Planning and Environmental Consultants

Lady's Island Hydrogeological Assessment - Phase 1 Report - DRAFT

Hydrogeological Assessment of Lady's Island

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Prepared By:	**MKO** **Tuam Road** **Galway** **Ireland** **H91 VW84**

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ACRONYMS

EPA	Estimated Time Arrival
ERT	Electrical Resistivity Tomography
GSI	Geological Survey Ireland
LAWPRO	Local Authorities Water Programme
N	Nitrogen
NO_3	Nitrate
NPWS	National Parks and Wildlife Service
OPW	Office of Public Works
P	Phosphorus
PIP	Pollution Impact Potential
SAC	Special Area of Conservation
SPA	Special Protected Area
WCC	Wexford County Council
WFD	Water Framework Directive

1. INTRODUCTION

This report is a Phase 1 hydrogeological assessment of Lady's Island Lake (the lake) and its groundwater catchment. The report has been prepared for Wexford County Council (WCC) to support WCC's ongoing efforts to manage and improve the water quality of the lake.

As extensively documented in publicly available reports, journal articles, and media, the lake is in poor ecological condition and failing to achieve its favourable conservation status as a designated and nationally significant Special Protected Area (SPA) and Special Area of Conservation (SAC). The poor ecological condition is linked to poor water quality resulting from excessive nitrogen and phosphorus loading from surrounding lands, where the principal environmental pressures are associated with agriculture practices (e.g., farmyard discharges and land spreading of slurry) and wastewater discharges.

The water quality problems are cumulative as nutrients are added to the lake's catchment each year and are retained (thus accumulate) in lake sediments. Reporting by O'Connor *et al.* (2024)[1] concluded that nutrient loading will need to be reduced by at least 10-fold for the coastal lagoon to achieve its conservation objectives.

While a great deal of information and knowledge has been gained on causes and effects of nutrient loading to the lake, much is yet to be understood about the potential role that groundwater plays in nutrient delivery. A 10-fold decrease in nutrient loading is an impactful conclusion which carries consequences for the farmers/residents in the catchment. As such, it merits further scrutiny and confirmation. Verification of the current nutrient loading model by factoring in the groundwater component in greater detail is part of that.

1.1 Objectives

The objectives of this Phase 1 report are to:

- Describe the hydrogeological setting of the lake.
- Present a conceptual hydrogeological model of the lake's catchment, which synthesizes what is known about groundwater, how groundwater and the lake may interact, and the role of groundwater in delivering flux and nutrient loads to the lake.
- Summarizes data or knowledge gaps identified from the review of available data and information.
- Outlines a suggested approach for improving the characterization and understanding of nutrient delivery to the lake, including groundwater pathways.
- Recommends further work, in a subsequent phase, which can help to address any major data or knowledge gaps.
- To propose an approach towards identifying suitable mitigation actions for reducing nutrient loads from groundwater, as applicable, based on identified source-pathway-receptor linkages.

This Phase 1 assessment report is, therefore, based on the source-pathway-receptor model of environmental risk assessment which underpins water resources protection initiatives in Ireland. It also engages with the principal water balance components of the lake.

1.2 Scope

To prepare this Phase 1 report, a desk study review was conducted of data and information that are available in the public domain. This includes reports and journal articles published by public bodies and academia. References used are listed in the bibliography section of this report. Important data and information sources are the Environmental Protection Agency (EPA), Geological Survey Ireland (GSI), National Parks and Wildlife Service (NPWS), Office of Public Works (OPW), and Teagasc.

Catchment walks or other field work were not included in this Phase 1 assessment.

[1] *Commonly referred to as the CLEAR report.*

2. BASELINE DESCRIPTION

Lady's Island Lake is a coastal lagoon separated from the sea by a sand and gravel barrier. The lake covers an area of approximately 3.5 km^2, while its topographic catchment covers an area of approximately 19.2 km^2 (Figure 1). Without access to any groundwater level information, the groundwater catchment of the lake is, for now, assumed to be the same as the topographic catchment.

Figure 1: Lady's Island Lake Catchment Area (Background taken from OSI Discovery Series Sheet 77)

2.1 Geological Setting

The lake catchment area is characterised by glacial till deposits but also contains mapped paleo-channels of alluvium and outwash sediments. The alluvium is mapped along present-day streams and Holocene river terraces. Based on GSI mapping, the glacial till is derived from metamorphic rocks and sandstones and shales, depending on location (**Figure 2**). The till extends beneath the lake where it is covered by lake sediments which have accumulated from suspended sediments brought in by streams, artificial drains, and surface runoff. A small area of fen peat has developed and is mapped in the southeastern part of catchment.

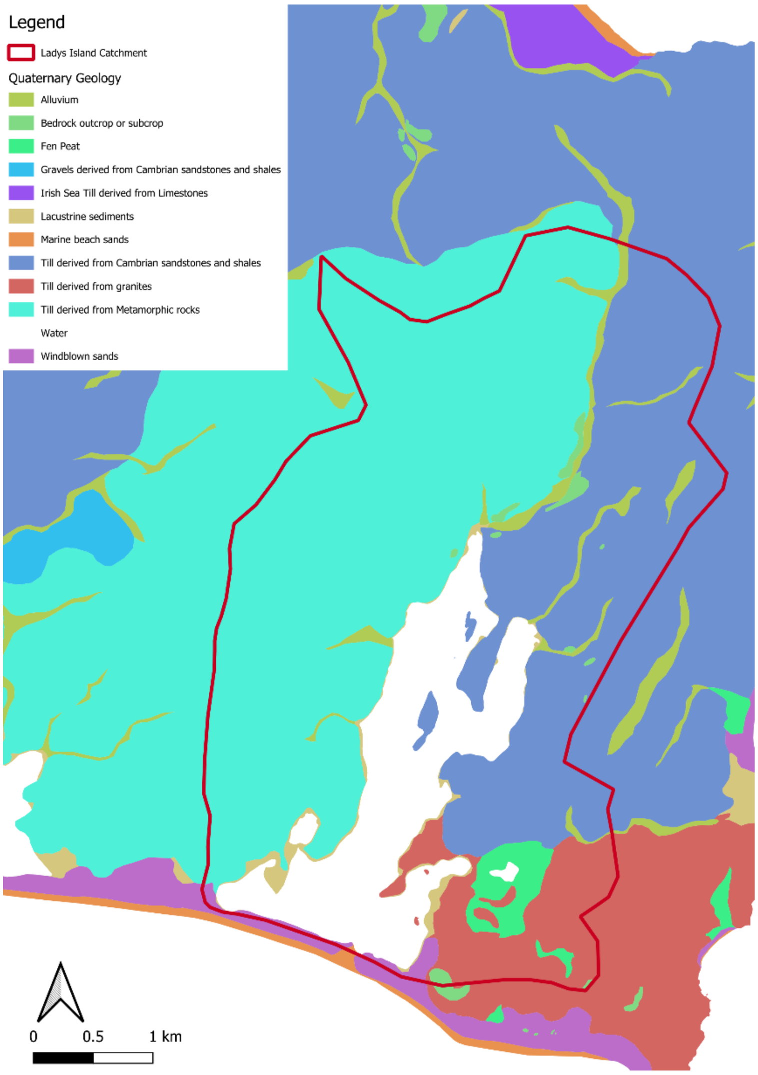


Figure 2: Quaternary Geology (Source: GSI)

The thickness of the glacial till varies across the catchment. There are no borehole data available in the public realm to confirm interpretations of sediment thickness. However, GSI's groundwater vulnerability map (**Figure 3**) offers clues, whereby the till appears to be thicker on the west side of the lake compared to the east. To the west, both groundwater vulnerability and subsoil permeability (**Figure 4**) are mapped as Low. Using GSI's vulnerability mapping criteria (**Table 1**), this combination means that depths to bedrock may be 10 m or more. Along the western shoreline, vulnerability is mapped as Moderate in an area of Low permeability subsoil. This implies that subsoil thickness is expected to be in the range of 5 to 10 m. To the east of the lake, vulnerability is High and subsoil permeability is Moderate. Per **Table 1**, this combination implies that the tills are between 3 and 10 m thick. In a few locations to the east where vulnerability is mapped as Extreme, the tills are close to or at ground surface. Accordingly, the thickness of the till is inferred by GSI to be decreasing generally from west to east.

