like buffer zones, maintaining livestock-proof fences along watercourses, and botanical indicators of reduced nutrient input.

13. If the project is oversubscribed – that is, if the budget available is not enough to pay the number of farmers who wish to participate – farms should be prioritised by the project team based on their expected influence on the lake and its catchment. This could mean, for example, that a farm which adjoins the lakeshore or inflowing streams may be given higher priority to one which is more distant from the lake or to other water courses.

14. Broad-spectrum herbicides containing glyphosate should not be used for routine spraying of fields to kill off vegetation (e.g. prior to reseeding) by farmers participating in the proposed project, since glyphosate is known to be toxic to various aquatic species, and is considered potentially carcinogenic in humans. If glyphosate or other herbicides are used for targeting an invasive species, this should be done in a carefully-targeted way, by experienced professionals.

15. Multi-species swards, as trialled in Ireland and elsewhere, should be introduced as part of the Carra project. These have the potential to produce fodder with a much lower input of fertiliser than standard agricultural grass seed mixtures.

Participating farmers should have the option of re-seeding a part of the farm with a multi-species mix, based on the SmartGrass project, and should receive an extra payment to help fund the cost of this. Appropriate precautions should be taken while reseeding, in order to prevent soil erosion; these are discussed above.

16. Buffer zones should be established on land adjoining water courses and the lake shore. A buffer zone, in this sense, is an area of land which is planted with native woody vegetation, and fenced off from cattle or other stock. Two options for buffer zones are proposed:

- Basic buffer zones – 12 m wide (or 15 m wide if overall slope is > 8°)
- Prime buffer zones – 25 m wide

Two different levels of payment should be available, depending on which option a farmer chooses. This gives the farmer some flexibility in terms of how much land is used for a buffer zone.

17. When farm plans are being prepared by the farm advisors and farmers, consideration should be given to the matter of cattle breeds and cattle housing. As discussed above, slatted sheds are far from ideal, for a variety of reasons, and farmers should be encouraged to move away from using them. However, for some farmers this means either changing to alternative housing, or alternative cattle breeds. It is proposed that a payment would be available to assist farmers who opt to phase out their use of slatted sheds. Advice should also be provided by the farm advisor on the alternative options available.

18. It is important to help farmers to get a good price for food which is produced in a sustainable manner, on farms which are participating in the project. It is proposed, therefore, to establish a farmers' co-operative group in order to create and promote a premium brand for marketing the food produced on farms which are part of the project. The brand would be given a name which emphasises the high quality and local origin of the food – perhaps "Carra Master Food Producers". These locally-produced foods would then be sold and promoted under a common brand, with shared labelling and packaging, which would therefore become recognised and regarded as a high-quality, "green" brand.

4.2 DOMESTIC WASTE WATER & SEPTIC TANKS

4.2.1 AIMS

The main aim is to reduce nutrient pollution caused by septic tanks and domestic wastewater systems in the catchment, as part of the effort to halt nutrient pollution of Lough Carra. Another aim is to explore alternative or additional waste treatment systems which might also enhance habitats for biodiversity, such as wetlands or reed beds. An additional aim is the protection of groundwater and lake water from pollutants and pathogens which would have a negative impact on the quality of drinking water abstracted from the lake.

4.2.2 OPTIONS FOR THE CARRA CATCHMENT

The response to the 2019 Lough Carra Concept Note (the initial stage in the LIFE funding application) noted that septic tank improvements are potentially ineligible for funding as part of a LIFE project, since good septic tank management is a statutory responsibility. Since the correct functioning and maintenance of septic tanks is indeed a legislative requirement under the Water Services Act 2007 and the Water Services (Amendment) Act 2012, and there are already procedures in place for the inspection and regulation of tanks, the proposed Lough Carra project does not need to offer any extra subsidy or compensation for improvements to septic tanks. However, there is a need to see that the law is observed in this regard, and it would be beneficial for the local authority, in collaboration with the EPA, to increase the rate of septic tank inspections in the area. The domestic waste water National Inspection Plan 2018-2021 (EPA, 2018) outlines how septic tanks and domestic treatment systems are to be inspected, with the stated aim of protecting both human health and water quality. Inspections are carried out by local authority inspectors, who are appointed by the EPA. If a septic tank fails an inspection, the homeowner is given an advisory notice which specifies the problem, and describes the measures that need to be taken to fix it.

While the minimum number of inspections throughout the country under this plan is 1000, the number of inspections carried out in each local area is determined by the local authority, and the National Inspection Plan recommends that local authorities increase their rates of inspection in areas where there is evidence of septic tanks causing problems for human health or water quality. However, the aim is not to inspect all septic tanks, but rather to raise awareness and understanding, and encourage people to take responsibility for the correct functioning of their own domestic treatment systems. The proposed LIFE project could facilitate this by providing information to house owners in the catchment on the legislative

requirements, and also on practical matters such as desludging and the options available for constructing new systems.

4.2.2.1 Reed Beds & Constructed Wetlands

The option of installing constructed wetlands or reed beds is another possibility which offers strong potential for water purification and nutrient interception. While there are legislative requirements regarding the registration and functioning of septic tanks, and therefore these are not eligible for LIFE funding, reed beds are additional measures which help to filter and purify water, and provide additional benefits to biodiversity. Therefore, the LIFE project could provide guidance and information on how to set up reed bed systems, and offer a financial contribution to help with the cost of installation. A useful initiative which the project could include would be the establishment of a functioning constructed wetland on a demonstration site in the catchment, and the provision of workshops in order to teach interested people the techniques and principles of establishing a constructed wetland on a domestic scale.

When planned and built well, reed beds can be effective at removing both nutrients and fine particles from water. Reed beds are used in conjunction with a septic tank. Where a good septic tank is already in place, the reed bed can be established and connected to the existing tank. Where a new septic tank is being installed, the reed bed can be planned and planted at the same time.

Reed beds are suitable for treating various types of household waste water. This includes ‘black water’ (from toilets) as well as ‘grey water’ (from showers, baths and the kitchen sink). In most situations, these will be combined and routed to the septic tank. Solid waste settles in the septic tank, and the nutrient-enriched waste water flows on to the reed bed. Rainwater that runs off house roofs is also sometimes routed to a reed bed system, although this is hardly necessary and such water could well be collected and used for watering gardens and washing cars instead. The size a reed bed needs to be in a particular situation depends on the amount of effluent that will be routed through it, and also on the particular system (e.g. soil-based or gravel-based). As a very general guideline, a system of 100 m² in area would often accommodate the needs of a domestic household.

Soil-based or gravel-based constructed wetlands are two alternative systems to be considered. A soil-based system resembles a natural wetland, and has shallow water with reeds and other wetland plants growing in it. The waste water enters at one end and slowly filters through the system. In a gravel-based system, the waste water runs through a gravel bed in which the plants are growing, so there is usually no surface water. Either can be

effective when well-planned. Soil-based systems tend to take up more land area, but are also particularly good for wildlife, as they resemble natural wetlands.

A reed bed needs a liner at the base to separate the effluent and waste water from the surrounding groundwater. The liners are similar to pond liners and come in a variety of different materials and thicknesses. LDPE (low density polyethylene) or EPDM (ethylene propylene diene monomer) are often used. Raised earthen banks are built at the margins of the reed bed to support the edge of the liner and to contain the soil and water within. Alternatively, a low concrete wall is used in some situations.

4.2.2.2 Plants for use in constructed wetlands

Plants which grow in marshy habitats tend to have mechanisms which allow oxygen down to their roots. This can allow a variety of aerobic bacteria to live around the roots, and these break down pollutants in the effluent. The plants used in reed beds are species which naturally grow in wetlands. The main species used are as follows:

- Common reed - *Phragmites australis*
- Reedmace - *Typha latifolia*
- Yellow flag Iris – *Iris pseudacorus*
- Branched burr reed – *Sparganium erectum*
- Water mint – *Mentha aquatica*

The plants use up nutrients as they grow, and their roots, along with the gravel or soil and leaf litter, slow the flow of water, letting fine particles of sediment settle out, and also help to physically filter the water passing through. Constructed wetlands can be very effective at removing nitrogen from runoff water, but are somewhat more limited in their capacity to remove phosphorus (Vymazal, 2007). This is because they can eventually become saturated with phosphorus. However, a solution to this is to occasionally cut and remove vegetation or leaf litter. This can be composted for garden use, thereby recycling nutrients within the site.

Reedmace (*Typha latifolia*)

Common reed (*Phragmites australis*)

Water mint (*Mentha aquatica*)

Burr reed – *Sparganium erectum*

Yellow flag Iris (*Iris pseudacorus*)

4.2.2.3 Variations & Precedents

Different reed bed systems vary somewhat in layout and design, but the general procedure is as follows. The area is excavated and the soil set aside. An earthen embankment (or a concrete wall) is constructed around the edge. The liner is then put in place, and the piping is set up at either end. The soil is then replaced or, in the case of a gravel-based system, gravel of different grades is laid down in layers. The plants are then planted and allowed to establish before the outlet pipe from the septic tank is connected. Harty (2017b) estimated a price range of €3000 - €7000 for installing a reed bed for treating domestic effluent, but obviously the cost will vary depending on the capacity needed, the choice of materials used, and other factors.

Reed beds can also be used to treat farmyard runoff. While there are legal requirements in place for dealing with runoff from farmyards or milking parlours (DAFM, 2016), constructed wetlands can be incorporated as part of the solution. Integrated Constructed Wetlands (ICWs) and Constructed Farm Wetlands (CFWs) are variations on the standard reed bed which were developed to deal with runoff water from farmyards. Carty et al. (2008) and DEHLG (2010) give practical details on setting up a reed bed of this type, tailored for farmyard runoff.

Constructed wetlands have been used for municipal sewage treatment in several Irish counties and for smaller-scale domestic sewage treatment in many areas around the country (Harty, 2017a). The Anne Valley Project has made extensive use of constructed wetlands (Harrington et al. 2013; Everard, 2012) to improve water quality and increase amenity value in the Anne River system in County Waterford. Constructed wetlands have also been used as part of lake-restoration projects, such as at Lake Finjasjön, Sweden, which was badly nutrient polluted by sewage; a 30-hectare constructed wetland was used to intercept nutrients in effluent from the sewage treatment plant (Annadotter et al. 1999). The project (which also included dredging of sediment) was successful in reducing P concentrations, increasing water transparency, reducing algal blooms, and encouraging the regrowth of native phytobenthos. Harty (2017b) provides a practical guide to establishing various types of reed beds and constructed wetlands in Ireland.

4.3 FORESTRY

4.3.1 AIMS

The main aim is to identify and implement changes in forestry practices, in order to reduce nutrient pollution, sedimentation, and acidification of water courses in the catchment and of Lough Carra itself. This is part of the wider endeavour to change land management and land use in the area. An additional aim is to enhance habitats for biodiversity in the area. This is an area in which changes in forestry practice could be particularly beneficial, including for birds, bats, mammals, woodland plants, and invertebrates. Another aim is to improve the aesthetics of forestry in the area, as some plantations can look quite jarring and unnatural in the landscape, particularly when an area of non-native conifers abuts an area of open ground. A further aim is to address the negative view that many people, including many farmers, have of forestry, and to nurture an interest in native woodlands.

4.3.2 OPTIONS FOR THE CARRA CATCHMENT

Since almost all of the forestry plantations in the catchment are owned and operated by Coillte, Coillte will be an important partner when it comes to implementing these actions. While draft management plans have recently been drawn up for the four Coillte BioClass areas in the area (Moorehall, Tower Hill, Derrinrush and Cloonee), Coillte has not made the details of these available at present. However, Coillte has committed to managing these areas for biodiversity rather than for commercial interests. Actions for which Coillte would be

eligible as part of the LIFE project need to focus on enhancement measures for biodiversity, since nutrient-inception measures for forestry plantations are not considered eligible under the LIFE rules.

The proposed actions will focus on enhancing biodiversity at Tower Hill. Ash trees have previously been planted there to benefit the bat population, but Coillte has reported that these are now suffering from ash dieback, a serious fungal disease of ash trees. It is proposed, therefore, that these diseased ash trees be replaced with native oaks, as this would not only be of benefit to the bat population but also to a wide range of wildlife.

The structure of the building at Tower Hill is considered to be unsound, with a danger of the ground floor collapsing and potentially destroying the bat roost in the basement. Coillte has suggested that reinforcement work on this structure could be included as part of the LIFE project, in order to protect the bat population. This should be considered as part of the discussions for the revised 2020 Concept Note, but may well be prohibitively expensive unless additional funding can be secured from other sources.

4.4 TURF-CUTTING

4.4.1 AIMS

The aims are to identify and implement measures which would prevent or mitigate any damage that might result to water courses in the catchment from turf-cutting. In particular, this would include damage from peat particles being released into water courses, as well as potential impacts from dissolved humic substances and nutrients entering the system. Another aim is to improve peatland habitats for wildlife.

4.4.2 OPTIONS FOR THE CARRA CATCHMENT

While turf-cutting in the catchment may potentially contribute to the silting up of trout breeding areas, and would also result in loss of peatland habitats, it is probably not an important contributor to nutrient pollution. It is also a controversial subject among many people in rural areas, with the potential to alienate potential participants in other parts of the LIFE project. It is important that the LIFE project should not acquire a negative reputation in this regard. For these reasons, it would be counterproductive to attempt to prevent people cutting turf as part of the project.

Options, therefore, are limited to educational or advisory actions. Part of the overall aim of the project should be to increase awareness of wildlife and natural habitats in the area, and to emphasise how special the area is in this regard. This nurturing of local biodiversity should include a focus on the peatlands in the catchment, perhaps with a leaflet or booklet being produced, and posters highlighting the biodiversity of bogs which could be made available through the local schools. Organising guided bog biodiversity walks for children and adults would also help to increase awareness and interest.

If leaflets are produced, they could also include some guidelines for how the worst effects of turf-cutting can be mitigated. This could include not excavating new drains which connect to streams or other water courses, and considering filling in drains which may no longer be necessary. Even where drains are considered necessary, it may be possible to temporarily block them while the turf is being cut, in order to prevent a large influx of peat particles being released. Leaving a buffer of natural vegetation between drains/water courses and areas being cut would also be helpful in preventing peat particles entering the system.

4.5 INVASIVE SPECIES

4.5.1 AIMS

As noted above, invasive species are a serious threat to the functioning of natural ecosystems. The aims here are twofold: to prevent the introduction of invasive species, and to control the numbers of those which are already present.

Ireland does not have a good record of preventing invasive species introductions. Sixteen years ago, Hynes (2004), speaking of the threat that zebra mussels posed to Lough Corrib, Lough Mask and Lough Carra, made the following observation:

"*Given the relatively unpolluted nature of the Great Western Lakes, their biodiversity and their importance to the economic viability and leisure facilities of the region, it is clear that the introduction of the zebra mussel into these waters would represent an ecological calamity and an economic disaster."*

Since then, this 'ecological calamity' has fallen on Lough Corrib and Lough Mask, both of which are now infested with the species. Also, sadly, the Great Western Lakes can no longer be described as relatively unpolluted. It is imperative that Lough Carra be protected from zebra mussel introductions, and this should be an important aim of the LIFE project.

Regarding invasive species which are already present, the aim should be to control their numbers to the extent that the pressure they cause on native species is reduced as much as

possible. Ideally, one might aim to eliminate these species from the area, but this may not be possible in practice.

4.5.2 OPTIONS FOR THE CARRA CATCHMENT

4.5.2.1 National Parks & Wildlife Service - Control Measures

Part of the NPWS's contribution to the project will be the provision of a predator-control officer in the area. This will be a contractor, financed by the NPWS, whose presence in the catchment is intended to increase the measures taken to control non-native problem species. As noted above, the presence of fallow deer *Dama dama* and American mink *Neovison vison* has become a significant problem in the area. In addition to addressing these, the control officer will also take measures to reduce numbers of feral greylag geese *Anser anser* around the lake.

4.5.2.2 Preventing Zebra Mussel Introductions

As noted above, zebra mussels are easily introduced to lakes on boats, fishing equipment, and other surfaces which have recently been in contact with infested water bodies. Since Lough Carra is a major angling lake, there is a particular risk of introductions on anglers' boats, especially as zebra mussels are already present nearby in another important angling lake, Lough Mask. While small items such as paddleboards can be sterilised using a disinfectant such as Virkon Aquatic, a boat should not be put onto the lake without being held out of water for at least one month, if it has previously been in other lakes. Outboard motors can also contain a small volume of water, and again there is a danger of spreading zebra mussel larvae if a motor is used on a boat in Lough Carra after having previously been used on another lake.

It is preferable, therefore, that Lough Carra boats would remain on Lough Carra, and that other boats would not be put onto the lake. While a quarantine system can be envisaged, it is not thought to be workable due to the many access points to the lake. A system whereby a sticker or metal plate can be issued to Lough Carra boats has been proposed, so that Lough Carra boats can be easily recognised, and boats without this sticker or plate would not be allowed on the lake. It is thought that the angling clubs would be prepared to help enforce this system, as it is clearly in the interests of Lough Carra's ecological quality. This system would also apply to sailing boats, which would be allowed on the lake only with the correct Lough Carra insignia.

While boats are a major risk factor in spreading zebra mussels, zebra mussels can also be spread on all sorts of fishing equipment, waders, ropes, life jackets, toys, swimsuits, kayaks, canoes, water ski boards, and paddleboards. It would therefore be preferable that these are not brought into the lake if they have recently been used in any other water body, or that they would first be sterilised. Regular anglers in the region, who also fish on other lakes, should be encouraged to maintain two sets of fishing gear, one for use only in Lough Carra, the other for lakes infested by zebra mussels. It would also be useful if some local retailers could stock a suitable disinfectant such as Virkon Aquatic.