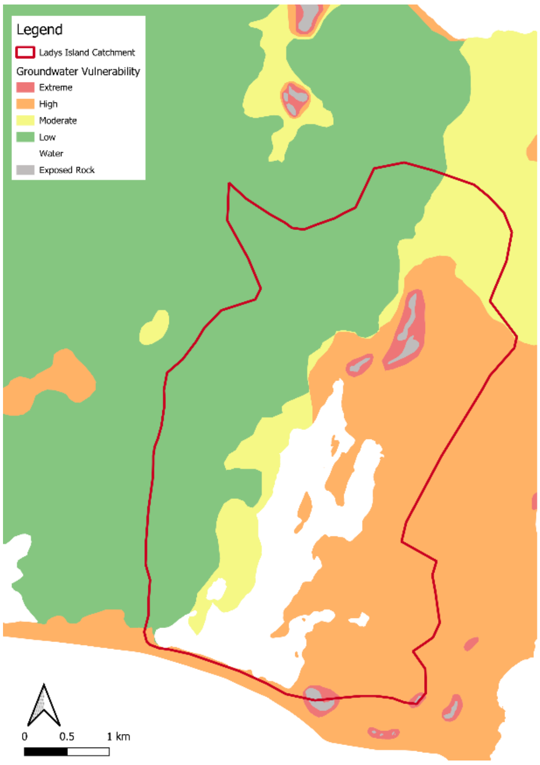


Figure 3: Groundwater Vulnerability (GSI)

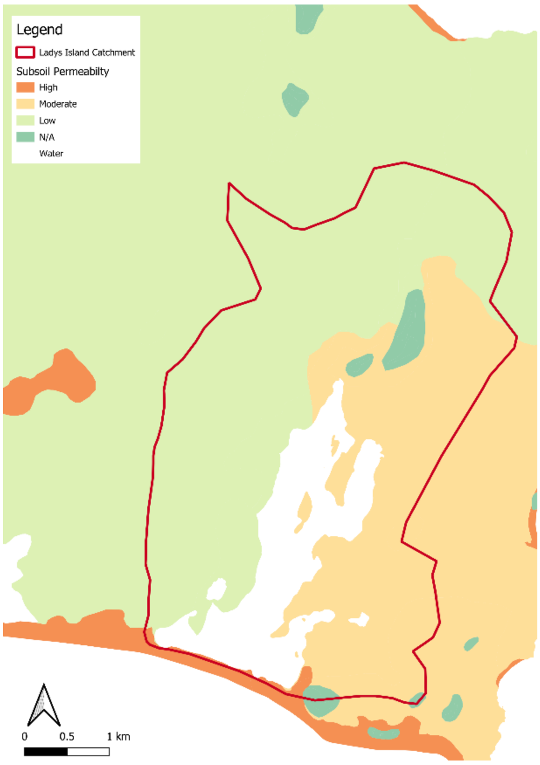


Figure 4: Subsoil Permeability GSI)

Table 1: Groundwater Vulnerability Criteria (Source: GSI 2003)

Depth to rock	**Hydrogeological Requirements for Vulnerability Categories**				
	Diffuse recharge			**Point Recharge**	**Unsaturated Zone**
	high permeability (*sand/gravel*)	Moderate permeability (*sandy subsoil*)	low permeability (*clayey subsoil, clay, peat*)	(*swallow holes, losing streams*)	(*sand & gravel aquifers only*)
0–3 m	**Extreme**	**Extreme**	**Extreme**	**Extreme (30 m radius)**	**Extreme**
3–5 m	**High**	**High**	**High**	**N/A**	**High**
5–10 m	**High**	**High**	**Moderate**	**N/A**	**High**
>10 m	**High**	**Moderate**	**Low**	**N/A**	**High**

i *N/A = not applicable.*
ii *Release point of contaminants is assumed to be 1–2 m below ground surface.*
iii *Permeability classifications relate to the engineering behaviour as described by BS5930.*
iv *Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability.*
(amended from Deakin and Daly (1999) and DELG/EPA/GSI (1999))

The glacial till rests on metamorphic and granitic rock types, depending on location (Figure 5). Geological fault traces have been mapped crossing the lake's catchment area, trending roughly north-south.

Windblown sands are deposited as a dune barrier system to the south between the shoreline and the lake. These sands have high permeability and provide for hydraulic connectivity between the sea and the lake (tidal influences). Lagoon (lake) sediments vary from mud (more so in the northern end) to coarser sands and gravel (south).

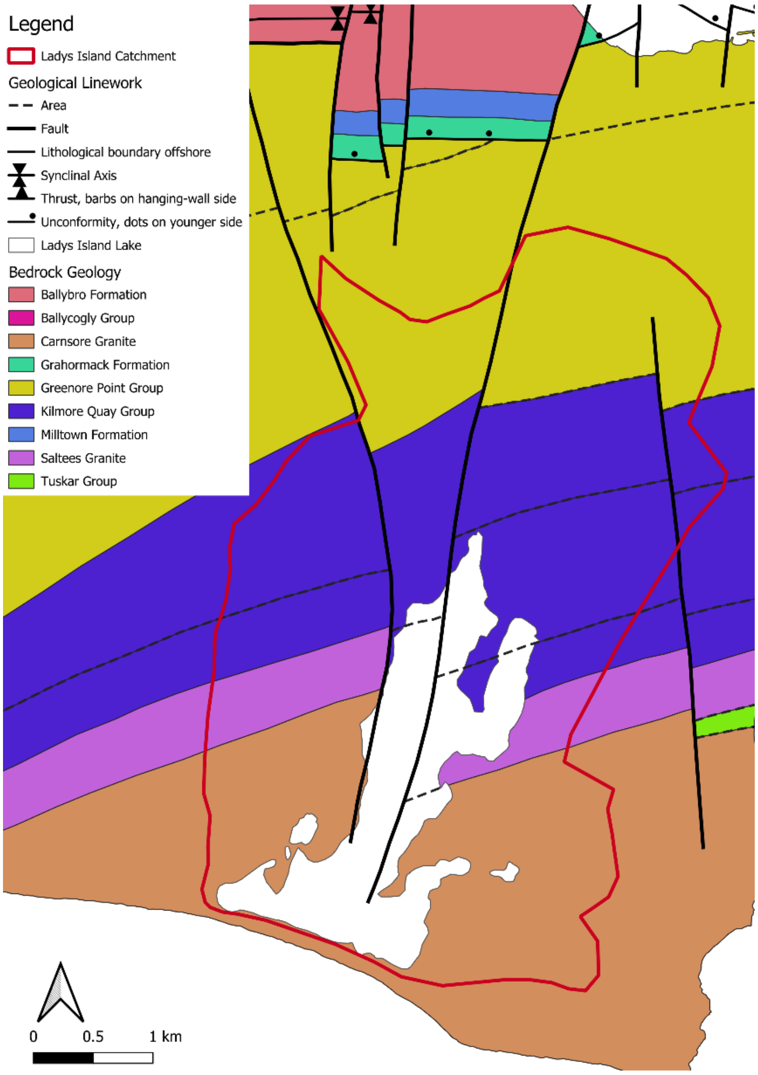


Figure 5: Bedrock Geology (Source: GSI)

2.2 Hydrology

Deep well drained mineral soils are mapped throughout the catchment (**Figure 6**), including the Low subsoil permeability areas to the west. Well drained soils overlying Low permeability subsoils is an atypical scenario in the Irish context but appears to be substantiated by references to sand and gravel substrate in feeder streams on the west side of the lake (specifically stream 3, 4, and 6; Hurley 2025).

Up to twelve small but distinct streams flow into the lake, mostly from the west and north (**Figure 7**). Additional artificial drainage channels exist, and surface runoff is also delivered diffusely, especially in the low-lying and heavily vegetated peat areas in the southeast.

The EPA has mapped seven river water bodies for WFD reporting purposes and their subcatchment areas range in size from <0.5 to approximately 5.9 km^2 (LAWPRO, 2025a). The largest is associated with the Kisha stream to the north, forming the 'Kisha_010' water body.

Some of the streams originate as 'rises' (seeps/springs) in the glacial till. Field drains are also present, mainly in the western and northern parts of the catchment. The drains have been dug by farmers for ground improvement purposes, reflecting more challenging drainage conditions in these parts of the catchment.

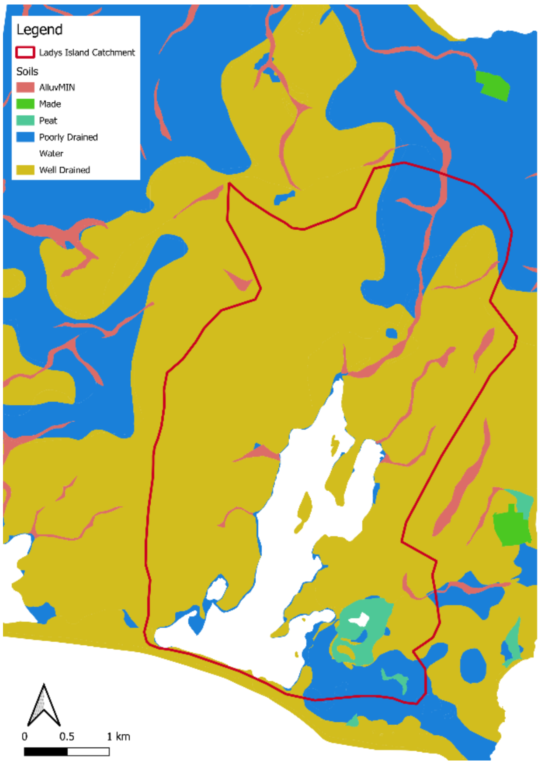


Figure 6: Soils (Source: Teagasc/EPA)

Figure 7: Feeder Streams and Recent Sampling Locations by EPA and WCC (Source: Hurley 2025)

There are no stream gauges (hence, individual flow contributions are poorly quantified. EPA's Hydrotool provides flow metrics for the Kisha Stream only, at node '13_251' representing the Kisha subcatchment, with a subcatchment area of 5.9 km^2 (**Figure 8**). The naturalised flow percentiles from Hydrotool are presented in **Figure 9**. The estimated Q_{95} flow (i.e., the flow that is exceeded 95% of the time) is 0.012 m^3/s and the estimated annual mean flow (AMF) is 0.093 m^3/s, represented by the (approximate) Q_{30} flow.

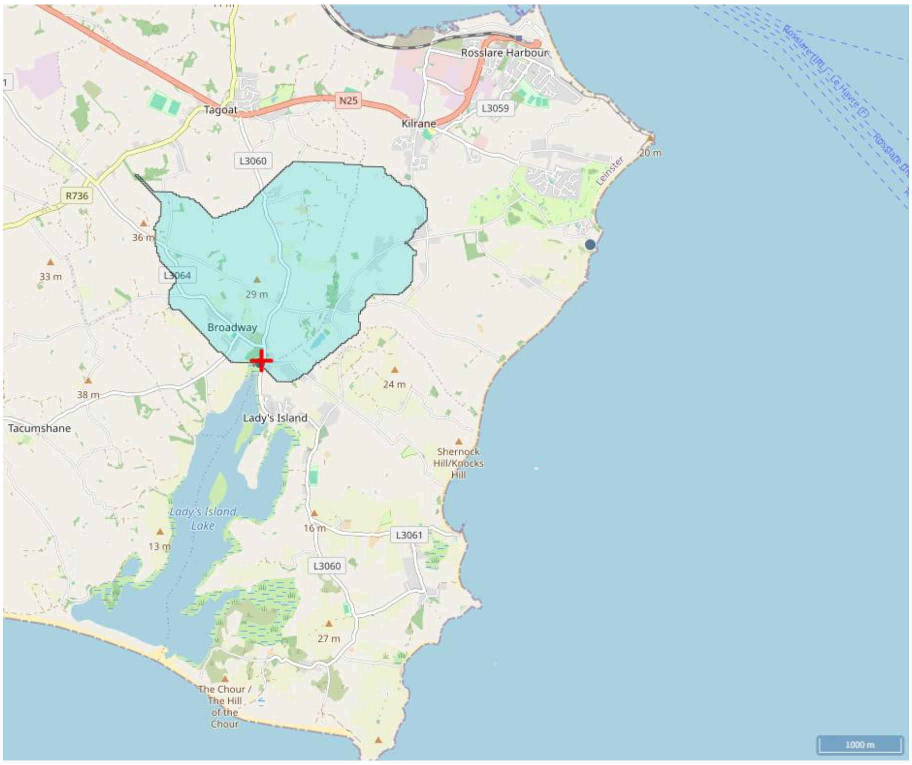


Figure 8: Subcatchment (Blue Shaded Area) of Hydrotool Node 13_251 (Source: EPA)

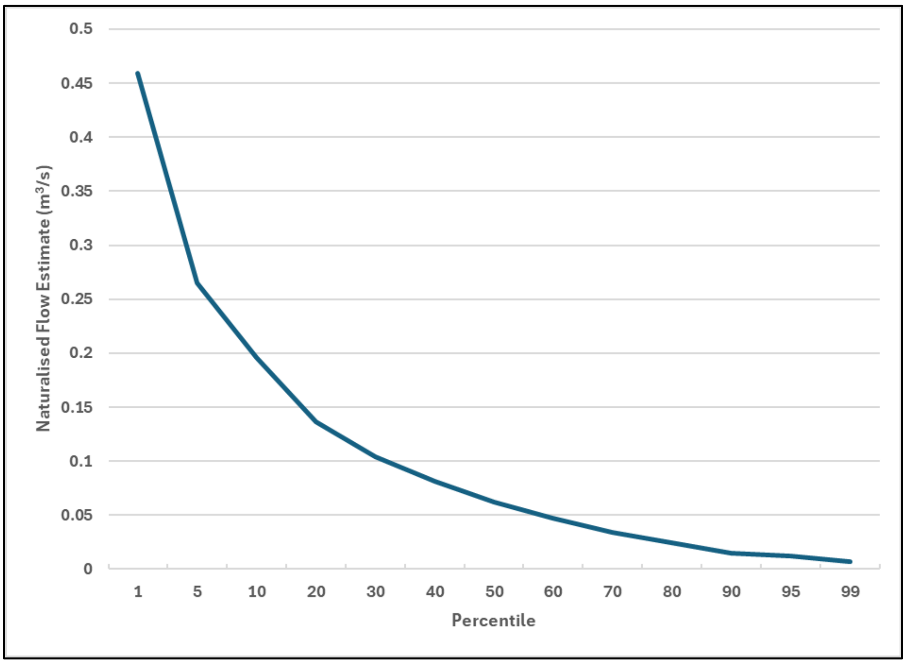


Figure 9: Naturalised Flow Estimates, Kisha Stream, Hydrotool Node 13_251 (Source: EPA)

Pro-rating specific runoff values derived from Kisha to the remainder of the total catchment area would give a total Q_{95} flow contribution to the lake of 0.032 m^3/s. The Q95 is a low-flow metric which is often regarded as an indicator of groundwater baseflow to streams, as streams rely on groundwater baseflow during prolonged dry weather conditions. A Q_{95} value of 0.032 m^3/s represents approximately 23% of effective rainfall (284.1 mm/yr)[2] across the catchment which means that 77% of effective rainfall is contributed by surface inflows (streams, field drains, and surface runoff directly into the lake). These figures are consistent with, and presumably derived in the same manner by, O'Connor *et al.* (2024) who also estimated the "*annual average inflow to the lake is 4.715 million m³ which represents a 1.57m rise in lake level. From year to year, this inflow volume can vary by a factor of up to 2.*"

2.3 Hydrogeology

Precisely how and in what quantities groundwater enters the lake cannot be ascertained with certainty from the available data and information. Because the catchment is underlain by 'poorly productive' bedrock types, groundwater recharge to, and discharge contributions via, bedrock are expected to be limited. In the bedrock, groundwater flow takes place via fractures and fissures. Conventionally in poorly productive bedrock, the degree of fracturing and groundwater fluxes decrease with depth. Bedrock flow and discharges may be facilitated by a 'transition zone', which is a broken, weathered zone in the upper few metres of bedrock (EPA 2010). While the transition zone is not typically a significant groundwater resource, it can be a significant pathway for pollutant transfer to surface waters. Whether such a transition zone is present with the lake's catchment is not yet known or confirmed, but it is assumed, as it is quite common in this type of hydrogeological setting elsewhere in Ireland.

Groundwater is also expected to be delivered via the subsoils, manifested by springs or seeps along the lake's margin and field drains. There are few such recorded or documented springs to date, but they do exist. 'Lady's Well' (a holy well) gives rise to a short stream segment just south of the town of Lady's Island (to the east of the lake). The apparent flow is a few litres per second. The phrase "*A short water course appears to flow from a spring ....*" is also referenced by Hurley (2025) in the townland of Reedstown. 'Springs' (unspecified in numbers, character, and locations) are further referred to by Hurley (1997).

Groundwater flow and discharges via subsoils may influence the understanding of nutrient loading to the lake and any mitigation measures that may follow. The Quaternary sediments are not uniform in composition. Paleo-channels are implied by existing mapping, and the area has undergone several cycles of glaciation (Collins and Cummins 1986). The cited authors refer to meltwater/outwash sands and gravels in the area. Hurley (1997) also refers to pipelaying works in the town of Lady's Island which revealed "*sorted sands and rounded gravels at depth within the till*".

Applying Darcy's Law, a preliminary, illustrative estimate of groundwater flux is presented below for the area to the east which is mapped as Moderate permeability subsoils:

$$Q = K \times i \times A$$

Where,

Q = groundwater flux (m^3/d), calculated.

K = hydraulic conductivity, or permeability (m/d), considered to be 10-6 m/s, or 0.864 m/d for a Moderate permeability subsoil type.

i = hydraulic gradient (assumed to be 0.01 without actual site data).

A = cross-sectional area of groundwater flux, considered per km length and 5 m saturated thickness in subsoil (i.e., 1,000 m by 5 m = 5,000 m^2).

[2] *Based on Hydrotool, the long-term average annual rainfall (period 1981–2010) over the catchment is 837.4 mm/yr and the average annual evapotranspiration rate is 553.3 mm/yr, which means the effective rainfall is 284.1 mm/yr.*

Hence, Q becomes 43.2 m^3/d per km length of discharge. The total length of the eastern shore of the lake is approximately 3 km, hence, the total groundwater discharge from subsoils from the east becomes approximately 130 m^3/d.