An information campaign, and new signs at appropriate places (Moorehall, Brownstown etc.) is needed to emphasise how serious this matter is, and how important it is to take precautions. Many of Lough Carra's kayakers are from clubs or from GMIT, and these are likely to be aware of the risks of spreading zebra mussels. However, an information campaign aimed at tourists, local landowners, and members of the public in general is important. This should include an information initiative in the local schools, so that children growing up in the region will be aware of the issue.

4.5.2.3 Non-native fish

Bottom-feeding coarse fish, such as carp or bream, should not be stocked in Lough Carra, as their feeding behaviour constantly stirs up sediments, resulting in nutrients (especially phosphorus) being released into the water. These fish feed on a variety of benthic invertebrates, in some cases sucking up mud in order to filter out food items. Not only does this help to release phosphorus into the water, it also destabilises the lakebed sediments, and disturbs young submerged plants. Roach is a related non-native species, which has been present in Lough Carra, at least in small numbers, for several years (Huxley & Huxley, 2015). While roach feeding behaviour is not as disruptive as that of carp, their presence in the lake is a concern. Roach is considered a medium-impact invasive species by the National Biodiversity Data Centre [11]. The EPA (Tierney et al. 2015) regards roach as an invasive species having a significant negative impact, which have been increasing their range within Ireland. Other fish species which are present in Lough Mask, and which may have a negative impact on Lough Carra if they find their way up over the weir on the Keel River, include rudd and bream (Huxley & Huxley, 2015).

11 NBDC list of medium-impact invasive species. Available at: https://www.biodiversityireland.ie/wordpress/wp-content/uploads/Invasives_taggedMediumImpact_2013RA-2.pdf

4.6 FLOODING & PUBLIC DRAINAGE

4.6.1 AIMS

Since flooding can cause disruptions to biological communities and the functioning of ecological systems, as well as being a hazard to people, the aim here is to manage the catchment in ways which minimise the risk. Since this is a whole-catchment issue, the solutions are far from simple, and would involve an integrated approach incorporating inputs from the local authority, farmers and landowners, the OPW, Coillte, Teagasc and the EPA.

4.6.2 OPTIONS FOR THE CARRA CATCHMENT

Since lakes are affected by activities taking place throughout the catchment, there has been an increasing focus in recent years on whole-catchment approaches, including for nutrient management and prevention of siltation. Flooding is another area in which management of the entire catchment is important. Natural Flood Management (NFM) is a term used to describe this whole-catchment approach as applied to the management of flood waters.

In Natural Flood Management, the soil, floodplains, natural or planted woodlands, wetlands and reedbeds are all taken into consideration, as well as the layout and morphology of streams and rivers in the catchment. The aim is to allow water to be stored temporarily within the system when input from rain is high, and then gradually released. Naturally, this is less damaging and disruptive than having large volumes of water suddenly surging through the whole system. Internationally, the NFM approach has been found to be both effective and cost-effective (Murray, 2017). Flooding also increases the transfer of nutrients and sediment from the land to the lake, and so flood-management should be part of the broader suite of actions intended to reduce nutrient pollution in Lough Carra.

In 2019, the Inishowen Rivers Trust, Co. Donegal initiated a study into the potential for using Natural Flood Management measures in the Inishowen area. While the report from this study, headed by Professor Mary Bourke of Trinity College Dublin, is not yet available, a presentation was given (Bourke, 2018), in which she noted the importance of developing good flood management practices because the usual flooding season is becoming more extended in Ireland, and the country is expected to be increasingly subject to more severe winter and spring flooding.

A number of recent publications have focused on Natural Flood Management. Murray (2017) described the potential benefits to be gained from such measures, and made recommendations for their implementation in Ireland (see below). Forbes et al (2015) produced a report for the Scottish Environmental Protection Agency (SEPA), which also

stressed the need for better natural flood management in the light of predicted increases in the frequency and severity of floods due to climate change. Rooney (2016) emphasised the need for greater sustainable drainage systems (SuDS) in urban areas. A recent Yorkshire Dales National Park Authority handbook (YDNPA, 2017) offers a range of practical solutions for implementation by farmers and landowners. The Irish Department of Agriculture, Food & the Marine recently published a guide to ways in which natural woodland areas can contribute to good water quality and the provision of 'ecosystem services' such as natural flood management (DAFM, 2018). The use of native woodlands to improve and maintain water quality has also been trialled under the KerryLIFE project.

These various documents and projects provide extensive details on many aspects of Natural Flood Management. A number of important conclusions, which are of particular relevance to Lough Carra, can be extracted as follows:

- Dredging of rivers and schemes (often referred to as arterial drainage) tends to worsen downstream flooding and so has a negative impact on the catchment. It is also disruptive to aquatic ecosystems, and very expensive. Dredging has been carried out extensively in the Carra, Mask and Corrib system over many years.
- Compaction of land by machinery makes the soil less permeable, which results in water running across the surface of the land after heavy rain. This causes soil erosion, leading to nutrient pollution and sedimentation in water courses.
- Spraying vegetation in fields using broad-spectrum herbicides (such as glyphosate) leaves the soil bare and vulnerable to being washed into water courses after rain. The practice of leaving areas of soil bare in winter causes the same problem.
- Native woodlands and areas of semi-natural vegetation, such as scrub, tend to slow down water movement, and their roots also help keep the soil open and non-compacted. Therefore, areas of natural woodland are generally useful for NFM. Clearing land of woodland and scrub has the opposite effect.
- However, coniferous forestry plantations are generally counter-productive, as they usually have drains to direct water toward watercourses. They also tend to lack natural woodland floor vegetation, which would otherwise help in slowing water flow in times of flooding. Furthermore, the fertilisers which are used in planted commercial forests can contribute to nutrient pollution.

- Hedgerows are useful in slowing down water flow across land, and in stabilising soil along field margins and ditches. Retention and maintenance of existing hedges, and planting of new hedges, using native plants, is important for NFM.
- Bogs are important in several ways, including in flood management. A functioning peatland can hold large volumes of water and so helps to regulate the controlled flow of water through the system by acting as a reservoir. Therefore, peatland restoration is a worthy activity, and also contributes to the general biodiversity of the area, cuts down on erosion, reduces sedimentation, and facilitates long-term carbon storage.
- Hydrological modelling, by which the flow of water through the system is mapped and quantified, is useful in designing an overall management plan for a catchment. However, the lack of a completed hydrological model is no reason not to progress with the various improvement measures discussed here, as lots of small improvements throughout the catchment will contribute to the overall effect of improved flood management, even in the absence of a pre-existing model.
- A river floodplain is a part of the river; constructing a building in a floodplain is effectively placing the building in the river, and is to be discouraged.
- Physical changes to landscape can redirect the flow of water from its previous course. This is something to keep in mind when new developments are planned, especially those which involve extensive earthworks.
- Where wetlands have been altered, drained, or filled in to facilitate agriculture or construction, the natural flood buffering capacity of these systems is lost. Therefore, it is important that that practice is discontinued. The restoration of wetlands, and the regeneration of the natural vegetation, is of great benefit to NFM. The construction of reed beds can also contribute to this. Wetlands and reed beds also have benefits for biodiversity, notably birds.
- Roads, car parks, paved areas, concrete yards and buildings all prevent rainwater from soaking into the soil, and therefore result in runoff water, which must be diverted somewhere. This water often ends up in natural water courses. Not only does this increase the flow of water through the system after heavy rain, it also results in sediment and dust being washed into the system, as well as any animal dung, leaked oil, or spilled chemicals which may be in the area. In some cases, constructed wetlands (reed beds) can be useful as filters for such runoff, although they can become clogged up with sediment if there is a high percentage of solid material in the runoff water.

It is clear that, in order for Natural Flood Management to work effectively on a large scale, there is a need for various agencies and stakeholders to co-operate and to form a joint plan for the system, and to communicate effectively throughout the implementation of the plan. This should include the local authority (Co. Council), the Office of Public Works (OPW), contractors carrying out road construction or maintenance, companies which construct concrete yards or paved drives, the Environmental Protection Agency (EPA), and any businesses which have large areas of concrete or other impervious surfaces from which water is allowed to drain.

5 PROJECT PARTNERS AND ASSOCIATED BENEFICIARIES

The success of the Lough Carra LIFE Project will depend on the involvement and co-operation of several stakeholders. As discussed above in the introductory sections, stakeholders are listed either as associated beneficiaries or partners for the purposes of the LIFE application.

The preparation of the Concept Note will require the agreement of each of these parties to be involved, and an indication will be given in the Concept Note on the role and contribution of each. When the full application is being prepared, assuming that the Concept Note has been successfully approved, a more detailed and costed plan for the contribution of each party will be drawn up. The current status of each party is summarised here.

5.1 Co-ordinating Beneficiary

5.1.1 Mayo County Council

Mayo County Council has agreed to be the Co-ordinating Beneficiary. Mayo County Council is the local authority, and has statutory responsibility for a number of public services in the county. The Council implements an Environmental Monitoring Programme which includes lakes, rivers and bathing waters, as well as inspections of septic tanks and domestic water treatment systems. The Council will lead the project and take responsibility for its overall management, including actions for advisory and management groups, promotion of the project, project headquarters, project team recruitment, meetings and activity reports, and will be responsible for implementing some of the project actions.

5.2 Associated Beneficiaries

5.2.1 Lough Carra Catchment Association (LCCA)

The Lough Carra Catchment Association is the group which conceived the LIFE Project bid, and which has been most involved in promoting the idea, liaising with potential partners, and raising public awareness of issues in the lake and catchment. The group will undertake

specific scientific and community aspects of the project, and will be involved in educational works in the area.

5.2.2 National Parks and Wildlife Service (NPWS)

The National Parks & Wildlife Service is responsible for implementing the EU Nature Directives, and will be the leading party on aspects of the LIFE Project which relate to Natura 2000 sites, nationally designated features, and ecological survey aspects of the project. They will identify suitable ecological monitoring methodologies and will lead on habitat and invasive species management, as part of their 'masterplan' for the region. As part of the NPWS contribution, they will employ a predator control contractor to deal with the issue of invasive species in the area.

5.2.3 Geological Survey Ireland (GSI)

Geological Survey Ireland will take the lead on groundwater investigations within the catchment, and the identification of specific groundwater-related pressures to be addressed through the project. GSI will also employ the Groundwater Officer.

5.2.4 Environmental Protection Agency (EPA)

The EPA will provide information and data from the National Monitoring Programme, and datasets from Catchment Characterisation under the WFD. They will be involved in the advisory group, and have given an initial indication that they will undertake some of the water chemistry monitoring as part of their contribution to the project.

5.2.5 Coillte

Coillte is willing to be an associated beneficiary in the project, and has BioForest biodiversity management plans in place for Moorehall, Tower Hill, Cloonee and Derrinrush, all of which will now be managed for biodiversity. Coillte will also carry out additional biodiversity enhancement measures for bats at Tower Hill, and are investigating the possibility of reinforcement work on the structure of Moorehall in order to protect the bat roost which is present in the basement.

5.3 Project Partners

5.3.1 Department of Agriculture, Food and the Marine (DAFM)

The Department of Agriculture, Food and the Marine (DAFM) has indicated its support for the project and has committed to considering incorporating measures coming from the project into future agri-environment programmes. Discussions with DAFM are ongoing with a view to their being an Associated Beneficiary and further involvement.

5.3.2 The Local Authority Waters Programme (LAWPRO)

The Local Authority Waters Programme will provide support and advice on catchment characterisation, provide results of local catchment assessment findings, and provide recommendations for specific actions in parts of the catchment most impacted by nutrient pollution.

5.3.3 Teagasc

Teagasc has agreed to be a partner in the 2020 application. It is hoped that Teagasc will co-ordinate with the project management team so that farmers are not given conflicting advice on nutrient management plans and other aspects of the project. While the environmental protection measures in Teagasc's ASSAP programme are not sufficient to protect the catchment and the lake from the negative impacts of agriculture, involvement in the LIFE Project will allow them to build on their work in this area.

5.3.4 Office of Public Works (OPW)

The Office of Public Works will again be a partner in the proposed project, and will trial different approaches to channel maintenance, in an attempt to reduce nutrient inputs into watercourses in the catchment, and to reduce sedimentation. The OPW has also expressed an interest in establishing constructed wetlands on a trial basis on some of its benefitted lands around the lake.

5.3.5 Vincent Wildlife Trust

The Vincent Wildlife Trust is the leading expert organisation on lesser horseshoe bats in Ireland and in Moore Hall. The trust has affirmed its willingness to participate in the project, and will provide technical advice on enhancement measures to benefit bat species.

5.3.6 Inland Fisheries Ireland (IFI)

Inland Fisheries Ireland will provide local fisheries information, and will be a link to angling clubs. IFI carries out monitoring of the trout population in Lough Carra, and this will form a part of the ongoing monitoring effort in the lake.

5.3.7 National Federation of Group Water Schemes (NFGWS)

The National Federation of Group Water Schemes, which abstracts water for 1100 houses in Lough Carra, has confirmed its interest in the project, and is keen to be a partner in the 2020 application. NFGWS will take part in promoting source protection measures and good practice to both land use managers and water users.

6 HOW DO WE MEASURE SUCCESS?

6.1 Monitoring

The following sections describe various types of environmental monitoring, both that which is already carried out in the catchment and proposed new monitoring measures to be implemented as part of the LIFE Project.

6.1.1 Reasons for Monitoring

The proposed project would involve several changes to land management and nutrient use in the catchment. The degree of success/failure of these measures must be evaluated for a number of reasons:

- Farmers can be compensated for changes made and results accomplished.
- The most successful strategies can be identified and rolled out on a broader basis.
- Nutrient management plans for individual farms can be refined and improved if required, and the knowledge gained can be used to inform the broader implementation of such plans.
- Value for the money invested in the project can be measured and verified, and members of the public can see that results are being achieved.
- Improvements in habitat diversity, ecological quality and water quality can be recognised and verified.
- It can be demonstrated to other potential sources of funding, such as the Department of Agriculture, Food and the Marine, that the conservation efforts should be continued after the 5-year term of the LIFE project, and are deserving of ongoing support and funding as part of a future Carra Programme.

6.1.2 Limitations

One complication with evaluating the success of nutrient-reduction measures is that lake sediment can itself be a source of nutrients. This is particularly the case with phosphorus. Phosphorus (P) which enters a lake can be locked up over a long period by forming stable compounds with other substances (especially iron). In addition to this ‘bound’ P, further P

can become loosely ‘adsorbed’ onto particles in the sediment (Scheffer, 2004). When P concentrations in the water are reduced, this loosely-bound P can be slowly released, a process known as ‘internal loading’. This process can result in high P concentrations being maintained for years or decades after the supply of external nutrients has been reduced (Moss et al. 1996).

While this is a complication, it need not prevent the success of nutrient-reduction efforts to be measured, as the following strategies can be adopted:

- Some of the sampling stations should be situated near the mouths of streams and rivers which flow in from the sub-catchments in which changes in land-use are taking place. The aim here will be to take measurements before any local effects are neutralised by mixing.
- Because Lough Carra is a multi-basin lake, with the different basins separated by narrow and shallow straits, the lake as a whole is not well mixed. Therefore, changes which occur in one part of the lake do not apply equally in other areas (Hobbs et al. 2005). Again, this will allow localised effects to be measured without their being neutralised by mixing with water from the rest of the lake.
- It has been demonstrated (Doddy et al. 2019b) that marl crust metrics can detect intra-lake changes in nutrient concentrations within a year. Therefore, marl crust analysis would be useful as part of the evaluation process.
- The depth of the euphotic zone is partly dependent on water turbidity, because turbidity reduces light penetration. Phytoplankton are major contributors to turbidity in lakes, and can respond very quickly to changes in nutrients (Moss et al. 1996). Therefore, if nutrient declines in some parts of the lake cause less frequent or less dense phytoplankton blooms, it is plausible that this may result in measurable effects on submerged vegetation.

In addition, if participating farms are clustered in certain parts of the catchment, this would be expected to make it easier to measure effects than if only isolated farms were involved, as any effects on nutrient-release would also be concentrated in these sub-catchments.

6.2 EXISTING MONITORING

Monitoring is currently carried out on Lough Carra by various agencies.

6.2.1 EPA monitoring

6.2.1.1 EPA Water Chemistry

The Environmental Protection Agency (EPA) currently conducts sampling for water chemistry at seven locations throughout Lough Carra (EPA, personal communication). This is done several times each year, although the frequency varies between years. For example, records from 2017 show that samples were taken on 11 different dates, whereas in 2018 samples were taken on four different dates. The tests conducted on these samples are wide-ranging; in addition to standard tests for nutrient concentrations and chlorophyll, testing is conducted for concentrations of various toxins, and variables such as pH, alkalinity and dissolved oxygen. For example, a summary of P and N data for 2017 and 2018 is given in Table 2.

Table 2: Mean nutrient concentrations in Lough Carra measured by the EPA in 2017 and 2018, n (2017) = 11, n (2018) = 4.

Year	Total Oxidised Nitrogen as N (mg/L)	Total Phosphorus (mg/L)
2017	0.22	0.007
2018	0.12	0.007

During the period May 2016 - May 2017, the EPA carried out investigative monitoring of a number of inflowing streams, as well as the outflowing Keel River (EPA, personal communication). Results for P and N concentrations are summarised in Table 3.