If the groundwater concentration of nitrate in subsoil is equivalent to the indicative sample result from Lady's Well spring (8.4 mg/l-N, Section 2.4) then the total annual load of N from groundwater in subsoils from the east (only) becomes 130 m^3/d × 8.4 mg/l = 397.35 kg/yr. This is an indicator of loading. It must be multiplied up further to take account of the total discharge from subsoils all around the perimeter length of the lake and to account for potential discharges from bedrock. The calculation shows the importance of developing catchment-specific data for groundwater that can be used mass loading analyses.

There are, to date, no boreholes or monitoring wells from which hydraulic properties, groundwater flow patterns, or level fluctuations can be described. From first principles, it is assumed that groundwater flow will mimic topography, i.e., flow converges on the lake.

There are private supply wells at farms, but these have not been mapped or dipped for groundwater levels. Hurley (1997) refers to 30-40 such wells in the Lady's Island and Carna areas, used for irrigation purposes. Many more private wells may exist today. In Hurley's reporting in 1997, the 30-40 private wells are between 30 and 60 m deep and yield between 0.2 to 17.5 m^3/hr. The upper end value would be considered a particularly good yield from a 'poorly productive' bedrock, but accuracy and circumstances of reporting cannot be verified with the available information. Hurley (1997) states that the "*source of this groundwater is unknown*".

As much as groundwater discharges to the lake, groundwater also interacts hydraulically with the lake. The interaction is conceptually well understood although specific characteristics are not documented with any data to date, mainly because groundwater level monitoring is necessary to do so. The lake, as a coastal lagoon, is tidal, fluctuating by approximately 2 m annually (**Figure 10**). Groundwater closer to the lake is also expected to show tidal responses, especially if/where groundwater is under confined conditions. Any groundwater discharges to the lake will occur under prevailing hydraulic gradients.

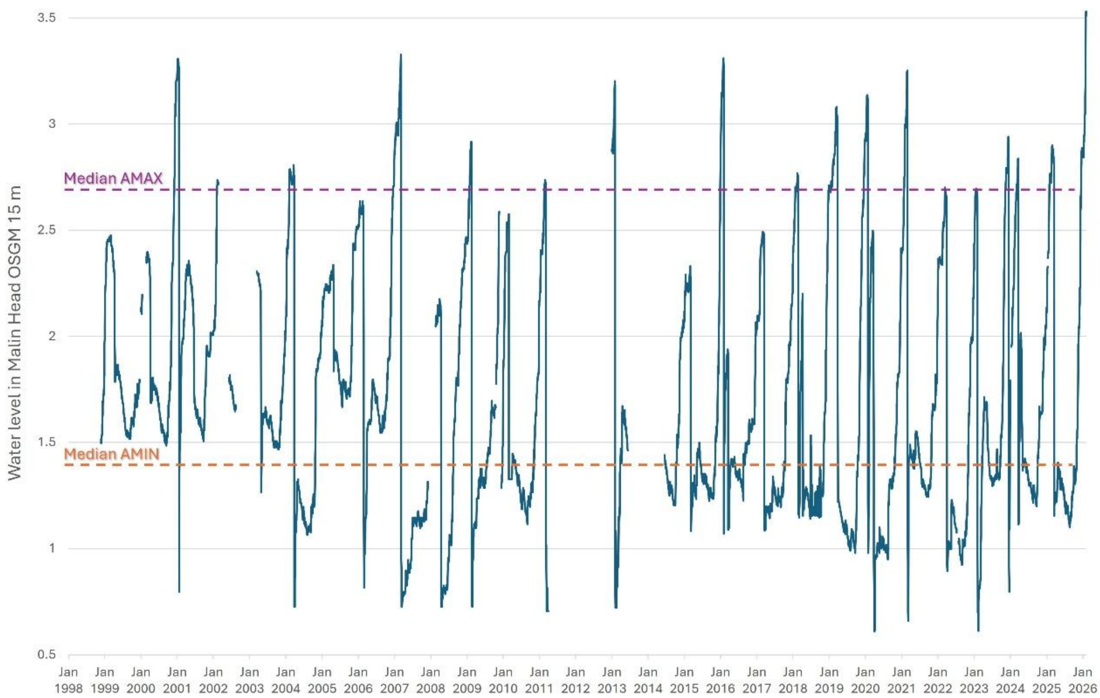


Figure 10: Recorded Lake Levels (Source: OPW)

The lake level time series reflects the management of lake levels, with lake levels continuing to rise each winter to between approximately 2.5 and 3.2 mOD until sand barrier is purposefully breached (cut) each year in March. This is a flood mitigation measure, i.e., to prevent flooding of agricultural lands mainly but also to preserve bird nesting sites. Once the breach is arranged, the lake drains out with lake levels falling to a level typically between 0.7 and 1.2 mOD. The breach naturally closes by wave action and sediment re-deposition, and once the breach is sealed, the lake level rises from the various inflows behind the sand barrier.

The degree to which groundwater level fluctuate, and the distance from the lake that groundwater levels are influenced by the lake's hydrodynamics, are not known.

2.4 Environmental Pressures

The principal land use in the catchment is agriculture, represented by both pasture and tillage farming, and tillage being dominant on the western side of the lake (**Figure 11**). Agriculture is named by LAWPRO as a *significant pressure* in the catchment, affecting the water quality of the lake. Nitrate is also considered the principal *significant issue* in terms of water quality, which is confirmed by O'Connor *et al.* (2024). The nitrate (as well as other nutrient constituents) is delivered by surface water pathways, which is extensively documented by stream samples to date. The nitrate is likely also delivered by groundwater pathways, but there are no wells sampled within the catchment to confirm this. The extent to which any nitrates may be denitrified along groundwater pathways has also not been established.

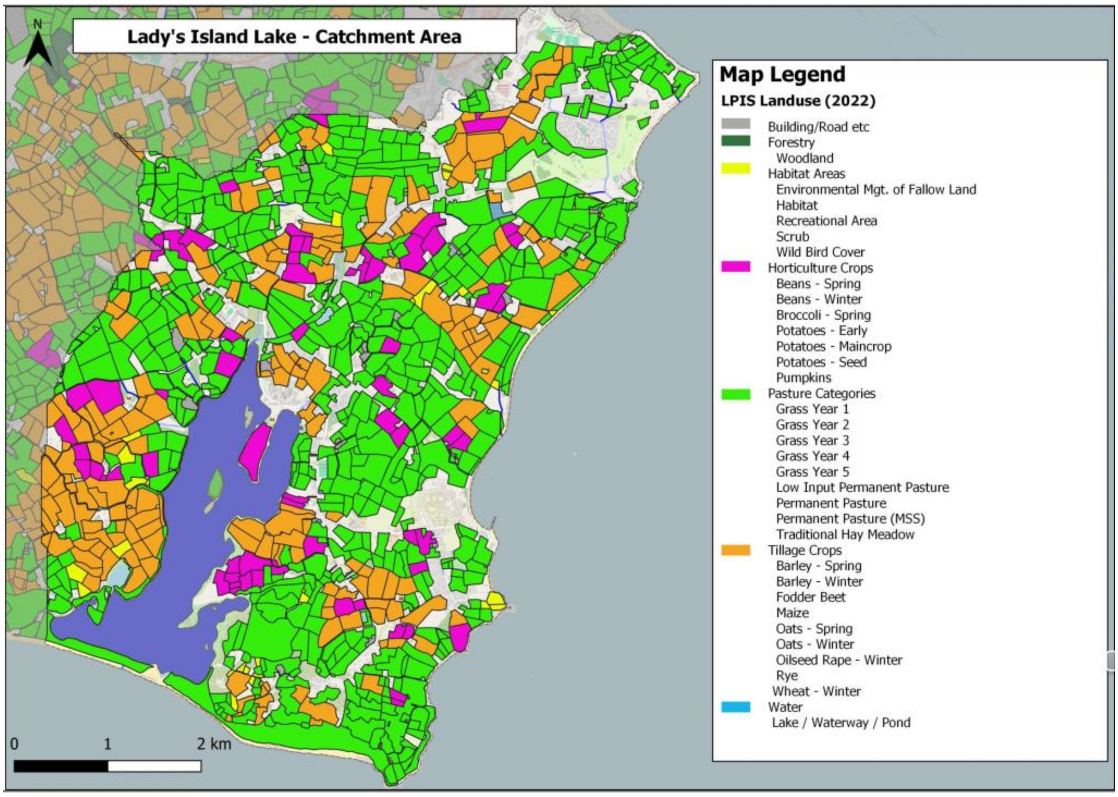
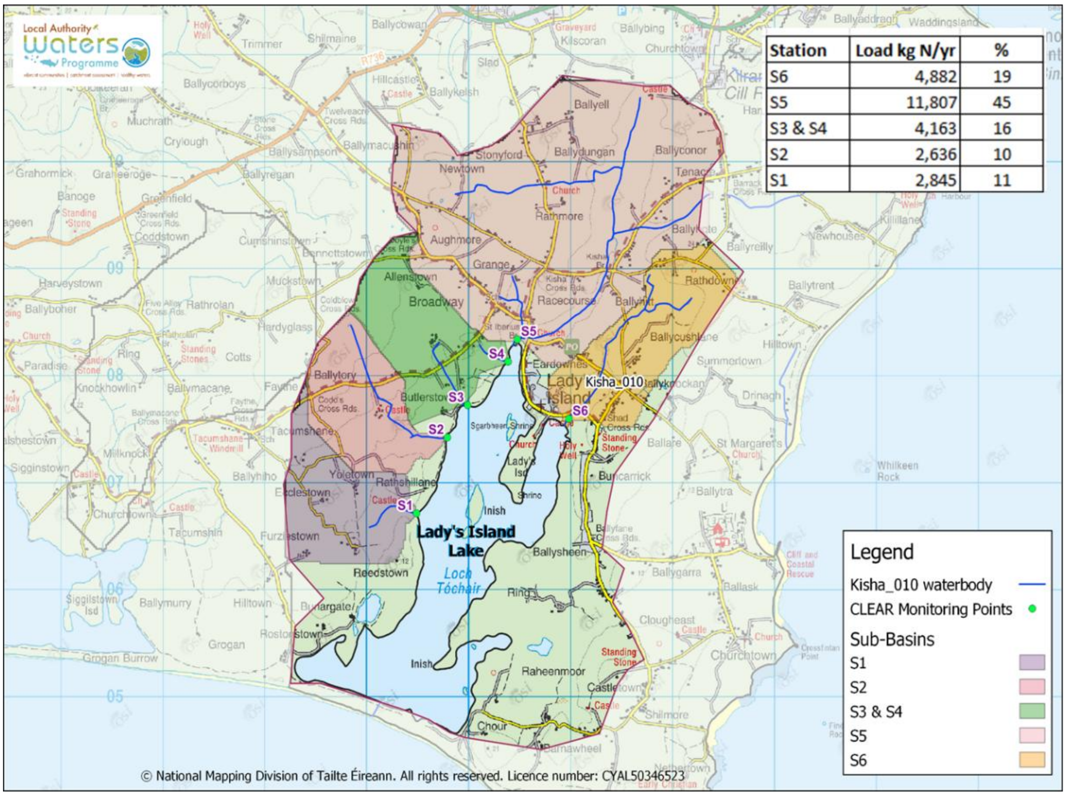


Figure 11: Agricultural Land Uses (Source: LAWPRO 2025a)

Phosphates are also affecting the water quality of the lake. In both cases, i.e., nitrate and phosphate, specific diffuse source evaluations linked to agricultural practices and farms/dwellings appears to be needed. While an urban wastewater discharge is a known source of nutrient load to the Kisha stream, and is being addressed, septic tanks and other domestic wastewater treatment systems may also be contributing to diffuse pollution across the catchments. The latter can be an issue where drainage characteristics are poor, providing for inadequate percolation.

Initial attempts to measure and determine relative nitrogen (N) load contributions from the different streams in the lake's catchment have been made by LAWPRO (2025b). Reproduced in **Figure 12**, the largest stream load is from the Kisha subcatchment (S5) in the north, accounting for nearly half of the estimated stream load. This is mostly due to the larger flow associated with this subcatchment compared to the other smaller streams. As can be seen from **Figure 12**, there are no stream contributions in the southeast, as there are no inflowing streams in this part of the lake catchment areas. Agriculture is practiced in this part of the catchment as well, and soils are mapped as well drained and subsoils are mapped with Moderate permeability. It is implied, therefore, that nitrates enter the lake in this part of the catchment by groundwater pathways alone.



Station	Load kg N/yr	%
S6	4,882	19
S5	11,807	45
S3 & S4	4,163	16
S2	2,636	10
S1	2,845	11

Figure 12: Estimated Loads of N from Feeder Streams (Source: LAWPRO 2025b)

Reported concentrations of total oxidised nitrogen, for which nitrate is the principal constituent, ranged from 2.4 to 7.9 mg/l-N in streams sampled in 2023 (LAWPRO 2025a). Total ammonia ranged from 0.038 to 0.35 mg/l-N. There are no comparable groundwater samples. A sample taken from the stream that originates at 'Lady's Well' (which is a spring and reflects groundwater) showed a mean "*nitrate + nitrite*" result of 8.4 mg/l-N (range 4.6-12.0 mg/l-N), as reported by Neill (1984). The results from other feeder streams were lower (range 0.2-2.8 mg/l-N).

For samples collected by WCC on 28 April 2025 (WCC 2025), nitrate concentrations in feeder streams ranged from <1 to 8 mg/l-N, with the maximum collected in the streams that is associated with the same spring referenced above.

Based on monthly sampling of six streams, O'Connor *et al.* (2024) documented similar concentration ranges to LAWPRO and showed that nutrient inputs to the lake occur mostly in the winter months, with maxima in February-March. An annual nutrient budget was presented which indicates that up to 60 tonnes of N and 1.5 tonnes of P enter the lake, with significant update of N and P in the lake sediments. O'Connor *et al.* (2024) recognised that "*a potential error in this budget is in the calculation of the contribution of groundwater nutrients"*. As a check on this, stream nitrogen concentrations in May through August (when groundwater baseflow are highest as a percent of total flow) were calculated to be approximately 82% of the annual average concentration, and it was concluded that the "*stream nutrient concentration is taken to include the groundwater fraction*". This still does not quantify potential loads in other non-sampled streams, temporal differences in baseflow in the sampled streams, or groundwater loading from areas where streams are not present. Even if the total nutrient loading can be quantified from lake sample results, there are open questions surrounding the groundwater loads, spatially and temporally.

Compared to the 60 tonnes estimated by O'Connor *et al.* (2024), LAWPRO estimated that 26 tonnes of nitrogen per year are entering the lake via inputting streams, thus not accounting for groundwater.

2.5 Receptor Condition

According to the latest water body status classification period (2019-2024), Lady's Island lake is at Poor ecological status, based on monitoring. The streams flowing into the lake, including Kisha, are at Moderate ecological status, also based on modelling. Thus, neither the lake nor the streams meet WFD Good status objectives. As an SAC, the lake is also not achieving Favourable conservation status.

Based on the latest available risk characterisation (for the 3rd cycle of WFD implementation), the lake is *At Risk* of not meeting WFD objectives in 2027. The inflowing streams are in *review*, thus not yet classified. Agriculture, wastewater and hydromorphology are all identified pressures in the lake catchment (EPA 2019).

The Bridgetown groundwater body (GWB), which encompasses the lagoon and tributaries, has a Good status designation and is *Not At Risk* of not meeting WFD objectives. The GWB covers a total area of 137 km^2, extending west to Kilmore on the south coast and north to Bridgetown on the east coast, and is arguably too large to capture any potential groundwater issues that are more local to Lady's Island lake.

2.6 Conceptual Hydrogeological Model

The conceptual hydrogeological model of the lake is shown in west to east cross-section in **Figure 13**. In the east, infiltration/groundwater recharge is a dominant pathway where soils are free-draining and Moderate permeability subsoils are mapped. In the west, vertical infiltration through the mapped well-drained soils is impeded by Low permeability tills. This creates perched conditions; whereby shallow water moves laterally and quickly to nearby drains and streams (**Figure 14**). The underlying GSI-mapped Low permeability till restricts vertical infiltration and thus recharge to bedrock. A third scenario, not depicted in **Figure 13** or **Figure 14**, is in the north of the catchment, where poorly draining gley soils (of the Macamore soil group) are mapped at the surface. Here, overland flow and near surface water pathways are more important, giving rise to the Kisha stream, which is the largest stream in the catchment.

Conceptually, therefore, more groundwater contributes to the lake's water balance in the east compared to the west and north. This means more favourable conditions for groundwater migration of nutrients to the lake exist to the east.

The bedrock, being mapped as 'poorly productive', is conceptually not a major source of inflow to the lake. Instead, the principal pathways are surface runoff from the land, shallow groundwater in saturated subsoils, and groundwater flow along the weathered top few metres of bedrock (potentially a 'transition zone'). Groundwater discharges will occur as seeps and springs, and likely also take place through the lakebed, depending on the degree of groundwater-surface water connections and interactions.

The nutrients will mainly enter the lake in the wetter autumn and winter seasons (October-April). This is also the principal groundwater recharge period. In contrast, soil moisture deficits in the drier summer months reduce runoff and groundwater recharge. Autumn rains produce a 'first flush' effect, mobilising any nutrient constituents that accumulate in the topsoil.

2.7 Potential Impact Potential Maps

The EPA have produced Pollution Impact Potential (PIP) maps for nitrogen (N) and phosphorus (P) across the country which show the highest risk areas in the landscape for losses of N and P to waters. The maps are informed by models that consider flow paths and delivery points to waters and incorporate spatial data on farm management, soils, and hydrogeology. High risk areas for P-loading to waters tend to have poorly draining soils and dominant overland flow pathways. High risk areas for N-loading to waters typically have freely draining soils and more significant groundwater pathways.