Table 3: Nutrient data recorded during investigative monitoring in the Carra catchment, 2016 – 2017. Means are derived from all results within detection limits; full data are given in Appendix 1.

Location	Co-ordinates	Direction	Total P as P (mg/l)			Total oxidized N as N (mg/l)		
			Mean	SD	n	Mean	SD	n
Annie's River (Bridge)	E120002 N273804	Inflowing	0.020	0.012	27	0.764	0.244	27
Bridge NE of Cloondaver	E120617 N272772	Inflowing	0.030	0.020	26	0.928	0.438	20
Pilgrim's Walk, Ballintubber	E115137 N279311	Inflowing	0.024	0.012	26	0.930	0.582	26
Carrowslattery Bridge, Brownstown	E120558 N271468	Inflowing	0.024	0.017	26	1.448	0.635	25
Clooneen Bridge, Clooneencarra	E121013 N274725	Inflowing	0.020	0.013	25	0.776	0.211	25
Mullingar Bridge, Cloondaver Stream North	E122374 N273337	Inflowing	0.031	0.013	25	0.882	0.417	22
Rinanneen Bridge, Lawarreen Stream	E120167 N274709	Inflowing	0.017	0.005	25	0.913	0.232	24
Keel Bridge, Aughinish	E116267 N268105	Outflowing	0.012	0.005	26	0.451	0.097	10

As an associated beneficiary, the EPA has expressed a desire to support the proposed project, and has given an indication that it may be possible to carry out some of the additional water chemistry tests that would be required. This would be helpful to the project, and would also be useful for the EPA in terms of increasing their own knowledge and records of Lough Carra. In the EPA 2019 Research Funding Call, hard-water lakes were identified as habitats on which more characterisation and information are needed. This applied specifically to habitat type 3110 (Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.), a lake type of which Lough Carra is perhaps the best example in the country. The EPA stated that there is a knowledge gap regarding the “biological, physical and chemical characteristics” of such lakes, and that these lakes are “protected habitats for

which current water quality standards may not provide sufficient protection"[12]. Therefore, this would be an excellent opportunity for the EPA to become involved, so as to further their own stated goals as well as assisting with the aims of the proposed LIFE project.

6.2.1.2 EPA Macrophyte Assessments

Assessments of macrophytes are carried out in the lake once every three years. Six metrics are used, based on research by Free et al. (2006). These metrics were developed on the basis of characteristics which were found to have a response to total phosphorus (TP) concentration in lakes (159 lakes were included). 'Elodeids', 'trophic score', and 'tolerant taxa' were positively associated with TP (indicators of poor lake quality), whereas '*Chara* score', 'depth of colonisation', and 'mean depth of presence' were negatively correlated with TP (indicators of good lake quality). Scores for Lough Carra since these metrics were developed are given in Table 4. Full details on how these scores were developed and calculated are given in Free et al. (2006). The next round of monitoring is due in 2020.

Table 4: Macrophyte scores from EPA monitoring in Lough Carra

Year	Metric 1 *Chara* score	Metric 2 Elodeid score	Metric 3 Tolerant Taxa score	Metric 4 Trophic score	Metric 5 Zc (depth of colonization) score	Metric 6 mean depth of presence score
2008	0.80	0.80	1.00	0.70	0.90	0.40
2011	0.90	0.90	1.00	0.70	1.00	0.50
2014	0.80	0.70	1.00	0.80	1.00	0.40
2017	0.80	0.80	1.00	0.80	1.00	0.40

6.2.1.3 EPA Phytoplankton Assessments

Phytoplankton in Lough Carra are monitored in 3-year cycles, again using a system devised by Free et al. (2006), based on groups of organisms which were found to be associated with TP, and relationships between chlorophyll a in samples and lake TP. Phytoplankton index scores are negatively associated with phosphorus (broadly speaking, high score = good lake

[12] EPA Research Programme 2014–2020 - Water Research Call 2019 – Technical Description Document.

quality). Again, further details on how these scores were calculated are given in Free et al. (2006).

Table 5: Phytoplankton Index (combined) scores from EPA monitoring in Lough Carra

Years	Year 1	Year 2	Year 3	3-year score
2007 - 2009	0.85	0.85	0.83	0.84
2010 - 2012	0.79	0.84	0.81	0.81
2013 - 2015	0.87	0.81	0.80	0.83
2016 - 2018	0.837	0.915	0.852	0.868

6.2.1.4 Invertebrates

Free et al. (2006) also developed a system of quality metrics based on littoral invertebrates. However, no figures are available for Lough Carra; the results for the periods 2013 – 2015 and 2016 – 2018 state that littoral invertebrates were 'monitored but not used'.

6.2.2 LAWPRO

Lough Carra is listed as a Priority Area for Action under the River Basin Management Plan for Ireland 2018-2021, and LAWPRO (the Local Authorities Water Programme) has recently been carrying out some monitoring in the Carra catchment. The initial work, beginning in June 2019, consisted of characterising the surface waters in the catchment, and assessment of biological communities, but some physico-chemical information was also recorded, including pH, temperature, oxygen concentration, and conductivity. Further tests were done in September 2019, and water chemistry analysis was included at this stage to help characterise the particular pressures on the lake from fertilisers, particularly nitrogen and phosphorus. While particular recommendations will be made in due course based on the investigative work of LAWPRO, certain impacts have already been noted, including decreased dissolved oxygen saturation in rivers and streams within the catchment, and many channels being filled with abundant aquatic vegetation. These impacts are attributed to causes, including deposition of sediments from soil erosion on farms, livestock having access to water courses for drinking, and physical changes to water courses due to

channelization (Mitchell, 2020). This investigative work by LAWPRO is planned to continue until 2021, and may be renewed with further funding.

6.2.3 IFI

IFI (Inland Fisheries Ireland) monitors fish stocks in Lough Carra as part of Ireland's obligations under the Water Framework Directive. This began in 2009 and is carried out one year in every three, although the 2018 survey was pushed forward to 2019. Huxley (2013) presented figures for some years prior to the start of the WFD monitoring, showing that trout populations have shown considerable fluctuations (expressed as catch per unit effort) between 1981 and 2009. In this period, the lowest estimated population was recorded in 1986. The population then rose substantially by 1996, and again by 2001. However, the 2009 figure was down to a level below the 1996 figure. Figure 11 shows the results of IFI's assessments for three species during the period 2009 to 2015. IFI have advised that figures for 2019 will be available by April 2020.

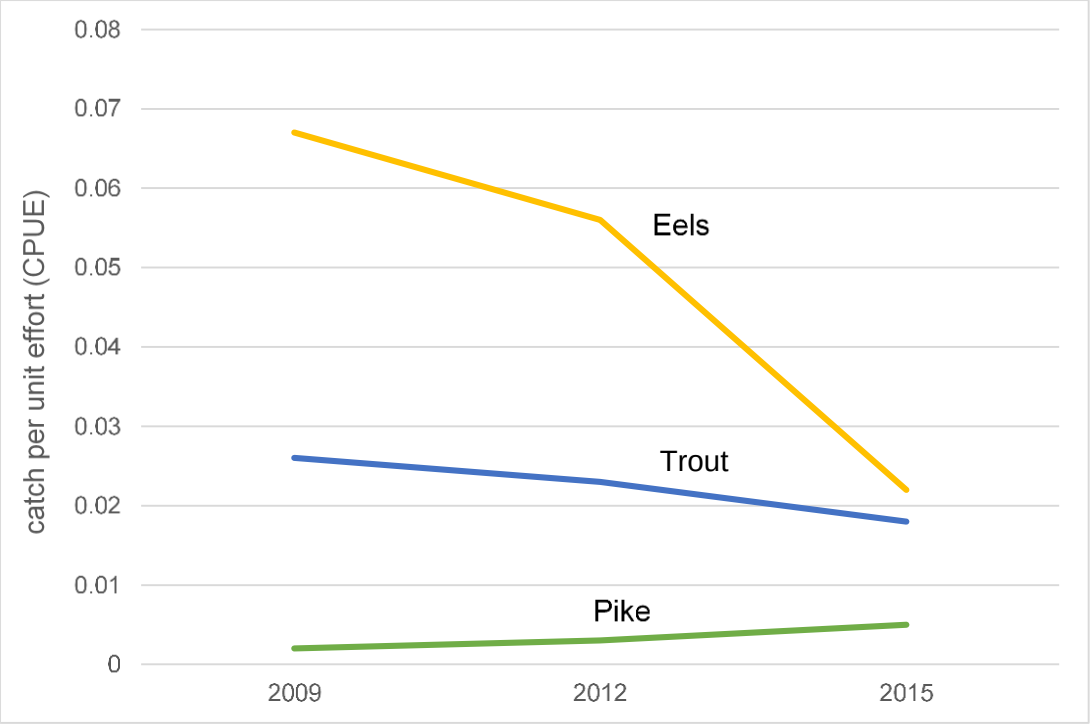


Figure 11: Fish stock figures for Lough Carra for eels, trout and pike. Source: IFI. The 2015 IFI report notes that the 2015 figures for trout and pike are not fully comparable with previous data as "an extra panel was added to the supplementary nets (now 2-PBB) to provide additional information on large coarse fish".

IFI monitoring efforts are also important in detecting non-native fish species in Lough Carra, and in tracking numbers of roach, an invasive species already present in the lake. Roach were recorded for the first time by IFI during the 2015 survey.

6.2.4 NPWS

The National Parks & Wildlife Service (NPWS) also funds various surveys from time to time, some of which have focused on Lough Carra (Roden & Murphy, 2013; Huxley, 2007; Lockhart, 1982). As noted above, Roden & Murphy (2013) found decreased water transparency in the lake, a reduced euphotic zone, increased water chlorophyll, and degraded marl crusts – all indications of nutrient pollution. Huxley (2007) found significant changes in the extent and distribution of reeds and bulrushes in the lake.

6.3 PROPOSED NEW MONITORING

Additional monitoring, to be conducted as part of the LIFE project, is proposed in the following sections.

6.3.1 WATER CHEMISTRY MONITORING

For the purposes of the proposed LIFE project, additional water chemistry monitoring will be required. This would involve more frequent analysis of nutrient concentrations and chlorophyll, as well as water colour and transparency. Chemistry tests should measure concentrations of nutrients throughout the year, in the lake and in the inflowing water bodies. This information should be examined in the context of comparable data from previous years to see if there are overall trends in nutrient concentrations, and if these are in line with the changes in farming practice being undertaken in the catchment. Water chemistry tests give a momentary measure of the chemical environment, and can be influenced by factors such as recent rain or flooding, and have further drawbacks in marl lakes as discussed above. Nonetheless, they can give a faster indication of change than biological factors, which tend to respond to longer-term ambient conditions.

It is proposed that ten additional sampling points be added to the existing seven, and that sampling and analysis be carried out on a monthly basis during the project. As one of the main objectives of the project is to reduce nutrient load on the lake, and to validate the success of changes in farming practices, it is proposed that several of the additional monitoring stations be situated in proximity to inflowing streams.

Table 6: Locations of existing EPA sampling points and proposed additional sampling points in Lough Carra

Station	Existing/Proposed	X Coordinate	Y Coordinate
1	Existing EPA sampling point	116679	276821
2	Existing EPA sampling point	116920	274951
3	Existing EPA sampling point	116920	273416
4	Existing EPA sampling point	119142	272765
5	Existing EPA sampling point	118753	271265
6	Existing EPA sampling point	117994	270228
7	Existing EPA sampling point	117290	268746
8	Proposed new sampling point	116191	277335
9	Proposed new sampling point	115972	274728
10	Proposed new sampling point	119173	273976
11	Proposed new sampling point	119775	273520
12	Proposed new sampling point	119978	272696
13	Proposed new sampling point	119810	271976
14	Proposed new sampling point	118914	270227
15	Proposed new sampling point	116710	267850
16	Proposed new sampling point	116599	267887
17	Proposed new sampling point	116196	267932

In addition, it has been proposed that two continuous monitoring stations will be installed for real-time monitoring of water chemistry, including nutrients, water colour, and water transparency. Possible locations for these are proposed as follows:

- Unnamed island at the mouth of Annie's River, Lower basin (N53.704, W-9.217).

This region of the lake is known to be degraded as a result of nutrient pollution (Roden & Murphy, 2013; Doddy et al. 2019b). Five of the inflowing streams monitored by the EPA in the period May 2016 - May 2017, which enter this lower basin, had mean phosphorus concentrations of >0.02 mg/l (TP as P), a particularly high concentration for water entering a marl lake (Doddy et al. 2019a).

- Carn, Upper basin (N53.732, W-9.269).

This region of Lough Carra appears to be in relatively good ecological condition (Doddy et al. 2019b) at present. However, EPA investigative monitoring in the period May 2016 - May 2017 showed that an unnamed stream entering this upper basin had mean phosphorus of 0.024 mg/l (TP as P). Considering this high figure, and the extensive farmland in the region, this part of the lake needs careful monitoring as it is in danger of decline.

- Kilkieran, Middle basin (N53.704, W-9.263)

This middle region of Lough Carra is in reasonable condition, with marl crusts present (Doddy et al. 2019a), but local residents have noted the increase in green algal scums washing up on the shore, especially in summer (personal communication to the author), and reed cover is spreading and expanding along parts of the shore. Again, this region is close to farmland and the existing decline in ecological condition is likely to worsen if preventative measures are not put in place in the near future.

- Adjacent to Keel River (Lower basin, N53.659, W-9.263);

This is the point of main outflow from Lough Carra. From here the Keel River flows toward Lough Mask. EPA investigative monitoring in the period May 2016 - May 2017 found that water exiting the river via the Keel Bridge had substantially lower concentrations of both P and N (mean 0.012 mg/l and 0.715 mg/l respectively) than water entering the lake at all of the individual inflowing streams monitored, indicating a net nutrient build-up in the lake. This is particularly serious in the case of phosphorus, which is known to accumulate over long periods (Donohue et al. 2010).

6.3.2 ECOLOGICAL & BIOLOGICAL MONITORING

In addition to water chemistry, it is vital to have a comprehensive suite of ecological monitoring techniques in use during the proposed project. This is especially important for a marl lake like Lough Carra because, as discussed above, the marl sediment in these lakes acts as a phosphorus-buffer, meaning that the full extent of P-content in the lake will not be detected by water-chemistry tests. The EU Water Framework Directive also stresses the need for ecological assessment techniques.

LAWPRO (the Local Authorities Water Programme) is already carrying out some biological monitoring, including aquatic invertebrates, in the catchment, and this work is to continue at least until 2021, with the possibility of an extension. While LAWPRO's remit is to assess water bodies and gather data to determine the current level of impact (rather than to carry out routine monitoring), the data will still be a valuable contribution to the proposed project. The LIFE project should therefore co-ordinate with LAWPRO in order to ensure that the same methodology and standards are used, and that these are rigorous and provide comparable results. This co-operation will also ensure that sufficient monitoring is carried out, and that it is done in a complementary fashion, without unnecessary duplication of tests.

The following biological indicators offer good scope for the purposes of ecological monitoring, and should be incorporated into the proposed project.

6.3.2.1 Crayfish

The white-clawed crayfish (*Austropotamobius pallipes*) is a native species which is classified as vulnerable in the IUCN Red List, and is under threat from water pollution, siltation, and competition from non-native crayfish (Reynolds et al. 2010). The highly-infectious crayfish plague, carried by introduced crayfish and spread by boats and on fishing equipment, is a particular threat (Matthews & Reynolds, 1992). Due to this vulnerability to a range of threats, the white-clawed crayfish is a useful indicator of ecological quality. During the proposed project, this species could be monitored regularly at fixed stations using standard procedures (Reynold et al. 2010). The use of environmental DNA (eDNA) for the early detection of both invasive crayfish and the plague pathogens that they carry has recently been developed for practical use as a conservation measure (Robinson et al. 2018). Since eDNA can be detected in water samples, without the invasive crayfish needing to be trapped, it can signal the presence of even low abundances of animals (Dougherty et al. 2016). Similar work on eDNA from crayfish is currently being carried out by Dr Luca Mirimin at Galway-Mayo Institute of Technology (GMIT). Dr Mirimin has expressed an interest in the Lough Carra project, and it is proposed that monthly water samples from Lough Carra be analysed at GMIT as part of this ongoing research.

6.3.2.2 Charophytes

Underwater vegetation surveys to measure the abundance and community composition of charophytes should be undertaken on an annual basis. Again, the results would be analysed in the context of previous reports to recognise any improvements or changes over time.

Because these communities are perennial and present throughout the year, they complement water chemistry tests by giving a longer-term picture of water conditions. Charophytes are widely regarded as being especially useful as bio-indicators due to their sensitivity to nutrient pollution and turbidity (Baastrup-Spohr et al. 2013), and have been successfully used in the ecological monitoring of marl lakes in Ireland, including Lough Carra (Roden & Murphy, 2013). Due to the inefficiency of grab sampling for charophyte surveying, it is proposed that annual vegetation surveys be carried out by snorkelling during the project. It is also essential that specimens be identified correctly to species level, as lower taxonomic resolutions do not provide optimal data (Roden & Murphy, 2013); therefore, charophyte surveys should be carried out by experienced and competent personnel. As charophyte beds are perennial communities, and are expected to reflect long term trends in ambient conditions, it is considered that detailed annual surveys will be more useful and cost-effective than more frequent, but less thorough, sampling. Existing survey data, including detailed vegetation maps (Roden, 2001; Roden & Murphy, 2013), will serve as a useful baseline, to which future records can be compared as the project proceeds.