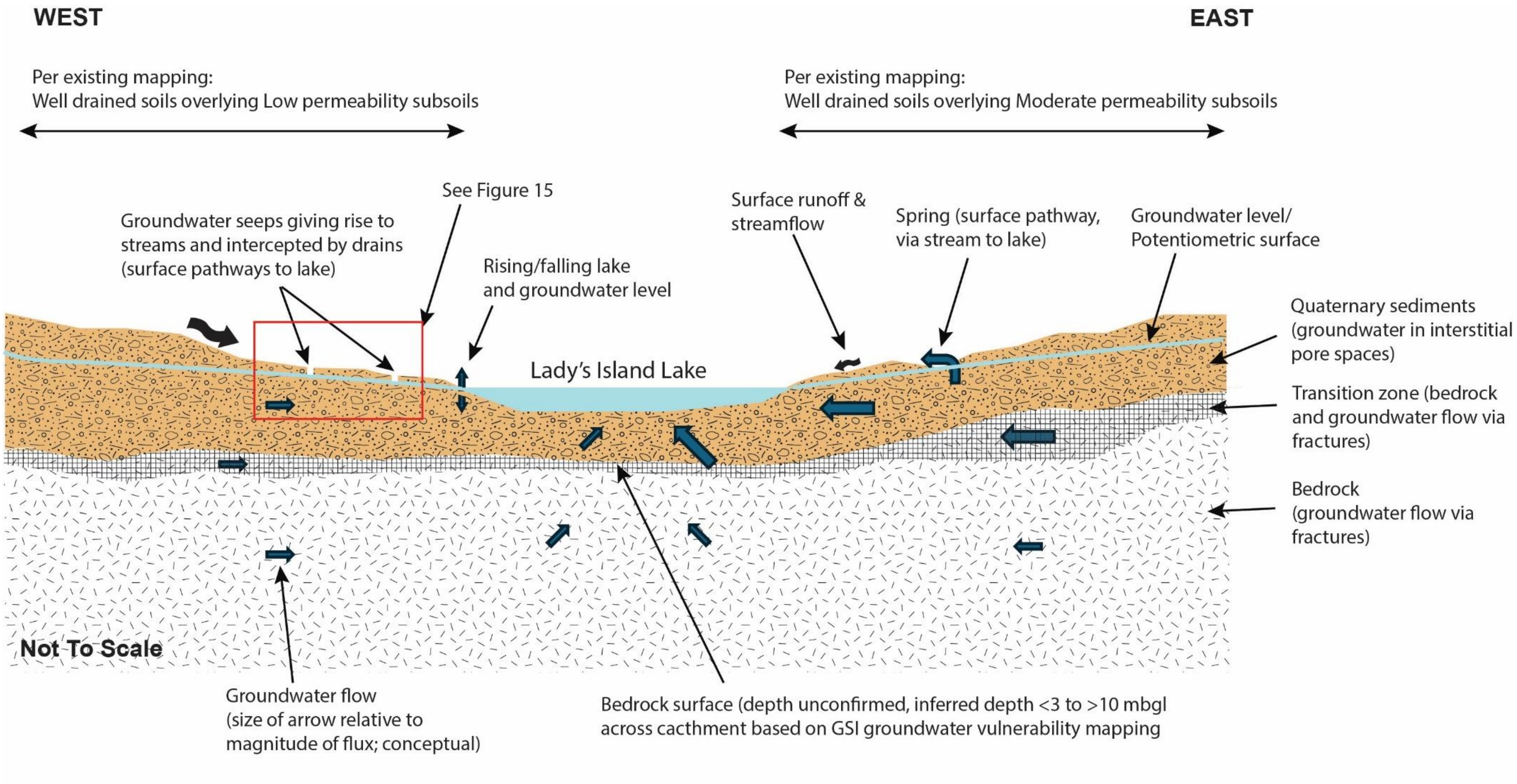


Figure 13: Conceptual Hydrogeological Model , West to East Across Lake

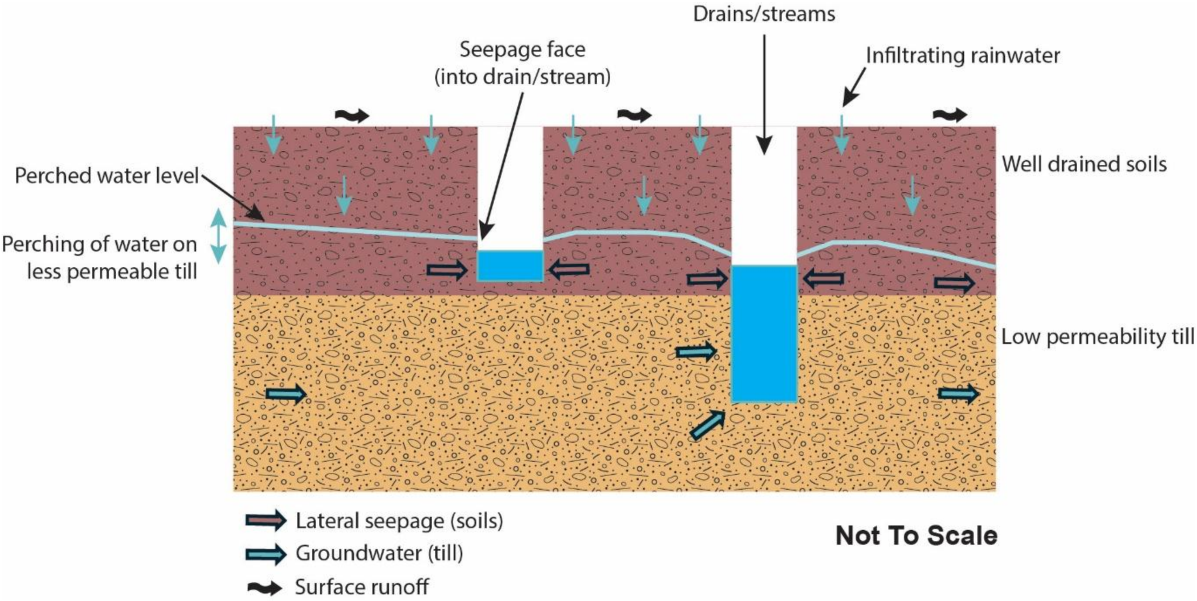


Figure 14: Detail of Inferred Shallow Hydrogeology West of the Lake

The PIP maps for P and N in the lake catchment are reproduced in **Figure 15** and **Figure 16**, respectively. The PIP maps generally match the catchment drainage characteristics- High PIP-P on poorly draining areas especially north in the catchment, and High PIP-N on the more freely draining areas to the east.

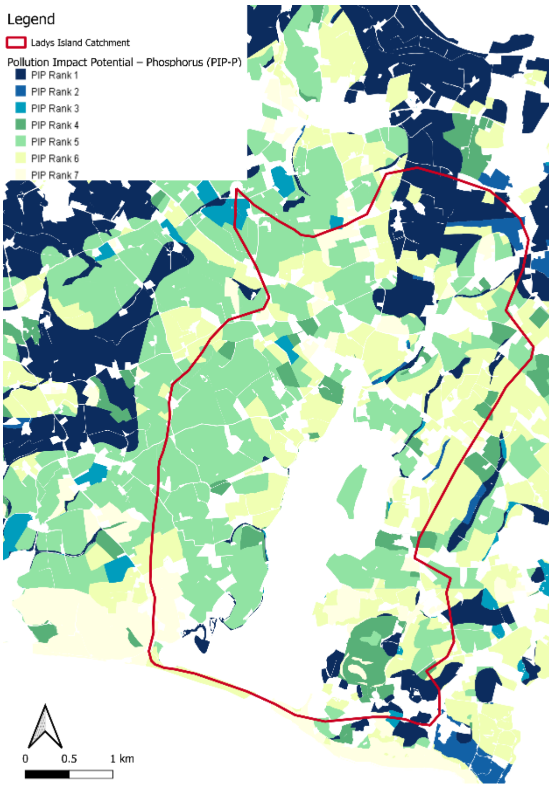


Figure 15: PIP-P Map for the Lady's Island Lake Catchment (Source: EPA)

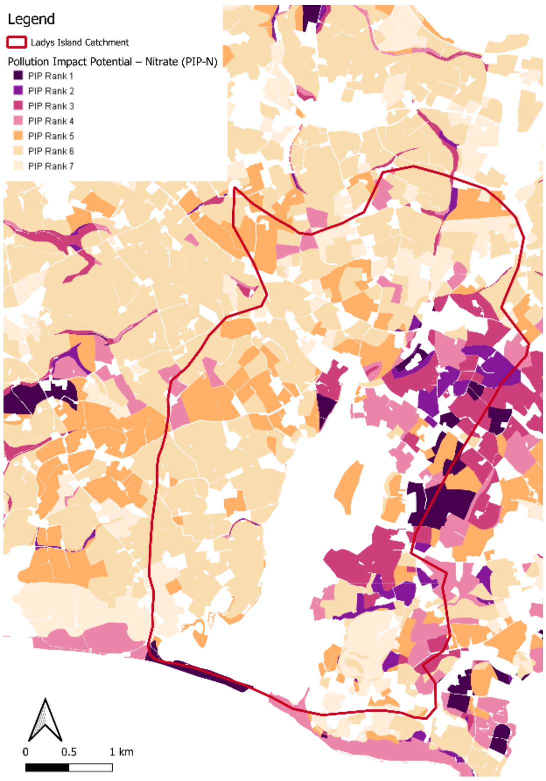


Figure 16: PIP-N Map for the Lady's Island Lake Catchment (Source: EPA)

The PIP maps work less well on the western side of the lake. The maps show lower risk PIP scopes for both N and P to the west, yet reported concentrations of both N and P in the feeder streams are elevated. This is unusual in that N and P typically do not arise from the same areas in the Irish agricultural landscape. This warrants further examination, as described in Sections 3 and 4.

Moreover, N has been identified as the *significant issue* in the lake. The area to the east is conceptually the principal source area for N to the lake, via groundwater. Nitrate especially is not attenuated in soils but can denitrify in poorly draining areas and deeper in bedrock. Given the paucity of groundwater data in the catchment overall, further work is recommended to verify the conceptual model (Section 4).

3. DATA AND KNOWLEDGE GAPS

Data and knowledge gaps are many, and principally in the catchment away from the lake. In the context of this Phase 1 assessment report, they fall into these categories:

- Subsoil characterisation across the catchment
- Groundwater levels and flow patterns across the catchments
- Groundwater quality and delivery of nutrients to the lake
- Relative groundwater vs. surface water loads
- Groundwater-surface water dynamics
- Soil chemistry and nutrient levels

3.1 Subsoil Characterisation

Subsoil mapping (type, permeability category, potential thickness) has been conducted by GSI at the regional scale. The review of the GSI information raises questions that are relevant to the understanding of pathways and delivery of nutrients to the lake. Most importantly, the pathway scenario on the western side of the lake should be verified. Current mapping shows well-drained soils overlying low-permeability and thick subsoils. This combination produces a scenario in which water infiltration to the deeper groundwater environment and vertical pollutant migration are impeded. This results, conceptually, in perching and ponding/flooding of water, which may explain the greater number of streams and field drains to the west compared to the east. Recommendations to confirm this pathway scenario are described in Section 4.

Moreover, actual subsoil permeability values (ranges, mean values) are needed to be able to quantify subsurface pathway characteristics (Section 4).

3.2 Groundwater Levels and Flow Patterns

There are no groundwater level data within the catchment in the public realm. Groundwater is used and private wells exist. The conceptual hydrogeological model and associated interpretations would benefit from the recommendations provided in Section 4.

3.3 Groundwater Quality and Delivery of Nutrients to the Lake

There are stream sample data to show elevated concentrations of N and P in the feeder streams to the lake. There are no corresponding groundwater quality data to date. There is a preliminary nutrient loading model, and there is also an acknowledgement that the role of groundwater is poorly understood or quantified (O'Connor *et al.* 2024). Accordingly, Section 4 presents recommendations to address this important knowledge gap.

To the east, the available mapping seems to favour nitrate migration via groundwater pathways. To the west, there are open questions around fate and transport of N and P. Specific issues which need to be examined closer in the west are potential perching of water above the till and the role of field drains in further enhancing runoff to the lake.

3.4 Relative Groundwater vs. Surface Water Loads

Because of the paucity of groundwater level and quality data, and because of the sparsity of surface water flow and quality data, further work is necessary to verify relative nutrient loads. The necessity arises to be able to identify suitable mitigation actions in the catchment, notably putting 'the right measures in the right places' (LAWPRO/EPA 2022), as outlined in Section 4. The applicability of measures on the western side of the lake is currently particularly uncertain, requiring further work to confirm pathways and export loads from the various land uses that take place.

3.5 Groundwater-Surface Water Interaction

Lake levels are extensively monitored, but groundwater levels are not. Conceptually, groundwater and the lake interact hydraulically, and this interaction will influence how nutrient loads are delivered to the lake (temporally and spatially). For this reason, further groundwater-related work, especially, is required, as outlined in Section 4.

3.6 Soil Chemistry and Nutrient Levels

Soil chemistry will equally be important in determining nutrient export calculations from surrounding lands to the lake. There are no publicly available studies or data from the lake catchment in the public domain and based on an initial approach (pers. comm.), data and information from the catchment may be sparse. As such, any subsequent phase of work would benefit from soil sampling and analysis, guided by Teagasc's work in other catchments around the country.

4. RECOMMENDATIONS

Recommendations to address the data or knowledge gaps in Section 3 are described below. All work would be agreed and coordinated with WCC and LAWPRO.

4.1 Subsoil Details

The following recommendations apply:

- Conduct surface geophysical surveys along select transects to document depths to bedrock and identify any potential higher-permeability intervals or weathered zones within the glacial till deposits or at the top of bedrock, respectively. This can be accomplished by electrical-resistivity tomography (ERT) surveys. This non-intrusive investigation technique would be preceded by catchment walks to identify suitable transects and to obtain landowner permissions to traverse their lands.

- Conduct trial pitting to 4.5 m depths to describe the subsoils in the types of details not offered by the GSI mapping – compositions, textures, colours, structure, verification of thickness.

- Conduct borehole drilling to depths beyond trial pits for depth to bedrock verification, subsoil particle distribution analyses, and geological characterisation. The boreholes can also serve as the basis for installing monitoring wells across the catchment.

4.2 Groundwater Levels and Flow Patterns

The following recommendations apply:

- Install monitoring wells in select locations for groundwater level and quality monitoring purposes. Monitoring wells would target subsoils and shallow bedrock.
- Measure water levels in installed wells, periodically by dipping water levels and continuously by deploying pressure transducers in select wells.
- Measure water levels in existing private wells, based on prior permissions sought by farmers/residents in the lake catchment.

All such work would require prior catchment walks to identify suitable locations and to 'survey' and obtain relevant permissions from land- and private well- owners. All such work would also be conducted over a longer time-frame of years, initially for characterisation purposes, subsequently for monitoring purposes (e.g., effects of measures).

4.3 Groundwater Quality and Delivery of Nutrients to the Lake

The following recommendations apply:

- Sample new and a select set of private wells for laboratory analyses, focussing on nutrients and those parameters that can either influence nutrient concentrations or provide insights into delivery pathways and mechanisms to surface waters.
- Sample and measure flows at select surface water locations to improve load calculations at select times of the year.

The sampling of wells will require land- and private well-owners and would be conducted over a longer time-frame of years, initially for characterisation and load verification purposes, subsequently for monitoring purposes (e.g., effects of measures).

The groundwater quality monitoring would supplement surface water monitoring, likely implemented by WCC or LAWPRO. Surface water sampling would, in turn, be accompanied by flow/discharge measurements of springs, streams and drains. Selection of locations would involve review of information from catchment walks and a recommended drone survey that produces thermal imagery (Section 4.7).

4.4 Relative Groundwater vs. Surface Water Loads

Based on any updated surface water and groundwater quality data, an updated loading model should be considered as an improved basis for deciding on suitable and appropriate mitigation actions.

4.5 Groundwater-Surface Water Interactions

The combined data review also provides as basis for quantifying groundwater-surface water interactions, with an emphasis on potential differences between the western and easter sides of the lake. This includes consideration of the peat fen area in the southeastern part of the catchment.

4.6 Soil Chemistry and Nutrient Levels

The following recommendations apply:

- Advance contact with Teagasc for soil chemistry and soil nutrient information as these, in combination with the updated/improved understanding of delivery pathways, would influence where suitable and appropriate mitigation actions are targeted in the future.
- Conduct research into experiences from similar catchments elsewhere in Ireland where the fate and transport of N and P have been evaluated, in groundwater especially.
- Engage with LAWPRO and Teagasc on local knowledge of catchment characteristics and study findings.
- Consider collecting soil samples to examine soil mineralogy and soil nutrient concentrations.

4.7 Other

In parallel with the outlined work to improve groundwater knowledge, these recommendations apply:

- Conduct a drone survey equipped with a high-resolution thermal camera to identify springs and seeps that may not be visible to the naked eye. Thermal imagery is perfectly suited for this purpose. The drone would be flown along the lake's perimeters and also cover the western parts of the catchment, where a greater number of small streams and field drains in an apparent well-drained soils setting points to potentially important shallow pathways. The drone observations would be supplemented by catchment walk information to map out potential sampling and measurement locations.

- Conduct a thorough review of all freshwater sample (flow and water quality) data collected from springs and streams to date, based on historical monitoring activity by WCC (and others) and the recent investigative assessment monitoring by LAWPRO. The review would collate all available data to look for potential change points in the dataset. This type of re-analysis can become relevant when discussing suitable and appropriate mitigation actions (Section 6).

- Further monitoring of the Kisha_010 water body streams is recommended to confirm its status by monitoring rather than relying on modelling. Monitoring of streams (and springs) would be accompanied by flow measurements for load estimation purposes.