6.3.2.3 Emergent & littoral vegetation

Shackleton (1975) mapped the emergent and littoral vegetation in Lough Carra, using a combination of shore-based and boat-based observations, as well as sampling of submerged vegetation by diving. The submerged plants mapped included Chara spp., and several species of *Potamogeton*. Emergent plants included primarily reeds *Phragmites communis*, bulrushes *Schoenoplectus lacustris*, and fen-sedge *Cladium mariscus.*

During 2003 and 2007, Huxley (2007) mapped stands of reeds and bulrushes, and compared the results with those of Shackleton in order to determine any changes in the extent and distribution of vegetation stands over time. It was found that there had been increases in reed (*Phragmites*) beds in parts of the lake, notably Moorehall Bay, between Kilkeerin and Otter Point, the channel between Kilkeeran and Derrinrush, and a bay to the south of Cloonee House. It was also found that reeds had spread into areas which had been free of emergent vegetation in 1975. In addition, certain reedbeds were found to have become denser in the intervening years, and some areas were turning into willow carr. Bulrushes (*Schoenoplectus*) had shown substantial increases since the 1975 study, and it was considered unlikely that this change was due to natural processes, instead likely being due to increases in nutrient concentrations in the lake. It was recommended that an ongoing monitoring programme for reedbeds in the lake be established, and that Shackleton's 1975

map be digitised for future use. These recommendations should now be carried out as part of the LIFE project.

6.3.2.4 Euphotic depth

Measurements of euphotic depth give a useful general indication of water clarity, with high euphotic depths indicating high-quality, oligotrophic lakes. Since euphotic depth gives an indication of mid-term to long-term conditions in the lake, it is complementary to spot checks such as Secchi depth and water transparency (both of which are measurements of conditions at a particular moment in time). Euphotic depth is best assessed by snorkelling, and could therefore be assessed on a yearly basis at the same times as the charophyte surveys described above.

6.3.2.5 Marl crusts

As one of the finest shallow marl lakes in Europe, Lough Carra has extensive benthic cover of marl crusts. In recent years, it has been shown that these contain complex microbial communities, including many species of cyanobacteria and algae (Kennedy et al. 2012; Doddy et al. 2019a), and that these communities are useful bio-indicators due to their particular sensitivity to nutrient pollution. Moreover, these marl crusts have a crucial phosphorus-buffering function (Hobbs et al. 2005). Doddy et al. (2019b) developed a set of metrics for assessing ecological quality based on marl crust characteristics, and showed experimentally that these metrics could detect short-term changes in trophic conditions, including changes between areas of different trophic status within Lough Carra. It was also found that areas of degraded phytobenthos could recover when nutrient concentrations were reduced, and that such recovery could be observed and measured within less than one year. It is proposed, therefore, that regular (e.g. 3-monthly) sampling and analysis of marl crusts be undertaken during the project, at fixed locations adjacent to the sub-catchments in which improvements in farming methods are taking place, as a means of measuring and validating reductions in nutrient-output.

6.3.2.6 Water beetles

Ochthebius nilsonii is a particularly rare beetle, which has most of its known global range in a small number of marl lakes in the west of Ireland. Nelson et al. (2019) reported the discovery of *O. nilsonii* in Lough Carra. Since this beetle is highly characteristic of

oligotrophic, clear-water lakes, it is likely to be a useful indicator species. Moreover, sampling is easily conducted (Nelson et al. 2019), as its habitat is the marginal marl crust zone. Therefore, *O. nilsonii* should be monitored during the proposed project.

6.3.2.7 Brown trout

As native predators, brown trout *Salmo trutta* form an important part of the ecological community structure in Lough Carra, and are particularly sensitive to water quality. Effects on lower tiers of the food web (e.g. nutrient supply to phytoplankton) can also impact predators. For example, phytoplankton blooms often result in deoxygenation of water, as the plankton biomass eventually disintegrates and is decomposed by bacteria. Therefore, fewer blooms would result in water that is both clearer and higher in oxygen, both of which conditions are favoured by trout. Monitoring of trout should continue through the duration of the proposed project, in order to recognise any measurable trends which may result from changes in land-use and farming practice. This is a good opportunity for a collaboration with IFI. This monitoring work should also focus on examining any increases or other changes in the population of invasive roach which is present in Lough Carra.

6.3.2.8 Proxy Indicators for the agri-environmental project

For the purposes of the agri-environmental project, changes in nutrient input in the catchment should be measured using terrestrial proxy indicators, as well as being measured more directly in the lake water and in the inflowing streams. Since land management in the catchment has a direct influence on the lake and inflowing watercourses, proxy indicators can give a reliable measure of how nutrient reduction is progressing. Nutrient reduction will involve restoring intensive agricultural grassland to species-rich meadow; assessment of botanical communities is a good proxy indicator in this case, as shown in the Burren Programme. Recording sheets should be drawn up, based on those used in the Burren Programme, for recording plant species in grasslands which are part of the participating farms. This will allow a baseline to be established at the outset; as the project proceeds, any trends in plant diversity can be recognised and measured.

7 PUBLICITY & COMMUNITY INVOLVEMENT

In order for the project to be as successful as possible and to have the potential to develop into a longer-term programme, similar to the ongoing Burren Programme, it is important to develop broad community support. This would involve keeping the local people informed about the project, showing them the various benefits, encouraging them to become involved, and keeping in touch with them on a regular basis.

7.1 EDUCATIONAL FACILITIES & PUBLICATIONS

It would be useful for the Project Management Office to include a library of project-related publications and access to digital resources. In particular, this would hold books on local mammals, birds and fish, identification keys and manuals on native flora and fauna, and books on grassland management, biodiversity conservation, high-nature value farming, angling, boating and aquatic ecology. It would also contain publications from the state agencies and the EU regarding the state of Ireland's biodiversity, environmental legislation, sustainable food production, and best farming practices. Computer facilities could also be available to provide access to biodiversity databases and scientific publications.

Posters and leaflets to advertise and popularise the project could also be made available through the Project Management Office and in local schools and libraries. The Lough Carra Catchment Association might also consider publishing more leaflets and booklets on topics relevant to the LIFE project. Two have already been produced, covering the nature and cultural history of the area, and the marl crusts in the lake. Future potential topics include aquatic animals, butterflies of the area, and charophytes of the lake.

7.2 WEBSITE

A project website would be another useful component in informing the public about the project, and could also inform interested parties from further afield about the ecology of the area. The website would explain the various elements of the project in an accessible manner, and would also explain to farmers what benefits they might achieve from participation in the project, and how to apply. In time, testimonials from participating farmers would be very useful.

The existing loughcarra.org website does a good job of explaining many aspects of Lough Carra, including some that directly relate to the proposed project, such as aquatic ecology,

terrestrial ecology and land use. It has been proposed that this existing website be developed as a project website, and that its running and management be adopted by the Lough Carra Catchment Association. This will mean that the role of this familiar and established website will be expanded to encompass the needs of the LIFE project.

One of the purposes of the website should be to promote the research interest of the area and its habitats. As a shallow, oligotrophic marl lake, Lough Carra is rather rare in a European context, and would likely be of interest as a research subject to researchers in other parts of Europe, particularly Eastern Europe where karst landscapes are also present. Any research collaborations between these two areas would surely be beneficial to both.

7.3 WORKSHOPS, FARM WALKS, & SCHOOL VISITS

Events in which people can get involved in a practical manner are especially useful for building interest and enthusiasm in the project. Again, this is an important precursor to developing the proposed LIFE project into a longer-term programme which can continue to flourish after the initial five years.

- Workshops on issues such as planting buffer zones, establishing wetlands etc. would be of particular relevance to farmers participating in the project, but it would also be good to involve members of the wider community in these workshops.
- Workshops on practical identification of various species, especially plants and invertebrates, would also be of relevance to participants and of interest to the broader public. Workshops on these areas which are suitable for children should also be provided.
- It is important to support farmers who are involved in the project and doing their best to operate in an environmentally responsible manner. Farm walks, which would demonstrate how good quality food can be produced in a sustainable manner, would be useful in building respect for these farmers and showing members of the public that good quality, local produce is worth a premium price, and should not be sold as a low-value budget product. It is essential that good farmers are paid good prices for their products.
- Involving schoolchildren in the Carra project is important so that these children will grow up with an understanding of the importance and eminence of the wildlife and biodiversity of the Lough Carra region. The enthusiasm of schoolchildren can also be helpful in encouraging their parents and families to become involved. In addition to providing biodiversity workshops for children, it would be worthwhile making an effort

to get schools involved more directly. Schools could encourage children to do projects which focus on some of the local wildlife and habitats. Teachers could also encourage children to do essays or drawings on these subjects. Occasional visits to schools by various wildlife experts to give talks or demonstrations would be another way to encourage enthusiasm and interest from the children.

7.4 LOUGH CARRA FESTIVAL

It is suggested that an annual Lough Carra Festival be held. This event would be intended to be both educational and entertaining and to provide a way for both local people and visitors to enjoy celebrating the lake and its ecology, scenery and heritage. While this would promote tourism and help local businesses, its most important purpose would be to instil in local people the realisation that Lough Carra is a special place of international importance, worthy of celebration, respect and pride. This change of mindset in local people is a vital aspect of the project, as it has the potential to feed into so many other parts of the ongoing conservation efforts in the region.

The proposed festival could include the following components:

- Educational talks by invited experts on the lake's ecology. Suitable candidates would be Ken Irvine, Marten Scheffer, Cilian Roden.
- Educational walks around the lake by local ecologists or naturalists, such as Chris Huxley.
- Events to recognise and celebrate some of the local antiquities and historical sites.
- Concerts and recitals of music by local and visiting artists.
- Art workshops for children and adults which would focus on the wildlife of the area. Gordon D'Arcy would be a good choice to teach these.
- Art exhibitions, especially of material focusing on the local scenery or biodiversity.

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9 APPENDICES

9.1 APPENDIX 1: Nutrient concentrations measured by the EPA during investigative monitoring in the Carra catchment, 2016 – 2017.

Date:	Location	Coordinates E/N	Total Oxidised Nitrogen	Total Phosphorus
			mg/l N	mg/l P
23/05/2016	Annies Bridge, Annies River	E120002 N273804	0.47	0.012
13/06/2016	Annies Bridge, Annies River	E120002 N273804	0.63	<0.01
06/07/2016	Annies Bridge, Annies River	E120002 N273804	0.55	0.013
19/07/2016	Annies Bridge, Annies River	E120002 N273804	0.31	0.011
08/08/2016	Annies Bridge, Annies River	E120002 N273804	0.38	0.012
22/08/2016	Annies Bridge, Annies River	E120002 N273804	0.82	0.024
08/09/2016	Annies Bridge, Annies River	E120002 N273804	0.57	0.019
28/09/2016	Annies Bridge, Annies River	E120002 N273804	0.46	0.014
10/10/2016	Annies Bridge, Annies River	E120002 N273804	0.41	0.015
24/10/2016	Annies Bridge, Annies River	E120002 N273804	0.67	0.018
14/11/2016	Annies Bridge, Annies River	E120002 N273804	0.67	0.02
29/11/2016	Annies Bridge, Annies River	E120002 N273804	1.3	0.019
12/12/2016	Annies Bridge, Annies River	E120002 N273804	0.76	0.021
12/01/2017	Annies Bridge, Annies River	E120002 N273804	0.93	0.018

16/01/2017	Annies Bridge, Annies River	E120002 N273804	0.9	0.019
23/01/2017	Annies Bridge, Annies River	E120002 N273804	1	0.017
23/02/2017	Annies Bridge, Annies River	E120002 N273804	0.85	0.034
23/02/2017	Annies Bridge, Annies River	E120002 N273804	0.88	0.03
04/03/2017	Annies Bridge, Annies River	E120002 N273804	0.89	0.034
06/03/2017	Annies Bridge, Annies River	E120002 N273804	1.1	0.03
13/03/2017	Annies Bridge, Annies River	E120002 N273804	1.1	0.021
21/03/2017	Annies Bridge, Annies River	E120002 N273804	1	0.021
03/04/2017	Annies Bridge, Annies River	E120002 N273805	0.82	0.07
12/04/2017	Annies Bridge, Annies River	E120002 N273806	0.79	<0.01
02/05/2017	Annies Bridge, Annies River	E120002 N273807	0.93	<0.01
08/05/2017	Annies Bridge, Annies River	E120002 N273808	0.84	<0.01
23/05/2017	Annies Bridge, Annies River	E120002 N273809	0.61	0.013
23/05/2016	Bridge NE of Cloondaver	E120617 N272772	0.37	0.02
13/06/2016	Bridge NE of Cloondaver	E120617 N272772	<0.2	0.019
06/07/2016	Bridge NE of Cloondaver	E120617 N272772	<0.2	0.019
19/07/2016	Bridge NE of Cloondaver	E120617 N272772	<0.2	0.017
08/08/2016	Bridge NE of Cloondaver	E120617 N272772	<0.2	0.026
22/08/2016	Bridge NE of Cloondaver	E120617 N272772	0.54	0.047

08/09/2016	Bridge NE of Cloondaver	E120617 N272772	0.22	0.039
28/09/2016	Bridge NE of Cloondaver	E120617 N272772	0.88	0.022
10/10/2016	Bridge NE of Cloondaver	E120617 N272772	0.5	0.017
24/10/2016	Bridge NE of Cloondaver	E120617 N272772	0.66	0.018
14/11/2016	Bridge NE of Cloondaver	E120617 N272773	0.87	0.029
29/11/2016	Bridge NE of Cloondaver	E120617 N272774	0.87	0.022
12/12/2016	Bridge NE of Cloondaver	E120617 N272775	1	0.024
12/01/2017	Bridge NE of Cloondaver	E120617 N272776	1.3	0.027
16/01/2017	Bridge NE of Cloondaver	E120617 N272777	1.3	0.025
23/01/2017	Bridge NE of Cloondaver	E120617 N272778	1.1	0.022
23/02/2017	Bridge NE of Cloondaver	E120617 N272779	1.2	0.092
04/03/2017	Bridge NE of Cloondaver	E120617 N272781	2	0.051
06/03/2017	Bridge NE of Cloondaver	E120617 N272780	1.5	0.041
13/03/2017	Bridge NE of Cloondaver	E120617 N272782	1.3	0.028
20/03/2017	Bridge NE of Cloondaver	E120617 N272783	1.1	0.035
03/04/2017	Bridge NE of Cloondaver	E120617 N272784	0.77	0.084
12/04/2017	Bridge NE of Cloondaver	E120617 N272785	0.72	<0.01
02/05/2017	Bridge NE of Cloondaver	E120617 N272786	0.36	0.012
08/05/2017	Bridge NE of Cloondaver	E120617 N272787	<0.2	0.019

24/05/2017	Bridge NE of Cloondaver	E120617 N272788	<0.2	0.021
23/05/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.3	0.022
13/06/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.32	0.019
06/07/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.35	0.02
19/07/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.36	0.024
08/08/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.33	0.023
22/08/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.54	0.038
08/09/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.35	0.033
28/09/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.44	0.017
10/10/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.52	0.019
24/10/2016	Carra Bridge Pilgrims Walk	E115137 N279311	0.63	0.018
14/11/2016	Carra Bridge Pilgrims Walk	E115137 N279311	1.1	0.022
29/11/2016	Carra Bridge Pilgrims Walk	E115137 N279311	1.1	0.018
12/12/2016	Carra Bridge Pilgrims Walk	E115137 N279311	1.8	0.018
12/01/2017	Carra Bridge Pilgrims Walk	E115137 N279311	2.4	0.026
16/01/2017	Carra Bridge Pilgrims Walk	E115137 N279311	1.7	0.022
23/01/2017	Carra Bridge Pilgrims Walk	E115137 N279311	1.5	0.019
23/02/2017	Carra Bridge Pilgrims Walk	E115137 N279312	1.3	0.047
04/03/2017	Carra Bridge Pilgrims Walk	E115137 N279311	1.5	0.024

06/03/2017	Carra Bridge Pilgrims Walk	E115137 N279311	1.3	0.032
13/03/2017	Carra Bridge Pilgrims Walk	E115137 N279311	1.5	0.016
21/03/2017	Carra Bridge Pilgrims Walk	E115137 N279311	1.4	0.018
03/04/2017	Carra Bridge Pilgrims Walk	E115137 N279312	1.1	0.071
12/04/2017	Carra Bridge Pilgrims Walk	E115137 N279313	0.91	0.011
02/05/2017	Carra Bridge Pilgrims Walk	E115137 N279314	0.49	0.011
08/05/2017	Carra Bridge Pilgrims Walk	E115137 N279315	0.42	0.015
23/05/2017	Carra Bridge Pilgrims Walk	E115137 N279316	0.53	0.02
13/06/2016	Carrowslattery Bridge Brownstown	E120558 N271468	0.55	<0.01
06/07/2016	Carrowslattery Bridge Brownstown	E120558 N271468	0.36	0.02
19/07/2016	Carrowslattery Bridge Brownstown	E120558 N271468	0.32	0.014
08/08/2016	Carrowslattery Bridge Brownstown	E120558 N271468	0.32	0.027
22/08/2016	Carrowslattery Bridge Brownstown	E120558 N271468	0.84	0.026
08/09/2016	Carrowslattery Bridge Brownstown	E120558 N271468	1.3	0.029
28/09/2016	Carrowslattery Bridge Brownstown	E120558 N271468	1.3	0.017
10/10/2016	Carrowslattery Bridge Brownstown	E120558 N271468	1	0.016
24/10/2016	Carrowslattery Bridge Brownstown	E120558 N271468	1.9	0.016
14/11/2016	Carrowslattery Bridge Brownstown	E120558 N271468	1.6	0.023
29/11/2016	Carrowslattery Bridge Brownstown	E120558 N271468	1.4	0.019