- Another imperative for improved flow monitoring within the catchment is climate change. Projections in Ireland are for i) wetter conditions overall, ii) increased magnitude and frequency of pluvial and fluvial flooding during the winter season, and iii) increased frequency of short duration dry weather events in early summer (Campanyà *et al.* 2025). Enhanced flow monitoring will be helpful for improved load analyses and tracking, recognising that climate change will tend to increase nutrient losses from agricultural lands if nutrient application rates in the catchment are not reduced. Climate change may also require more frequent breaching of the sea barrier to manage lake flood levels. As such, the current groundwater-surface water hydrodynamic regime is expected to change.

5. SUITABLE AND APPROPRIATE MEASURES

Restoring the lake to favourable conditions will require nutrient load reductions. O'Connor *et al.* (2024) concluded that at least 10-fold nitrogen load reductions will be necessary. Diffuse sources of pollution are presently deemed more significant than point sources in this regard, even if the elevated ammonium and BOD concentrations in certain documented samples indicate that point sources of pollution (e.g., the Lady's Island wastewater treatment plant discharges) are also present in the catchment.
To be able to apply a 'right measure in the right place' approach (LAWPRO/EPA 2022), a solid evidence-base is necessary for decision-making. This speaks to both sources of pollution and pathways of delivery to the receptor. Thus, both must be addressed in future deliberations about suitable and appropriate measures. There is a wealth of information available in the public realm of applicable measures for N and P reductions. There are also statutory instruments in place which require enforcement. Because of the significance and sensitivity of the lake as an SAC, tailored measures may need to be considered that go beyond those instruments which are currently available.

Rather than source questions, this Phase 1 assessment mainly addresses pathway questions, as these engage with the 'appropriate' aspects of mitigation actions, i.e., which measures can be more effective?

From the current baseline information and conceptual hydrogeological model, there are three flow contributions to the lake:

- Overland and near surface flows in the poorly draining area in the north. In this setting, a high density of drainage ditches would be expected, for verification.
- Deeper groundwater flow in the more freely draining eastern side of the lake, discharging as springs or seeps, or diffusely via the lakebed. In this setting, a low density of drainage ditches would be expected.
- Shallow groundwater flow through shallow more permeable sediments overlying lower permeability till in the west of the lake.

Verifying and assessing the relative significance of each scenario will need field-based work and evaluation. If field visits or other investigative works confirm these observations and provide clearer depictions of pathways, then this can benefit how measures may be approached. For example, buffer-type measures would be less effective where deeper pathways are more important.

As such, the recommendations in this report (Section 4) focus on gaining an improved understanding of pathways to help steer potentially inconvenient discussions about source terms and reduction potentials. The pathway understanding also helps to steer subsequent monitoring and interpretation of results. For example, lag times of nitrate transport and attenuation may be involved that delay effects in the receptor and hence affect the ability to draw conclusions about the effectiveness of measures. Such lag times can be estimated, especially for nitrate on the east side of the lake, once details of variables that influence migration (such as actual subsoil thicknesses and permeability values) are produced.

A suitable process for considering measures is shown in **Figure 17** and reproduced from guidance presented by NFGWS (2020) and LAWPRO/EPA (2022). The work recommended in this report speaks to the identification of critical source areas and which measures (source controls, pathway interception, and mobilisation controls) might have the greater likelihood of being effective. Details of the process are described in the referenced LAWPRO/EPA (2022) guidance.

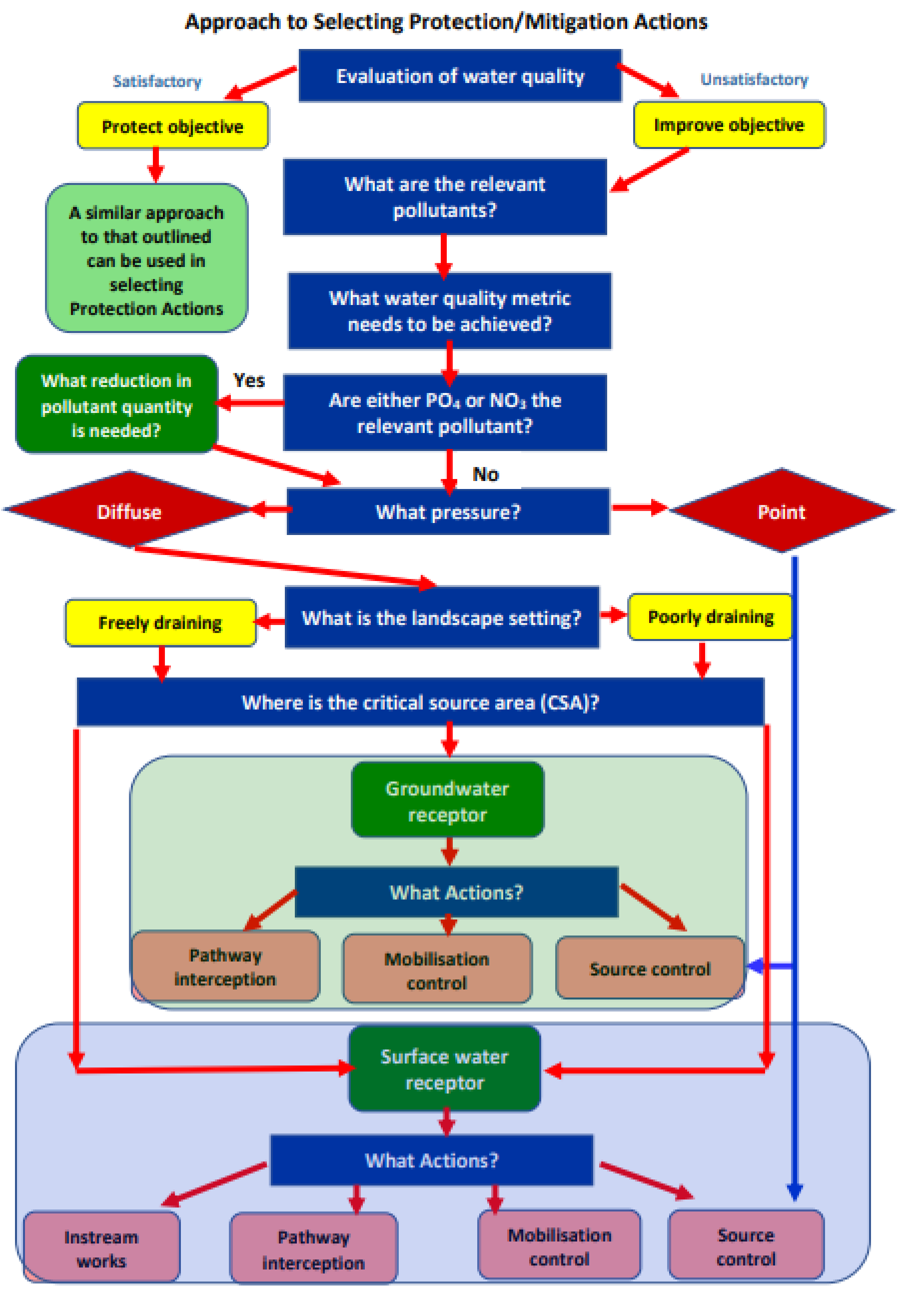


Figure 17: Approach for Selection of Measures (Source: NFGWS 2020; LAWPRO/EPA 2022)

6. PROPOSED NEXT STEPS

Proposed next steps in the sequence of works are:

1. To conduct catchment walks for purposes of reconnaissance to i) ground-truth features of interest identified in this Phase 1 report (such as springs); ii) map and measure field drainage conditions throughout the catchment; iii) identify potential suitable locations for geophysical surveys, trial pitting, and borehole drilling within the catchment; and iv) engage with landowners to survey private wells and to gain permissions to both sample and dip existing wells, conduct field work, and agree on permanent well installations on private lands.
2. To conduct a drone survey for thermal imagery along the lake margins and areas west of the lake, specifically to identify springs and seeps that may be targeted for subsequent sampling and/or flow measurements.

Both the proposed catchment walks, a drone survey will be prior arranged and coordinated with WCC, to take advantage of the existing knowledge and contacts within the catchment. Based on this, a scope of work for further investigation and monitoring will be proposed, comprising one or more of:

- A surface geophysical survey
- Trial pitting
- Borehole drilling and monitoring well sampling
- Groundwater level measurements
- Deployment of data loggers
- Periodic sampling and monitoring of groundwater and surface water
- A re-analysis of N and P loads and updating of the conceptual hydrogeological model.
- Ultimately, the updated information will be used in discussions about suitable and appropriate mitigation measures.

As stated previously, there is a need to obtain more detailed information on the western side of the lake especially, so it is anticipated that catchment walks would initially focus on these areas. To take advantage of the existing local and scientific knowledge, it will be beneficial in the planning and implementation phases to engage with those entities who have worked in the catchment already, notably WCC, LAWPRO, Teagasc and EPA's catchment science and management unit.

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