12/12/2016	Carrowslattery Bridge Brownstown	E120558 N271468	1.9	0.026
12/01/2017	Carrowslattery Bridge Brownstown	E120558 N271468	2.1	0.019
16/01/2017	Carrowslattery Bridge Brownstown	E120558 N271468	2.3	0.019
23/01/2017	Carrowslattery Bridge Brownstown	E120558 N271468	1.8	0.02
23/02/2017	Carrowslattery Bridge Brownstown	E120558 N271469	2.4	0.082
04/03/2017	Carrowslattery Bridge Brownstown	E120558 N271468	2.5	0.02
06/03/2017	Carrowslattery Bridge Brownstown	E120558 N271468	2.1	0.04
13/03/2017	Carrowslattery Bridge Brownstown	E120558 N271468	1.8	0.021
21/03/2017	Carrowslattery Bridge Brownstown	E120558 N271468	1.8	0.022
03/04/2017	Carrowslattery Bridge Brownstown	E120558 N271469	1.4	0.07
12/04/2017	Carrowslattery Bridge Brownstown	E120558 N271470	1.4	<0.01
02/05/2017	Carrowslattery Bridge Brownstown	E120558 N271471	1.4	<0.01
08/05/2017	Carrowslattery Bridge Brownstown	E120558 N271472	1.2	0.013
23/05/2017	Carrowslattery Bridge Brownstown	E120558 N271473	1.2	0.013
23/05/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.51	0.014
13/06/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.77	0.01
06/07/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.66	0.014
19/07/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.42	0.018
08/08/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.51	0.013

22/08/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.99	0.033
08/09/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.58	0.02
28/09/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.42	0.017
10/10/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.42	0.015
24/10/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.66	0.021
14/11/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.68	0.019
29/11/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.83	0.02
12/12/2016	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.72	0.017
12/01/2017	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.95	0.018
16/01/2017	Clooneen Bridge (Clooneencarra)	E121013 N274725	0.9	0.02
23/01/2017	Clooneen Bridge (Clooneencarra)	E121013 N274725	1	0.017
23/02/2017	Clooneen Bridge (Clooneencarra)	E121013 N274726	0.93	0.025
06/03/2017	Clooneen Bridge (Clooneencarra)	E121013 N274725	1.1	0.032
13/03/2017	Clooneen Bridge (Clooneencarra)	E121013 N274725	1	0.021
21/03/2017	Clooneen Bridge (Clooneencarra)	E121013 N274725	1	0.021
03/04/2017	Clooneen Bridge (Clooneencarra)	E121013 N274726	0.85	0.074
12/04/2017	Clooneen Bridge (Clooneencarra)	E121013 N274727	0.82	0.01
02/05/2017	Clooneen Bridge (Clooneencarra)	E121013 N274728	0.99	0.01
08/05/2017	Clooneen Bridge (Clooneencarra)	E121013 N274729	0.97	0.011

23/05/2017	Clooneen Bridge (Clooneencarra)	E121013 N274730	0.72	0.016
23/05/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
13/06/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	0.015
06/07/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
19/07/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
08/08/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	0.01
22/08/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
08/09/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	0.018
28/09/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
10/10/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
24/10/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
14/11/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	0.01
29/11/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	<0.01
12/12/2016	Keel Bridge Aughinish	E116267 N268105	<0.2	0.025
12/01/2017	Keel Bridge Aughinish	E116267 N268105	0.4	<0.01
16/01/2017	Keel Bridge Aughinish	E116267 N268105	0.45	<0.01
23/01/2017	Keel Bridge Aughinish	E116267 N268105	0.43	<0.01
23/02/2017	Keel Bridge Aughinish	E116267 N268106	0.32	0.011
04/03/2017	Keel Bridge Aughinish	E116267 N268105	0.49	0.011

06/03/2017	Keel Bridge Aughinish	E116267 N268105	0.54	0.012
13/03/2017	Keel Bridge Aughinish	E116267 N268105	0.59	0.012
21/03/2017	Keel Bridge Aughinish	E116267 N268105	0.56	0.014
03/04/2017	Keel Bridge Aughinish	E116267 N268106	0.43	0.033
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02/05/2017	Keel Bridge Aughinish	E116267 N268108	<0.2	0.011
08/05/2017	Keel Bridge Aughinish	E116267 N268109	<0.2	<0.01
23/05/2017	Keel Bridge Aughinish	E116267 N268110	<0.2	<0.01
23/05/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.51	0.025
13/06/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.26	0.024
06/07/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.2	0.043
19/07/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	<0.2	0.021
08/08/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	<0.2	0.028
22/08/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.88	0.044
08/09/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.4	0.047
28/09/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.95	0.025
10/10/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.57	0.021
24/10/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.86	0.021
14/11/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.97	0.033

29/11/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	0.98	0.025
12/12/2016	Mullingar Bridge Cloondaver Stream	E122374 N273337	1.1	0.027
12/01/2017	Mullingar Bridge Cloondaver Stream	E122374 N273337	1.3	0.034
16/01/2017	Mullingar Bridge Cloondaver Stream	E122374 N273337	1.3	0.029
23/01/2017	Mullingar Bridge Cloondaver Stream	E122374 N273337	1.2	0.025
23/02/2017	Mullingar Bridge Cloondaver Stream	E122374 N273338	1.6	0.055
06/03/2017	Mullingar Bridge Cloondaver Stream	E122374 N273337	1.5	0.055
13/03/2017	Mullingar Bridge Cloondaver Stream	E122374 N273337	1.3	0.027
21/03/2017	Mullingar Bridge Cloondaver Stream	E122374 N273337	1.3	0.039
03/04/2017	Mullingar Bridge Cloondaver Stream	E122374 N273338	0.8	0.058
12/04/2017	Mullingar Bridge Cloondaver Stream	E122374 N273339	0.68	<0.01
02/05/2017	Mullingar Bridge Cloondaver Stream	E122374 N273340	0.45	0.012
08/05/2017	Mullingar Bridge Cloondaver Stream	E122374 N273341	0.3	0.018
23/05/2017	Mullingar Bridge Cloondaver Stream	E122374 N273342	<0.2	0.031
13/06/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.66	<0.01
06/07/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.66	0.018
19/07/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.45	0.018
08/08/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.54	0.011
22/08/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.77	0.021

08/09/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.73	0.018
28/09/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.94	0.018
10/10/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.77	0.013
24/10/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.91	0.013
14/11/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	0.95	0.017
29/11/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1.1	0.018
12/12/2016	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1	0.018
12/01/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1.2	0.021
16/01/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1.2	0.016
23/01/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1.2	0.019
23/02/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274710	0.93	0.032
06/03/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1.3	0.03
13/03/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1.3	0.016
21/03/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274709	1.1	0.019
03/04/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274710	0.88	0.017
12/04/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274711	0.81	<0.01
02/05/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274712	0.94	<0.01
08/05/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274713	0.87	0.013
23/05/2017	Rinanneen Bridge Lawarreen Stream	E120167 N274714	0.71	0.015

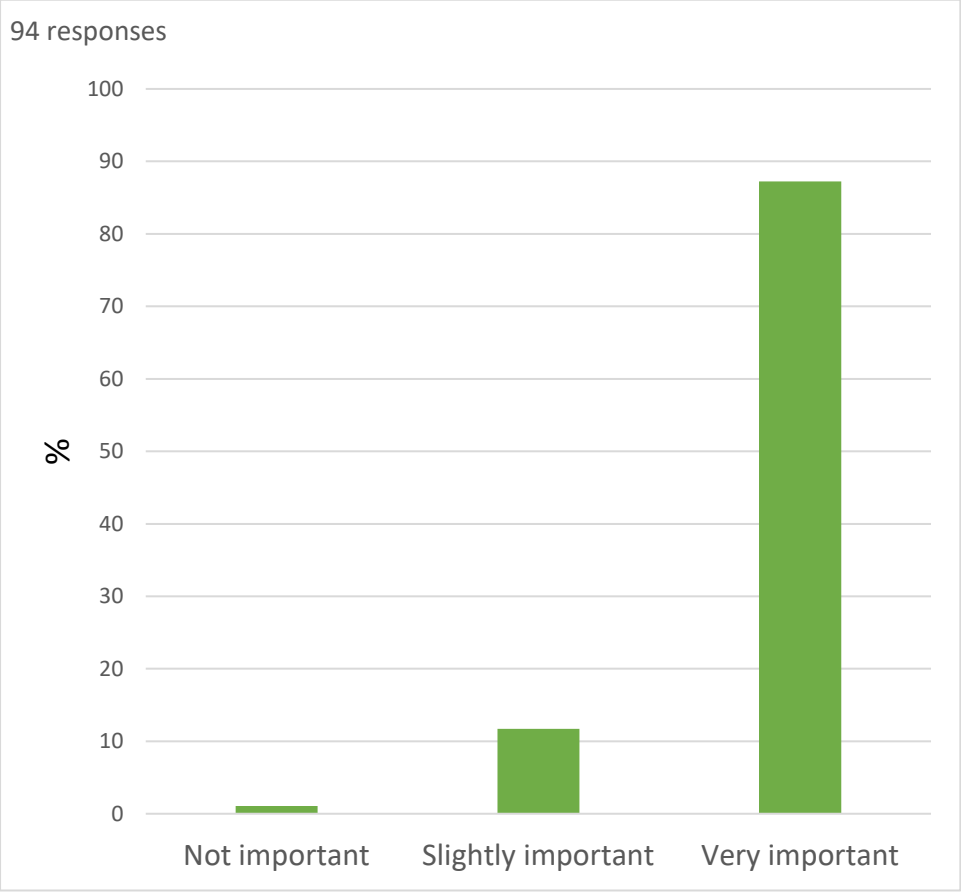
9.2 APPENDIX 2: Farmers' Attitudes Survey

A survey of farmers in the Carra catchment was carried out in early 2020 by the Lough Carra Catchment Association in collaboration with Woodrow Sustainable Solutions. Ninety-four farmers participated in the survey. The results are as follows.

Question 1:

Lough Carra is a source of drinking water for many people in the area. In your opinion, how important is it to maintain high water quality standards in the lake?

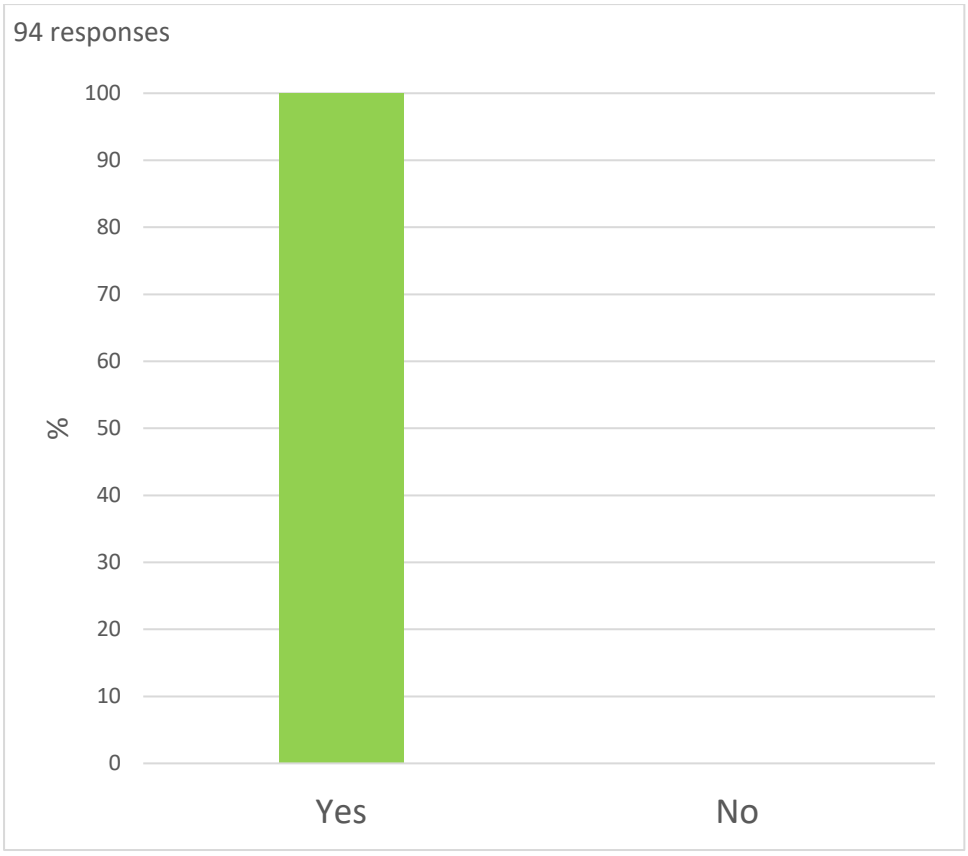
- ❑ **Not important**
- ❑ **Slightly important**
- ❑ **Very important**



Question 2:

There is a long history of boating and fishing in Lough Carra, and the lakeshore and islands contain several historic buildings. In your opinion, is Lough Carra important to the heritage and culture of this part of Co. Mayo?

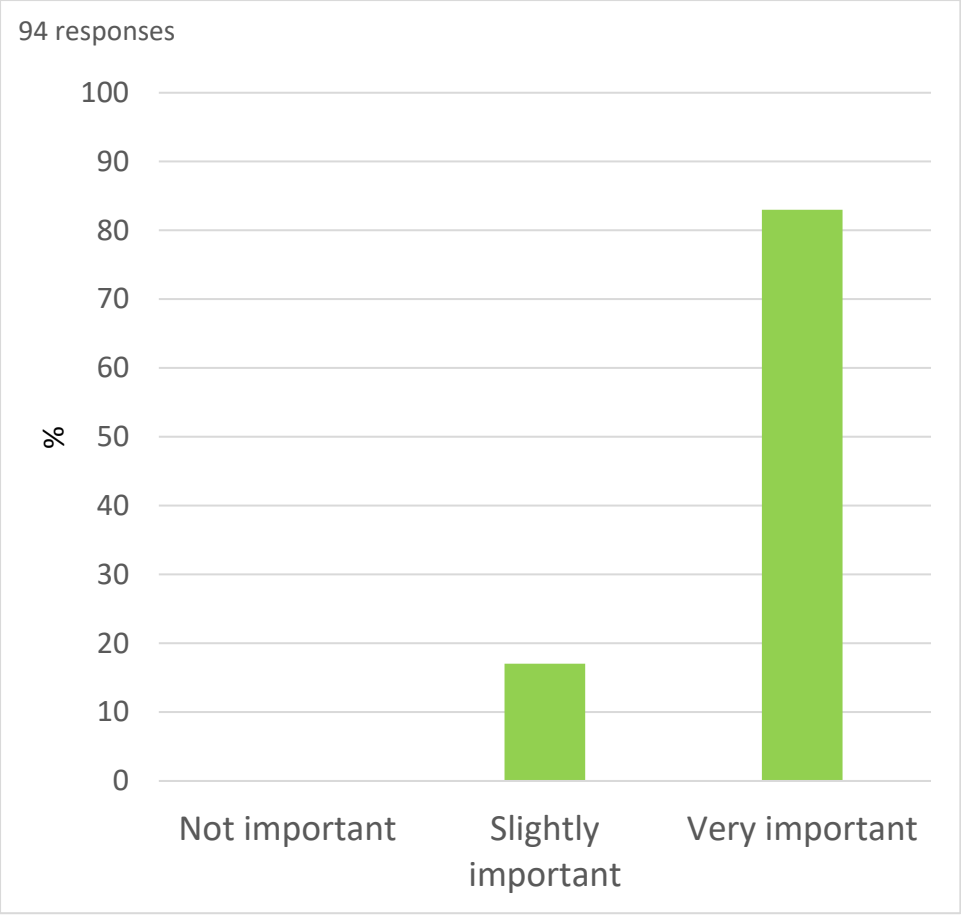
- ❑ **Yes**
- ❑ **No**



Question 3:

Lough Carra has been described as one of the finest marl lakes not only in Ireland, but in Europe. How important is it for people in the area to value the lake and keep its water in good condition?

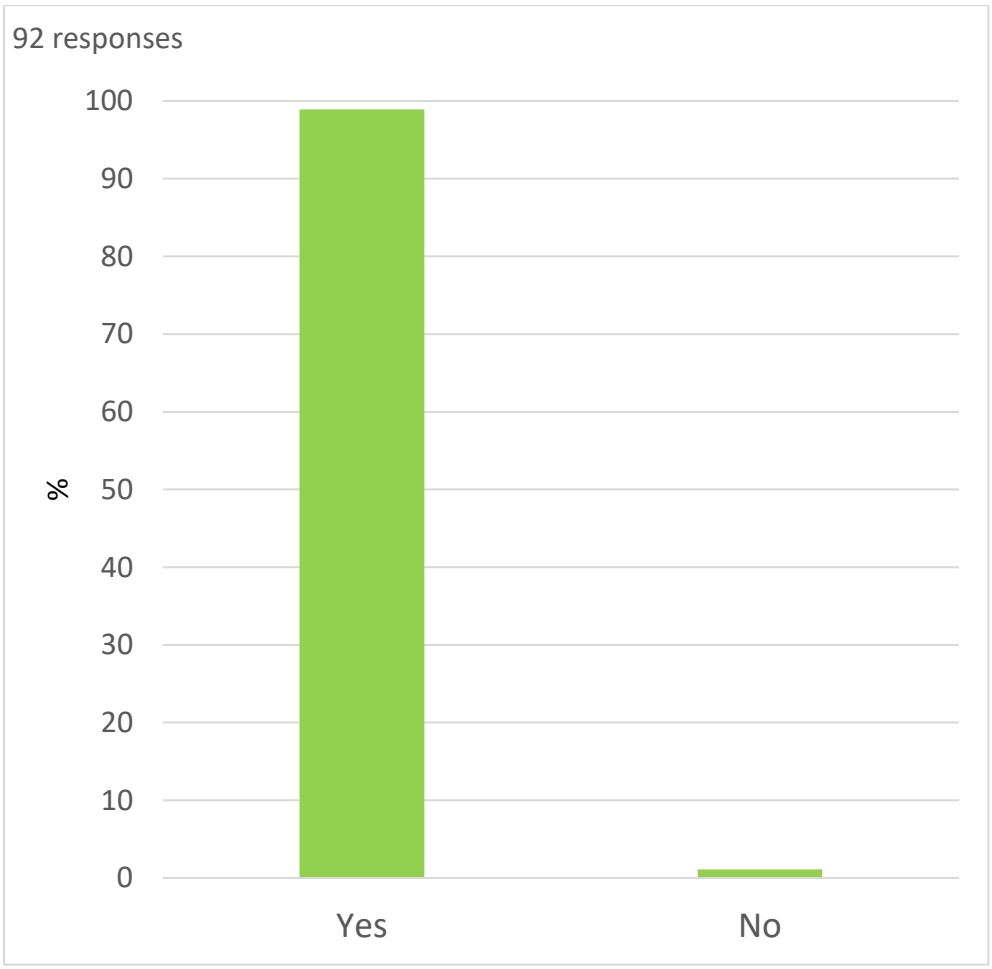
- ❑ **Not important**
- ❑ **Slightly important**
- ❑ **Very important**



Question 4:

Unfortunately, scientific studies over the past several years have shown a decline in water quality in Lough Carra. Is this something that farmers in the region should be concerned about?

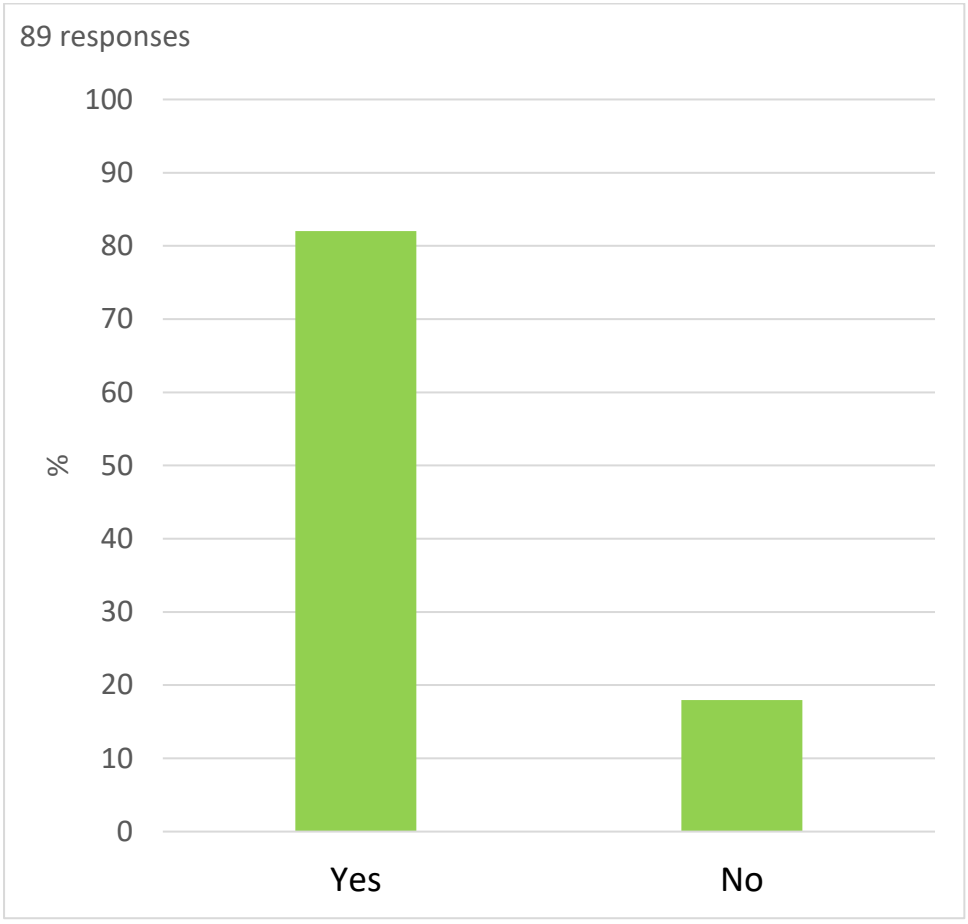
- ❑ **Yes**
- ❑ **No**



Question 5:

Have you noticed any changes in the lake yourself, such as cloudy or green water, green algal scum on the shore, fewer mayflies, or changes in the fish populations?

- ❑ **Yes**
- ❑ **No**



Question 6:

What do you think might be causing the decline in Lough Carra's water quality?

The following responses were given:

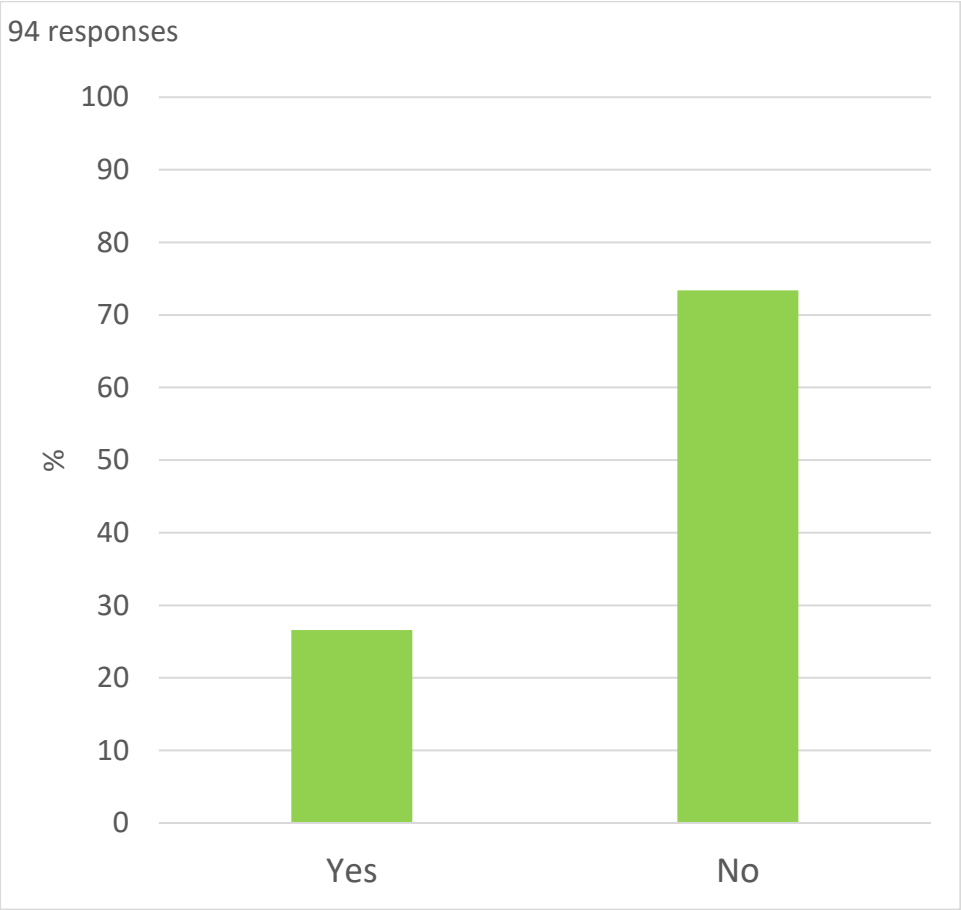
- Modern living
- Land run off
- Rain & slurry
- House farm
- Farming hoses
- The rivers not being cleaned
- Too much rain
- Forestry, rivers not cleaned
- Unknown
- Fertilisers, slurry & septic tanks
- Enrichment
- Pollution, land runoff
- Runoff
- Land run off, slurry etc.
- Land runoff and too much rain
- Weather, nutrient runoff
- Pollution from farming and septic tanks
- Agricultural fertilisation
- Farming tanks
- Farming land runoff
- Forestry
- Farming, septic tanks
- Extra rainfall
- Farming & household, weather
- Farming
- Agricultural & domestic sources (e.g. raw sewage, slurry, silage effluent)
- Agricultural practices - mostly slurry. Also septic tanks
- Scrub, weeds, trees along shoreline
- Rain, land runoff
- Slurry
- Nutrient increase
- Farm and house
- House and farm runoff
- Pollution and runoff into rivers
- Agri & domestic
- Runoff
- House and farm waste
- Pollution from farmers spreading slurry and fertiliser
- Pollution
- Farm and household waste
- Septic tanks & agriculture
- Septic tanks, slurry, runoff

- Farm runoff, septic tanks
- Pollution from septic tanks and farm slurry
- Slurry, septic tanks, poor runoffs
- Septic tanks, slurry
- Pollution
- Pollution from river tributaries
- Pollution runoff
- Slurry, land runoff, domestic waste
- Too much rain
- Pollution
- Slurry pollution
- Overuse of chemicals & fertilisers on farms
- Drainage - water not getting out of lake - bath effect
- Putting out slurry with waterlogged fields
- Septic tanks
- Housing, farming, forestry
- Slurry spread in spring, rising water table, runoff from land
- Septic tanks, pig slurry west and south of the lake
- Variety of farming, septic tanks, forestry
- Septic tanks
- A lot of things like slurry
- A number of things
- Septic tanks, slurry, big farmers
- Slurry, pig slurry
- Forestry, pig slurry
- Slurry, sheep dip, chemicals from houses
- Septic tanks, dairy farming
- Big dairy farmers are at fault
- Rain, farm, house
- Runoff, wetter weather, more rain
- Wet weather
- Water levels and no drainage out of it
- No drainage out of lake
- Fertilisers
- Weather, rain, land runoff

Question 7:

Do you feel that the current model of farming, as carried out in this area, leads to prosperity for small farmers?

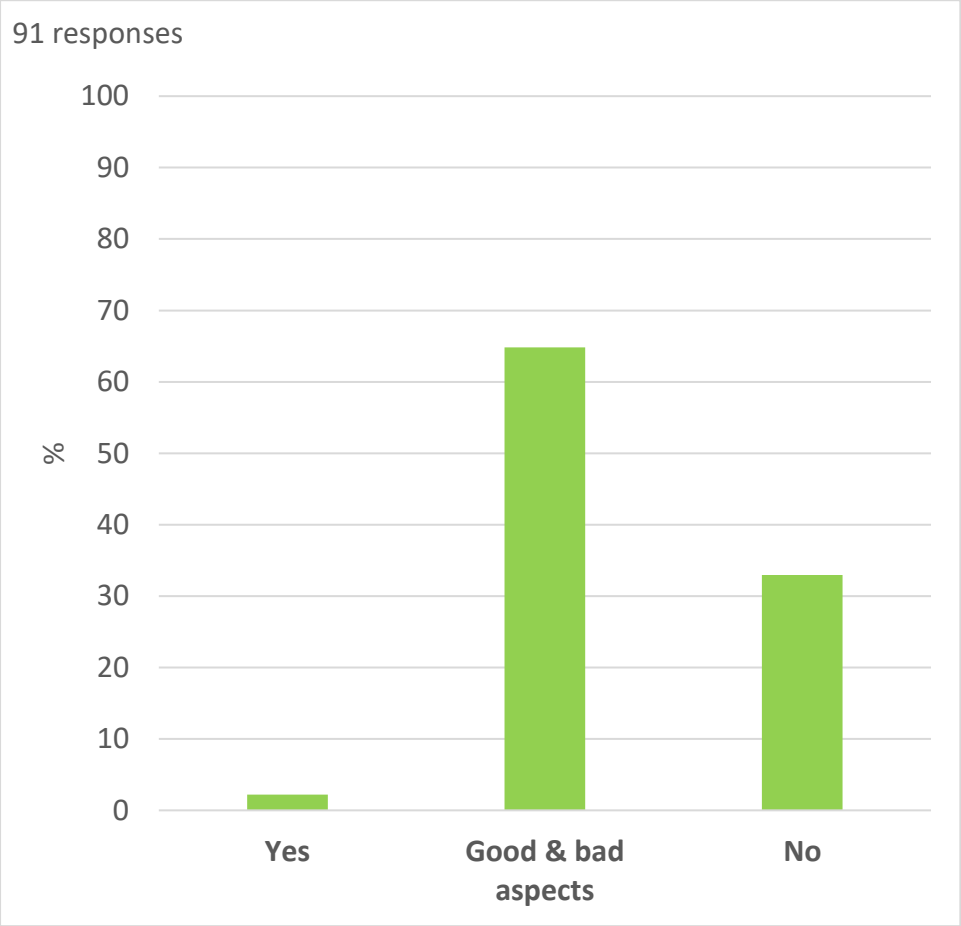
- ❑ **Yes**
- ❑ **No**



Question 8:

Modern farming practice for beef farmers tends to focus on maximum production of grass, fast production of cattle, with the resulting meat being sold at a low price? In your opinion, is this model of farming good for farmers in this region?

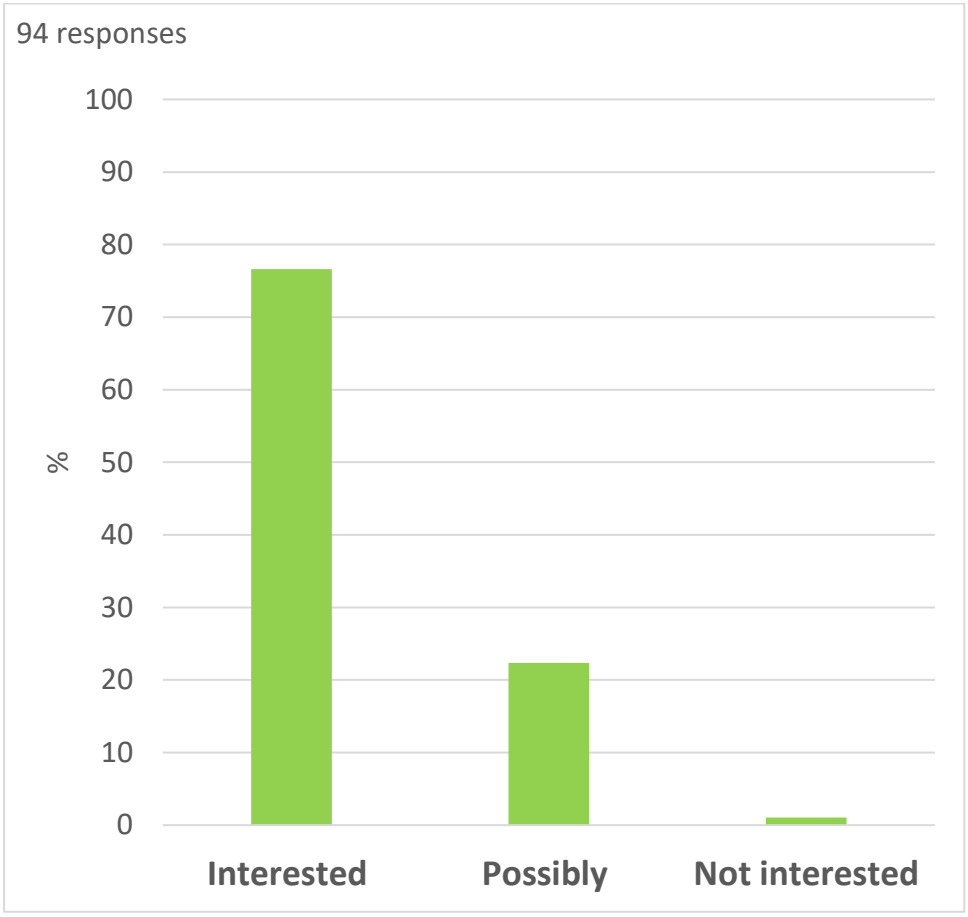
- ❑ **Yes**
- ❑ **Good & bad aspects**
- ❑ **No**



Question 9:

Would you be interested in options that could help improve the water quality in the lake, as well as providing farmers with a more sustainable and long-term way of making a living from farming?

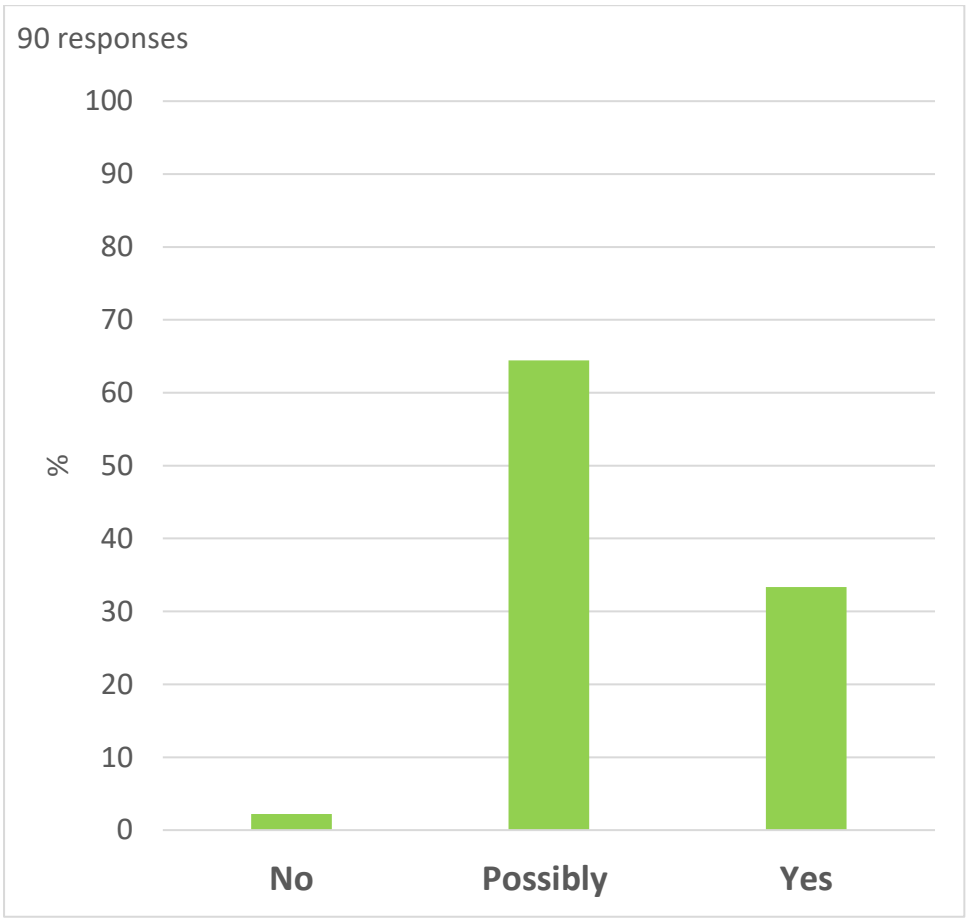
- ❑ **Interested**
- ❑ **Possibly**
- ❑ **Not interested**



Question 10:

Farming methods in Ireland have changed a lot in recent decades, and some traditional farming methods have fallen by the wayside. Do you think that there could be a benefit in combining both traditional and modern methods?

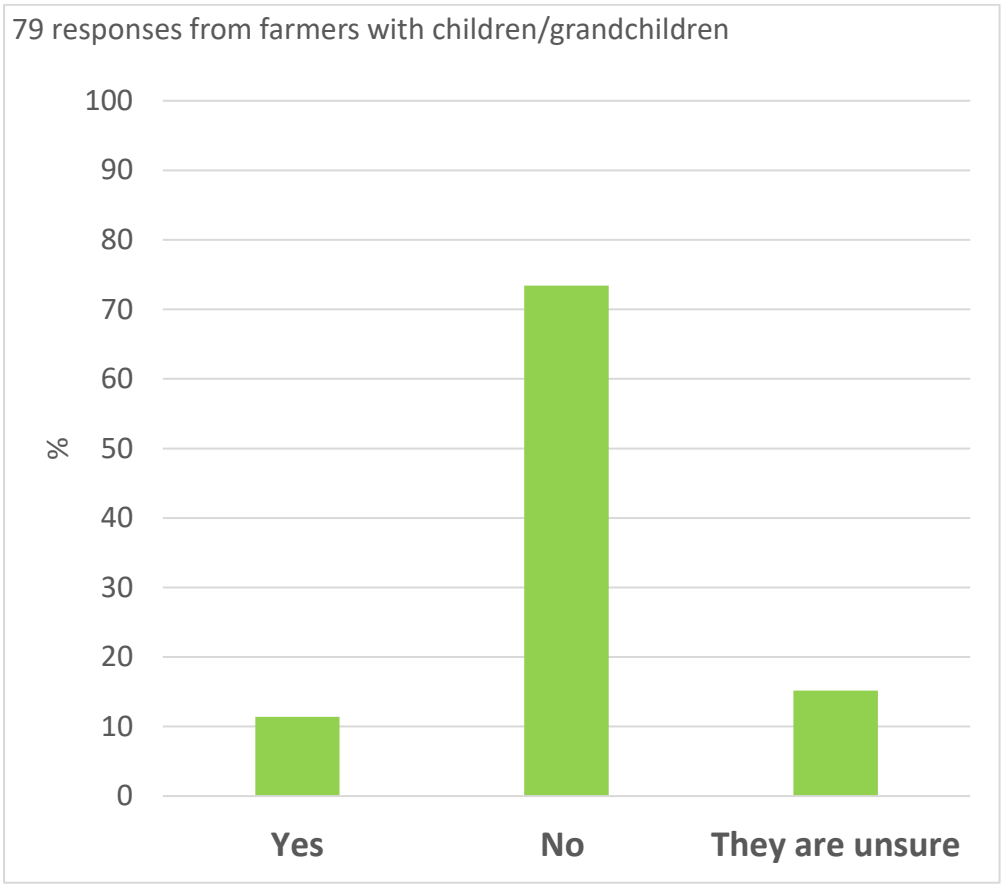
- ❑ **No**
- ❑ **Possibly**
- ❑ **Yes**



Question 11:

If you have children or grandchildren, do they feel that they can make a good living from farming in this area into the future?

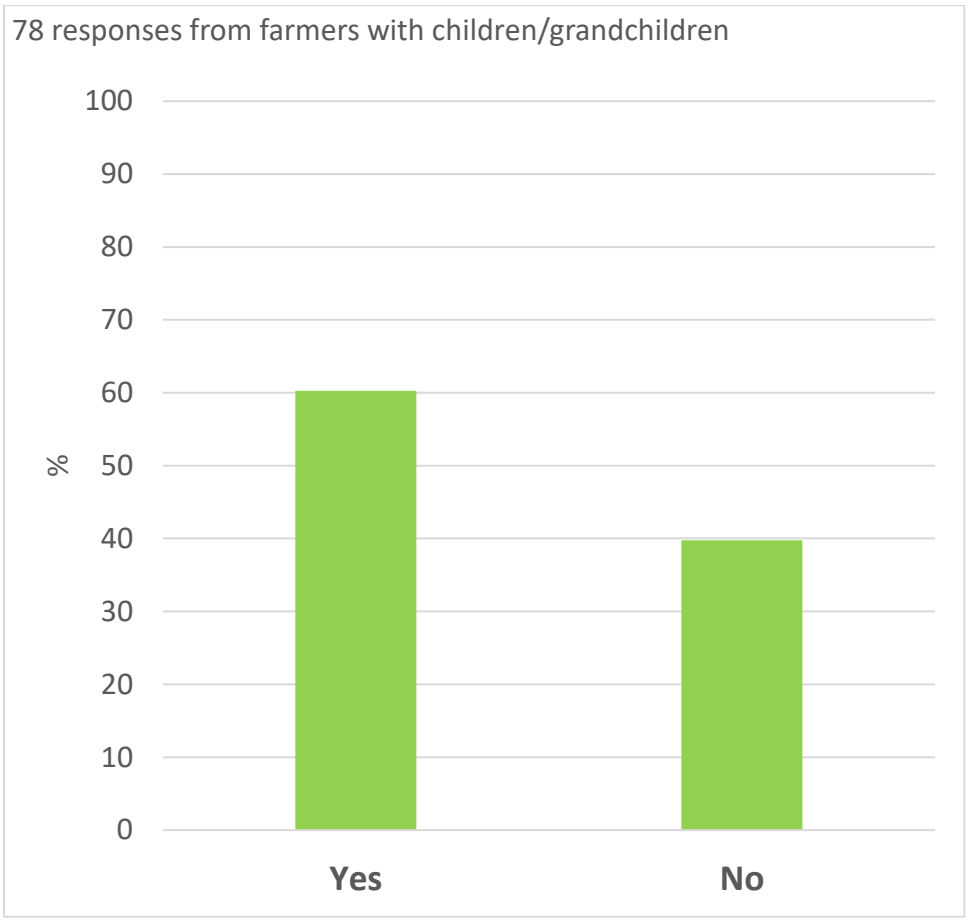
- ❑ **Yes**
- ❑ **No**
- ❑ **They are unsure**
- ❑ **I have no children/grandchildren**



Question 12:

Thinking now about your own feelings, would you like your children and grandchildren to be able to make a good living from farming in this area into the future?

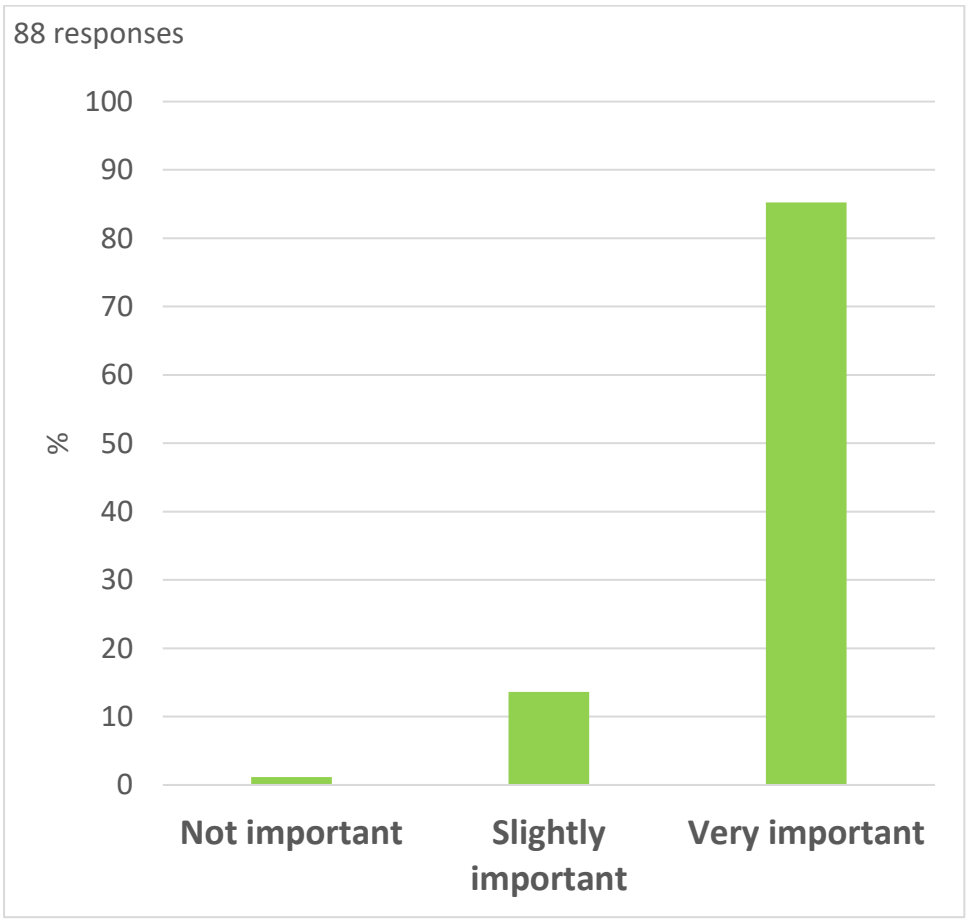
- ❑ **Yes**
- ❑ **No**
- ❑ **I have no children/grandchildren**



Question 13:

Thinking about the way that farmers are seen by the general public, some people think that farmers do not care about protecting the land and the natural environment. Is it important to you that the natural environment is maintained in good condition in the long term?

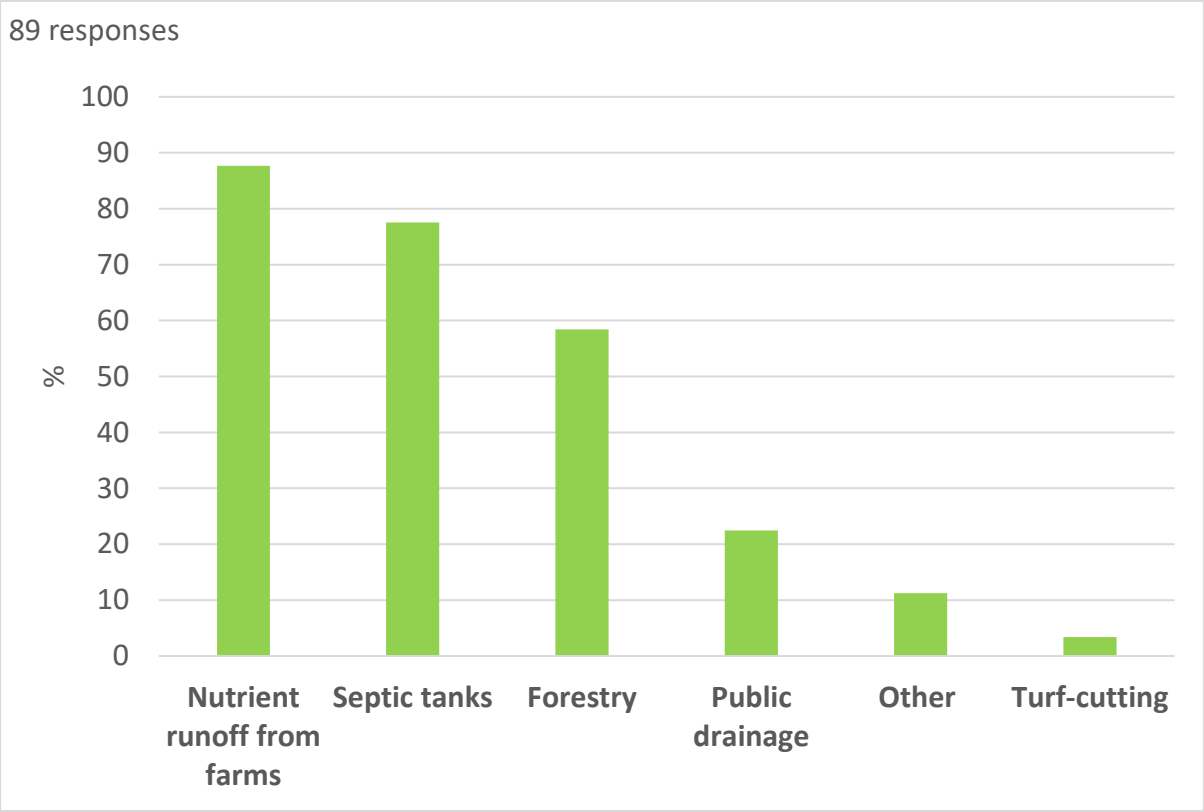
- ❑ **Not important**
- ❑ **Slightly important**
- ❑ **Very important**



Question 14:

In your opinion, which of these is the biggest threat to Lough Carra?

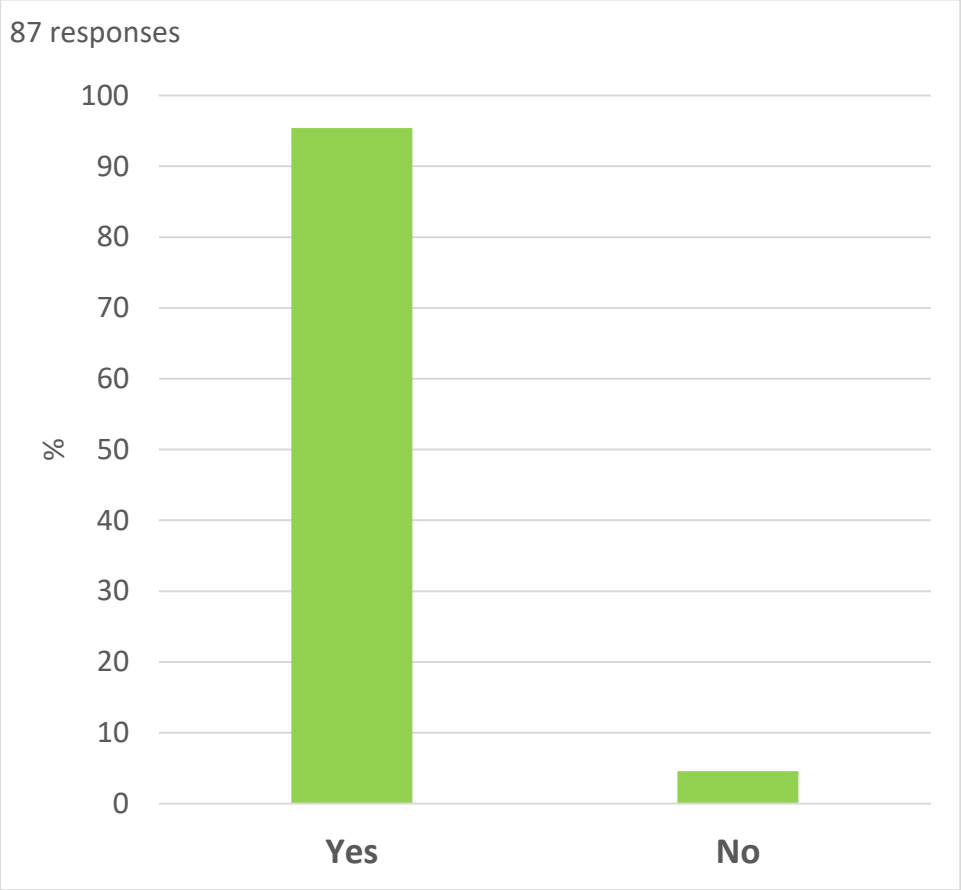
- ❑ **Septic tanks**
- ❑ **Turf-cutting**
- ❑ **Nutrient runoff from farms**
- ❑ **Public drainage**
- ❑ **Forestry**
- ❑ **Other**



Question 15:

Do you take any particular measures on your farm to protect the environment?

- ❑ **Yes**
- ❑ **No**



Many farmers specified the particular measures they take. These were given as follows:

- not spreading slurry near drains & rivers
- schemes
- all I can
- only spread slurry and spray weeds when weather is suitable
- never spread slurry or fertiliser if rain forecast
- I don't use chemicals and I don't spread slurry on any low lands
- planting trees & hedges
- no slurry spreading in winter
- comply with good farming practice
- step back from river
- spread slurry at right time

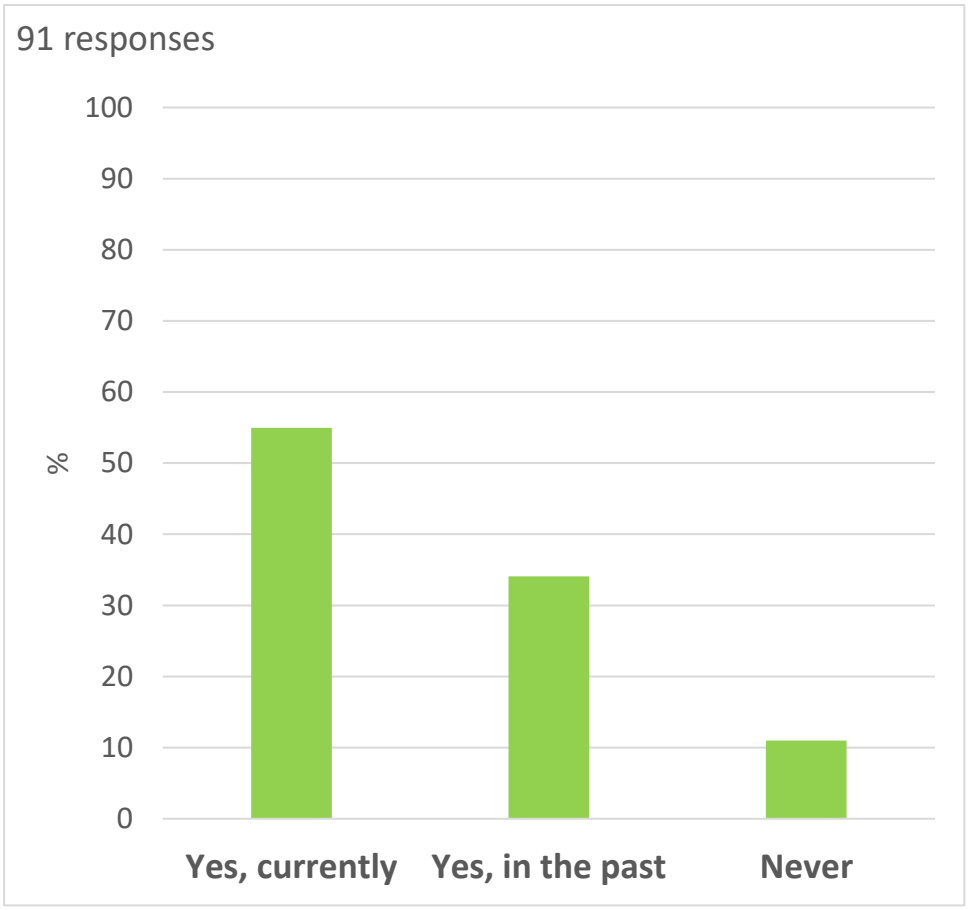
- care taken with chemicals re spraying
- trying hard
- careful use of chemicals and abide by laws
- stock outwintered
- don't spread slurry in poor weather conditions
- tidy yard
- no spreading of slurry/fertiliser near river
- Fencing
- schemes
- schemes
- native trees, don't apply slurry or fertiliser, encourage native plants
- recycle all plastic and containers
- every measure
- not overstocking, no slurry runoff
- maintaining existing landscape
- schemes
- GLAS
- Runoff land
- Land scheme
- schemes
- low stock
- all I can
- use of natural cleaning products and washing powder (septic tank)
- watercourses fenced off
- agri scheme - less fertiliser, eco-friendly household products
- fencing, cutting back on fertiliser
- fencing, piped water troughs, hedging, no slurry spreading till July
- Fencing off, agricultural schemes
- secure fencing, no slurry spreading till July
- keep fencing good, keep farm tidy
- don't spread slurry till July, good fencing
- GLAS agri scheme
- environmental schemes
- No pollution runoff
- GLAS programme
- keep river fenced at required buffer distance
- every measure
- loads - no runoff
- spread slurry in July
- don't overstock
- slurry only spread in May, empty septic tanks annually
- spread slurry at correct time of year
- spread slurry in July onwards, cut hay, no sprays
- no weedkillers, stone walls, trees, slurry spread after silage
- Birdseed, no topping till after July, no weedkillers
- keep hedgerows
- water collection and re-use
- Upgraded septic tank

- GLAS
- collect effluent
- no cattle housed for winter
- GLAS
- GLAS
- mind the land
- grow hedgerows, make hay, keep stone walls
- Bird and bat boxes, hay meadows, GLAS scheme

Question 16:

Are you, or have you ever been, in any agri-environmental programmes, such as REPS, GLAS or ASSAP?

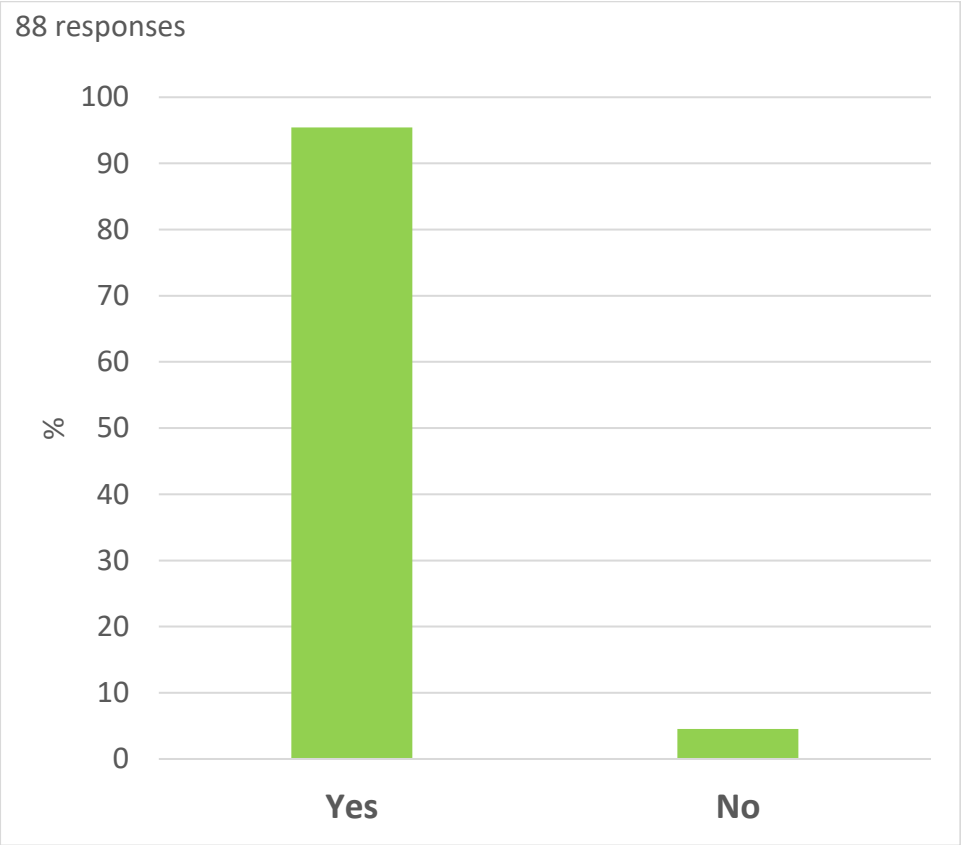
- ❑ **Yes, currently**
- ❑ **Yes, in the past**
- ❑ **Never**



Question 17:

Do you think that agri-environmental schemes like these are a good way to help farmers to work in ways that are better for the natural environment?

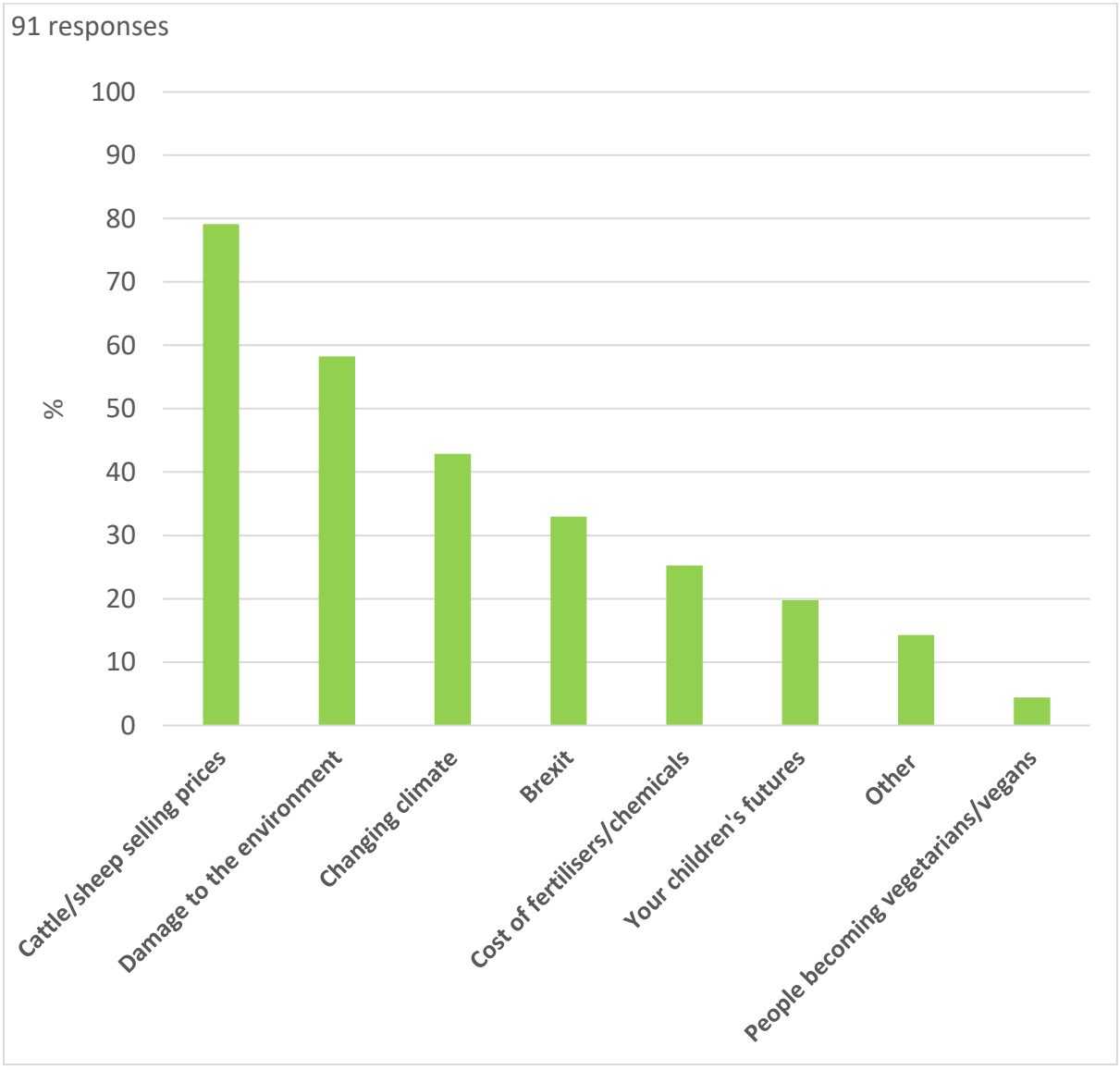
- ❑ **Yes**
- ❑ **No**



Question 18:

As a farmer, what are your biggest concerns at the moment? (tick all that apply)

- ❑ **Cattle/sheep selling prices**
- ❑ **Brexit**
- ❑ **Damage to the environment**
- ❑ **Cost of fertilisers/chemicals**
- ❑ **Changing climate**
- ❑ **Your children's futures**
- ❑ **People becoming vegetarians/vegans**
- ❑ **Other**



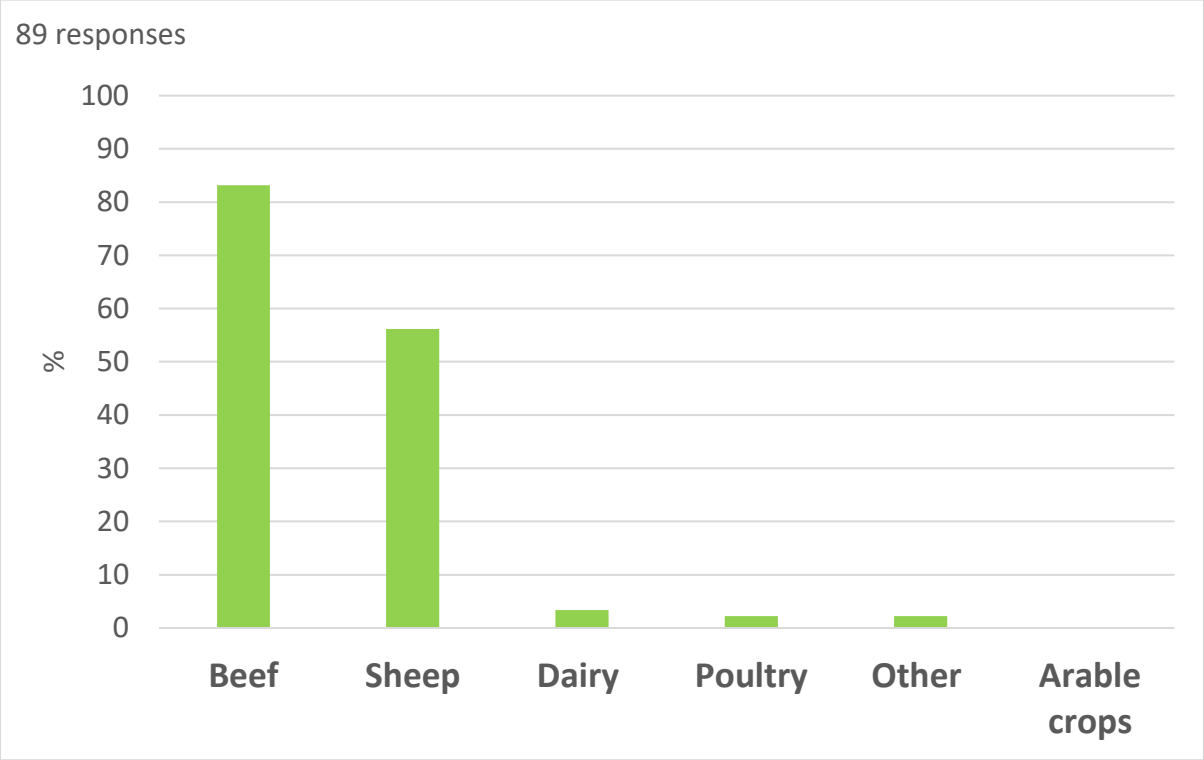
Some respondents chose to specify their own particular concerns. These were given as follows:

- too many regulations re farm buildings
- cost of everything
- no money in farming, getting old
- everything getting more expensive, no help on farms now
- red tape, farmers being told what to do
- All really
- everything getting dear
- Department rules
- small farmers should be protected
- no markets, low CAP payments
- Regulations, cost of everything increasing
- Department rules and regulations
- no market for stock

Question 19:

What kind of farming do you do? (Tick all that apply)

- ❑ **Beef**
- ❑ **Dairy**
- ❑ **Sheep**
- ❑ **Arable crops**
- ❑ **Poultry**
- ❑ **Other (please specify)**



Question 20:

Do you have any final comments or anything you would like to mention?

The following answers were given:

- I feel there is a lot more in towns and cities that can be done to help the environment
- The council and Board of Works should maintain the drains flowing into the lake
- Take my comments seriously
- Talk to local people
- Wrong time spreading slurry
- Should be better watch on slurry spreading
- Spring slurry spreading
- Give farmers living near rivers and lakes grant aid to buy organic fertiliser
- Change slurry time
- Change slurry spreading
- Biogas plant to take slurry off the land and encourage clover for fertility
- The introduction of aerobic digesters
- More people should be concerned and more people should be getting involved
- Move slurry spreading to later
- Have slurry regulations change to later in spring
- More control on slurry spreading
- Regulations should be changed to prevent slurry being spread till April
- Change farming methods
- The septic tanks issue is critical and needs to be addressed immediately
- There needs to be full grants for new septic tanks, don't spread slurry till at least April
- Anyone with septic tanks issues should get 100% grant to get it fixed immediately.
- Slurry spread far too early in year - April is early enough
- Public awareness & action
- Slurry
- More finance to solve problems
- Lifestyle & actions change
- We would like the river adjoining our land cleaned and maintained now
- Later slurry spreading, mid-April
- Bring in retirement scheme
- Didn't know about LCCA
- Septic tanks in this area - it is limestone, septic tank waste seeps into the water quickly due to cracks in the limestone
- Farmers obey rules, it's the rules that are not right
- Stop spreading slurry in spring, bring back hay, stop making silage, stop letting pig slurry be spread in the area
- Madness spreading slurry in January, February & March when water table is high. No policing of slurry spreading. Septic tanks not emptied
- Get more environmental schemes for farmers
- Any money from Europe comes with a lot of paperwork & rules
- Awareness campaign - I didn't know about LCCA
- Keep cattle for summer

- 25% of our money is taken by Teagasc each year for paperwork, average acreage in Mayo is 25 acres, we are not the problem?
- April, May slurry spread
- CAP should stop paying big farmers & give it to greening measures
- Department inspectors punish farmers
- Move slurry to April